EXPERIENCES DURING THE IMPLEMENTATION OF SCADA SYSTEM FOR THE FIRST PROJECT OF AUTOMATIZATION OF MIDDLE VOLTAGE DISTRIBUTIVE NETWORK IN SERBIA AND MONTENEGRO

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INTRODUCTION

Realization of Pilot project of system for remote supervision and control of middle voltage distributive network (MV DN) within PD “Elektrovojvodina” represents the beginning of the phase before last in realization of whole automation of technical jobs of power energy distribution. Namely, system for remote supervision and control of power energy object (PEO) HV/MV (PS 110/x kV, PS 35/x kV and SS 20 kV) already has long tradition and comprises large number of named PEO that are in competency of Elektrovojvodina. The other component of the system for assistance in jobs of the distribution, DMS program, had also found its place in all parts of Elektrovojvodina. By realization of two Pilot projects, the system for remote supervision and control started to spread to middle voltage distributive network as well. Needs for automation of middle voltage network comprise both from the tendency to provide continuity in supply of quality power energy to consumer consumption in the most economical manner and the fact that large number of middle voltage (MV) objects and huge frequency of planned and unplanned operative events cause number of manipulations and changes of configuration of MV network, so significance of program assisted guidance of distributive network is enormous both in technical and economical sense.
Introduction of remote supervision and control in middle voltage distributive network started with the realization of Pilot project in two locations (the area of Power Distribution Novi Sad and the area of Power Distribution Sombor), with two technical solutions and equipment from two different producers, with the aim to obtain and compare experiences from two different solutions. This will be of key importance with further widening of the system. The thing that is mutual for both systems is their collectiveness that is attempted in realization of all segments of the system, from the installation of controllable energetic equipment and remote terminal units in PEO, via realization of telecommunication subsystem, to the implementation of SCADA system in control centers. The Project encloses making of all necessary project-technical documentation: The idea project, The Project of accomplished object and Project-technical documentation for realization of telecommunication subsystem.

COMPONENTS OF THE SYSTEM FOR REMOTE SUPERVISION AND CONTROL OF MV NETWORK WITHIN REALIZED PILOT PROJECT

The system for remote supervision and control of MV network is complex system that comprises following subsystems:

- Switchgears in object of MV network;
- Remote terminal units and associated equipment for fault detection and continual supply of the system located in managing object;
- Communication subsystem and
- SCADA subsystem in control center.

Among PEO involved in Pilot systems are, according to certain criteria chosen, distributive power stations and network switch disconnector on overhead lines. In those object the old uncontrollable energetic equipment is changed with the new controllable equipment: MV installation in power stations is changed with the integrated MV blocks (Ring Main Unit - RMU) with controllable switch disconnectors in feeder field and switch disconnectors with fuse in transformer fields, while all existent overhead disconnectors are changed with controlable switch disconnectors with electromotor mechanism.

For the needs of remote supervision and control of this equipment, in every PEO involved in Pilot system, Remote Terminal Units (RTU) and all following equipment for needs of fault detection in MV network and acquisition of specific measurement values (voltage and current measurement transformers/sensors, that is Rogowski coil, detectors of voltage presence, detectors of phase and earth fault) are installed.

For the realization of telecommunication (TC) subsystem radio systems has been chosen as reliable and inspected system within present system for remote control, which is in ownership and full competency of Elektrovojvodina. Because of the large dispersion of PDO on the area of one power distribution, realized radio system has to uphold “store and forward” function. This function is realized and tested for the needs of one of the objects involved in the Pilot project. By TC subsystem cyclic muster of objects (remote terminal units) in system for supervision and control is enabled, as well as “on event” communication between controllable objects and control center. Cyclic muster (pooling), besides the acquisition of measurements, is intended to testing of correctness of communication way between supervised object and control center. For the transmission of acquired data to the control center standard IEC 60870-5-101 protocol in balanced mode, that enables mentioned way of “on event” communication, is used. It is suitable for the systems with large number of controllable objects, such should this system be in future.

SCADA subsystem in control center comprises computer, network and communication equipment and SCADA program package. SCADA application is installed on dual server configuration and HMI control workstation with two monitors.

