RECONSTRUCTION OF FOUR BIGGEST DISTRIBUTION CONTROL CENTERS IN CROATIA

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1. INTRODUCTION

After a long period of planning and negotiating about new control centers in Croatian distribution, finally in December 2004 Contract has been signed for reconstruction of four biggest ones: Zagreb, Rijeka, Split and Osijek. Beside the reconstruction of old SCADA system (PDP based systems installed during 1980s), new system will also have advanced SCADA functions and functions for network analysis. Originally, this project was named SCADA/DMS.
In the first phase of the project, only central hardware and SCADA/DMS functions will be installed, while communication and RTU parts will still remain. The project has duration of 28 months and installation will be in phases separately for four centers, Zagreb as first and Osijek as last. It is planned to commission system for Osijek in August 2008.
To be able to better understand scope of new system, let us first to quote definition of DMS according to document: IEC 61968-02-1 1998. "System Interfaces For Distribution Management - Part 2 Glossaries":
"System which integrates all tasks in distribution utility and can consist of following parts:

- Information about customers and metering
- Trouble Call System
- Call center
- Network Operation
- SCADA system
- Network Analysis
- Work Management
- Planning and network design
- Geographical information system
- System maintenance"

According to that DMS definition, we can say that present project in four biggest distribution control centers in Croatia is actually Network Management System, subset of DMS, because only network analysis functions will be installed with SCADA system. NMS has goal to control and operate distribution network. NMS consists of special software to insure interface between Operator and System: control via single line diagrams, preparation of network for daily schedules, and allows operator to interact with other functions and subsystems, like GIS, TCS, and Network Analysis.
In documentation of different system suppliers we still can, due to historical reasons, find term DMS in names such as SCADA/DMS, but according to mentioned standard it should be SCADA/NMS (Supervision Control and Data Acquisition /Network Management System).

Lots of countries with experience with market opening and liberalization has installed SCADA/NMS systems, and presented them as successes in achieving of goals for distribution network operations.

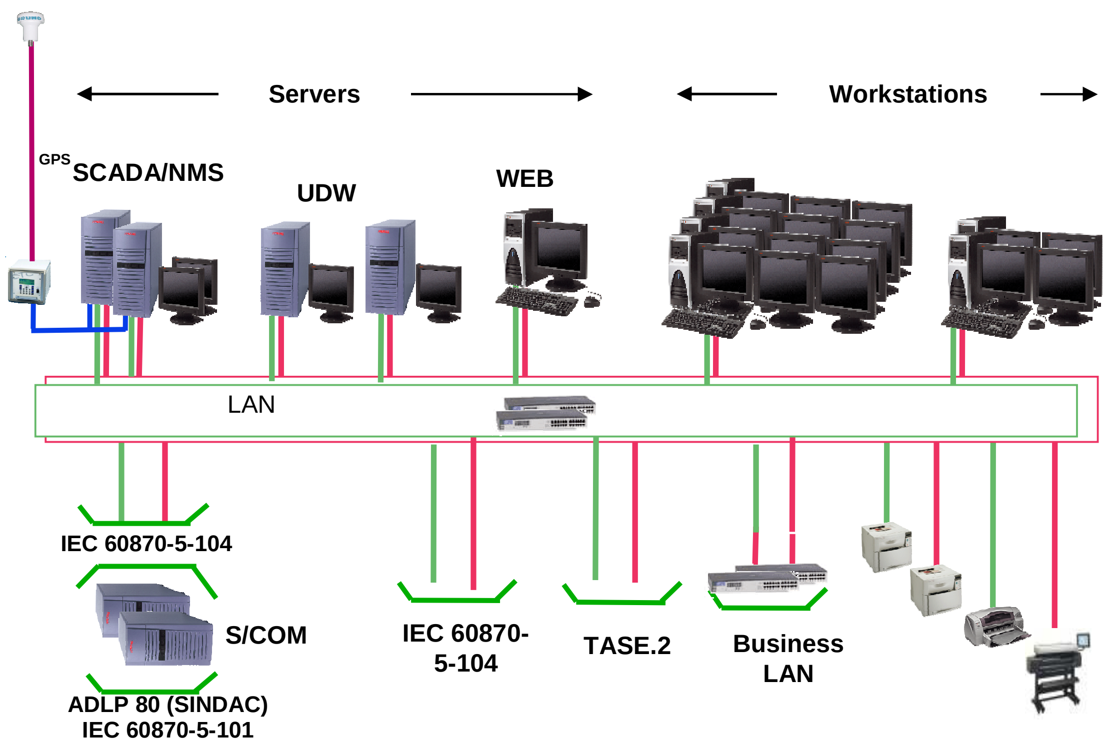
After few first steps for installation of such NMS systems in Croatia, factory and site acceptance tests, we can conclude that this is very long, demanding and multidisciplinary task.
With basic and advanced functions of SCADA systems, in four biggest distribution control centers will be installed following NMS functions:

