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Advanced and Rapid Tool in Control Room to Determine the Cause and Location of Events in Transmission Network

SUMMARY

Operating personnel in control room act on SCADA alarm generated on data from station computer. Using new technologies and advanced technical solutions assistance tool can be designed. This tool provides quick help in busy situations for operator. For this new tool with three types of case studies insight will be given in this paper. Introduction part has short information about numbers of alarms and events in Control centre, and their distribution during one month period. Basic principles for alarm handling in SCADA system is given with all limitations. New tool, Intelligent Alarm Processing system is designed and implemented in control room. It has connection to SCADA system with standard data exchange format CIM/XML and run in real time, with only few seconds delay. This system based on Multilevel Flow Model has root cause analyses implemented for power system. Detail fault location algorithm description with block scheme for this Intelligent Alarm Processing system is part of third chapter. Special attention must be paid for modelling protection data in SCADA system which are sent to this new tool. Demonstration of Intelligent Alarm Processing system operation is reported in fourth chapter. Three characteristic disturbances in transmission network were elaborated. Most complex and challenging disturbances for operator in control room is cascading event. This case study is presented in detail in four sequences through graphical user interface. Second case study is also challenging for operators, heavy winter storm with numerous isolated events. In this case study very effective graphical presentation and alarm list with three types, primary event, consequences and detail list for this events were demonstrated. This list pointed out exactly and clearly what happened in the network. Last case study presents common disturbances which appears on daily basis, where this tool is of great assistance because it points on transmission elements very fast.

KEYWORDS

Intelligent alarm processing, control room data processing, root cause analyses, IAP, SCADA, control centre, alarm management, CIM/XML, operator assistance during disturbances

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INTRODUCTION

The Transmission System Operator Company (HOPS) uses one SCADA system for monitoring and control function and for maintenance purposes [1]. Data inflow in control room are increased during operating hours and during disturbances as shown on Figure 1. Number of alarms at the Regional control center Osijek, in October 2019.

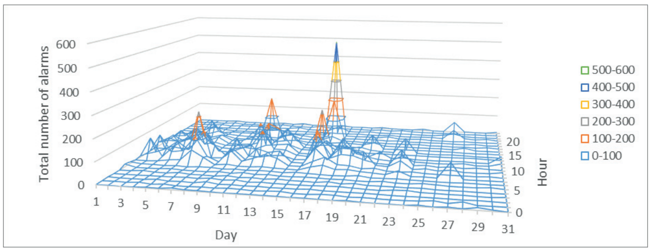


Figure 1. Number of alarms at the Regional control centre Osijek, in October 2019.

In order to investigate the alarm load situation, the actual alarm rates are constantly measured and monitored. On Figure 1., number of alarms at the Osijek area Regional control centre in October 2019 are presented. The x-axis shows 31 days in the month October, the y-axis shows 24 hours, and the z-axis shows the number of alarms. The alarm rate curve is not uniform during day and night. Generally, for all area control centres, the alarm rate is highest during working hours (08:00-16:00). It should be noted that during this period, the alarms were mainly caused by maintenance work. Modern TSO's have advanced technologies in control room and combine them to create many smart grid applications for daily business process [3]. One relatively new tool for helping to have better power system visibilities during massive data inflow is Intelligent Alarm Processing (IAP) system.

EVENT AND ALARM MONITORING IN A SCADA SYSTEM

Alarm monitoring and presentation in a SCADA system is limited to basic functions:

- Priority classification and colouring.
- Grouping of alarm and events based on assigned classes.
- Alarm and event list filtering.

In most SCADA systems, there is no possibility to present group alarms or events in event lists based on network element connection or to use sub lists. The only possibility is to present individual alarms or events and to use predefined filtered lists. Static grouping of alarms is possible, but it requires a large amount of engineering work and lacks "drill down" support. Each event is presented in its own line, and in case of larger disturbances in the system, due to a large number of events, it could be difficult for the operators to locate the event which points to the root cause even, in pre-filtered alarm lists. Different event presentation types used in SCADA systems are described in Table I, [2].

Table I. Presentation of events in a SCADA system.

