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FUNCTIONAL SAMPLE DOCUMENTATION FRA system



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ELVAC SOLUTIONS s.r.o.
Hasičská 53
700 30 Ostrava-Hrabůvka
www.elvac.eu

Technical Support:
+420 597 407 507

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MACHINE TRANSLATED

Definition of the scope of the FRA system



The FRA **software package** is a web-based and configuration desktop application that allows monitoring of power line faults.

The FRA **software package** is designed for the Windows operating 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.

Contact:

ELVAC SOLUTIONS s.r.o. member of the ELVACH Group
pasičská 53700 30 Ostrava – Hrabůvka
CZECH REPUBLIC

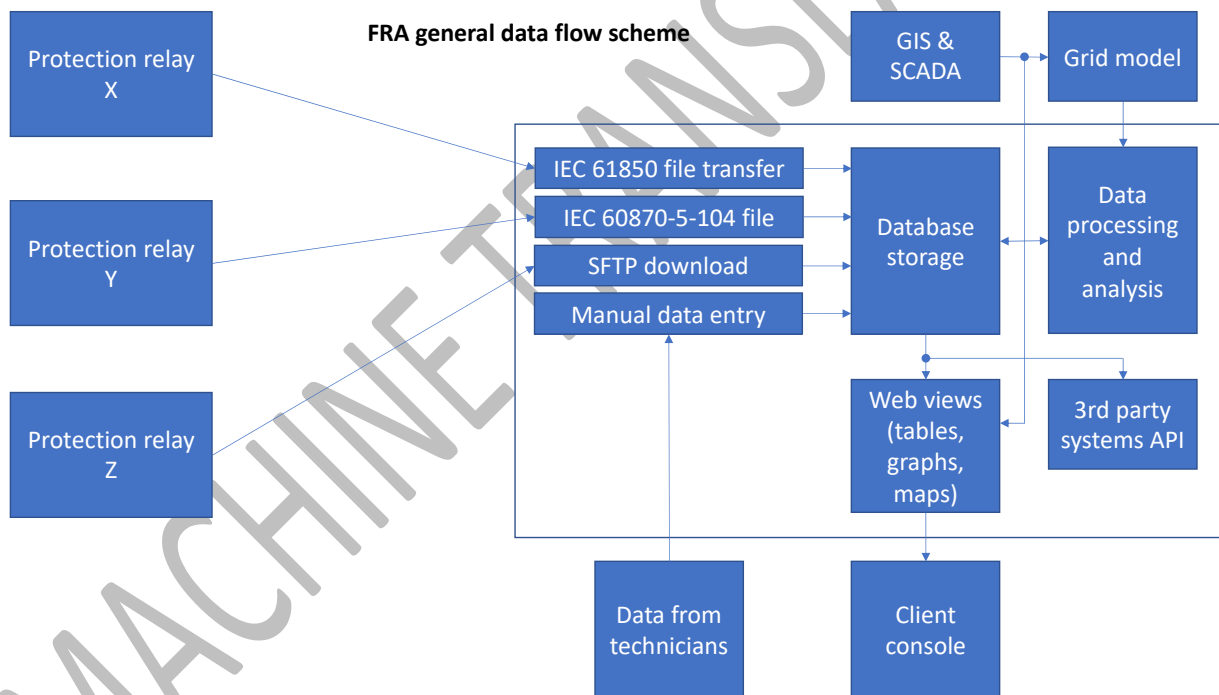
solutions@elvac.eu

www.elvac.eu/solutions

1. Description of the FRA system functional sample

The functional sample of the FRA system aims to cover the full range of the system's capabilities for centralization and analysis of fault records, especially for the purpose of verifying full functionality, but also for demonstrating capabilities to potential applicants for deployment in their power grid. As part of the project implementation, the components of the functional sample were used in the first phase for development purposes and partial verification of functionalities, and at the end of the project, the functional sample was connected to pilot operation in a real power grid.