1. Dynamic network Coloring: beside of standard coloring mode, island coloring, source coloring, color district coloring, voltage level coloring, interconnection tracing...
2. Load calibration: preparation of network for Load flow calculations by adjusting of database values with real-time measurements of current, voltage and power.
3. Load flow calculations: calculations of voltage and current values through out the network in on-line and study database.
4. Short circuit calculations: calculations of short circuit currents for different kind and place of fault.
5. Load forecast: calculation of values in network in order to plan and predict future behavior.

In continuance of this paper, after short description of system configuration, accent will be on preparation and using of NMS functions.

2. SYSTEM CONFIGURATION

New central part of SCADA/NMS systems have hardware configuration shown on picture 1. It consist of HP Alpha servers DS25 in redundant configuration (on-line and hot stand-by) for SCADA and historical database (UDW), HP Windows workstations with one, two or three monitors, Intel based web server, redundant LAN, printers and new communication interface, S/COM.



Picture 1: System configuration for SCADA/NMS systems in Croatia

Software system is based on HP True Unix operating system for SCADA/NMS and UDW, Windows Server 2003 for web server and Windows XP for workstations. All SCADA software is installed on Alpha servers, while workstations are used only for graphical interface and HMI. Historical database uses ORACLE platform for data storage.

System complies to open systems standards and can be integrated with other systems through number of interfaces:

- ODBC for real-time and historical database
- COM/DCOM for application integration
- Web interface based on JAVA runtime environment…

3. S/COM

New communication interface, S/COM, is custom made product and integrates functions of front end processor and protocol converter. Since all communication and station equipment remains for this project, together with ADLP-80 communication protocol, it was necessary to adapt its communication to standard protocol IEC 60870-5-104. S/COM is based on QNX operating system and on standard industrial PC and has following functions:

- communication with RTUs and substation automation equipment over ADLP-80 protocol what required development and design of new hardware components to use in standard industrial PC
- communication with RTUs and substation automation equipment over IEC 60870-5-101 protocol where it is possible to replace communication equipment
- communication with SCADA/NMS system over 60870-5-104 protocol.

4. NETWORK MODELING

Preparation work on the system, if we say that installation was successful, starts with defining of naming convention for all elements of distribution system (stations, voltage levels, busbar, bays, switches, indications, measurements, transformers...). Goal of this naming convention is unique format for names of elements and easier maintenance of database.

Second step is creation of topology while drawing the network and entering some basic data in off-line database (minimum for name and voltage level). Topology is the basis for all NMS functions to be installed and must have connection of all network from each energy input (substation 400/ 220/110 kV or power plant) up to last point of consumption we want to have in new system: feeders 10(20) kV in substations X/10(20) kV, transformers 10(20)/0,4 kV or even customers in 0,4 kV. In this part of work it is very important to decide where to model sources in the network, because for all network analysis it is necessary to have them (P Q, P V, or “slack bus”) and consumers. These sources are invisible to operator, and instead of them dispatcher sees values and directions of currents and powers on the borders of his network.
Beside for network analysis, sources can be used for dynamic network coloring to determine which part of the network is energized. Alternative is to use voltage measurements for that determination, what is case in these four new systems.
Creation of network topology allows user to use all options and modes of dynamic network coloring.

Third step is entering data for NMS functions. In principal, all electrical data which influence values and distribution of voltages and currents must be entered for: transformers, lines, sources, compensators... Data about switches and busbar do not influence results, but can be useful for control of results and limits supervision. All these data can be easily associated with technical database in utility, which can be used to import data in off-line database and to shorten period for entering the data.

