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PILOT PROJECT FOR REMOTE MONITORING AND CONTROL SYSTEM IN MEDIUM VOLTAGE ELECTRICAL DISTRIBUTION NETWORK

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INTRODUCTION

The deregulation of energy market, together with structure reorganization of vertically integrated companies in electrical utility (generation, transmission, distribution) requires efficient and reliable management of distribution network. The main goal is to provide enough quantity of high-quality electric energy to the customers with simultaneously making the business more competitive. In order to meet these goals in an effective way, utilities are required to implement Information Technology (IT) and Distribution Automation Systems (DAS) inside control centers covering all tasks in business operations. Also, for more utilities, faults on the medium voltage (MV) distribution network are the largest single source of supply interruptions. Distribution Automation Systems by monitoring, control and their automation facilities can reduce outage time and upgrade service level. Having that in mind, implementation of modern distribution automation systems are very important for power distribution utilities [1,2,4].

Distribution automation systems are complex systems consisting of following subsystems and devices:

- primary equipment in substations and overhead MV electrical networks adjasted for remote monitoring and control:
    - Ring Main Units (RMU) in distribution substations,
    - Outdoor pole mounted line reclosers and overhead switches,
- fault detectors in MV network,
- control units for remote monitoring and control - Remote Terminal Units (RTU) for MV substations and overhead MV electrical networks,
- equipment and devices for communication infrastructure between network equipments and network control center,
- program support in network control center (SCADA).

EQUIPMENT IN MV NETWORK FOR REMOTE CONTROLING

Network equipments for remote monitoring and control are:

- circuit breakers in secondary substations,
- line reclosers in overhead MV network.

Circuit breakers in secondary substations

Circuit breakers in secondary substations in “Elektrovojvodina” are all without automatic reclosing features. For remote monitoring and control of these substations, first is necessary adaptation of

primary equipment, or changing it with compact Ring Main Units. Adaptation of existent circuit breakers is not cost-effective, so, changing existent equipment with compact Ring Main Units obtains the optimum improvement in design, maintenance and operating performance [5]. Ring Main Units with automatic reclosing capabilities ensures recovering of power supply to the customers in less than a few minute. Protective and automatic reclosing devices housed inside RTUs are consist of three relays for phase faults, one relay for ground faults and one automatic reclosing relay. Built in fault indicator and voltage detector enable fault locating and fault recording capabilities, help to reduce restoration time during a permanent outage by identifying a affected section on a timely manner [5,6,7,8]. For data acquisition, remote supervision and control it is necessary implementation of RTU which is “plug and play” and don’t require additional adaptation inside substation.
New substations, which will be builded in the future, should be equipted with units that meet contemporary demands of automation distribution.

Line reclosers in overhead MV network

Line reclosers and switch disconnectors in overhead MV network of “Elektrovojvodina” are without automatic reclosing feature. So, for remote supervision and control, they need to be changed with switching devices with fault interruption and automatic reclosing capabilities. Today, it could be found many types of overhead switching devices on the market: line reclosers, auto reclosers, pole mounted sectionalizers, switch disconnectors and circuit breakers. They are controlled by a microprocessor based devices and can automatically restore power supply for customers wich are deenergised by a temporary fault. They can be used in manual mode or remotely controlled in combination with a Remote Terminal Unit. As they enable different level of automation features, it is appropriate in project phase to choose switching device which will be incorporated in our overhead MV network [5,6]. It depends on requirements, automation capabilities of switching devices and their cost/performance ratio.
Fault interruption, isolation of faulty sections and auto-reclosing capabilities gives operators the perfect tool to improve network reliability and availability.

FAULT DETECTORS

In electrical distribution systems, fault management is one of the main function of distribution automation in order to reduce outage time [9].
The most often faults in distribution network are short circuit fault and earth fault. Grounding of network, as well as their topology and characteristics determine the philosophy and algorithm of fault detection and location.
Fault indicators are microprocessor based devices mainly used in medium voltage networks, either radial or open ring operated, for detection of the fault and finding the fault location. They can be installed on the current conductors to be monitored, bus bar, cable or overhead line [3,4,5].
Passage of a fault current triggers fault indicators which are able to detect and measure it. The passage of the rated threshold current through indicator results in a signal, either optical or electronic, thus marking the direction of the fault current, starting from the feed point in HV/MV substation. Using measured values and built-in algorithm, as a final result, the estimated distance from the feed point is obtained [5,6].
Although recommendation is to implement fault indicators in both ring main feeders 20 kV (ingoing and outgoing field 20kV), it is enough to provide them only in outgoing field 20 kV, because the fault appearance inside substation is less possible then in the network.
The fault current is measured by one or three core sensors, so, these feature is used for current acquisition, too.
Implementation of fault indicators in MV cable and overhead network is the first step of distribution automation. Remotely controlled fault detectors connected with SCADA in control center significaly reduce permanent outage time with low level of investment.
For the next step of distribution automation (isolating faulty section of the line) it is necessary to have the voltage detectors, too. Voltage detectors indicate the fault as absence of the voltage occurs. When a fault occurs, the circuit breaker of the supplying HV/MV substation is opened first. During the dead time of the line, the first Remote Terminal Unit (RTU) downstream of the line sends a message to next RTU to check the status of the fault indicator in that substation. Having received the message, the second RTU responds to the first RTU and sends a corresponding message to the third RTU. For

