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# Smart grid substation equipment maintenance management functionality based on control center SCADA data

## SUMMARY

Classic approach to preventive maintenance of equipment in power system substations was based on periodical maintenance according to regulations and best practices recommended by vendors. SCADA system in HOPS is used primary for real-time monitoring and control of the equipment in substations. Real time data available in SCADA databases contain useful information for substation maintenance optimization based on operational conditions. Malfunctions and failures in the substations are monitored via SCADA system. Analyses of these data can be used to evaluate maintenance strategy and plan the reconstructions and replacement of the equipment.

This article presents current maintenance management approach in HOPS, which is the only transmission system operator in Croatia, and possible improvements in efficiency of equipment maintenance using SCADA data. Prerequisite for the analyses of these kinds of data is standardization and unification of information names and structures. HOPS put a lot of effort in standardization of SCADA data during last refurbishment of control centers. Use of SCADA data for analysis drives the need for standardization and vice versa.

Examples of statistical analyses of the SCADA data are done on multiple levels. High level analyses is used to provide the global overview of the real time data. It can point to suspicious information that require detailed analyses. The signals that appear often in the list can indicate that there is a problem in the primary equipment, monitoring system or alarm configuration. Low level analyses can be done on target information important for equipment maintenance. In this paper some low level analyses are presented for switching equipment, transformer lifetime, equipment in operation, and tap changer operation. An analysis is made for number of switching operations for breakers and disconnectors in different operational conditions. Preventive maintenance should be done based on number of switching in normal operations and even more often for breakers that are often interrupting fault current. SCADA data can be used for availability of the equipment and duration of failures thus providing valuable information to managers. An analysis on RTU communication availability is shown.

## KEYWORDS

SCADA data – Equipment maintenance – Maintenance management – Smart grid – SCADA data standardization – Analyzing alarms and events – Analyzing measurement – Key performance indices.

# INTRODUCTION

Transmission System Operator Company (HOPS) has two major criteria for defining company efficiency, technical and economic criteria. New smart grid and information-based applications can be suitable to create, trace and analyze those criteria [1][2]. Maintenance management for substation equipment is crucial one in accomplishing both technical and economic efficiency criteria. Former periodic maintenance process can be enhanced towards more preventive and condition based maintenance. To make this shift possible it is important to collect and correlate data from substations and direct consequence of this process is gathering of substantial amount of data in control center [3].

Main role of control centers is monitoring and control the power system but beside that, modern centers should have new additional roles and one of these roles will be smart grid platform for maintenance functionality in TSO. To achieve that, station SCADA systems gather as much data as possible from each piece of substation equipment and then that data is being forwarded into control centers' SCADA systems. Almost all acquired data is stored in central utility data warehouse at TSO. Smart grid applications should process those data in centers for maintenance purposes assisting preventive and conditions based management for substations equipment maintenances.

# DATA POINTS AVAILABLE IN CONTROL CENTRE SCADA SYSTEM

HOPS is only transmission system operator in Croatia and is responsible for operation, maintenance and construction of entire high voltage transmission network (400kV, 220kV and 110kV) as presented in figure 1. Peak load of Croatian power system network is 3 GW. Production installed capacity is 4.5 GW. Transmission network is controlled remotely through modern SCADA system. All internal transmission substations and numerous substation in neighboring TSOs are connected to that system