Fourth step is definition of results (voltages, currents, powers…) to be shown on single line diagrams in parallel with real-time data. Of course, all calculations in the system give full results, which can be seen in files or reports, but presentation of results can be very useful in parts of the network that is not remotely supervised, like MV network.

At the end all data have to be transferred in real-time database to ensure good performance of the system. Demand for all NMS functions is to complete in few seconds, and that could not be fulfilled if data are taken from other database instead of real-time database.

5. LOADS IN THE NETWORK

Special process in data preparation for NMS functions are data for network loads. Easiest part is to define where to put them, but most difficult how to define them.
To define one load in the network, equally important for network analysis as sources, one can choose out from three methods:

1. Typical load method,
2. Customer classes method,
3. Billed energy method.

First method looks simplest in which load is defined to have typical value which is constant number of kVA, maybe with constant power factor. This kind of load is in reality at least accurate, and that is why for each load can be entered data for daily profiles: pairs of relative values of P and Q (values form 0 to 1) for each hour in a day which is multiplied with typical value to give real load.
Further on, in the system it is possible to define profiles for four seasons in the year, and for each season more day types: Monday, Tuesday and Thursday together, Wednesday, Friday, Saturday and Sunday, and special day, to make total of 28 daily profiles for each load.
To use second method (customer classes) it is necessary to define several classes of customers and with them maximum of 28 daily profiles. Classes can be defined as households, industry, small stores... and after that to each load in the network class with the number of customers of that class are connected.
Third method is based on the formula to get typical load out of monthly billed energy and number of customers on that load. With that value of typical load, also 28 daily profiles can be assigned.

$$S_{Typ} = \frac{n}{170.37} \cdot \left(\frac{E_{Cust}}{n} \right)^{0.8865} \cdot \left(\frac{2.204}{n^{0.557906}} + 1 \right)$$

S_{Typ} = Typical load in kVA
E_{Cust} = Monthly billed energy for load in kWh
n = number of customers

6. NMS FUNCTIONS

As mentioned before, in the first phase of this project for biggest distribution control center as NMS functions will be installed:

- Dynamic network coloring,
- Load calibration,
- Load flow calculations,
- Short circuit calculations,
- Load forecast.

6.1 Dynamic network coloring

Function of DNC is already present in lots of old existing systems, but now this function is based on the topology of the whole network, and not only on topology for one picture.
For each window on operator's workstation different DNC mode can be used. In new systems all DNC modes are defined as global or local.

Global mode of DNC is shown with the same colors on all workstations with following options to use:

- Status coloring: energized, de-energized, earthed, inconsistent;
- Island coloring: same color is applied to parts which form one island. Groups are divided with open switches;
- Color district coloring: user can predefine in off-line database what part of the network he wishes to have different color, and to show them on workstation;
- Node coloring: each node is group of all equipment connected together and separated from other group with lines, transformers or open switches;
- Source coloring: every part of the network fed from different source is colored differently: Source can also be transformer, line of feeder;
- Voltage level coloring: each voltage level has different color;

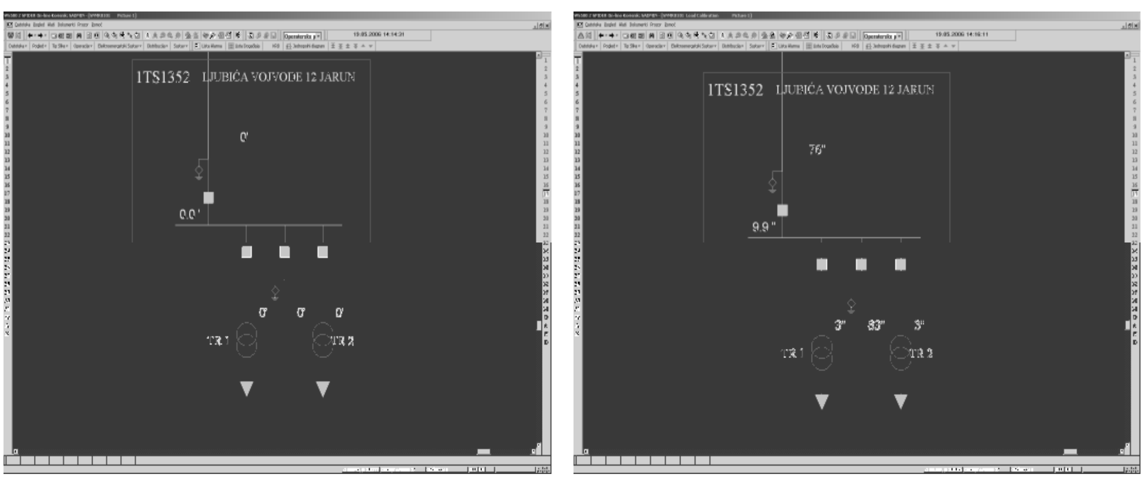
- Tag coloring;
- Subsystem coloring: during data entry all elements are assigned to subsystems to be used for authority definitions.

