EXPERIENCE FROM DESIGNING A SYSTEM FOR REMOTE SUPERVISORY AND CONTROL OF MEDIUM VOLTAGE DISTRIBUTION NETWORK

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Abstract
Although the technical solutions in automated objects in medium voltage distribution networks have been operating more than 15 years, integration of contemporary plants for remote supervisory and control into the existing objects is still the engineering challenge. One of the reasons for this statement is the practical problems arising from the integration of automated system into existing transformer stations and pole-mounted switches. The second reason is high expectation from the automated systems in medium voltage network which should justify relatively high investments in distribution companies. In this paper practical experience from designing a system for remote supervisory and control of medium voltage distribution networks, is presented. The problems and possible solutions in designing power and telecommunication subsystem of the Pilot system are presented.

I. INTRODUCTION

The medium voltage (MV) network is responsible for 85 % of the quality of supply problems affecting the final customer. Automation of MV networks pretends to solve contingencies efficiently and reliably, whilst minimizing the consequences of faults and outages, in both extent and duration. Operation of switches and breakers in medium voltage/low voltage substations (TS MV/LV), strategically located in the network is the basis to achieve this goal (1,2,3).

Distribution system automation is multidiscipline engineering task. Although the technical solutions in automated objects in MV distribution networks have been operating more than 15 years, integration of contemporary plants for remote supervisory and control into the existing power distribution objects is still a challenge. One of the reasons for this statement is the practical problems arising from integration of automated system into the existing substations and pole mounted switches. These problems arise due to different type and age of existing power distribution equipments, low technical-technological level of power distribution, landscape configuration etc. The second reason is a high expectation from the automated systems which should justify relatively high investments in distribution companies. In these applications, high efficiency of the system for remote supervisory and control, integration of new blocks into existing substations and poles, simply maintenance and system safety, are required.

In this paper practical experience from designing a system for remote supervisory and control of medium voltage distribution networks on the Pilot project in *Elektrovojvodina "Novi Sad"*, is presented (1). The problems and possible solutions in designing power and telecommunication subsystems of the Pilot system are presented. The following issues are considered: analysis of the customer demands, creating a plan of activities based on the tender, observing the existing state in the distribution network, GPS positioning of the involved objects, functional analysis of the power and telecommunication subsystems, preparation of the single–phase MV feeder schemes, preparation of the substation disposition schemes, checking the static loading of the network poles with remote automated switches, checking the grounding of the poles and substations, over-voltage protection on the poles due to atmospheric conditions, evaluating the quality of radio signals, physical protection of the automated objects etc.

The paper consists of six parts. In the second part the basic elements of the Pilot system for remote supervisory and control of MV network in the city of Novi Sad, are presented. In the third part the main steps of system design including power and telecommunication subsystems, are presented. Fourth part contains some problems and possible solutions in the designing of the Pilot system for remote supervisory and control of MV network. In the fifth part the conclusions are made, while in the last part the references are listed.

II. PILOT SYSTEM

The realization of the Pilot system of remote supervisory and control of medium voltage distribution network in *Elektrovojvodina "Novi Sad"* started in January 2006. The Pilot system in the city of Novi Sad MV network included five transformer stations medium voltage-low voltage (TS MV/LV) in the urban area and five pole-mounted switches (PMS) in the rural areas around the city. The selection of the automated TS MV/LV and pole mounted switches is out of the scope of this paper. All the TS MV/LV are of the concrete pre-fabricated type, with single or double transformers, containing five MV cells. The poles of the 20 kV overhead networks are iron made, 9 -11 m of height. The radio signal is the communication way between Dispatching Centre and the automated objects of the MV network in the Pilot project. The largest distance between Dispatching Centre and the pole mounted switch is about 9 km, while the largest distance between Dispatching Centre and automated TS MV/LV is about 1.8 km.