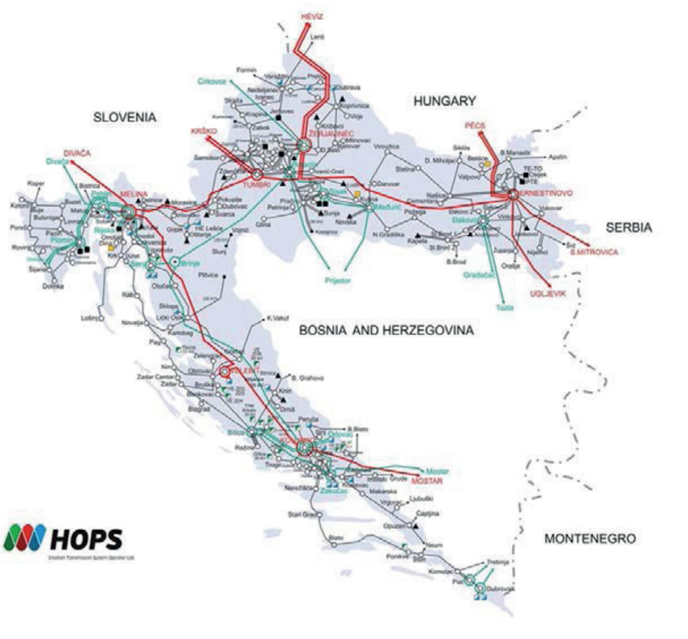


*Figure 1.* Detail schemes of Croatian transmission network with substations and power plants.

Station computers and RTUs in transmission object collect all local information and transfer most of it to the SCADA in control center. HOPS SCADA aggregate all information in database. General data in SCADA is as follow:

- 185 substations and power plant switchyards on 110, 220 and 400 kV voltage level,
- 84.000 indications,
- 9000 measurements.

SCADA in control center is a fundamental application and it is a source for many others. One of important applications is Energy Management System (EMS). Some general data that described the size of HOPS EMS model is presented in Table 1.

*Table 1.* Size of the EMS model.

| Region | Station | Subnet | Bay | Generator | Transformer | Line | Load | Capacitor | Reactor |
|---|---|---|---|---|---|---|---|---|---|
| OSIJEK | 25 | 75 | 420 | 3 | 56 | 52 | 50 | 3 | 1 |
| RIJEKA | 45 | 123 | 818 | 14 | 106 | 73 | 90 | | |
| SPLIT | 55 | 174 | 1198 | 41 | 121 | 90 | 86 | | |
| ZAGREB | 60 | 182 | 955 | 28 | 169 | 112 | 145 | 3 | 1 |
| **Total** | **185** | **554** | **3391** | **86** | **452** | **327** | **371** | **6** | **2** |

HOPS has been created from four companies that are now four regions within HOPS. Besides historical differences, there are other big differences between regions:

- Geographically differences (lowland, seaside region, mountain region, islands),
- Very different climate,
- Different structure of generation and load,
- Some specifics in operations rules, control and protection equipment.

Each of the transmission region is operated by its own regional control center. Therefore, data in SCADA databases are different. Some of the regional centers took more generalized approach where they send grouped data from substation indicating that there is an error on particular part of the equipment, while other regional centers send detailed data describing the type of the error. This can be shown on example of breaker failure indication. In some regional control centers there is only a group signal named "Breaker failure" while in other regional control centers individual signals like "Loss of SF6" can be found.

Table 2 presents an average number of indication and measurement per equipment in database. Individual number of indications differs based on age of equipment in substations. Newer substations have significantly larger number of information in database.

*Table 2.* Average number of indications and measurements per equipment.

| Voltage | Generator | Capacitor | Reactor | Bus | Transformer | Line |
|---|---|---|---|---|---|---|
| 0-110 kV | 5,8 | 17,0 | 1,1 | 0,2 | 9,1 | |
| 110 kV | 3,0 | 20,0 | 86,0 | 0,4 | 53,6 | 95,2 |
| 220 kV | 1,9 | | | 0,5 | 60,6 | 50,0 |
| 400 kV | 3,2 | | 4,7 | 0,6 | 28,2 | 31,1 |
| **Total** | **4,5** | **18,5** | **3,8** | **0,3** | **45,9** | **74,7** |

SCADA database contains real time information for the following equipment:

- Operational data for primary equipment (active and reactive power measurements, current and voltage, switching status, transformer regulating control operation, etc.),
- Protection relay operation data,
- Primary and secondary equipment failures and warnings,
- Communication information (RTUs, switches, SCADA).