For the purposes of development, testing and verification, several different sources of fault records (digital protections of several types from several manufacturers) communicating several protocols are solved within the functional sample, for which input channels and tools are created within the FRA system. The data obtained in this way is then processed, stored and presented in the same way as if it were in real operation. In order to ensure conditions close to those of operation, it is therefore necessary to add a simplified model of the SCADA system to the functional sample, or to emulate its parts related to the FRA system.



The above general diagram indicates the data flows and functional blocks involved in the collection, analysis and visualization of data in the FRA system. All interfaces under consideration support standardized communication protocols and data structures to ensure easy integration with third-party systems and integration into existing distribution network control centers.

2. HW and SW configuration design

The HW and SW components used to compile the functional sample of the FRA system are based on common standards and technologies used by distribution companies in the field of energy (especially in the EU), while these components are only extended by building elements from the FRA SW package and the RTU unit supplemented by support for downloading fault records from substation protections.

Available digital protections from global manufacturers SIEMENS and ABB were selected as sources of fault records for the debugging and testing phases, and it was desirable to compare not only products of different brands, but also other product lines from one manufacturer. To meet these requirements, we managed to provide protections of the Siprotec 4 and 5 series from SIEMENS, as well as protection type REX640 from ABB. These three protections were further supplemented by the RTU7M unit in the configuration used on reclosers, where this unit performs the function of full-fledged digital protection with the possibility of acquiring standard fault records in the Comtrade format.

3f voltage and current generators, such as OMICRON devices, are often used for excitation of protections in testing – this device was then supplemented during tests at Brno University of Technology with an RTDS device, which allows simulating the behavior of certain points in the network model in real time. With regard to the discrepancy between the ranges of the basic analogue outputs of the RTDS system and the protections used, in our case it is possible to use the data link between RTDS and protection using the IEC 61850 protocol with Sampled Values support (this support was available with ABB protection).

Other elements included in the functional sample also include a second RTU7M unit, in this case configured as a communication gateway / data concentrator. A newly developed FW extension module is deployed here, supporting the download of recordings from IEC 61850 protections, the downloaded recordings are stored in the RTU data space of the unit and then it is possible to transfer them to the FRA server in the selected way (the RTU unit supports SFTP and IEC 60870-5-104 file transfer). More information on the support for downloading fault logs added to the RTU7M is available in the document "RTU7M firmware for downloading IEC61850 records" (ES-FW-TACR_FRA_CS-20250128).

One physical server with two virtual machines with MS Windows OS was used to operate the FRA server with the FRA SW package installed. One of the virtual servers was reserved for SW components and the FRA system database, the other machine for simulation of the SCADA system (simplified data concentrator, communication tools, offline GIS data) and tests of transmission of fault records from third-party systems via increased disk space.

For the purpose of displaying the web interface of the FRA system, but also for running a thick FRA client designed for administration, configuration and diagnostics, a common PC with MS Windows OS without specific requirements for its parameters has been reserved.