example, from RTU3 there is no response, which means that either the fault indicator in the third substation is not “on”, or that the communication path has been blocked by the fault. So, RTU no. 2 makes a conclusion that the fault is on the following section, opens the corresponding switch and sets it in the “blocked” mode. Next, after a certain time delay, the circuit breaker in supplying HV/MV substation is reclosed, and the feeder is reenergized. Voltage detector in substation no. 1 detects presence of voltage for a sufficient long period and resets the fault indicator connected to this section.
Further, if devices in the field are connected with SCADA in network control center, the recorded information is transmitted to SCADA central server. SCADA system adds some more information to the received data, if needed, and all information transfers to Distribution Management System (DMS), in which fault location, fault isolation and supply restoration are the main functions.

REMOTE TERMINAL UNITS

Constant efforts to improve substation supervision and control for many years has brought control units specialized for MV substations and MV overhead line switches in secondary distribution networks.
Main functions of remote terminal units connected to MV distribution objects are [4]:

- data acquisition, remote monitoring and control in real time, that means:
  - control and monitoring of switching devices,
  - data acquisition of switch position and status change,
  - data acquisition of signal alarms,
  - data acquisition and process analogue values,
  - control of switching devices in MV ring main feeders 20 kV and transformer feeder,
- storage of events, counters and measured values,
- chronological time-stamping of events,
- full integration with MV switchgear,
- designed for use without interposing relays,
- metering functions (current, voltage) without transducers,
- detection of phase-to-phase and earth faults,
- specific feeder application automations, such as:
  - automatic fault location and isolation,
  - automatic sectionalizing control,
  - automatic source transfer in purpose supply restoration of healthy section,
- integrated and configurable indications / alarm panel,
- configuration and programming on-site or via remote access,
- interlocking functions,
- back-up batteries supply for:
  - the motorized control of MV switchgear,
  - the enclosure electronic boards,
  - the modems and radios of the communication system,
- switching between “local / remote” control mode,
- synchronization of accurate time and common time reference,
- specifically designed for MV substations and outdoor version for MV pole mounted overhead line switches,
- compact design, small dimensions,
- communication with control center:
  - transmission media: PSTN, radio, dedicated line, DLC, GSM (GPRS), optical link, cable link …,
  - communication protocol: IEC 60870-5-101, MODBUS, IEC 61850 or other standardized protocol,
- possibility of both basic working mode:
  - cyclic or scheduled polling of peripherals,
  - “on event” mode - spontaneous calls originate directly from the peripheral when a severe alarm is generated in the field,
- “store and forward”, etc. repeater function, in case if radio link is used.

COMMUNICATION SUBSYSTEM

Communication between RTUs connected to distribution network objects and control center is provided by communication subsystem using high performance transmission media and communication protocols [9].

Communication subsystem should enable two basic working modes:

- cyclic or scheduled polling of RTUs and
- spontaneous calls caused by RTU when a severe, predefined alarm is detected, known as “on event” communication.

Criteria for choosing optimal transmission media are:

- amount of data to transmit,
- transmission frequency , etc. traffic density,
- structure and type of information to transmit to control center,
- transmission media reliability and availability,
- distance between peripherials and telecontrol center,
- geographically configuration of the area,
- costs of communication devices and media,
- maintenance of subsystem.

Communication subsystem for remote monitoring and control MV secondary distribution network should obey following requirements:

- small amount of data to transmit,
- low speed of communication (optimal row bit rate is 9600 bps),
- a large number of geographically widespread object,
- financial restriction due to large number of objects.