EMS system is integrated in SCADA system and contains data on power system equipment operating limits. In addition, EMS uses network model builder for calculating current topological state of the network.

# CURRENT PROCESS FOR PLANNING OF MAINTENANCE AND STATISTICS

ISOHOPS is programming system created in 1993 and last updated in 2011. The main purpose of the system is asset management and maintenance planning based on the HOPS' "Maintenance Rule Book" for the transmission network. It consists of two parts: technical database and maintenance rules. Technical database lists, categorizes and describes all equipment in HOPS' ownership. Maintenance rules proscribe schedules, type of work, authorization and accountability.

Independently another program system "Operating Events Statistics" (OES) monitors the availability of transmission network units over a one-year period. Flowchart for generating OES and collecting data with Yearly report, which result, is presented on figure 3. Operator in Control Center manually input data in application DOR (Daily Operating Report). Expert for operational analysis validates and checks data and after they are automatically transferred to program and database for OES.

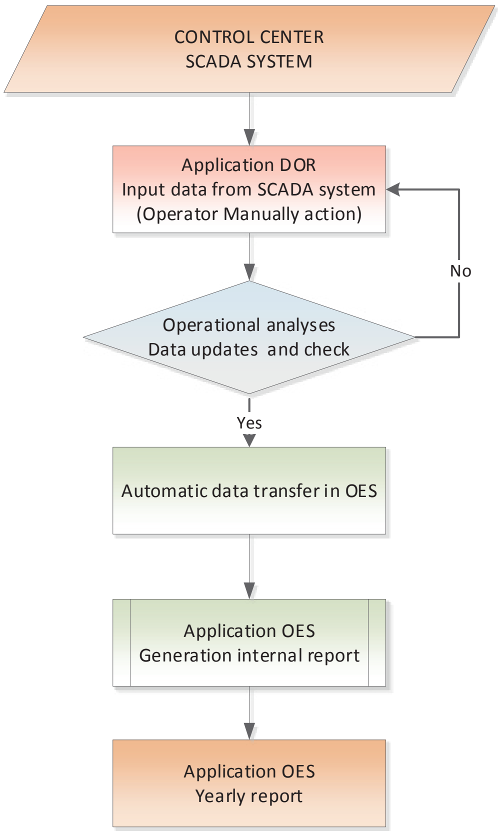


*Figure 2.* Basic flow chart for creating Operating events statistic (OES) from Daily operating report (DOR).

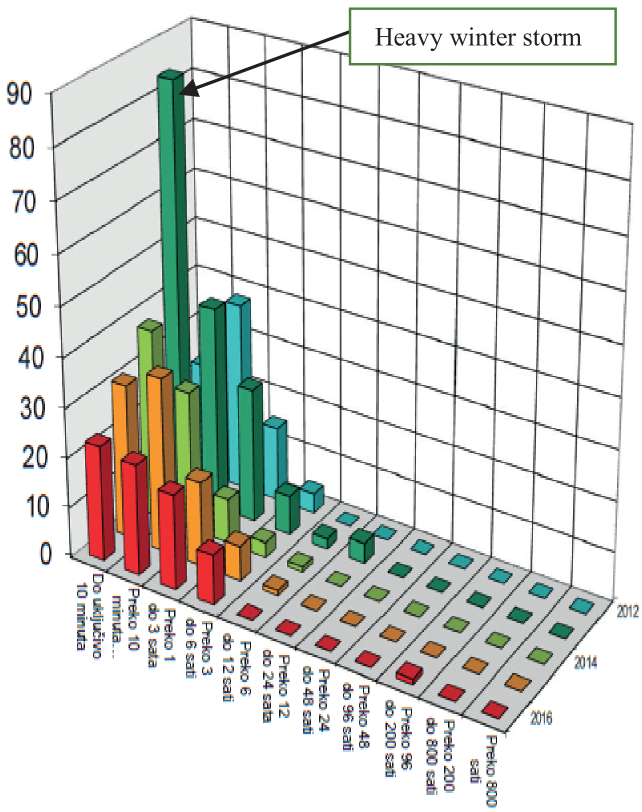


*Figure 3.* Details of yearly forced outages for Yearly report in period of 2012-2016.