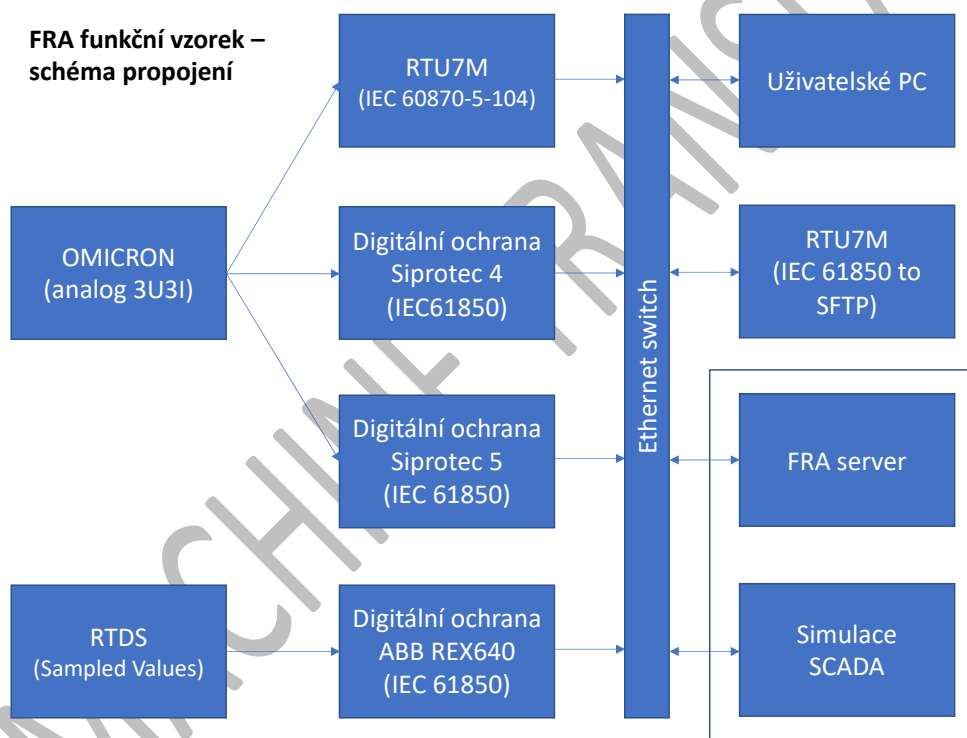
3. Communication infrastructure design

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)

3.1 Solutions for the development, debugging and testing phase

Using the HW and SW components described in the previous chapter, the following interconnection scheme was compiled for the purposes of development, debugging and testing:



Here is a description of each element in the schema and their roles:

1. OMICRON (3U3I analogue):

It serves as a source of simulated analog signals (three voltages and three currents) for testing digital protections and other devices.

2. RTDS (Real-Time Digital Simulator - Sampled Values):

It generates a Sampled Values data stream for transfer to digital protections, simulating real-time conditions.

3. Digital protections:

Siprotec 4 and Siprotec 5 (IEC 61850) – They serve as a protection relay for testing protection functions, they communicate via the IEC 61850 protocol, their input is an analogue signal from OMICRON.

ABB REX640 (IEC 61850) – An additional digital protection that is included in the test kit and supports communication using IEC 61850, the input is Sampled Values from RTDS.

4. RTU7M:

The first RTU unit acts as a recloser control system with integrated digital protection, communicating via the IEC 60870-5-104 protocol.

The second RTU acts as a communication gateway/data concentrator that downloads information from digital protections via IEC 61850 and forwards it to the FRA server via SFTP. It is a component that is part of the FRA system (FW for downloading records using the IEC 61850 protocol).

5. Ethernet Switch:

It serves as a communication interface for connecting all devices in the network and allows data exchange between individual elements of the assembly.

6. User PC:

It provides an interface for controlling, configuring, and monitoring the entire test system.

7. FRA Server:

It provides archiving and processing of fault records downloaded from all protections and RTUs of units. The FRA SW package is installed here.

8. SCADA Simulation:

It is used to simulate a SCADA system for transmitting signals about the occurrence of faults and the state of the distribution network topology.

