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EXPERIENCIES IN INTRODUCING SUBSTATIONS IN REMOTE CONTROL SYSTEM

D. Dini• , Public Enterprise "ELEKTROISTOK" , Serbia and Montenegro
Č. Spai• , Public Enterprise "ELEKTROISTOK" , Serbia and Montenegro
B. Papić, Mihajlo Pupin Institute, Serbia and Montenegro

ABSTRACT

The paper deals with experiences in preparation of existing 110/XkV and X/10 kV substations for remote control, as well as application of acquired experiences in building of new substations of the same voltage levels. The experiences dated back in the past, when the first implementation is achieved using conventional equipment, up to the modern solving of preparation and remote management/ control with special view at trend in building up of control systems and integrated control and protection systems. Demand for electricity market deregulation causes that control management system must encompass in the forthcoming period remote acquisition of electricity metering for calculation and analysis.

KEY WORDS
Substation, remote control, controls, signaling, measurement, control system

1. INTRODUCTION

Electric power system represents specific dynamic system with almost nearly regular accompanying changes in daily and season level regarding electricity generation and consumption, and which have been affected by incidental situations. Monitoring of changes is permanent obligation of relevant services over more criteria, and accordingly it is necessary to have information electric power generation and consumption balance, and electric power network state.

For efficient and optimal management of transmission and distribution part of the electric power system from a control center, it is required information from managed facilities in order to reach optimal decisions on the system management.

Before introducing this system, changes were undertaken in the organization at existing offices of electric power utilities, as well as expansion of activities in the field of investments, and installations maintenance, and telecommunications and especially significant was establishment of specialized operational expert team. An aim of the team was to develop activity plan on introducing remote control out of the investments field, technical solutions of preparation and substation management from a control center and functional system operation.

Dobrivoje Dini}, ELEKTROISTOK, Knez Milo{ 11, Belgrade

2. WORKS ON PREPARATION OF SUBSTATION FOR REMOTE CONTROL

The first step in establishing substation remote control in technical part is, after completion of study on management of regional electric power network, concrete preparation of substation remote control.
For creating information, type solutions at convenient facility's sections have been carried out and which facilitate further activities in introducing the remote control (RC).
An adaptation of substation for remote control is the most complex stage of introducing RC system in electricity distribution utilities. A basic task would be to establish the following functions:

- remote controls
- remote signaling of equipment operating/ switching status
- remote alarm signaling
- remote measurements
- electricity metering.

The basic approach on adaptation of this information on an existing facility is to use the following information:

- unification of technical solutions
- equipment standardization
- maximum utilization of the existing equipment
- equipment reliability/ dependability by operation.

Remote control system comprises more substations that have been constructed according to designs made in different time periods with diversity of technical solutions and various equipment. That is why the baseline purpose of the type solutions of substation adaptation for remote control are to find application with facilities from various periods.
Solution unification of all facilities has the following advantages:

- simple, standardized, and effective application of technical solutions by design and construction of more facilities,
- batch/ group procurement of equipment for more facilities and low project cost,
- equipment testing and maintenance,
- simultaneous adaptation of more facilities.

In the scope of adaptation for RC, the following engineering solutions are required:

- creation of operation conditions at facility in local and remote operating regime/mode
- local and remote control,
- establishing a signaling of equipment operating status at the facility of remote control
- establishing a signaling of protection operation alarm, power transformer alarm, and automatic unit tripping
- establishing an adapted measurement for remote control
- establishing DC and AC emergency supply
- operating conditions at facility in both operation regime.

Complete monitoring and control over existing facility is made possible by establishing the following remote functions:

2.1 Commands

Commands can be single and double.
Double commands are used to switch on and off facility's circuit breaker.
Single commands are anticipated/ designed to quit alarm signaling and to manage regime of transformer voltage control. Executing controls are monitored through the change in circuit breaker operating status, except in a case of alarm signaling quitting, for which a special solution has been anticipated.
By selection of operation regime at facility, it is performed only one manner of commanding while blocking the other. Commanding has been solved by execution from a single location exclusively.
Local commanding is carried out from control board, cabinet or relay kiosks by means of affirmative control switches.
Remote commanding is performed from dispatch center by means of remote terminal unit, and auxiliary relay contacts positioned at cabinet of galvanic separation. Auxiliary relay excitation is performed by DC voltage from remote terminal unit (RTU).
Selecting a manner of commanding is carried out bay switch from two positions: local and remote position. In the position "local", selection voltages are established for local command and signaling as well as

voltage blocking for remote control. The second position is "remote", in which case voltages are created for remote control, and operation regime signaling, and blocking of local command occurs.