Data collected is used to create a yearly report that consists of equipment statistics e.g. total number of transformers, transmission lines length, forced and planned outages of equipment broken down by various criteria. One of the indicators of company maintenance and business efficiency that derives from the "Operating Events Statistics" is in figure 3, and shows the number of forced outages for one year. The x-axis lists time intervals (up to 10 minutes, over 10 minutes to 1 hour etc.) On axis y forced outages are broken down by years.

Present-day approach to planning of maintenance results from compliance with existing regulation and internal maintenance procedures. Apart from reports on problems found during scheduled maintenance, there is no correlation with actual failure rate.

"Operating Events Statistics" is useful tool for analyzing key performance indicators but since it is compiled as an official yearly report, its use is limited because of lateness of the report and inflexibility of analysis.

Idea is to move more towards conditions based maintenance utilizing data collected in SCADA system in control center. Preventive maintenance, which relies on periodic maintenance work on equipment, can be improved with a new way of using SCADA data. First step is a work to have internal standardization of data point naming in company. Second step is analyses of alarms, events and measurements to create proactive maintenance.

# NEW PROCESS FOR ADVANCED EQUIPMENT MANAGEMENT

## Standardization of data points naming

A great challenge for HOPS has been the standardization of data points in SCADA database. Standardization has been done with utmost dedication and precision especially considering that both primary and secondary equipment in substations are diverse across regions and across time of installation. This affected naming, classification and grouping of signals in station SCADA, and consequently in control center.

Unification began in 2012 with refurbishment of SCADA systems in control centers. Figure 4 shows the number of indications per unique name for each area. Total number of indications per unique name is 14. The result of unifying effort is a catalog of unified process information that has decreased from 6500 unique names to 1500 names recommended for use in 185 stations. That corresponds to around 50 indications per unique name.

Catalog contains many information on each individual processing signal, and point name is a key to get all properties for this signal. Figure 5 shows hierarchical structure, classification and location of indication. For each type of equipment like relay protection, breaker, disconnector transformer, measurement, process information, auxiliary systems there are point classes (trip, alarm, failure, control etc.). This classification and unique information is good base for operational system analyses. The catalogue contains information of processing of signal, states of signals, place of delivery etc. Also suggested are the addresses according to IEC61850 for SIPROTEC 5 generations. For others types of IED it needs to be further defined [4].

| Area name | Number of indications | Number of names | Number of ind. per unique name |
|---|---|---|---|
| NCC_Supervision | 42 | 8 | 5,3 |
| NCC_Command | 8 | 7 | 1,1 |
| NCC | 3979 | 164 | 24,3 |
| RCC OSIJEK | 12935 | 1557 | 8,3 |
| RCC RIJEKA | 19178 | 1507 | 12,7 |
| RCC SPLIT | 22929 | 2443 | 9,4 |
| RCC ZAGREB | 23054 | 2628 | 8,8 |
| Training | 6 | 3 | 2,0 |
| **Total** | **82131** | **5885** | **14,0** |

*Figure 4.* Number of indications per unique name before work on unification.

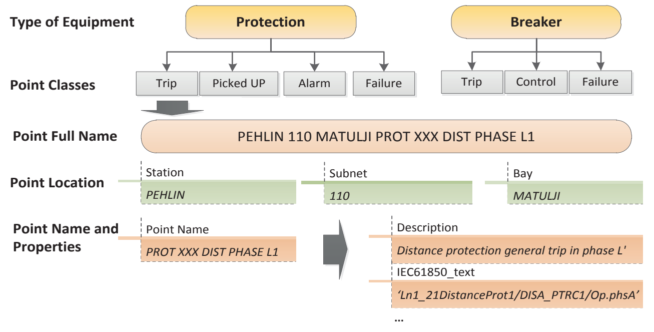


*Figure 5.* An example of indication classification and location.

