Obstacles to proper operation of substation telematics

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Abstract
The remote control and supervision of electrical power transmission systems are one of the most efficient ways of how to ensure balanced electricity generation and consumption, how to take under control the interruption of power supply for consumption, how to prevent electrical hazards for people, how to operate all of substation circuit devices remotely, how to preclude blackout etc. The local device, which gives a capacity to realize all the abovementioned functions, is the Remote Control Unit of a substation. Today the Remote Control Unit is an inseparable substation part of remote control and supervision, as well as a remote control centre or telecommunication path.

Keywords
Electrical power transmission system, Remote Control Unit (RTU), Supervisory Control And Data Acquisition (SCADA), Intelligent Electronic Device (IED), substation, telematics, relay protection, control, feedback, data transmission protocol (IEC 60870-5-101 Companion standard for basic telecontrol tasks, IEC 60870-5-103 Companion standard for the informative interface of protection equipment, IEC 60870-5-104 Network access for IEC 60870-5-101 using standard transport profiles).

1 Introduction
Elering OÜ (National Grid, Main Grid) is the Estonian transmission system operator (TSO). Using 110−330 kV high-voltage power lines, it unites Estonia’s largest power stations, distribution networks and corporate consumers in an integral energy system.

The main functions of Elering OÜ are listed below:
1. to transmit electricity at voltages of 6–330 kV to distribution networks and corporate consumers
2. to develop and operate a 110–330 kV electrical power transmission network covering the whole of Estonia
3. to ensure the reliability of Estonia’s electrical power system in conjunction with the power systems of the neighboring countries
4. to maintain the capacity balance of the electrical power transmission system and manage the power system across Estonia in real time
5. to ensuring the Estonian energy balance and operate the balance settlement for the balance providers

Fig. 1. Mapping of the electrical power transmission system
The electrical power transmission system is a centrally controlled technical system including:
1. power stations
2. consumers
3. the electricity supply network between the power stations and the consumers along with its respective management, telecommunications and protective systems.
   a. transmission network
   b. distribution network

The physical processes of generation, transformation, transmission, distribution and accumulation of electricity take place and are managed in the electricity system. The Estonian transmission system has a bulk of different equipment, which could be divided into two sections:
1. different voltage level substations (one or more transformers, switching devices, protection relays, control devices, communication devices)
2. transmission lines (overhead lines, underground cables)
2 Overview of telematics for electrical power transmission systems

The main parts of telemechanical control and supervisory for power grid are the SCADA system, RTU, IED devices and communications paths.

The abbreviation SCADA (Control Centre) usually refers to centralized and highly IT-computerized systems, which monitor and control entire sites or some other complicated systems spread out over large areas. All remote control actions, status supervision, measurements for analysis are performed via locally placed RTUs.

The substation RTU is intended for adequate reaction on information objects (control, status, measurement messages), receiving them from a side remotely connected to the SCADA system. On the other side, an RTU shall be connected to the executing device, which should react on the control action from the SCADA system.

The Remote Terminal Unit (RTU) is located at the substations for collecting data (state information, alarms, measurements) from the substation to the Control Centre as well as for the distribution of control commands from the Control Centre to the substation.

Therefore, to ensure reliability of a substation RTU during its lifecycle and to parameterize it correctly according to SCADA operating needs, remote monitoring and control requirements have been set for the substation RTU. The above-mentioned requirements specify a substation RTU in the following mode:

1. RTU operational area (functions, data transmission, time base, technical data, Electromagnetic and Environmental Compatibility etc.)
2. RTU hardware (modular topology, processor, I/O-, power supply modules etc.)
3. control and monitoring (control, state, measurement, event, alarms, indication)
4. time synchronizing
5. compatibility and interoperability with the SCADA
6. type of communication interface

The primary equipment of a substation should be connected to the IED device that fulfils the following tasks:

1. local control and monitoring function
2. protection function
3. provision of remote control and monitoring

In Fig 2 the primary equipment of the substation is marked by pink and the secondary equipment by blue colour.

Fig. 2. Fragment of the main electrical schema.