Possible transmission media and technologies for realization of communication subsystem for remote monitoring and control MV secondary network are:

- analog monochannel radio link,
- point-to-point communication over a digital radio with “store and forward” function,
- open digital mobile trucked radio networks realized under TETRA specifications,
- multi-point radio systems,
- WLAN - type of local area network that uses high-frequency radio waves to communicate between nodes,
- GSM system,
- PLC/DLC communication systems using electricity distribution power cabling as communication channel. This is very suitable way of communication for widespread distribution area,
- Two-way Cable TV Distribution Systems,
- fire optic cable. They can be put together with overhead MV lines or inside the same canal with underground power cable,
- communication via classic telephone cable (twisted-pair or coaxial telephone wires) - PSTN or leased lines.

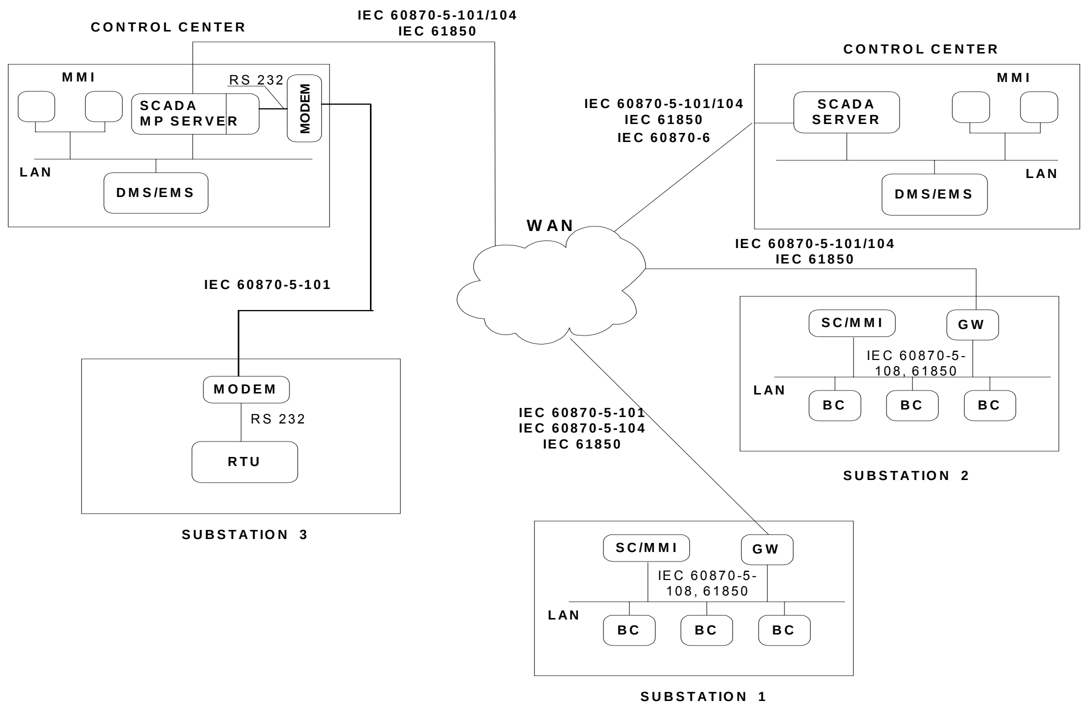
In realization of communication subsystem, decision about used transmission media depends on concrete area and electrical network, location of distribution objects we want to equip with remote supervising and control and costs of chosen variant. Project documentation for telecommunication subsystem should contain analysis of possible solutions and it is necessary to suggest optimal teletransmission link or combination of media which is appropriate for pilot project.

There is a tremendous amount of standards that are applicable to communication between IEDs (Intelligent Electronic Device) within the substation and between substation and control center. The most manufactures and vendors in the area of energy supply offer some standardized, open protocols (IEC 60870-5, IEC 60870-6, IEC 61850, DNP 3.0, MODBUS, CIM, …), but some of them have their own, proprietary standards. The European countries have provided equipment mostly based on IEC standardization. The most used IEC standard protocols for telecontrol systems are [10]:

- IEC 60870-5 Series - bit serial communication optimized for efficient and reliable transfer of process data and commands to and from geographically widespread systems over low-speed (up to 64 kbps) fixed or dial-up connections. The IEC 60870-5 Protocol Standard series specify communication protocols designed for telecontrol systems that require short response times in relatively low-speed networks:
    - IEC 60870-5-103 - applicable for substation automation systems with star coupled protection devices using point-to-point links and master-slave transmission procedure;