Standardized SCADA database can be used for improvements in maintenance process and for monitoring of Key Performance Index (KPI). SCADA database comprise important information on operational state of equipment in substations, diverse malfunctions in power system elements and power system information (alarms, events, measurements, etc.). When smart analytics are applied on raw SCADA data, a lot of useful information can be found and used for improving overall reliability of the system and at the same time optimizing maintenance costs.

## Analyses of number of events per signal and per type of signal

Figure 6 contrasts number of data points in the database with number of events for name/type of indication. Ideal case would be that each bay has the same names/types of indications, which would make comparison and analysis trivial. Figure 6 in lower right corner lists a number of indication names/types that have small number of data points in database but large number of events associated with them. There is continuous work on decreasing these kind of data.

Total number of indications in SCADA system is close to 90.000. In operational use, there are more than 5.500 different names/types. Those large number of signal names/types have historical causes. So for the all refurbishment process and new substations "Catalog of unified process information" is used to implement all signals in station computer and SCADA.

Analysis and reporting work is rather complex and to be effective it is essential to have standardized signal names. Process of standardization is important for itself but is also needed to be carried out for better equipment maintenance management. Without standardization it is impossible to implement advanced management application based on SCADA data in control center.

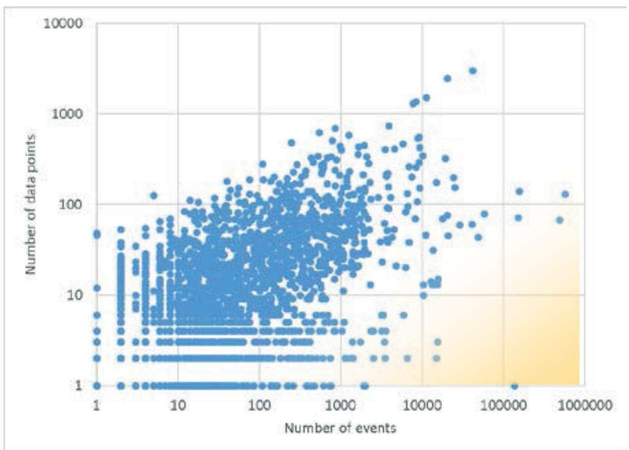


*Figure 6.* Number of data points in database vs number of events for name/type of indication.

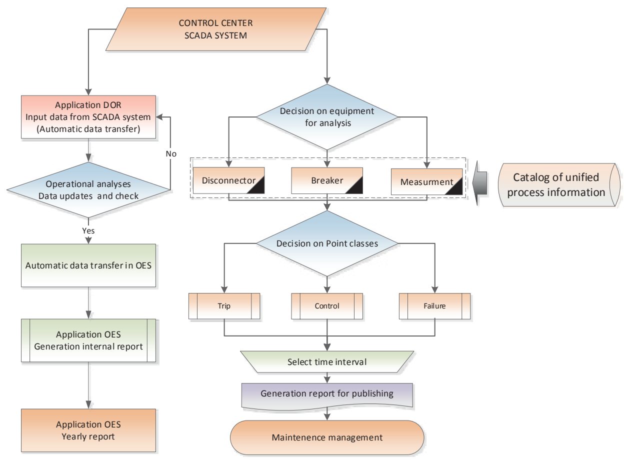


Figure 7. Flow chart for extended new process for maintenance based on SCADA data

## New Process for Maintenance

New process for maintenance relies on SCADA data to adapt planned maintenance schedule to respond to operational state of equipment. Decision on time interval for maintenance schedule is created after analysis of certain groups of data. The flow chart of this decision is on the right side of figure 7.