BACKGROUND NEEDED FOR THE REALIZATION OF THE PILOT SYSTEM FOR REMOTE SUPERVISION AND CONTROL OF MV NETWORK

Concept, laying out and dimensioning of the system phase

For the reason of clear concept and dimensioning of the system, as well as for the reasons of making the Idea project, user must clearly define demands connected to the functioning of the system as the integrity and all its components. Some of the elements that are necessary to specify in this phase are:

- Power energy objects (distributive power stations - DPS and overhead switch disconnectors) that are going to be involved with the Pilot project, data about their location in regard to the control center, all necessary foundations for these objects (for PS: single line diagrams, disposition of equipment in objects, for overhead switch disconnectors: type and characteristics of pole, type of the line)
- Estimated number of objects of MV distributive network that should be involved in the system for remote supervision and control;
- Controllable elements within primary energetic equipment;
- Functionality of remote terminal unit and possibilities and degree of local automatics;
- Algorithm of local automatics work;
- Signals (double and simple signalization), measurements and commands that should be involved in system for remote supervision and control;

- Characteristics and demands related to TC subsystem for the transmission of data between remote terminal unit and control center (sort of communication media, its functionality and transfer protocols);
- Continuity of supply in objects - specify device and time for which it is necessary to supply autonomy of work in case of power failure);
- Architecture of computer and related (network and communication) equipment in control center;
- Functionality that is demanded from SCADA application.

System parameterization and customization phase

During the system realization, in all its phases, close cooperation between purchaser (consumer) and supplier of the system is very important. During the parameterization and customization of system for remote control, with the supplier, as well as "on site", consumer must beforehand deliver his demands and all relevant parameters to the supplier. In this manner, philosophy and algorithm of work of the system in whole is built and additional jobs in period of experimental work are diminished. Time of experimental work is left to the system testing, according to the preset conception and correction of faults that could not have been anticipated.

Foundations that consumer of the system for parameterization of subsystem in controled objects should provide (parameterization of remote terminal unit) are:

- Measurement acquisition cycle;
- Manner of the transmission of measurements: periodically in chosen time interval, when the value of the measurement overrides defined threshold, samples, maximal and/or minimal value of the measurements;
- Value of the change of each measurement that will not be locally archived, nor sent to the center;
- Measurements that are locally archived;
- Measurements that are sent to the control center, without local archiving in remote terminal unit;
- Values of phase and earth fault currents with which alarm is generated and local sectionalizer function is activated;
- Algorithm of local automatics for isolating the line if there is a permanent fault, for each feeder field;
- Manner of local quitting of alarm generated by earth and phase fault current.

For the installation and setup of the SCADA program package, as well as for the input of technical data base and creating graphical display at HMI (Human Machine Interface) control workstation, following data are necessary:

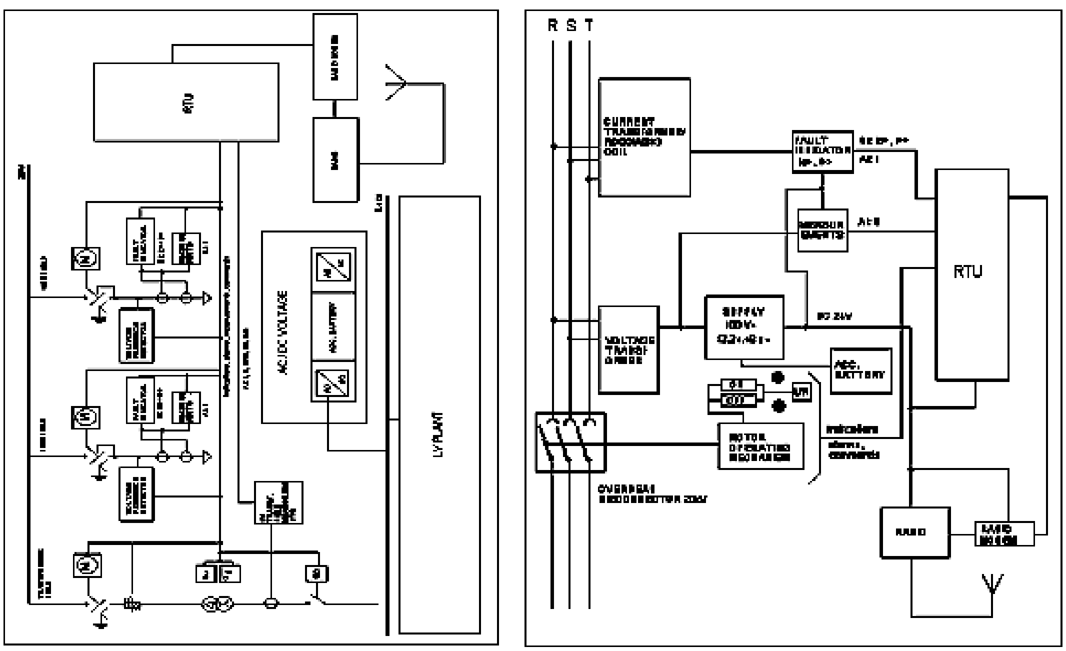
- Configuration and connection manner (architecture) of computer, network and telecommunication equipment in control center;
- Basic graphical display at control workstation - logical scheme of the part of distributive network involved in the Pilot project;
- Single line diagrams of PDO involved in the Pilot system with the description of measurement values and chosen alarms;
- Symbols for all breaker status that are used in graphical displays;
- Criteria and colors used in dynamic coloring of the power lines and elements of graphical displays;
- Manner of commanding of breakers and other devices;
- Constant limits in part of distributive network involved in the Pilot project;
- Allowed actions that dispatcher can perform over elements of graphical display (commands, manual entrance over switch gear and other equipment, manual entrance of measurements);
- Elements of technical data base: code of status, alarm, commands and measurements signals involved in RC system. Chosen manner of coding enables unique identification of each breaker element, signal and measurement in system for remote supervision and control of middle voltage network. Also, by this manner of coding, postulates for exchange of information and data between different SCADA systems and DMS are fulfilled as well as future integration of these systems;
- Nominal values and alarm limits of measurements;
- Appearance and content of events and alarm list;
- Register of alarms sorted by priority with specification of color for printing in the lists;
- Logic for isolating the line in fault, based on which SCADA will give its proposal for the action that should dispatcher carry out in case that local automatics at remote terminal unit is disabled.

REALIZED SYSTEM FOR REMOTE SUPERVISION AND CONTROL

Subsystem in controled objects - remote terminal unit

Realized subsystem for remote control in PDO (DPS and overhead switch disconnectors) comprises remote terminal unit (RTU) and related equipments that enable indication of fault (phase and earth), detection of powerless state in controled object, measuring of specified measurements (current, voltage, active energy and power) and devices of telecommunication subsystem for the transmission of acquired data to the control center.
Functional block diagram of the system for remote supervision and control in DPS and overhead switch disconnectors are shown at picture No. 1
Remote transformer unit, in the most general sense, has the following functionality:

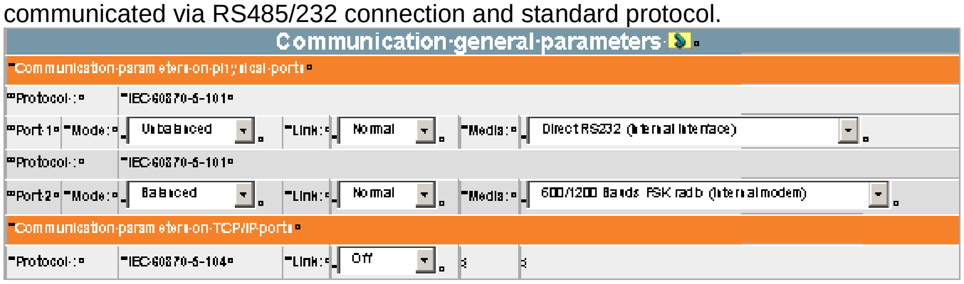
- Acquisition of signals for the status of breaking equipment and alarm signals (digital inputs);
- Acquisition of measured values (analog inputs);
- Commanding over breaking equipment (digital outputs);
- Chronology of the events;
- Synchronization of time to the unique source of precise time;
- Local automatics for automatic isolation the line in fault after the fault detection (phase and earth);
- Local archiving of data on events and values of measured electrical measurements;
- Possibility of blockade of remote control;
- Possibility of the communication with the remote control center via chosen media (radio) and protocol (IEC 60870-5-101, balanced mode);
- Transmission of data to the remote control center via cyclic muster (polling) and “on event”;
- Battery with the charger for continual feeding of the module in remote terminal unit, TC subsystem and motor operation mechanism of breakers.