2.2 Signaling
Signaling is divided in two groups:
- indication of high voltage equipment, and central switch status
- protective unit operation alarm.

2.2.1. Indication of the states of high voltage equipment (circuit breakers and disconnector) is position ON and OFF, then live line and no voltage for the overhead line condition as well as for the HV and MV busbars and central switch "local" and "remote" position.
All indications are taken from operating and idle contacts of HV apparatus and central (change-over) switch, whereby two separation relay match to double indication and voltage state at overhead line/ feeder bay and busbars from measured voltage indication relays.
Signaling energizing voltage of auxiliary relays placed at the cabinet of galvanic separation is generated, for each bay, by its own automatic device HV equipment state indication and for central switch general voltage of signaling.
Separation relay operating contacts are used for remote transfer device and are transmitted when contact relays are in closed position and signaling voltage is from remote transfer device.
2.2.2.Alarms are single signaling of protection operation, power transformer faults, protective automatic device tripping, and voltage disappearance from auxiliaries (DC or AC voltage). At existing facilities are applied relay combinations of various manufacturers for light and sound signaling of alarms, which are replaced with relay modules of local and remote signaling functions.
2.3 Measurements
As well as for the local transfer the same measurements are used for the remote transfer:
- currents in transformer and OHL bays,
- busbar voltage
- active and reactive power of transformer
- power transformer temperature
- position resistance of power transformer on-load tap changer
- active and reactive power metering
- DC voltage 110V busbar DC voltage.

Remote measurements happen in relevant measuring converters (of current, voltage, power, temperature and resistance), pulse sensor of electric meters. Remote measurements from converter are analogue information which measured values then convert into current signals and flow continually independent on operation mode.
Active and reactive power measurements are meter pulses/ signals that are transferred to the center by remote control unit, where they are accumulated and numerical value in time unit represents measured energy control value.

3. EXPERIENCES

So far gathered experiences in preparation and introducing of remote control of 110/X kV and X/10 kV substations, from the aspect of design and work execution, can be divided into three groups:

3.1 Substations of more than 15 years of age are, in the scope of preparation for RC, reconstructed to great extent due to deterioration and unreliability of a part of the old equipment and cables. Investment assessments and reconstruction scope plans have been done by competent expert teams who generally also managed activities on RC introduction.
To this group of substations belong the highest number of substations and that is why future analyses and strategies of RC will relate to them.

3.2 Substations of up to 15 years of age have been prepared for RC by minimum reconstruction and additional construction only for the part related to establishing required information by means of new

equipment and cable connections. In relation to the total number of substations, this group involves very small number of substations.

3.3 Design of new substation construction gives technical solutions that include introducing of facility into the RC system.

Design preparation for RC can be brought down to three cases:

- The supplement of the existing design is carried out and with the original design makes one documentation, only if the existing has (satisfying) quality.
- Completely new documentation is developed if there was none or has not been updated, and it is necessary to take photos of the existing built-up state and equipment. In the course of that it is necessary to eliminate use of the old and unreliable equipment and replace it with new and the scope of replacement will be determined by Investor.
- For new substations, Terms of reference and Project anticipate the functions of local and remote control.

4. CONVENTIONAL EQUIPMENT FOR REMOTE CONTROL

Preparation for RC in the past period understood establishing information for facility remote control function using new additional equipment as local interface for existing facilities (figure 1), and that as follows:

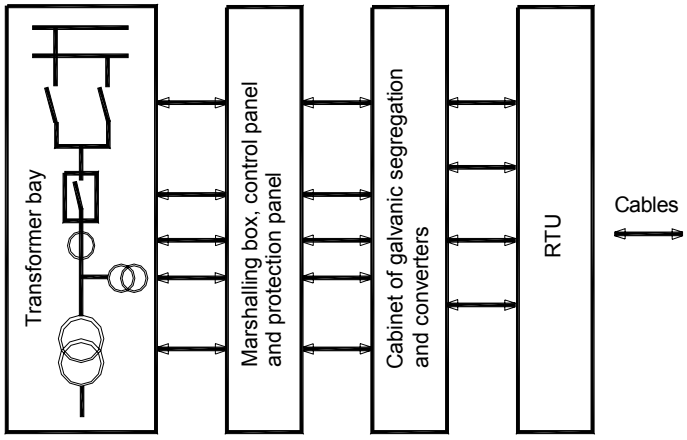

Figure 1- RC principle diagram

- Control and signaling cabinet enables remote control from the control centre, and high-voltage indication signaling. Generally, that were, up to now, relay cabinets for galvanic separation of facilities from remote station sensitive to overvoltages when switching overvoltages at facility occure. The new cabinets have got attestation for installation in electric power facilities.
- Modules of cabinet alarm signaling control the work of protective devices and simultaneously establish local light and sound signaling and remote alarm signaling. These modules are certified for installation in electric power facilities.
- Converters produce measured values in analogue form for remote transfer to control center. Converters can be placed in individual housing or in standard size modules, but selection depends on actual situation at the facility.
- Active and reactive power meters with pulse output convey impulses of certain energy quantum towards dispatch centre.
- Cables are used to connect local interface (cabinet and measuring converters) and remote stations, and they are one of the commanding and signaling cable types adapted for this purpose.
- Fire fighting and anti-burglary signaling unit is intended to signal when detects higher intensity smoke, and by trespassing the facility.

Cabinets of galvanic segregation and converters are conventional interfaces and so far very reliable equipment of the system.

- Remote terminal unit and control centre

In the elapsed period, a number of control systems have been built up using remote terminal units (RTU) as telemetric measuring devices. Terminal module of remote terminal unit provides signal reception from the above mentioned equipment and signal digitalization and transfer to supervisory control centre.
RTU must satisfy very strict conditions regarding characteristics of input terminals: galvanic segregation, breakthrough voltage, dielectric strength, resistance to damped oscillating signal, electromagnetic compatibility, and so on. Conditions for remote terminal units are defined in Internal Standard of Electric Power Industry of Serbia 75/84.
In RTU is mostly implemented standardized communication protocol on remote control devices - IEC 60870-5-1. The protocol provides transfer of great number of data through slow communication channels/ buses (max 1200 bps used) with very high level of data protection from undetected transfer error. Distribution of data by priority transfer classes provides minor but enough data delay at main computer necessary as for dispatching control at dispatching centre of Electric Industry of Serbia and Regional Control Centre(s) as well as at local controls of electric power system facility. The last statement understands the need that unit is capable to communicate with at least two master control centers, and is capable to define separated data set for transmitting in each centre. Most often used RTU in the present time is ATLAS RTU/ AT32, and the unit ATLAS SST still in operation and that since the early eighties, both products of "Mihajlo Pupin" Institute. Today, more than 80 of these units are connected directly or via regional control centre in the dispatching control system of Electric Industry of Serbia.
The described concept of single RTU at each facility represents optimal solution in the time when the processing unit of the device had high price, and when communications between facilities were of poor quality, slow and almost unmakeable. RTU had, at that time powerfull processing unit that could receive and process up to:

- 2048 digital inputs,
- 512 measured signals from converter,
- 1024 controls,
- 32 impulse inputs from electricity meters.

That high number of information was transmitted by modem connection, frequency shift keying modulation, via rented four-wire program lines, radio relay channels or via high frequency channels to control centre (regional control centre, dispatch centre). Time responses on master SCADA unit at control centre are as follows:

- measurement refreshing of 2 sec,
- display of digital information change 2 sec,
- chronological record of signal appearance at RTU - 10 ms, for all connected signals,
- command transfer from centre to RTU with maximum priority - 2 sec,
- reception of cumulative from pulse meters on 15 min.

Reliability of the implemented systems had been satisfactory with very few number of interventions in the initial couple years of operation. As the greatest problem appeared to be unreliability of communication channels, especially the ones not owned and unmanaged by Electric Power Industry of Serbia (rented telecommunication channels). Need for periodical annual inspection and preventive maintenance of units, in a sense of replacement of worn-out parts, was noticed two years ago and now is in realization. That will enable undisrupted operation of the units over the following decade, until conditions concord for reconstruction of as primary equipment as well as of the systems used for control.