# ANALYZING ALARMS AND EVENTS

Application deployed at HOPS gathers data from SCADA and correlates it with information from catalog of process information to create analysis and reports for various time periods. Analysis and reports are used for various purposes and one of them is maintenance management.

## Monitoring the operation of switching devices in network

SCADA system monitors 6278 switches in the internal network of HOPS. These switches are not operated with equal frequency. Figure 8 shows a number of switching operations for individual switches, grouped by type of switch (circuit breaker, disconnector and grounder switch), during a period of six months. It is indicative that there are 6278 switches monitored and only 2500 had at least one operation during that time period.

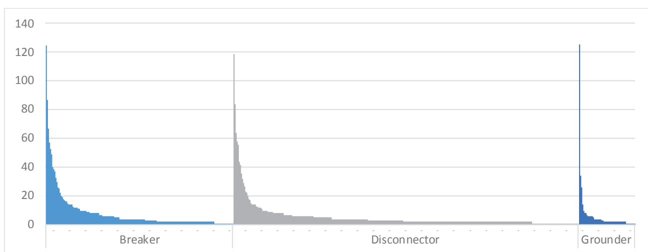


*Figure 8.* Switching operations for 2500 switches that had at least one switching operation during the period of six months.

Switching operations are one of components of evaluating the condition of the switch. Using the switching operations it is possible to plan proactive maintenance schedules for individual switches.

## Breaker Interrupting Fault Current

Data points are mostly contained in bays that can be topologically assigned to equipment. It is possible to correlate equipment in operation with data coming from data points. For identification of breaker interrupting fault current, it is necessary to determine if protected equipment was in operation prior to the outage and if they were, a trip protection signal needs also to be associated with breaker interruption.

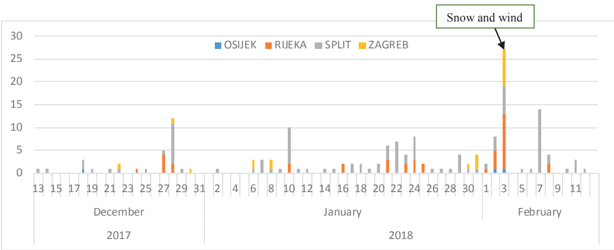


*Figure 9.* Number of circuit breaker interrupting fault current during period of two months.

Figure 9 shows daily number of breaker interrupting fault current per region for two months. When planning proactive maintenance breakers that interrupted fault current should be checked and appropriate service actions should be performed. Additionally the number of circuit breaker interrupting operational current should be added multiplied by factor determined by supplier of the breaker. Cumulative number of fault current interrupted by breaker is calculated.

## RTU communication

SCADA alarms and events can be also used to trace the efficiency of maintenance and availability of certain part of system. Figure 10 presents an analysis of communication loss alarm that is active in cases when there is no communication to RTU-s, figure on the left shows the number of times communication with RTU was lost, and figure on the right shows the duration of the loss of communication.