Priority coloring	Alarm grouping	Pre-filtered list
HIGH MEDIUM LOW	Trip events and alarms Breaker status Disconnector status Active power limit Protection relay failure Transformer failure	Breaker switching events & protection trips Active power limit violations Reactive power and voltage limit violation

INTELLIGENT ALARM PROCESSING TOOL

General description

An intelligent alarm processing (IAP) tool was integrated with the SCADA system in the control room using CIM/XML standard exchange format for data exchange of the network model, and OPC DA (Open Platform Communication, Data Access) and A&E (Alarms & Events) interfaces for alarms and events exchange in real time. During 2016, the IAP system was upgraded. The new version has its own web interface and MONGO database. The alarm processing method is based on MFM (Multilevel Flow Model) models and a root cause algorithm applied to power systems. The basic objects in the model are generators, lines, buses and loads. The model is automatically built from the imported network model. IAP is an operator support tool. It reads discrete and analog grid data, such as alarms, events, and analog signals, and provides automatic analysis to help the operators in the control room to understand the current fault situation in the grid. Main tasks are situational awareness, alarm grouping, and root cause analyses.

Fault location algorithm

This paper reports the experiences of a software system using intelligent alarm processing and real-time root cause analysis of complex alarm situations. The system provides an alarm management technology with the following functions.

- SCADA alarms from a single grid object (generator, transmission line, busbar, etc.) are grouped into single alarms, so the operator easily can see which objects have problems or are out of service.
- Nuisance alarms that are activated repeatedly over short time periods, so-called "chattering" alarms, are monitored by the system and shelved and un-shelved dynamically. Shelving means that the alarm is moved from the primary alarm list to a separate list for shelved alarms.
- Other alarms are caused by damaged or unused equipment and remain active for a long time, so-called "long-standing" alarms. These are also monitored by the system and are timed out after a fixed time period, currently four hours.
- The system contains a model-based algorithm that can analyse consequential alarm cascades and show the root cause alarms ("the real faults") in a primary list, and consequences in a secondary list.

For readings on intelligent alarm processing with on-line root cause analysis, see [4-11]. The combination of these methods leads to a large improvement of the alarm situation. In complex fault situations, hundreds of alarms may be shown in the SCADA system, while the IAP tool only shows one or two primary root cause alarms. The alarm management algorithm uses knowledge of the physical structure of the power grid, which it acquires from a SCADA/EMS network model. At HOPS, the internal IAP model is derived from the existing CIM XML description of the SCADA/EMS network model. The algorithm also uses operational real-time data from the synchronized SCADA system database, such as analog and discrete signals (power flow, voltage, amps, breaker and disconnector positions, and protection signals), and the real-time alarm and event stream, see Figure 2.

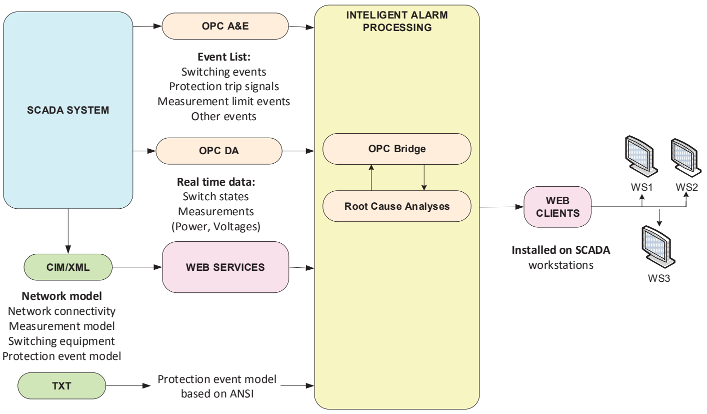


Figure 2. The IAP software integrates with the existing SCADA/EMS system.

All grid knowledge used in the calculations can be derived automatically from the CIM model. Whenever the CIM model is updated, it is imported to the system and compiled, which takes less than a minute. This means that the system needs no manual maintenance.

The real-time functionality consists of several software layers, which perform calculations on analog and discrete data to identify stale signals, bad data, delta changes, equipment which is out-of-service, faults states, and the global root cause analysis state for the whole transmission network.

The intelligent alarm processing system is a separate software application that can be integrated with a SCADA system in several different ways. It consists of a central server and one or several clients. The server executes on a separate computer. The server receives real-time data from the SCADA system via network protocol. The results of the analysis for the whole network are stored in the server and are distributed to all clients in all control centers in real time, see Figure 2.

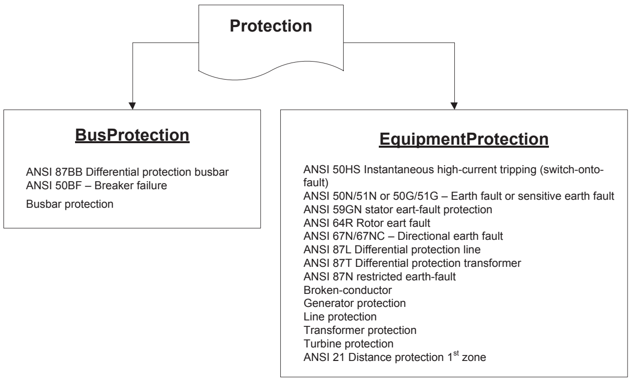
The system uses alarm grouping and root cause analysis. It presents its analysis in a graphical grid overview and in a set of intelligent alarm lists. The IAP system groups all SCADA alarms that belong to a single grid object into one single alarm message. In this way, it becomes easier to see which grids objects have failed.