MV/LV automated substation description

From the automation requirements point of view TS MV/LV consist mainly of several switching devices with electric driven mechanisms, a Remote Terminal Unit (RTU), communication equipment, a power supply with a battery and interconnections (4,6). By means of the digital inputs and outputs of the RTU, the status of switches (open/closed) is detected and the operations of opening or closing switches may be performed. Also, analogue inputs are connected to the sensors in order to measure the current and voltage of the lines. The power supply includes a battery that allows proper working of the system in the event of no LV supply.

Table 1 show main signals used in the automated TS MV/LV (4,6).

TABLE 1. Main signals used in the automated TS MV/LV.

Type	Description
Cubicle Control	Switch status (open/closed)
	Switch command (open/close)
	Earthing switch status (open/close)
Cubicle Sensors	Phase-to-phase and phase-to-earth fault indication
	Medium voltage presence indication
	Load current measurement
General	Substation operation status (remote/local)
	Substation alarm (cubicle, battery)

Figure 1 show typical Ring Main unit in an automated TS MV/LV.

Figure 1. Typical Ring Main Unit in an automated TS MV/LV.

Pole-mounted automated switch description

Pole - mounted automated switch is the second resource for network supervisory and control involved in the Pilot system. From the automation requirements point of view PMS consist of switching device with electric driven mechanisms, a Remote Terminal Unit (RTU), communication equipment, a power supply with a battery and interconnections (5,7). By means of the digital inputs and outputs of the RTU, the status of the switch (open/closed) is detected and the operations of opening or closing the switch may be performed. Also, analogue inputs are connected to the sensors in order to measure the current and voltage of the lines. Power supply includes a battery that allows proper working of the system in the event of no LV supply. TABLE 2 shows main signals used in the PMS (5,7). Figure 2, 3 show pole-mounted automated switches on the iron and concrete line poles of the MV overhead networks

TABLE 2. Main signals used in the PMS.

Type	Description
Control	Switch status (open/closed)
Sensors	Phase-phase and phase-earth fault indication
	Medium voltage presence indication
	Current and voltage measurement
General	Switch operation status (remote/local)
	Alarms (faults, out of supply, battery)

Fig. 2 Automated switch on the iron pole

The control unit is equipped with the sectionalizer automatic control option which converts the PMS into a disconnector switch. In coordination with the automatic network head switch or with the re-closer units, the PMS can differentiate between transient faults and permanent faults in the section in which it is installed, automatically isolating the line if there is a permanent fault. Besides the automated functions of PMS, there is an option of manual operation as well.

Fig. 3 Automated switch on the concrete pole

III. SYSTEM DESIGN

According to the tender the designing of the Pilot system for remote supervisory and control of MV network was performed in two parts:

1) Project of electric power subsystem, and
2) Project of telecommunication subsystem.

Analysis of customer demands
The designing process starts with the analysis of the customer demands. The main issue here is demanded set of alarms, signals and control functions from the automated TS MV/LV and pole-mounted switches, as well as the choice of telecommunication medium.

Plan of activities
The key of the successful designing is making a plan of activities based on the tender documentation. The plan usually consists of the following activities:

- Observing of the existing state in the distribution network,
- GPS positioning of the objects involved,
- Functional analysis of the power and telecommunication subsystems,
- Preparation of the single–phase MV feeder schemes,
- Preparation of the substation disposition schemes,
- Checking of the static loading of the network poles with automated switches,
- Checking the grounding of the poles and substations,
- Analysis of over-voltage protection on the poles,
- Calculation of losses of the radio signals,
- Physical protection on the automated objects etc.

3.1 Electric power subsystem

Technical documentation
Existing of updated technical database of the MV distribution network is crucial in the designing process. Preparation of the single–phase MV network schemes gives the clear insight into the position and role of the chosen TS MV/LV and poles in the MV feeders. Besides, it enables the understanding of functional demands of the customer in terms of fault management as the main power application of Distribution Management System (8).
Preparation of the existing TS MV/LV disposition schemes is the next step in the designing procedure. These schemes are used for integration of the Ring Main Units (6) into the existing TS MV/LV. Since the Ring Main Units are compact, there is no problem of replacing the old MV blocks with the new one. The Ring Main Unit is available in the variants expendable from the right and from the left side, enabling future network developing. However, the crew should be prepared for solving the problem of shortness of ongoing MV cables. The aluminum cable ends do not fit into the Ring Main Units, and these must be replaced with the cupper one. Installing the Ring Main Units need little re-engineering of low voltage compartment in the TS MV/LV.