Local DNC mode is shown with color defined interactively by operator. Following options can be used:
- Interconnection tracing;
- Source tracing;
- Load tracing;
- Main source tracing.

6.2 Load calibration

Load Calibration function is the basis for all other network analysis functions. This function in principal does balancing of the system in order to have realistic situation. From the beginning it can not be expected from user to enter all electrical and load data correctly, and to have all real-time data updated and correct. Because of that this function is very useful. First it collects all data about loads, together with used method and corresponding daily profiles and makes comparison with power sources in the network. Sources are considered to have as input some measured or calculated values. Next step is to calibrate loads to make there total, at worst, equal to power from sources. To make the calibration, all real-time measurements are used, but the one on higher voltage has bigger weight factor.

For example, if there is on 110 kV voltage level measurements of voltage and current on transformer bay, they have to be consistent with power measurements, as also measurements on lower side (i.e. 10 kV). Depending on topological placement of loads, their values are calibrated accordingly, but relative proportion between loads calibrated with the same real-time measurements must stay equal.
After that step, function starts load flow to take into account losses in the network and makes more detailed calibration. The result is the best possible distribution of voltages and currents through out the system. It is clearly visible that benefit from this function is to have states of the not supervised network parts, like MV network (Picture 2), but also for incorrect measurements that can be corrected. This is basically state estimation function for distribution network. Algorithm for estimation uses Hatchel's nonlinear method of least weighted squares with linearization in working spot.



Picture 2: Single line diagram and process data for 10/0,4 kV substation before and after load calibration