Picture No.1 - Functional block diagram of the system for remote supervision and control in DPS and overhead switch disconnectors

The manner of operation of remote terminal unit, from the acquisition of specified signals, to the local automatics for isolating the part of the line in fault and manner of transmission of acquired signals to the control center, is determined by its parameterization, based on values and demands of the consumer.

Parameterization of remote transformer unit. Remote terminal unit (RTU) which is used in the Pilot Project is compact and integrated solution designed for purposes of data acquisition, control and automation of MV network. It is used for PS MV/LV in combination with Ring Main Unit, as well as for MV line breakers with motor operation. Mentioned RTU integrates all necessary functionality, as well as the possibility of parameterization, with which it is adopted to all specific demands of power distribution activities. It is modular and easily widened, both with new MV fields and with external digital input and unlimited number of external measuring units or protection with which is communicated via RS485/232 connection and standard protocol.



Picture No.2 Parameterization of protocol at ports

Module for communication with DC has two ports for main and auxiliary (redundant) telecommunication way, as well as additional Ethernet port that can be used both for the connection with laptop and parameterization of the device and for communication with DC via Ethernet network. Each port is separately configurable. The choice of protocol for the communication is done by reading adequate driver.

In the system for remote control in Elektrovojvodina IEC 61870-5-101 protocol in unbalanced mode for HV network is used. Because of large number of expected remote terminal units in MV network, balance mode is chosen. In this mode each of sides (RTU, SCADA) can initiate communication.

Setup of protocol for each port is standard and is consisted of interoperability of parameters for transmission, application, balance mode, general parameters (link and ASDU number) and setup for prevention of parallel emission of two or more RTUs.

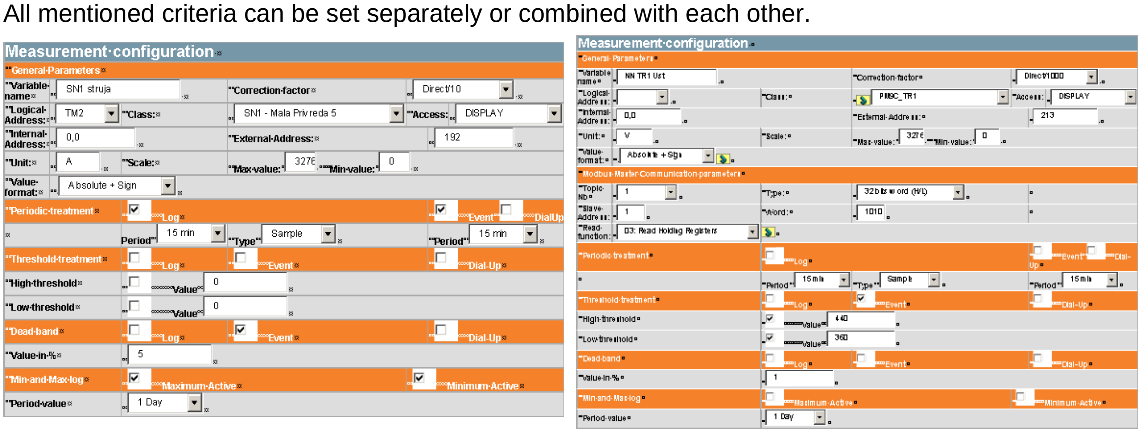
Each piece of information, except division in measurements, signals and commands, is sorted in one of the following categories:

- *alarm* (dial-up) - by whose appearance communication with DC is initialized;
- *event* - that is put in event list and sent to SCADA system during regular muster (pooling);
- *local variable* (log) - that is put in local list and is not sent to DC.

While parameterization of remote terminal unit for processing of measurements, it is possible to define following criteria for archiving or sending to DC:

- periodical saving of samples or average values in time interval of 10 sec to 1 hour (Periodic treatment);
- While overriding low or up set treshold (treshold treatment);
- While changing measurement values for set percentage (Deadband);
- Archiving the minimum and/or maximum for the last 1, 7 or 14 days.