GPS of the objects involved
GPS positioning of the TS MV/LV, as well as pole-mounted switches, is very important step in the designing process. Despite the fact that poles are standardized (iron made or concrete pre-fabricated, 11-13 m of height), these are all different ones. In order to perform static load analysis of the poles, it is necessary to have GPS positions, as well as photos of all the considered poles. Furthermore, the GPS and photo of the poles and TS MV/LV are necessary in designing the appropriate iron console for hanging up the automated switch and telecommunication unit on the pole as well as the antenna.

Static pole loading
Weight of the pole-mounted switch with lighting arrester including telecommunication unit, is up to 280 kg. Calculation showed that additional loading of the poles due to automated switches, including telecommunication unit, is not the critical one in most of the poles in good condition. Namely, calculated additional loading at the root of the pole due to the pole-mounted switch including telecommunication unit, is less than 2 % of the nominal value.

Grounding system
Experience shows that checking the grounding system of the poles and TS MV/LV is very useful. Furthermore, replacing the grounding system of the poles before mounting automated switches is highly recommended because of the impact of aggressive soil.

Over-voltage protection
Over-voltage protection on the poles due to lighting is solved by mounting three ZnO type lighting arresters on the each side of the disconnector switch. Nevertheless it is up to the distribution company to choose the pole mounted switch solution with or without lighting arrester according to the existing over-voltage protection practice. In the Pilot project the solution without lighting arrester is applied.

Physical protection
Physical protection of the automated objects is highly recommended. There are several efficient solutions for physical protection. Hanging up the telecommunication unit on the pole 3m above the ground, and using sensors for sending alarm in case of non-allowed physical presence to the Dispatching Centre, seems to be a good solution.

3.2 Telecommunication subsystem

Quality of radio signal
In case of radio communication between the Dispatching Centre and automated objects in MV network, the main task in designing the telecommunication subsystem is the radio signal quality analysis. Namely the losses in radio signal transmission have to be evaluated. The radio signal loss analysis is performed for both MV/LV automated substation, as well as pole-mounted automated switches, by using specialized software package *"Hertz Mapper"*. The first step in evaluating quality of radio signal is GPS positioning of the objects included in the Pilot system.

Losses in radio signal transmission were in range of 94.7 dB in case of automated TS MV/LV, to 130.9 dB in case of remote pole mounted automated switches. Experience shows that losing radio signal is not critical in the typical landscape and configuration of cities in Vojvodina. Some problems can arise in the urban areas in case of high buildings surrounding the TS MV/LV, or in case of very long distance between the main antenna in the Dispatching Centre and pole-mounted switches. However even in these circumstances the problem is solved by using appropriate antenna. The radio signal level in every single TS MV/LV and pole-mounted switch should be measured before mounting the antenna in order to determine its best position and orientation.

Antennas
Three types of antenna are used in the Pilot project:
Type A: Corner–reflector antenna for mounting on the TS MV/LV with following characteristics: vertical polarization, half-power beam width, frequency range 360-490 MHz, gain 11 dBi, impedance 50 Ω, max power 180 W. The antenna is mounted 7.5m above the ground.
Type B: Panel antenna for mounting on the poles with following characteristics: vertical polarization, half-power beam width, frequency range 406-512 MHz, gain 9 dBi, impedance 50 Ω, max power 500 W. The antenna is mounted 7 m above the ground, and 0.6 m under the switch.
Type C: Omni-directional antenna for mounting on the top of the Dispatching Centre building with following characteristics: vertical polarization, frequency range 406-430 MHz, gain 5 dBi, impedance 50 Ω, and max power 500 W. The effective height of main antenna is 45 m.