The IED device should be connected to RTU, which provides remote control operations and monitoring of functions for the SCADA system.

The substation has several of IED devices that could be connected to the RTU by optics to avoid electromagnetic interferences, but copper connections are also possible.

All the devices and systems (SCADA-RTU-IED) defined in the external telematics circuit are able to send and receive data between each other without any restrictions or error at any time if necessary and executes all specified actions accurately and at the right time.

Fig. 1. The example of substation RTU

110 kV transformer bay
Telematics networks consist of three main parts, which are divided depending on the network location:

1. Substation network (e.g. between RTU and IEDs)
2. Telecommunication service provider network (e.g. power transmission lines)
3. Control Centre network (SCADA)

A general overview of the type realization for telematics communications is represented in the following figure.

Actually the substation RTU resembles an industrial controller, particularly in terms of hardware that may have:

1. Digital input/output modules
2. Analog input/output modules
3. Optical modules
4. Processor module
5. External communication ports

However, the last point sets a difference between the RTU and the controller, while for the RTU communications with the SCADA is established and IED devices will use only internationally standardized data transmission protocols. Usually the controller producers realize the process of communication working out a vendor-oriented communication protocol.

Thus, the only data transmission protocol IEC 60870-5-101/104 (SCADA network) and IEC 60870-5-103 (substation network) will be used for connecting to the RTU, but for measurement transducers some prevalent protocol (e.g. Modbus, Profibus) will be chosen.

The operational measurements are also important for the Control Centre to control the primary equipment of the power system. To have a full control of the transmission network the measurement visualization should be locally and remotely performed.

The measurement transducer is the device that converts one form of a signal to another, allowing its measurement or display to be made appropriate.

The measurement transducer is the device that sends the measurement data to the SCADA using the RTU. Those devices are able to provide voltage and current based measurements to the RTU. The measurement transducer uses the external DC power supply to operate.

The measurement transducer meets the specific accuracy requirements, which are more strict for direct measurements than for calculated values (e.g. active and reactive power).

The substation measurement systems are divided into two fully independent groups like operational and commercial measurement systems.

Thus, the first one is provided to establish control of emergency, technological and service activities (e.g. to check the voltage and current of the switched off power line). With appropriate use of operational measurements the substation equipment is adequately estimated (e.g. needs for activation of backup power supply to the customer).

The second system, which is of the same importance, is an automatic commercial meter reading system (AMR), which is not part of operative telematics.
Some examples of measurement transducer’s requirements:

1. the mentioned PC software, respective connection cable and possible RS-485/232 (or some other type) converter belong to delivery
2. transducers for all bays have a LCD display or a 8-element indicator display equipped with background or direct illumination for local measurements. Transducers are placed into the relay cubicles so that measurements are visible without opening any door
3. transducers are connected with three current phases directly to the measuring winding of the current transformer
4. transducers are connected with three voltage phases directly to the measuring winding of the voltage transformer. The voltage circuits of the transducer are provided with their own MCB (miniature circuit breaker)
5. auxiliary supply for transducers is the substation battery DC voltage. One cubicle contains up to four transducers with one MCB of auxiliary supply

The one of the important requirements is the time synchronizing of RTU and other IED devices in the substation.

The purpose of the substation GPS reference clock and the time synchronizer (GPS device) is to ensure correct real local time and date run in the IEDs (incl. RTU). Due to the operation of the GPS system the transmitted signals from the substation in the SCADA system have always a correct and synchronized time stamp.

Previously, time synchronization was performed by the SCADA remote control centre, in case only IEC 60870-5-101 between RTU and SCADA was used. Nowadays the GPS system is used in a substation for time synchronization of all the IED devices (incl. RTU).

Thus, the RTU is only one device that sets up communication between the telematics upper and lower paths (substation and SCADA). It is therefore the only local binding knot of data exchange from outside to inside and vice versa. As a result, RTU working performance should be without any mistake in the RTU internal data transformation in both data shift directions.

Thus, all “participators” of the telematics system are responsible for faultless working, while the RTU can only receive and transmit those signals, which are accessible for cooperation and parameterization in the RTU for its response. Additionally, some logical functions are used in the RTU like grouping of information objects.