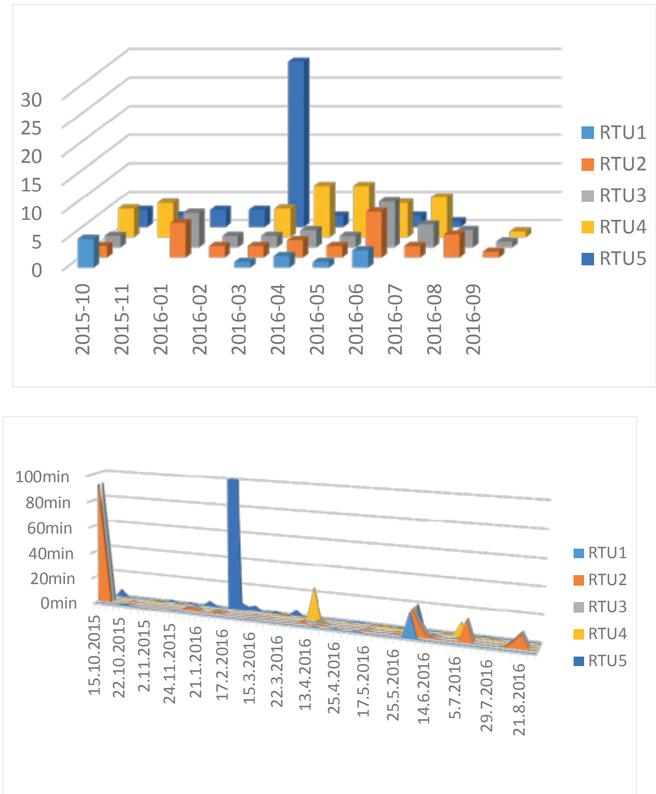


*Figure 10.* Unavailability of communication to RTUs, number of communication loss event (left), duration of communication loss (right).

Data available in SCADA systems are not sufficient to determine the cause of communication unavailability. Further detail analyses could be done if SCADA data are combined with telecommunication monitoring and asset management systems that can account for planned outages.

# ANALYZING MEASUREMENT VALUES

Transmission system control centers are primarily focused to ensure secure operation and control of a power system. SCADA systems provide continuous supervision of the whole network in real time but not all of this information is stored permanently in an archive. For measurement data this means that it is processed, downsampled and then put in permanent storage according to TSO rules. Minimum time resolution is 2 seconds for crucial data and 10 seconds for non-crucial data. Data is downsampled in other resolutions as well: 1 minute, 15 minute, 1 hour, and 1 day. Different time resolutions are used for different purposes.

This paper does not focus on usual analysis of measurements like calculation of total and peak load and generation of an area, which are usually done for purposes of accounting and reporting. In addition to old way of using measurement data, here is a proposition to use measurement data for asset management and maintenance planning.

## Transformer Measurement Data

Power transformer unit in transmission network is a crucial and expensive element, often unique and hard to replace. All of these are reasons that careful attention must be provided for a transformer during its lifetime. For this purpose transformer monitoring systems are widely used [5]. Transformer monitoring system are often custom made for specific power transformer and have complex specifications and design [6] [7]. Status and key performance indicators are tracked using three major sources of data: current or temperature monitoring [8], overvoltage monitoring and gas analyses. For gas analysis and monitoring of overvoltage inside windings there needs to be specialty equipment inside tank, but current and temperature is often available at SCADA as a normal measurement. The task of monitoring and calculating KPIs of transformers can be shifted to a SCADA system in control center. Almost all of the transformers at transmission system level and at power plants have measurements of at least power or current so they can be monitored, which is very valuable for asset management of the whole transformer fleet. Monitoring using current or power can be extended with other measurements, like oil and winding temperature [9], number of operating hours (days) in a year, number of tap changer operations. An example of information that can be gathered is shown in figure 11. These data can be used for calculating ageing rate of each transformer [10].

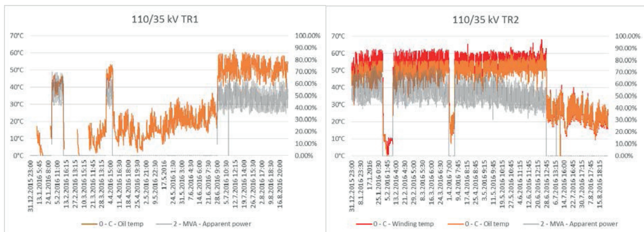


*Figure 11.* Temperature on left y-axis and power in percentage of rated power on right y-axis for two distribution transformers 110/35 kV in the same substation.

On figure 11 charts from two transformers situated in the same station are shown. It can be seen that the transformers are not working in parallel, only one is in operation at a time. Older transformer does not have winding temperature measurement but only oil temperature (left).

## Hours in Operation

For operation and asset management, it is important to know the hours in operation for each equipment. Number of hours in operation can be calculated using energized state or using active power measurement when it is greater than zero. Working hours for transmission equipment during period of 60 winter days is presented in figure 12. In transformer stations, there are usually more than one transformer, and in normal operation only one is energized, which is the reason a lot of transformers have been in operation for less than 100% of the time. Most of the time lines are in operation, which is reflected in very few lines out of service. Shunts are not needed during this time, and none of them were in operation during period in consideration.