For example, a transmission line which trips may trigger several alarms, such as:

- Breaker open alarms from both ends of the line.
- Zero voltage alarms.
- Zero megawatt or zero ampere indications.

Modelling of protection data from SCADA for IAP

To give the model better results [12], additional efforts have been made to the basic intelligent alarm processing algorithm, with a relay protection model and real time protection data from the SCADA system. In the analysis, it is important to distinguish the relay protection function that isolated the failure on network element where the problem appeared, from the protection function that tripped to isolate the disturbance in other parts of the network due to overload or malfunction in the primary protection. All relay protection trip signals in the SCADA system are classified and associated with ANSI codes. The IAP tool uses these codes to determine the location of the fault based on protection function logic (see Figure 3). The fault network element is pointed out in the transmission network scheme using a red arrow and simultaneously displayed in the primary alarm list created by the IAP system. The source of the protection signal list (file) is a unified database according to the HOPS codebook to which ANSI codes are associated [1]. The relay protection functions for determining the primary failure in the network are shown in Figure 3 and are an integral part of the IAP application module.



Protection

BusProtection

ANSI 87BB Differential protection busbar
ANSI 50BF – Breaker failure
Busbar protection

EquipmentProtection

ANSI 50HS Instantaneous high-current tripping (switch-onto-fault)
ANSI 50N/51N or 50G/51G – Earth fault or sensitive earth fault
ANSI 59GN stator eart-fault protection
ANSI 64R Rotor eart fault
ANSI 67N/67NC – Directional earth fault
ANSI 87L Differential protection line
ANSI 87T Differential protection transformer
ANSI 87N restricted earth-fault
Broken-conductor
Generator protection
Line protection
Transformer protection
Turbine protection
ANSI 21 Distance protection 1st zone

Figure 3. ANSI codes and protection functions used in the IAP analysis

According to the above, the basic data for the analysis are data from bus protections, protections of network elements (transmission lines, transformers and generators) and earth-fault protections. For the purpose of IAP analysis, there are three basic groups of relay protection trip signals according to the location of the failures:

- Independent failures in the transformer station itself. This group includes bus protection signals and breaker protection signals.
- Independent failures near the transformer station. This group includes earth-fault protection signals for transmission lines, differential protections, and tele-protection signals.
- Independent faults not near the transformer station. This group includes all other protection function signals.

CASE STUDY FROM CROATIAN TSO NETWORK DISTRUBANCES

Croatian highvoltage transmission network – basic facts

Croatian TSO has around 8.000 kilometres lines and 190 highvoltage substations (400 kV, 220 kV and 110 kV), Figure 4. Signals from all station computers are connected to SCADA system in control room, which means more than 100.000 indications, commands and measurements are inflowing in control room.

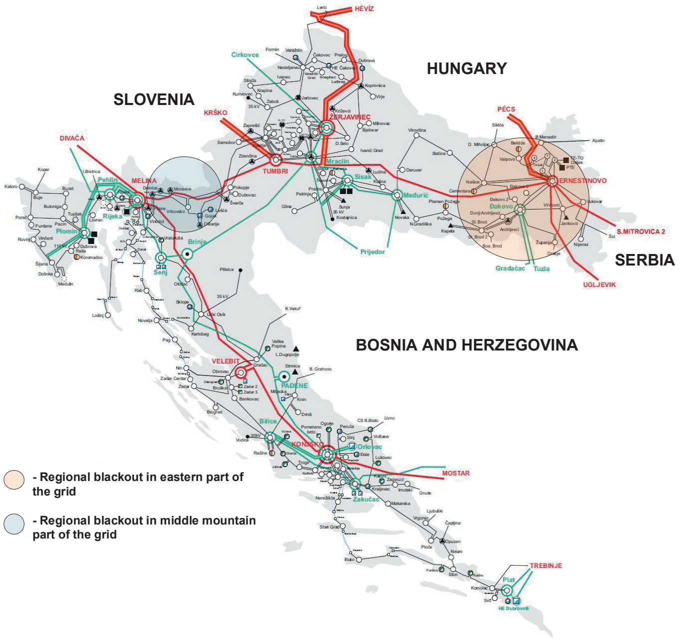


Figure 4. Croatian highvoltage transmission network

Two case study for IAP operations will be presented in this chapter. First, one is a cascading event, which cause regional blackout in eastern part of the network. Second event is from mountain part during local heavy winter storm with ice and snow.