All mentioned criteria can be set separately or combined with each other.



Picture No. 3 Parameterization of measurement of current in middle phase of MV power field and interphase voltage TR1 - Ust

The appearance of certain signals (alarms) such as phase fault, earth fault, Buholc, fault of transformer HV fuse or change of switchgear status, automatically initiates communication with DC and updates alarm state or status in SCADA system.

RTU device has preset signalization and measurement at MV side, coordinated with RMU. It is user's choice to choose which measurements and signals are of interest. For measurements at low voltage side it is necessary to specify measurement devices that communicate with RTU and periodically convey sample measurements.

Local automation. Installed energetic equipments in RMU have controllable switch disconnectors in all MV feeder fields. That enables both local (from RTU panel) and remote manipulation of these elements. Function of local automatics for isolating sections of line in fault by opening of these disconnectors after fault detection (phase fault or earth fault) and powerless state detection is also implemented. Functionality of local automatics can be switched on or of localy from the panel of RTU or remotely from DC. RTU has the possibility of setting more types of automatics:

- *Automatics of sectionalizer* - in time of parameterization of RTU number of detected faults in certain time period is defined, which is condition to fulfill for opening switch disconnector in the feeder that has predefined number of fault currents. This enables amputation of the part of the network that is under permanent fault and quick restoration of supply to all consumers that are at the part of the network before RTU.
- *Auto change over* (option for DPS) - automatic switching DPS to the part of the network that after the fault still has supply. Postulate for this function is that one feeder of DPS has the constant limit, that disconnector is normally opened. In this opportunity disconnector at the part of the network from which DPS was supplied until the detection of cut off is opened and disconnector that was up till then normally opened is now closed.
- *Voltage time* (option for overhead disconnectors) - this function simulates cycle that is like ARC at overhead disconnectors for the feeder of PS HV/MV that does not have sequence of ARC. The point is that at detection of lose of power, overhead disconnectors is automatically opened. After returning the supply, disconnector is switched on and countdown of time t begins. If repeated power loss is detected within time t, disconnector is again opened and further function of automatics is blocked until its local or remote resetting.

Taking into consideration that the most of chosen MV feeders at this Pilot Project are with ARC sequence, automation of sectionalizer with activation in powerless break between quick and slow ARC cycle is chosen. DPS with RMUs are mostly at cable feeders of PS HV/MV that do not have sequence of ARC, so that automatic isolation activates immediately after the first fault detection and opening of the circuit breaker in feeder of PS HV/MV. Detailed setting of automation is expected in test period of the whole system.

Additional functions of RTU. Among additional functions of RTU, besides function of local automatics, following functions can be mentioned:

- Internal memory at circle buffer principle for keeping of important events or measurements in case of telecommunication line fault. Internal memory has the capacity of 2300 pieces of information with time of information appearance (Time Tag);
- Function main-repeater, where RTU has the function of information transmission from DC to some other RTU in case of non existence or break of direct telecommunication line;
- Function repeater-repeater, where two or more RTU in line serve for transmission of data between RTU without direct communication with DC;
- Export of all pieces of information in files of .xls or .csv format and their transmission to laptop;
- Saving the parameterization and configuration of RTU as well as download of new configurations;
- Checking and testing all the functions of the system twice a day and posting the system or its part faults;
- Remote quitting of fault indicators, as well as switching the local automatics on or off;
- Trace function for following the messages between SCADA application and RTU by active protocol.