   - IEC 60870-5-101/104 - designed for electric power SCADA, where several substations may be assembled into an interconnected installation for controlling and monitoring the operational equipments of a widely distributed electric power system, from central point. The standard defines protocol for teletransmission of data between substations and between substations and control center. The protocol is based on the three-layer reference model EPA (Enhanced Performance Architecture). 104 protocol is used for transmission over a variety of digital data networks. It is a combination of the application layer of IEC 101 protocol and transport functions provided by TCP/IP. Within TCP/IP various network types can be utilized, including X.25, FR (Frame Relay), ATM (Asynchronous Transfer Mode) and ISDN (Integrated Service Data Network);
- IEC 60870-6 (TASE.2) - also known as Inter-Control Centre Communication Protocol, allows data exchange over WANs (Wide Area Network) between a utility control center and others control centers. Data exchange information consists of real-time and historical power system monitoring and control data, including measured values, scheduling data, energy accounting data and operator messages. This data exchange occurs between SCADA/EMS inside control centers;
- IEC 61850 - (Communication Networks and Systems in Substations), designed for Substation Automation in order to achieve standardization of data and service models, etc. open communication within substations. The functions of a Substation Automation System (SAS) are control and supervision, as well as protection and monitoring of the primary equipment and of the grid. These functions require high-speed data exchange and object modeling using Ethernet network and transfer times in the 1 to 10 msec region. The harmonization of data models between UCA 2.0 and IEC 61850 will be an important step towards a world wide accepted standard, when IEDs from all manufactures will be compatible.

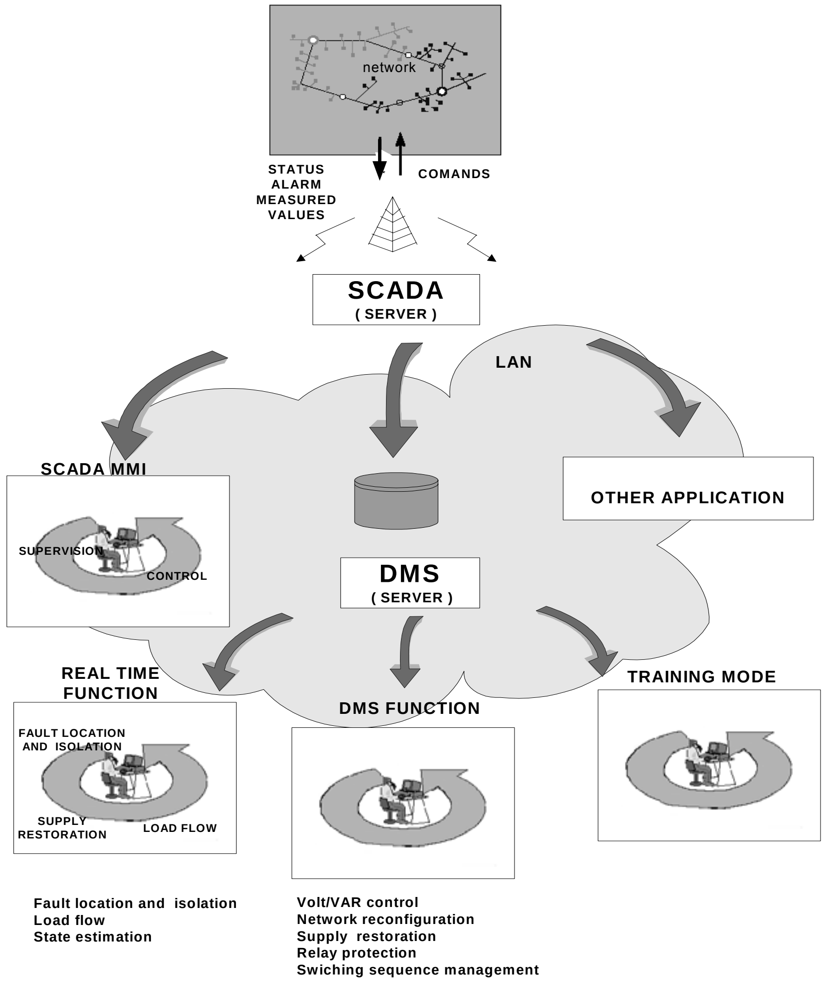
Picture 1 shows a variety of communication standards used for telecontrol purposes in the area of energy supply and distribution.