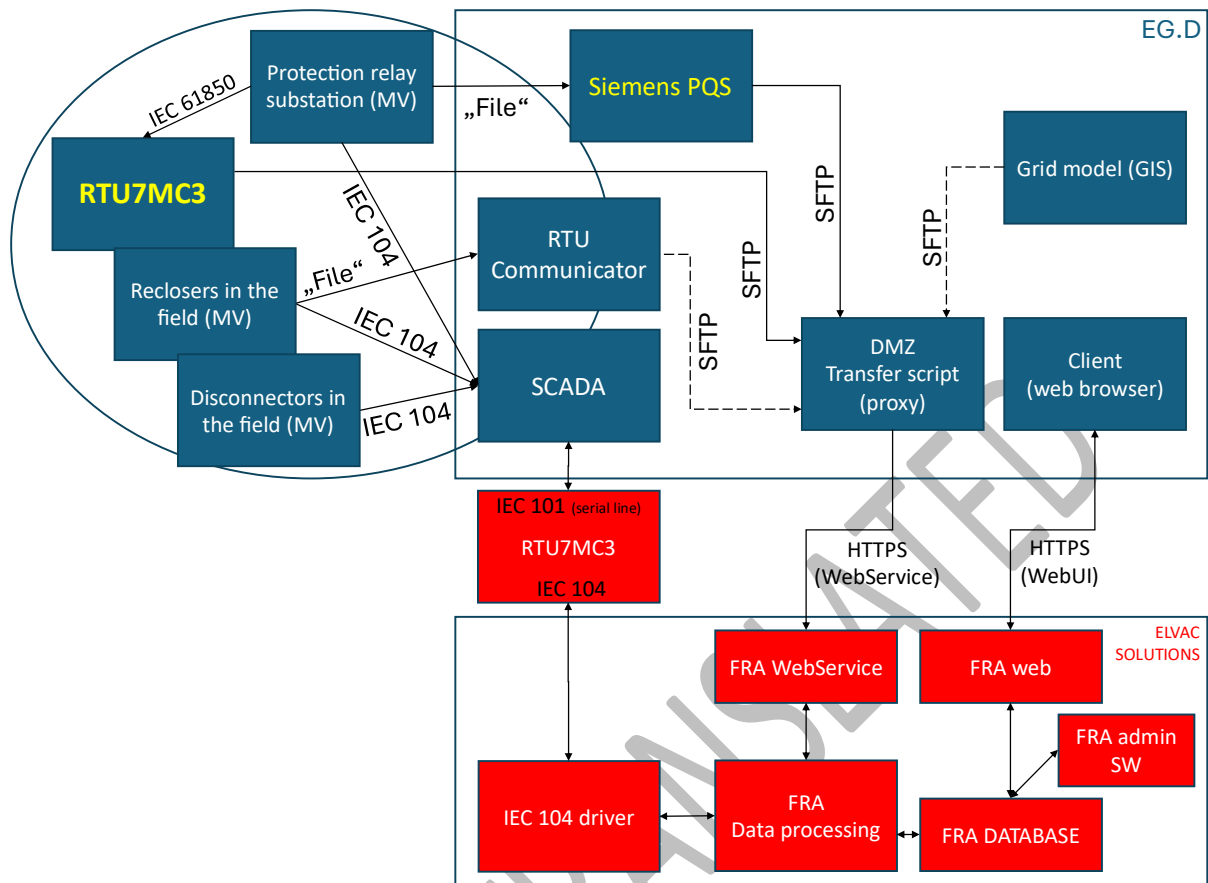
3.2 Solutions for the pilot stage

For the needs of pilot operation, 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 the FRA 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.

3.2.1 Basic block communication scheme of the pilot plant

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.

(continued on the next page)



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 the substation – source of fault information and fault records
2. Reclosers in the field (MV) – reclosers located in the MV network – a source of information on 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 HV network – source of information on the status of the switching element
4. RTU7MC3 – a communication unit for downloading records from IEC 61850 protections and transmitting them for further processing by SFTP protocol (or IEC 60870-5-104)
5. Siemens PQS – a tool of the protection manufacturer that ensures the download of fault records and their storage on a disk
6. RTU Communicator – communication concentrator ensuring the download of fault records from the recloser controllers
7. SCADA – distribution system operator's dispatch 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 localization 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 driver 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 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, control 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.