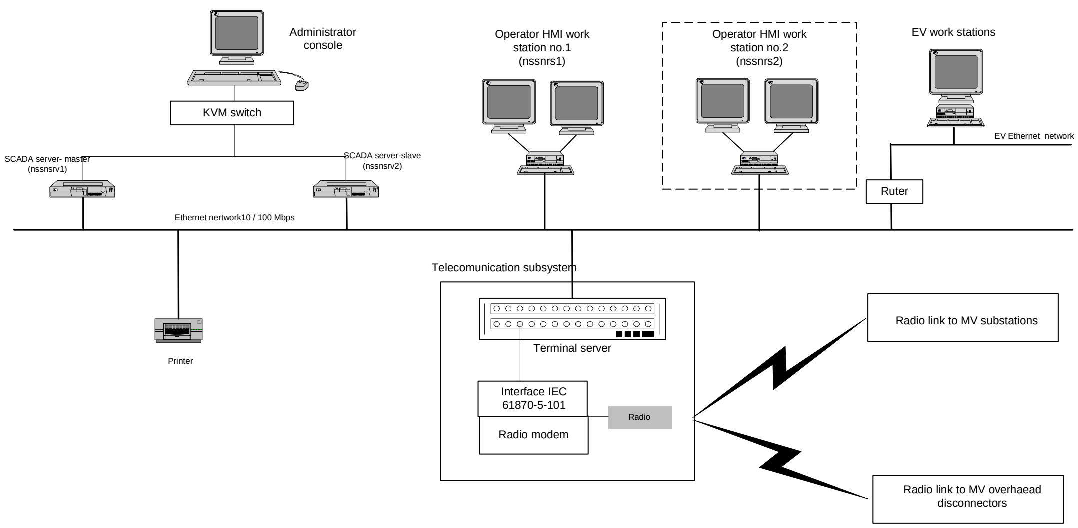
Subsystem in control center - SCADA program package

Short description. SCADA program package is real time program whose basic functions are acquisition of switchgear status, detected faults and alarms and measurements from the system, as well as managing of the equipment and functionality of equipment. Implemented SCADA application is realized through client/server architecture and is implemented on redundant server configuration (master-slave) and one client - HMI control workstation, while additional control workstations are provided for expansion of the system. Server part of the application is realized at Linux platform (Enterprise Linux v.4), while workstation works under Windows operation system and has the licensed XWINDOWS emulation, which enables multiple windows work of Linux applications under Windows platform. Communication subsystem is consisted of one multiport terminal server, radio modem with IEC 61870-5-101 protocol and radio station. Architecture of subsystem in control center is shown at picture No.4

Redundant servers - have two hard disks in RAID 1 configuration (mirror), which enables that while failure of one hard disk, master server can uninterruptedly continue working. Slave server carries out following of the process and in case of failure of master server, starts drivers for communication and resumes remote control system work. Management of servers is carried out via KVM (keyboard, video, mouse) switch, while redundancy of server and configuration of master-slave is regulated with watchdog function. Servers have enough processor power so they pool functions from more virtual machines, mentioned below.

Terminal server - Terminal server i.e. serial port server serves for asynchrony communication with serial equipment (RS232-RS485) and forwards the information to Ethernet network. Serial equipment is: RTU (mainly via modem), GPS receiver, protocol interface ...

Modem - Modems are used to enable communication connection between RTU and machine for acquisition (mainly via terminal server).



Picture No. 4 - Architecture of subsystem in control center

Functions of SCADA system. Installed SCADA program package supports following functions - virtual machines:

- Calculator machine - function of primary processing of information and DMS functions. Redundant configuration because of need for 100% availability;
- Acquisition machine - communication part of the system that manages work of installed communication equipment and different protocols, carries out cyclic muster and answers the RTU calls. Redundant configuration because of need for 100% availability;
- Archiving machine - function of cyclic transmission of measurements to SQL database and archiving event list;
- Configuration machine - this machine has referent data on setting system, objects, libraries, pictures, address information... It also has function of testing the new version of setting before updating databases of calculator and acquisition machines;
- Simulation machine - this machine can work off-line over snapshot of network or in connection with calculator machine, where it works with real time data and actual database. It serves for all kinds of simulations, as well as for dispatcher training through predefined scenarios with surveillance. Not scheduled in the project;
- Study machine - machine with broadened set of SCADA functions, including load flow. Because of already implemented DMS program in Elektrovojvodina, not scheduled in the project;

- Operator (control) console - machine that is not assume to work off-line, but in constant connection to calculator machine. There can be more machines like this one;
- Observer console - any computer in network with installed Xwindows server can be observer console and follow real time condition of network, without the possibility to command or manipulate the system.