5. NEW EQUIPMENT FOR REMOTE CONTROL

In the last ten years, what happened was technological revolution in the manufacturing of equipment for control with integrated functions. Comparing this with conventional equipment, it can be stated that new equipment posses lots of advantages and incomparably greater possibilities than conventional.
Remote control of the before mentioned group 1 substations will be targeted substation group and will be subject of analyses aiming to decide what solutions to accept. Analysis need to include:

- a scope of replacement of existing primary equipment,
- a scope of secondary equipment, first of all replacement of relay protection and automatic equipment,
- cable replacement.

In a case of greater reconstruction on facility, a study on reconstruction with proposed variants need to be prepared, and will include technical and economical analysis and decision on scope of works. A decision on preparation of substation for remote control will probably be made for unified protection solution of that part of facility, signaling, and control over state-of-the-art individual units or using integrated protection and control systems. New equipment is set of digital intelligent electronic devices (IED) with a number of possibilities and advantages in technical and functional meaning (fig. 2)

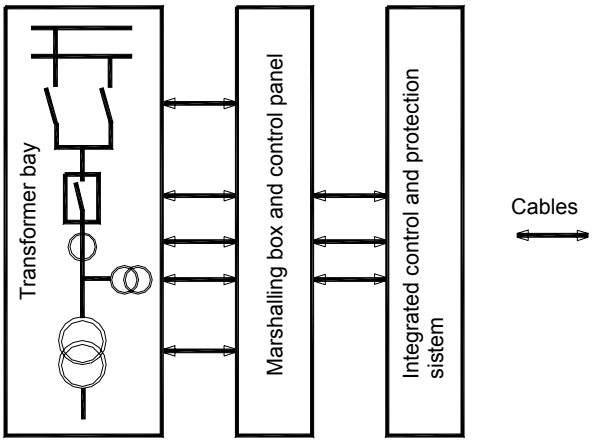

Figure 2 - IS- Integrated sistem (control and protection)

Purpose of the introducing of the facilities, which are the subject of interests in preparation for remote control need to be observed through two separate analysis:

- introducing of new equipment in facilities where already exists done preparation for remote control with RTU,
- introducing in remote control for facilities completely reconstructed or being constructed with new equipment and integrated control systems.

5.1. Facility with existing adaptation and RTU

Installation of new microprocessor-based equipment (IED units), first of all numerical protection, interlocking unit and different classes of units for intermittent occurrence measuring and recording, in some facilities already implemented into the dispatching control system is highly intensified in the past two years. Technical requirement for implementation of these facilities in Technical Management System was not approached systematically and not paid attention that deserves.

The most one installed have been numerical protections of the leading manufacturers (SIEMENS, ABB, ALSTOM, GE). they have been installed, tuned up and put in operation, and in this paper that segment is not considered. The existed protection had been dismantled, and relay outputs with new protection were connected to existing signaling cabinets, and being introduced in RTU. In that manner the same functionality has been achieved that had already existed with the old protective units. The number of signaling tapped and connected to the existing system has not been changed related to the conventional solution, so that the quality and functionality of the units installed has not been given much of a chance, but remained the need of maintenance of the overall equipment used with conventional RC solution.

Technical solution, which should be taken into consideration by installation of these units, is direct connection of these IED via communication channel to the existing RTU, or control system. That would simplify the installation, remote control system could be in disposal of information possible to obtain via communication protocol from protection. Information quantity and contents, exclusively in monitoring regime, would depend on need and technical transportation capabilities to supervisory control center.

All installed units dispose or may dispose of communication interface and standardized communication protocol. As communication interface optical communication interface is to be selected, which is immune to interferences and may provide reliable information as with units mounted in the close proximity of switchgear as well as with high communication speeds. Every manufacturer offers its own protocol (for instance SPA with ABB unit). which is more or less open and declared, but as option is also available international standardized IEC 870-5-103 communication protocol.