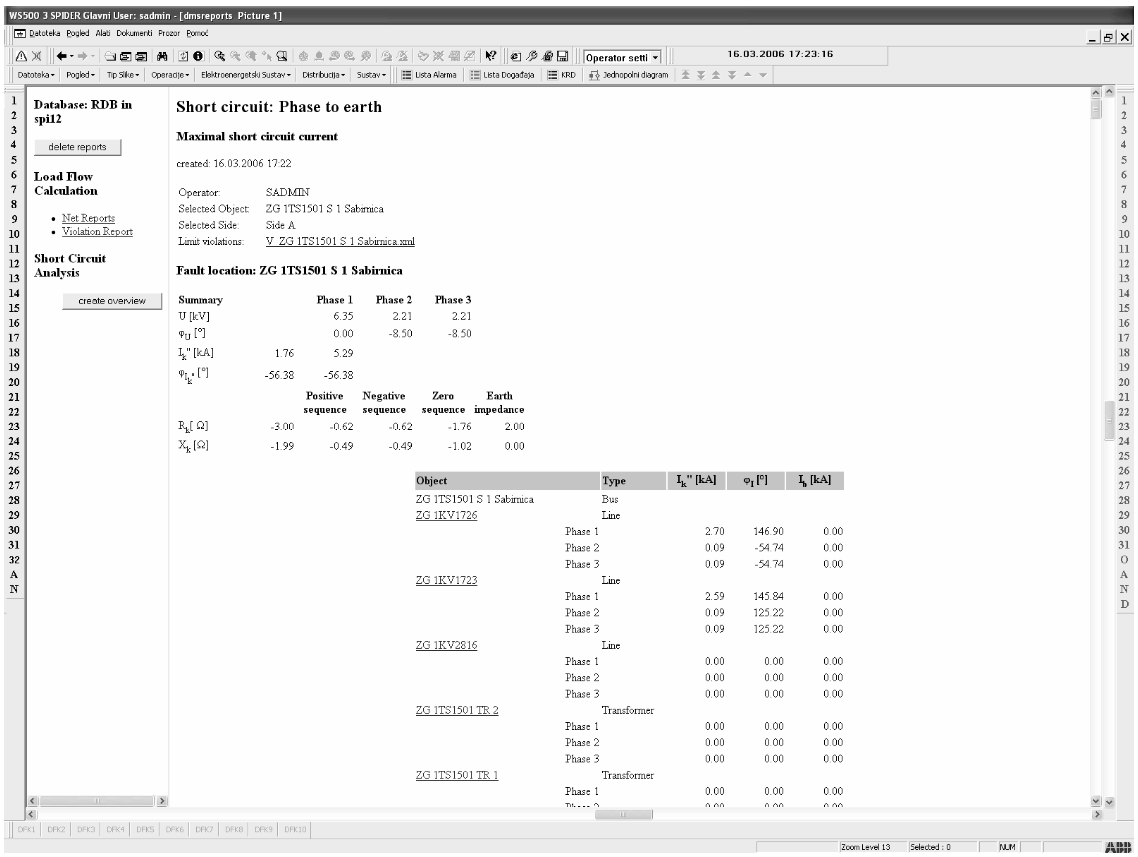
6.3 Load flow calculations

Load flow NMS function uses results from load calibration as input and executes only in connection with it. Results of load flow calculations can be written in file or seen with tool tip on selected network element. Load flow can be executed on-line or in study database.

In study database it is possible to make copy of real-time database with all existing parameters and calibrated loads. In real-time after topology change, load calibration is automatically triggered, but in study database that is not possible. Reason for that is to have calibrated loads as template for simulation of topology change or loading in the network and to see how will network react using load flow calculations.

6.4 Short circuit calculations

Short circuit calculations is not a function that can be executed periodically or automatically, but always need operator to enter initial parameters. First it is necessary to define place for short circuit: busbar, transformer, line; then to define type of short circuit: three phase, one phase to ground, two phase and two phase with ground; and sometimes, impedance on the fault location. Based on that, function starts calculations and shows result on single line diagrams, if defined so in off-line database, or in the form of report (Picture 3). Result is current on the fault location and distribution of currents in all parts of the network connected with fault. In case of unsymmetrical fault, even phase currents are reported.



Picture 2: Short circuit calculation report

6.5 Load forecast

Load forecast function has integrated model of expert system (artificial intelligence) capable of establishing correlation between historical values of different data types with time series, and based on that predict its future values. Basis for this function is historical database filled with data from SCADA system. Historical database uses ORACLE platform, thus making possible to access data from external applications. In this case, it is possible to establish connection between substation loading, and total loading in the network, with air temperature and/or other meteorological influence variables. Used expert model is generic and can be used for predicting all kinds of values (current, power, energy, flow…) with meteorological data like: temperature, brightness, humidity, wind…

To use this function we have to have good enough prediction of meteorological data for future time in which we want to predict system values. Usually this time is one or two days, or one week. Longer period will give less accurate prediction, based on weather data.
For prediction model function uses Kalman filter, and in case that correlation with weather data is not needed exponential smoothing is used.

When load forecast function is used at the beginning, prediction will not be correct enough because of small amount of historical data. Experience with this function gives period of at least two months to have useful prediction, optimally one year. Of course, thanks to used platform it is possible to import historical data from other systems.

When using load forecast function it is necessary to make three steps:

1. Initialization of the model – in this step function collects all historical data for values we want to predict (usually hourly values during day), historical weather data (one or more, but maximum of six), and makes correlation between them. User can define how long in past data will be accessed, by default this is one year.
2. Adaptation of the model – this step is needed only if initialization is done few days ago, and we want also to include data stored from then up to now. In that case model from previous initialization is adapted with new data.
3. Prediction (Forecast) – in this step given model takes into account entered data for future weather data and makes prediction of desired values, also as average hourly values during day.