Radio stations
There are several efficient and reliable radio station features for power distribution network on the market. However, in the considered Pilot system, the intention was to apply radio stations from the manufacturer that have already been in common use in *Elektrovojvodina Novi Sad* last three decades.

Two types of radio station are used in the Pilot project:
Type A: Local station mounted in the telecommunication unit in the TS MV/LV and on the poles, and
Type B: Base station mounted in the independent compartment in the Dispatching Centre.

For supplying the radio stations AC/DC converter 230 V AC-24 V DC, 200 W, is applied.

Over-voltage protection. The incoming cables in the radio-communication compartment in both object types (network supply, antenna, and communication cable) must be protected by over-voltage protection units.

IV. PROBLEMS, SOLUTIONS AND LESSONS LEARNED

Currently, the practice for automation of TS MV/LV has some limitations. The reliability of the installation depends on the following on-site works (9).

Wiring signals. Each switching device has several wires connecting the cubicle with the RTU. Typical numbers for a load switch are 9 wires for control, 4 wires for current sensors and 4 wires for voltage sensors.

Installing current sensors. Current sensors are used for phase-to-phase fault detection and load current measurement. They are installed around the MV cable. In order to properly detect the zero sequence current, the earth screen of the cables has to pass through the sensor twice. Otherwise, phase to earth fault indication will be incorrect. The number of current sensors for each switching device is 3, and they are placed in the cable compartment. It means that during the installation process the voltage in the lines has to be interrupted in order to earth the cable.

Installing voltage sensors. Voltage sensors are used for MV presence indication reset of fault indication and polarization of directional fault detectors. The sensors are mainly capacitors coupled directly to the live part of each phase. The small value of the capacitor makes the coupling impedance very high and therefore the signal of the sensor which is a few micro amps, is extremely dependent on the wiring. For dealing with these signals, the length, path and type of the interconnection wires are critical.

Setting parameters and checking. Every function of the automated TS MV/LV and pole mounted switch affected by the task on site has to be checked. Otherwise, there is no guarantee of its correct operation. Namely, all the control signals wired between the switching devices and the RTU have to be checked. Phase-to phase and phase-to-earth fault detectors have to be adjusted and checked. Current testing equipment is necessary to perform the test.

Short-circuit fault detector mis-operation. Phase-to-phase fault detectors can make problems of incorrect indications depending on the characteristics of the MV network. These kind of devices were developed for local indication lighting a lamp when the short-circuit current was detected. Mis-operations were not critical since local indication was reset after a period of time and did not have any influence in the network operation procedure. For automated TS MV/LV as well as pole mounted switch, no mis-operation is allowed since the indication will directly be reported to the Dispatching Centre.

Standardisation. The topology of the TS MV/LV has to be determined in advance in order to use specific products according to the installation. That means that the type of RTU sensors, relays, etc. depends on the number and type of switches and breakers in the TS MV/LV. Moreover, the different devices are often from different manufactures and there is always some engineering work of integration. Each substation is a kind of small project and the level of standardization and flexibility of substation components is quite low.

Authors in (9) recognized the above mentioned problems and limitations, and suggested new concept for distribution automation based on functionality of the new MV cubicles. New MV cubicles developed as single units assembled and tested in factory, satisfy electrical and automation requirements. That contemporary concept in distribution automation is mostly applied in the developing Pilot system for remote supervisory and control of MV distribution network in *Elektrovojvodina “Novi Sad”*,

V. CONCLUSIONS

Integration of contemporary equipment for remote supervisory and control into the existing power distribution objects is an engineering challenge. Devices in TS MV/LV are often from different manufactures and there is always some engineering work of integration. Each TS MV/LV is a kind of small project and the level of standardization and flexibility of substation components is quite low.

In this paper practical experience from designing a system for remote supervisory and control of MV distribution networks on the Pilot project in *Elektrovojvodina "Novi Sad"*, is presented. The problems and possible solutions in designing power and telecommunication subsystems of the Pilot system are presented.

The idea of writing this paper is to try to help designers and field engineers in application of contemporary equipment for remote supervisory and control into the existing MV distribution facilities.

VI. REFERENCES

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