BC - Bay Controler
GW - Gateway
SC/MMI - SCADA Controler
DMS - Distribution Management System
EMS - Energy Menagement System
RTU - Remote Terminal Unit
MP - Multiport

Picture 1 – Telecommunication protocols for telecontrol [10]

SUBSYSTEM IN NETWORK CONTROL CENTER



Picture 2 - Architecture of the subsystem in network control center

Subsystem in control center consists of equipments (communication equipments, servers, working stations and network) and program support. Program support for distribution automation is based on two applications (picture no. 2):

- SCADA - which ensures real-time and historical power system monitoring and control,
- DMS - which provides advanced network functions, such as: fault detection and localization, isolation of fault line section, power supply restoration on the healthy sections, network reconfiguration, network analysis and optimization, load and voltage/VAR control …

SCADA is core of Distribution Automation Systems. It is dedicated for real-time control and acquisition of process data from devices in substation and in the grid. SCADA provides a communication gateway to electrical network and, on the other side, to higher-level control center and other parts of DAS. It uses existing PC hardware, Ethernet LAN and existing communication standards and links. It can run on different platforms: Unix, Linux, Windows (NT, 2000, XP). SCADA application is often distributed over several computers: SCADA servers and HMI (MMI) workstations which are connected via Ethernet LAN. Database system which saves and organizes the data together with real-time functions are stored on SCADA server. Dual server configuration is recommended. Full-graphic visualization system which supports personnel’s activity runs on HMI workstations. SCADA system should be integrated with DMS system. DMS provides advanced automation functions [11]:

- preparatory analytical functions (Network model, Topology analyzer, Load calibration, Load forecasting),

- analytical functions (Load flow, Fault calculation, Reliability analysis, State estimation, Circuit breakers/fuses capacity, Performance indices, Motor start),
- basic analytical functions (Under load switching, Voltage control, Relay protection, Supply restoration, Network reconfiguration, Capacitor Placement, Energy losses, Volt/VAR control, Switching sequence management, Maintenance scheduling. Load management, Network development, …),
- composite analytical functions (Operation improvement, Fault management, Dispatcher training simulator …).

SCADA form the backbone of DMS, ensuring process data for advanced functions, making it more accurate and reliable on that way.
Connection of two servers (SCADA and DMS) can be realized via variety of standard communication mechanism: COM/DCOM, ADO, OPC, CORBA, RPC.
Final goal is full integration of these two parts in unique Distribution Automation System where configuration of data for the static database will be made from one input point for both (SCADA and DMS) databases. In this way uniqueness of data will be ensured therefore avoiding redundancy. GUI has to be also unique and it has to incorporate functions of both systems.

THE WAY OF REALIZATION

Automation of distribution network should start with realization of pilot project. Objects in MV distribution network have to be selected on the base of accepted criteria for choosing optimal location and number of controlled resources, having in mind that selected objects should comprise entity for testing functionality of the system.
Pilot system should incorporate:

- implementation of remote controlled indicators – fault current detectors on chosen overhead or cable MV network. Fault indicators are simple devices which significantly enable reducing power outage and don't require large investment,
- installation of remote controlled pole mounted line reclosers on chosen feeders of overhead rural MV network, which incorporate fault current detectors for automatic fault location,
- installation of remote controlled circuit breakers in substations 20/0,4 kV on chosen MV feeders in urban cable network enclosing fault current detectors (or/and voltage detectors);
- installation of telecommunication subsystem for transmission of acquired data to control center;
- implementation of subsystem in control center.

During realization of pilot project, and also in further implementation and expansion of the system, it is possible to decide between following solution:

- realization of whole system by one vendor by "turn key" solution, or
- self purchasing and interconnection (with help of vendor or manufacturer of equipment) single components in a system, what is enabled with existence of standardization in all segments.

Before starting next phase of expansion of the system, it is necessary to observe it at least one year to notice and correct eventually remarked disadvantages.
On basis of data from observed pilot project, cost/benefit analyzes of implemented remote controlled system in MV distribution network should be made. These results should define further expansion strategy.

CONCLUSION

Automation of distribution system is very complex task which comprises some different fields: primary equipments, telecommunications, and program support. So, the teams of experts of every field have to be involved in implementation phase. Experience of utilities with automated distribution network says that the best way of establishing system is step by step, through several levels.
Our company decides to start automation of MV network with realization of pilot project. Some substations and overhead line disconnectors in distribution network of the city of Novi Sad were chosen to be introduced in pilot project. Selection was based on the predefined criteria. During design of the project and choice of equipment there are many issues witch need to be addressed:

- algorithm for fault detection and localization, isolation of fault line section and restoration of the healthy sections inside RTUs,
- telecommunication subsystem should be designed with respect of actual distribution network,

- in order to assure accurate and reliable functions of DMS, uniqueness of data and easy usage from the personnel, SCADA and DMS programs should be fully integrated.

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