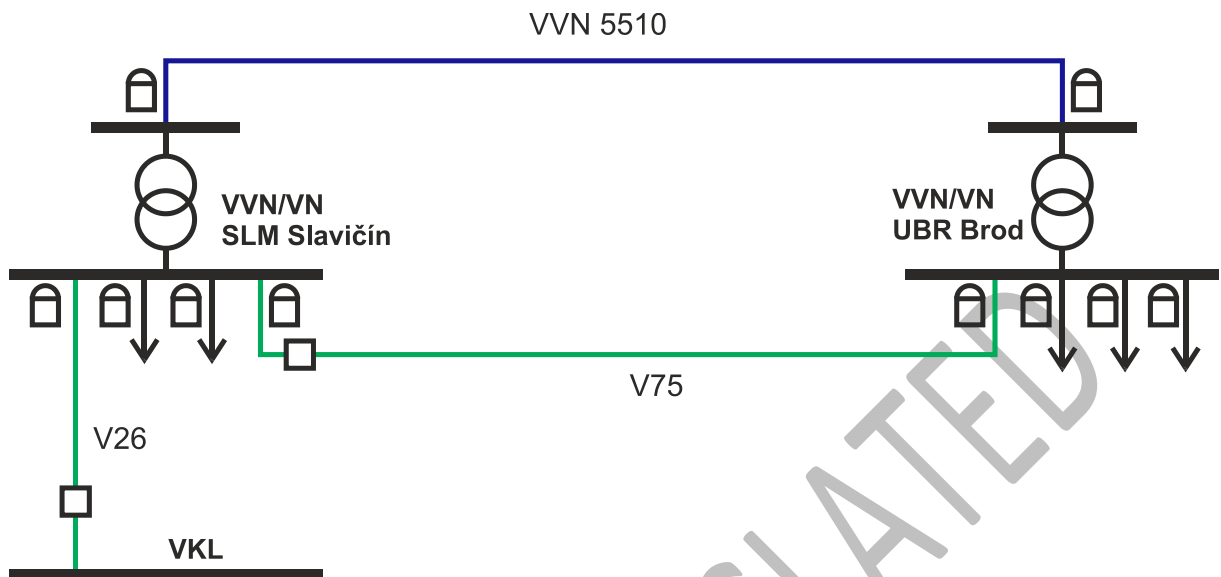
Note: Compression (ZIP) is used to transfer records in COMTRADE format and other data sets in order to reduce the volume of data transferred.

3.2.2. Actual location of parts of the FRA system within pilot plant

The HV/HV substations Slavičín (SLM) and Uherský Brod (UBR) were selected for pilot operation. At these substations, records are downloaded from all HV outlet protections (for record analysis and short-circuit localization – one-sided power supply of the line) and from selected HV outlets (fault localization of double-sided power lines – HV 5510).

The HV26 line supplied from the Slavičín substation and the VN75 line supplied by the Uherský Brod substation as standard with the possibility of supplying it also from the Uherský Brod substation are also part of the pilot operation of the Vdip2 system, so the records downloaded from the respective HV outlets are shared by both systems.

Simplified scheme:



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

The FRA system server is located at the headquarters of ELVAC SOLUTIONS in Ostrava.

Note – synergy with another research project

With regard to the involvement of another participant (Brno University of Technology) in the project called "Development of a system for locating Vdip failures of the 2nd generation", with the registration number TK04020187, which, among other things, also uses the download of fault records from the IEC61850 protocol protection to the RTU of units and at the same time also solves pilot operation in the EG distribution network. D, the possibility of mutual support was offered in the preparation and support of the pilot operation of both projects. Specifically, it is the sharing of RTU7M communication units at the Slavičín and Uherský Brod substations, which download records from all protections at the substation for the purposes of the FRA project, but at the same time provide records from selected HV outlets of the Vdip2 system. Another communication unit, RTU7M, is located at EG headquarters. D in Brno transmits signals from the SCADA system mainly for Vdip2, but a smaller number of signals can also be transmitted to the FRA system in this way. Likewise, it was not necessary to build separate communication routes and add handover points within the EG infrastructure. D separately for each of the projects, which significantly facilitated the necessary cooperation on the part of EG.D.

4. Installation and configuration of HW and SW

The installation and configuration of individual components initially consists mainly of the correct setting of communication parameters (interfaces, addresses, protocols) and ensuring physical interconnection. This connection on the data path side uses conventional network cabling, the interconnection of analogue signals for laboratory tests with digital protections requires the preparation of appropriate cabling to suit the voltage and current levels used. Data connection between systems in EG. D and the FRA server also uses a mobile data connection and the Internet – especially here it is necessary to pay attention to cyber security, which was ensured in close cooperation between EG's IT departments. D and ELVAC.