Parameterization of SCADA program package. For parameterization of contemporary SCADA systems there is no need for specific programming knowledge. All necessary setup of the system, such as defining the objects and appropriate behavior and inheritance of characteristics of the object, are defined just once for each type of objects. Object is assigned the attribute of alarm, event or signal that does not occur in any list. For the needs of the project three types of alarm are defined: system, priority 1 (very urgent) and priority 2 (urgent). Each alarm, event or measurement is assigned behavior that determines whether the information stays in the list until alarm confirmation, alarm disappear or stays in the list until confirmation and alarm disappear. From such defined objects catalogues are made that are further used for all objects of given type, and afterwards for each object only specific parameters such as ASDU (Application Service Data Unit) and appropriate IOA (Information Object Address) are entered. Graphical display of the cells, feeders, transformers with matched objects that are once defined, are stored in libraries that are later used unlimited number of times.
Appearance of the alarm list and event list is in accordance with the appearance of the list in existing SCADA system for HV network. Complete compilation of the lists, menus, system messages, as well as complete adaptation of the system to consumer (dispatcher) habits is necessary activity in the process of customization of SCADA program. Also, for SCADA systems which manage MV network, because of the size of network and large number of elements, topology estimate and topology coloring of elements, depending on qualification to feeder, transformer or some specific type of object are necessary. Topology estimate is necessary postulate for widened collection of functions of one SCADA system.
Upper functionalities are in basic collection of functions of SCADA control console, while from the particular installed package FDIR (Fault Detection, Isolation and Recovery) functionality can be singled out. This function encircles integrity of automation of MV network. On basis of collected information from observable PEO, function marks parts of network in three colors. The first color is used for the part of network that can immediately after the fault be put under power again. The second color is used for the part of network where the fault has appeared with certain probability, while the third color is reserved for the part of network where there is large probability of fault occurrence. Response of the function, coloring of the network on basis of function results, as well as the suggestion of manipulation for supply recovery is instantaneous after the appearance of the signalization that phase or earth fault has occurred in the network. By this function and remote controled elements, time for detection of potential place of fault is drastically shortened, as well as the time for recovery of supply for majority of consumers. This fulfils the basic aim of the Pilot project that by observation we come to concrete conclusions how big and where is the maximum function benefit, in regard to invested resources in automation.

FOLLOWING ACTIVITIES, CONCLUSION

After the assembly and installation of all system parts, connection, parameterization and optimization of the system in whole, functional examination in each PE object and in control center is done. Functional examination considers checking of all functions of the system:

- Acquisition of each specified signal of status and alarm, as well as change of measurements in PEO;
- Correct transmission of all data according required protocol (by cyclic muster and initiated by remote terminal unit) to SCADA system at control center;
- Display of information at HMI control workstation and their archiving in SCADA subsystem;
- Functions of control console (commanding of switchgear, managing of switch for local/remote operating mode and enabling function of automatic isolation the line whit fault detection, manual entering over elements of graphical display, correct display of information in lists and trend diagrams, ...);
- Functions of local automatics of RTU.

Phase of test work, which on EV demand lasts 60 days, is scheduled for system testing in both Pilot projects, additional optimization and parameterization that cannot be seen in advance, as well as rejection of prospective remarks and faults.
After letting the system work it is necessary to follow the work of both systems for at least one year for the purpose of:

- Checking of applied conception and philosophy of system work;
- Comparing two applied technical solutions (possibilities, stability, reliability, availability of the system, functionality and simplicity of usage of SCADA application from dispatcher point of view, ...);
- Finding the needs and possibilities for their improvement and using full functionality that in implementation phase was not predicted or seen;
- Checking criteria for choosing PEO that will be involved in system for remote control;
- Finding adequate solutions for smaller distributions;
- Methodical following of indicators of reliability and availability of the part of the network involved in Pilot project (number of consumers that are without the supply, lasting of break in supply of power, overall power of consumption of electrical energy of consumers that are left without supply, undelivered electrical energy, time needed for fault resolving) for calculation of SAIFI, SAIDI, CAIDI, AENS and making the detailed technical-economic analyses of payability of introducing remote control in MV distributive network;
- Performing conclusions on dynamics and manner of realization of further broadening the system.

During this period forthcoming activities are connecting existing SCADA system for remote supervision and control of PEO HV/MV (PS 110/x kV, PS 35/X kV and RP 20 kV) to DMS application and SCADA system for remote supervision and control of MV distributive network, both in domain of exchange of acquired data and user actions and on making unique graphical user environment for all three systems.

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