IEC 870-5-103 protocol enables IED to connect with master units of the other manufacturers. Usage of this protocol can provide great amount of information. In the monitoring regime is possible to obtain:

- effective voltage and current values of the system whereat the unit is connected
- circuit breaker operation status
- actuating of all levels of protection functions implemented in the unit, with chronological recording of events
- records of analogue and digital numbers by outage/tripping with high time resolution (trip record)
- unit setting parameters.

What of these data make sense to be transported to the supervisory center depends on the quality of the transportation path between the facility and the supervisory center. If transportation path of high trafficability performance is provided, it is possible to transport all the data to the master system, then after ensure that these data are disposable to all data-required services. For dispatch management, the instantaneous values of voltage, current and power are interested as well as operation status along with signaling when alarm signal appeared and for protection and analysis service, tripping and HRD records represent subject of interest, which at the moment are obtained only on site and direct reading from the unit. The manufacturers of the units offer this functionality as option if customer access by modem connection via public telephone network, because phone socket exists almost in every facility, but this solution has sense in a case of availability of only insignificant number of installed units. The judgment of the writers of this paper is that we should strive to solution which could over always live connection ensure data transport enabling instantaneous processing and analysis. That technical solution requires installation into facility some kind of "gate way" unit capable to provide separation of common fast link towards the center into the existing RTU and the new IEDs installed at facilities. In that way, SCADA server at master control center would also collect the data direct from IEDs.

Another approach should be for the case of slow and poor quality channels towards facilities where RTU has to have implemented master protocol, and from slave IED would gather data and transport them by means of existing channel to control center. In this case, from IEDs could be collected only data on instantaneous measurement values, operation status, and HRD record, because no technical conditions exist for transport of the trip record over slow channel. As benefit this solution would have easy and cheap installation, maintenance -free controls cabinet, signaling and measuring converters of reconstructed bays and would enable step by step installation of units in the transitional period when EI of Serbia realizes/ establishes links between the facilities in the scope of the telecommunication project/ design using OPGW cables and proper terminal communication equipment.

5.2. New facilities with integrated systems

Construction of new facilities involves also installation of integrated systems of monitoring, control and facility protection/survaillance. These systems arrive along with primary equipment and usually are, like primary equipment, of the same manufacturer. The systems are of the local distributed character with communication concentrator that provides compilation of all data from the facility and in information sense as unique teleinformation entity. These systems are installed with or without local presentation system, but option with communication unit must be included that provides connection with supervisory control center over a standard protocol and over standard communication interface. In that case, the system with its configuration software tools can be configurated to transfer data set to master center. Selection of communication interface depends on available communication channel (from radio to ethernet), and communication protocol most often used is IEC 60870-5-101. So far, several of this facilities are connected in the system of dispatching control:

- 220/110/35 Bor 2 Substation with integrated ABB system in the Elektroistok's control center - Regional control center "Bor",
- 110/20 Nova Pazova Substation with SIEMENS LSA system in the control system of the Electricity Distribution Utility "Ruma" - Elektrovojvodina Novi Sad
- 110/20 Kacarevo Substation with SIEMENS SINAUT LSA system in the control center of the Electricity Distribution Utility "Pancevo" - ELEKTROVOJVODINA Novi Sad

Such realized links provide complete monitoring and control over facility. In the monitoring regime it provides transport of measurement, signaling, alarm, and HRD to supervisory center, providing also commanding over switchgear operating in the remote control regime. Communication protocol provides satisfying response and due to use of radio link it is a must to ensure capability of functioning

other manufacturers' units on the same radio channel. The most common application is that on the same radio channel have to communicate already existing RTUs and new systems with their own protocol variants.

CONCLUSION

In the forthcoming period there is a need for reconstruction of substations of different size and character, and also for significant investments in modernization of the existing facilities aiming to set up efficient and reliable electric power system.

The necessity to take into consideration all variants of quality -delivering implementation and operation of new units by existing conditions with dispatch control is more than obvious. Various variants presented in this short analysis should only give initiative in order to, at existing facilities, with installation of good quality secondary equipment components, get certain quality also in the control centers with expanding data set they are collecting. Also, it has existed a wish to move domestic suppliers of RTUs and systems for control centers (the greatest in number) to carry out in reasonable time modification of their systems so they could be able to respond to the needs and capabilities in operation of units installed or the ones to be installed.

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Dobrivoje Dini}, ELEKTROISTOK, Knez Milo{ 11, Belgrade