### 3 Obstacles in the telematics system

Before the system is maintained and commissioned, the telecommunication network should be planned taking into consideration some aspects, which definitely influence the telematics technical solution.

The engineering part is the first step to set telematics consisting of the definition of the network type and the features of all telecommunication network components, which should physically and logically reckon and match to each other:

1. topology network (star, ring, fully reserved, tree, partial connections or mesh, bus)
2. the identical physical communication ability (voltage level, optical wave length, optical cable plug etc.) for communicative devices
3. the logical interoperability of the device’s communication interface (standardized data transmission protocol like IEC 60870-5-103)

Thus, all of the telematics “participant” devices should match to each other in terms of hardware and software, including:

1. copper wiring, current/voltage rate compatible
2. optical fibres, same wavelength inside the optical cabling, suitable type of plugs etc.
3. use of the same open communication “language” (e.g. IEC 60870-5)
Concurrently three abovementioned points are sometimes the hindrance how to connect all telematics system devices together. In the case of the mismatched interface the technical problem may be solved by use of additional converter-devices, which reduce the reliability of the whole telematics system. The “open” communication languages are often used to ensure the transparency of the telecommunication system, whereby the check for the problems and modification of the existing telecommunication system could be easily carried out by independent (not from vendor side) specialists.

3.1 Communication compatibility

A few years ago the capability of the devices of different manufacturers to telecommunicate using the international standardized protocol was not realized successfully because of differences in the interpretation of the international communication protocol standard IEC 60870-5-103 by manufacturers. Thus, many IEDs and RTUs could not telecommunicate between different vendor devices in spite of their label “IEC 60870-5-103 compliance”. Unfortunately the same situation is quite frequent even today. The most adequate control of telecommunication suitability is to check the compliance from the international testing companies, which publicize compliance reports of devices from the manufacturers of power energy areas.

3.2 Time synchronization

Similar inconveniences mentioned above occur in the time synchronization system. Every protection device and RTU should be time synchronized with required accuracy, but the techniques are the responsibility of the device manufacturer. Thus, physical interface and time synchronizing mode varies from vendor to vendor:

1. physical interface - D-Sub 9 pins, 2-pole plug, optical interface etc.
2. time synchronizing protocol – Irig-B, DCF77, GPS, time strings, 1 ppm, IEC 60870-5-101/103, IEEE1588 (Precise Time Protocol) etc.

The time synchronization device should be adapted to all IEDs and RTUs in the substation and it is most important to follow an identical time synchronizing mode excluding the individual solutions.

The IEDs need also an interface for remote service communication, which is not part of operative telematics.

The operation that defines the quality of the device’s operation is the parameterization of the IEDs and RTUs. The parameterization of the IED (protection relay) includes several parameterization levels:

1. protection function (the essential purpose of the protection relay)
2. logic (the additional non/standard logic in the protection relay)
3. telemetric (the definition of information objects for RTU/SCADA).

The only point directly bound with telematics is point number three. Thereby defined information objects for the Control Centre should be linked from previous parameterization levels. The main idea is to precisely define all the addresses of information objects. In the case of using IEC 60870-5-103 these are type identification and information number. The same numbers should be inserted into the configuration of the source and receiver devices (IED and RTU) to transmit the exact amount of information objects to the SCADA correctly.

3.3 RTU

The RTU parameterization is to define the information objects of the data transmission protocol (address, type etc.), exchanging them with the SCADA system. One of the tasks of the RTU could be the ability to perform some logical time-uncritical functions. The RTU can be named as a repeater or converter for sending information from the substation lower part (IEDs) to the Control Centre. As a rule, the international data transmission protocol standards IEC 60870-5-101/104 are well known and often used in the EU. Thus, almost all the RTUs and SCADA systems manufactured in the EU support the above mentioned data transmission protocol standards. As a result, protocol features and additional parameters should be set up in the RTU for SCADA system, e.g. the standard IEC 60870-5-101 distinguishes information types like double command DC_NA, double point DP_TA/TB, single command SC_NA, single point SP_TA/TB etc. and their addresses. The information object address, type and data unit identifier elements should be defined correctly on both sides (RTU and SCADA system). Otherwise the collapse, malfunction or no-reaction situation may occur as a result of mismatched parameters of the information object between the RTU and SCADA system. The following figure shows double command, double point, single command, single point and floating point measurements, which are parameterized in the RTU.