A complex task is the appropriate setting of stimuli and action of protections, parameters of fault records, transmission of signals about the occurrence of failures between individual components, etc. These settings must be made after careful study of the documentation for individual devices and then the correct function must be verified by a test. The protection settings should reflect the common parameters used in the distribution networks, which should subsequently be reflected in the generated test signals, so that the outputs of the FRA system achieved within the functional sample are similar to common practice. On the other hand, it is also possible to induce limit situations in the test environment, which may occur only exceptionally in normal operation, which is advantageous for verifying the functional properties of the system in the entire range of possible conditions. The protection settings verified in the laboratory environment on a functional sample could subsequently also be applied to the protections located at substations.

The configuration of the RTU7M working as a communication gateway downloading records from protections and forwarding them to the FRA server is relatively easy thanks to the clear and intuitive web interface or SW on the PC and consists mainly in setting up communication interfaces and adding as many "IEC61850 devices" configuration blocks as we need to include in the system. According to the protection documentation, it is necessary to set the correct path to the records, and then correctly assign identifiers in the FRA server settings so that the records are classified to the appropriate HV or HV pin.

The system installation and configuration of the FRA server corresponds to common practices for MS Windows Server, including compliance with all cybersecurity policies. For the FRA system to work, it is also necessary to install a PostgreSQL database on the server, the web interface uses the standard IIS service as a basis (for the purpose of access from the outside as part of pilot operation, it is necessary to set up the appropriate passes and routing).

5. Installation, configuration and commissioning of SW

The SW modules of the FRA system are divided into several services that are triggered automatically when the system is lost. A part of the powerful core, data and notification subsystem is followed by a web portal and a web service for data transfer via the HTTPS protocol. To download data via the SFTP protocol, a transfer script in PowerShell is used, which requires the configuration of addresses and paths. In the configuration database, it is then necessary to either manually add individual devices (protections) and connect them with fault signals, or it is possible to import a complete model of the selected area of the distribution network and only configure the identifiers. More information about the FRA SW package, its configuration data and settings are provided in the SW technical documentation, the use of the web user interface is described in more detail in the FRA SW User Manual. There is also a short video presentation showing how to work with the FRA system.

For the purposes of tests performed on a functional sample, several sub-areas of the distribution network were imported, for which models were created to subsequently generate fault waveforms, which became the source of the signal for protection. A number of real-world fault records were also available from faults that had previously occurred in the relevant parts of the network – these records could be manually imported into the system or emulated by automatic download via the RTU7M.

The preparation of configuration data for pilot operation was a more extensive task, as it was necessary to import the data provided by the distribution network operator, validate this data, add the address database and then put everything into operation.



The photo above shows a view of the test bench / functional sample of the FRA system in the laboratory testing phase.

Validate and debug a functional sample

The functional sample of the FRA system was subjected to a series of tests using simulated fault signals covering the entire spectrum of possible operating conditions, including boundary conditions. Further tests were carried out with fault records from real failures that had previously occurred in operating conditions.

One of the parameters assessed was the reliability of downloading the recording from protection, the time needed to transfer it to the server and subsequent processing. Reliability can be rated as high, as there were no more record losses after debugging the initial communication timeout problems. The time needed to download the record from the protection and transfer it to the server in the case of the default network of the functional sample with a direct connection between the components was always up to 30 s, the subsequent processing and data writing for an individual failure record is based on 5 s, in the case of a failure on the HV with two fault records entering the fault localization, the processing time is about 10 s. to download records of about 15 seconds.

After performing a higher number of test cycles and filling its database, the functional sample assembly was also used to tune the statistical computational functions of the FRA system.



ELVAC SOLUTIONS s.r.o.
Hasičská 53700 30 Ostrava-Hrabůvka

Tel: +420 597 407 500
E-mail: solutions@elvac.eu
www.elvac.eu