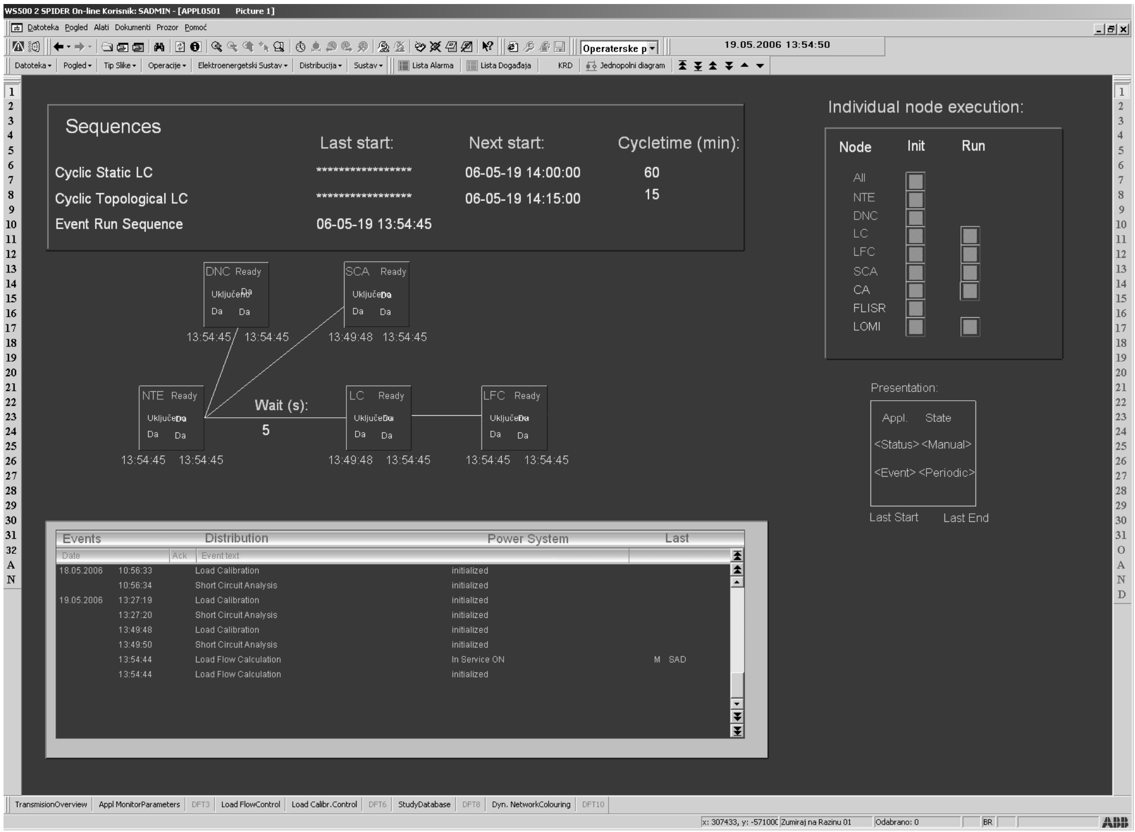
Results of forecast can be analyzed on graphical interface, or as one value in the trend on operator's workstation.

7. USE OF NMS FUNCTIONS

After data entry, topology creation and population of real-time database, it is necessary to know how to use all functions, to initialize them and to understand the results.
On operator's workstation user can (depending on authority level) control all functions. Each function can be stopped, started or configured for cyclic execution or event execution.

Each workstation has defined special picture (Picture 4) for supervision of functions in order to have full information about all NMS applications and to see their execution. Monitoring of functions include data about all attributes of applications: cyclic start or event start, active or stopped, waiting for preceding application, i.e. load flow calculations can not be performed before end of load calibration function, or if there is any error in function.
On the same picture user can define period for cyclic execution, delay time after topology change (it is reasonable to wait until all statuses in network have been stable to calculate the network) and to start function manually.
Short circuit calculations and Load Forecast can be started only on request with definition of all input parameters.
Results of all functions are shown on single line diagrams for operator and written in xml formatted files, which can be accessed from workstation or some other computer via web interface (Internet Explorer). All reports have type of calculation, time and location of elements and results in forms of tables.

It is important to say that performance of this system for NMS functions is very good, meaning that all calculations are done in few seconds. Because of fast performance it is possible to use them in real-time system.



Picture 3: Monitor for NMS functions

8. CONCLUSION

Project for NMS implementation is very long and complex process, very demanding for data entry and modeling of whole distribution network and takes lots of time. But, bigger effort made for that means better and more accurate results. Accent in project must be given on operator’s education for NMS functions, as for system engineers, network designers and power engineers. With good education and accurate results all users will be more confident when using functions, be able to make conclusions out of the results and be more efficient in network operations and development. With that, planned goals for lower losses, faster operation and optimal investments will be achieved
With new system users will get also possibility to access data from web interface, thus making control center more transparent and more user-friendly to employees in other departments.