<table>
<thead>
<tr>
<th>IEC Specific</th>
<th>Point Specific</th>
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<tbody>
<tr>
<td>Type</td>
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<tr>
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<td>1001</td>
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<tr>
<td>M_ME_NA</td>
<td>1002</td>
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</tbody>
</table>

Fig. 4. Properties of some IEC 60870-5-101 information objects

The configuration of the telematics system is the most important, charge critical and herewith highly responsible task of secondary equipment building work, which depends substantially on co-operation between the Client and the Contractor (e.g. telematics device vendor). The main reason is having a continuous check of IED/RTU parameterization process and taking under control completed tests by the on-side commissioning tests.
Usually it is preliminarily done in the scope of supply first to avoid any incomprehensibility. But there may be several modifications of the offered telematics devices, therefore the final technical solution should be agreed on again during the technical project phase.

3.4 Measurement transducer

The configuration of measurement transducer is not complicated, but the main difficulty is to define the right address and correct range of measurement in the RTU. The most widely spread mode of communication between the RTU and the measurement transducer is the application as well the industrial protocols like Modbus or Profibus, as IEC 60870-5-103. If in the third solution the star topology is appropriated, then Modbus and Profibus are needed for loop-connection. Thus, it is only possible to make a mistake with the configuration during the definition of the information object address, dead band, threshold and also over the measured rate, which should be calculated according to certain rules. But those errors are easy to discover and adjust. Sometimes it is time-consuming to match different vendor devices (e.g. the measurement transducer of X-manufacturer and the RTU of Y-manufacturer) despite the same communication protocol supporting.

3.5 Configuration of telematics device

The IEDs, RTUs and measurement transducers are digital devices, which have relevant parameterization software. For the legal use of that software and sometimes for others accessories (e.g. digital licence, hard lock) the licence code is necessary. But if all software is delivered correctly, there is still no chance to keep calm for a long time. The reason of that is continuous development and improvement of substation telematics devices. The result is production of more and more free updates as well as upgrades for pay. If the configurations of the telematics device are made by a previous version of software, then it might not be more functional by a newer one. The cause of such ”surprise” can be an older operational system, weak main possessor or even the older hardware of the device. The vendors are trying to avoid similar solutions, which requires total modification of the whole device from hardware and software, but there are still numerous intricacies. Additionally the ability to download from the telematics device is also important. Unfortunately not all of parameterization failures could be downloaded from their “owners” (mostly concerning RTUs). This drawback feature should be taken into consideration to ensure always the right backup parameterization failures for the future.

When the telematics system is launched, all of the telematics devices should have the right documentation, manuals, current configuration/parameterization failures and the software created should be gathered for the Client archive. Keeping records of correct configuration/parameterization failures is especially important taking into account the principle that all the telematics devices are system devices. Thus, modification of one telematics device configuration could influence other devices, which could be also reparameterized to have a result effect. As a result, the Client should gather all of logically bound failures of the telematics device configuration/parameterization again after some possible improvement works in the substation telecommunication system.

4 Conclusions

Planning, maintenance and commissioning of substation telematics are parts of complicated, highly reliable needs for high technical competence work. Successful accomplishment is only possible with a well preplanned Client ideology of substation telematics that means the Client should have telematics competent personnel (with “know-how” knowledge), following close co-operation between the Client and the Contractor. It is the reason how the final target of the project will satisfy an efficient technical solution avoiding many misunderstandings. The Contractor’s best practice is to construct the telematics according to the Client requirements, to attract Client’s attention to possible improper decisions, to check the work done, carrying out the F.A.T as well as S.A.T. with and without the Client. The main task of the Client is to prepare relevant agreements for technical solution during the technical project level.

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