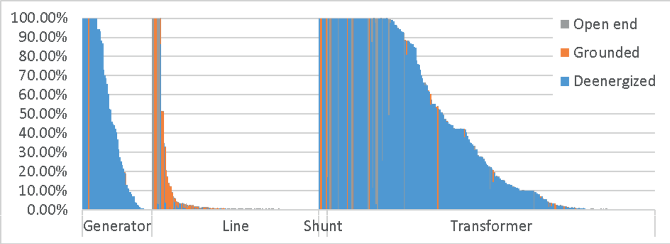


*Figure 12.* Percentage of hours not in operation of the total period considered.

## Off and on load tap changer operations

Statistics on change of tap positions should be recorded and analyzed because statistically more than third of transformers between 100 kV and 200 kV had failures on tap changing equipment [11]. This also allows for modification of maintenance procedures and optimal transformer maintenance schedule.

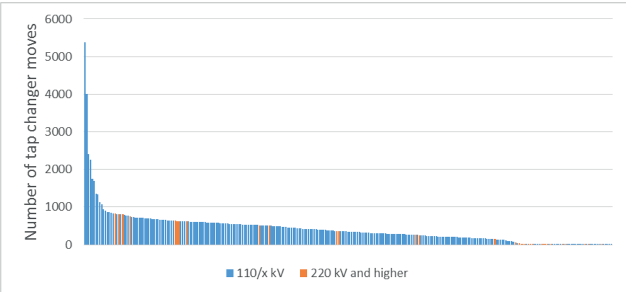


*Figure 13.* Number of tap changer operations during first 8 months of year 2016 per transformer (281 transformer units).

Using Figure 13, transformers can be classified into three groups. Just a small number of 110/x kV transformers have more than 4 tap changing actions per day (observed in 228 days) which are caused by lack of voltage controllers on some 400/110 kV and 220/110 kV transformers. This figure should indicate where increased maintenance of tap changers is required.

# CONCLUSION

Croatian TSO set up its SCADA system to collect wide range of signals from substation equipment. This is used for the main task for SCADA system of TSO, which is the control of transmission network. Great amount of data in SCADA databases can be used for development of new processes and functions.

New technologies and standardization of SCADA data enables optimized and smarter approach to preventive and proactive maintenance, which is based on actual conditions of equipment by using real time information. Identifying anomalies in SCADA data can find single or series of faulty equipment. Making statistical reports and KPIs is important for measure of maintenance efforts. Goal is to improve the preventive based maintenance process and start using condition based maintenance and proactive maintenance. In first phase creating various reports from those data will be a starting point towards upgrading the maintenance rulebook. Analyses of SCADA data can be used to follow the efficiency of measures taken to improve systems or processes. EMS data combined with SCADA data can be used to extract valuable information on operating conditions of the equipment that can be used to determine if preventive maintenance is necessary or already scheduled maintenance can be postponed without big risks.

Crucial step of the project is standardization and unification of data points of the SCADA database in "Catalog of unified process information". Whole process of data engineering in bay, station computer, and SCADA system have to strictly follow those rules if advanced data analytics is to have good results. Quality of description of data points is directly correlated to the quality of conclusions made by analysis of the SCADA data. On the other hand use of SCADA data raises the quality of information on data points so it is important that cleaning of data points is done at the same time as use of SCADA data for analysis. Catalog should be a living documents requiring continuous work on updating the Catalog.

Next phase and continuous work should be updating the maintenance rulebook with proactive and condition maintenance, with mechanisms in place to have continuous monitoring of the effect of new and old rules on maintenance. Another piece of work is defining the Key performance indices for equipment data. Study has to be done in order to determine the proper values for those indices.

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