Cascading event in the eastern part of transmission system

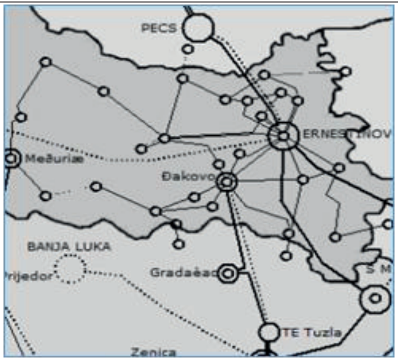
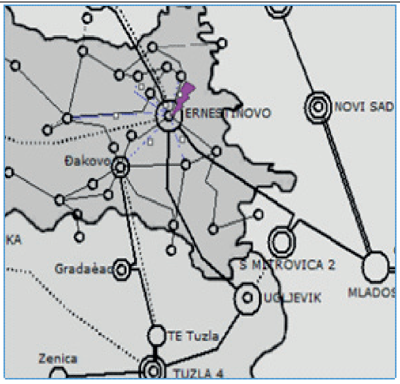
DESCRIPTION OF EVENT AND FAULTS

The substation SS 400/110 kV Ernestinovo is a main point of supplying the transmission system region Slavonia with electrical energy. SS Ernestinovo, with 5 tie lines on the 400 kV level, is very well connected with other parts of the HOPS grid and neighbouring TSOs. Inside the SS, there are two transformers of 400/110 kV and 10 tie lines on 110 kV level. On the 14th of May, at 8:18 am, due to a technical error during maintenance, busbar protection on the 110 kV level disconnected all elements connected to one of two 110 kV system busbars. A few of the 110 kV and 220 kV tie lines were overloaded and tripped as consequences. The final state was that 20 substations lost voltage.

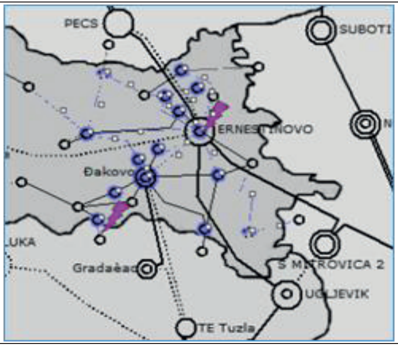
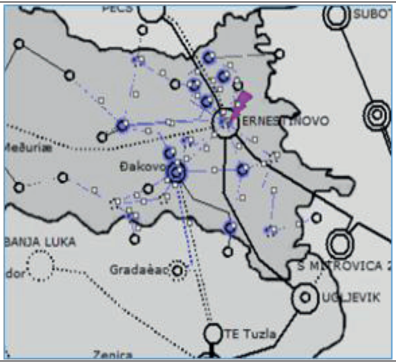
The initiating event was a power transformer trip in the 400 kV Ernestinovo substation. Subsequent analysis by HOPS identified that one busbar protection relay on the 110 kV side of the Ernestinovo substation was triggered, effectively clearing one of the main buses. About three minutes after the initiating event, an important transmission line at the 220 kV level south of SS Ernestinovo tripped. This in turn led to a regional voltage collapse with several line trips until stable conditions were reached.

INTELLIGENT ALARM PROCESSING

Short presentation will be given in this chapter with screenshots from IAP system. In four slides in one sequence order IAP system will be presented and how it works in real time.

Grid state at: 08:18:18 a.m.	Normal operating conditions in eastern part of transmission grid. Outaged lines are presented with dotted line. Ernestinovo is key point for supply of the region. 220 kV grid was slightly weakened in Đakovo substation. One line was in maintenance. This fact will drive to voltage collapse case in second part of this cascading event.	 PECS ERNESTINOV Međuriæ Đakovo BANJA LUKA rijedor Gradaèac S M TE Tuzla Zenica
Grid state at: 08:18:59 a.m.	Due the combination of maintenance and technical error, busbar protection on 110 kV level tripped one system in main supplying substation. Root cause is marked as a purple arrow pointed on 110 kV circle. Blue lines are lines without voltage, while consequences are marked with small, white dots. From that moment grid was weakened and starts to glide to point of no return .	 ERNESTINOVO NOVI SAD Đakovo KA Gradaèac S MITROVICA 2 UGLJEVIK MLADOS TE Tuzla Zenica TUZLA 4

After this fault which was classified like a root cause in IAP system, cascading event takes place in next four minutes. The event has two main characteristics, line overloading and fast voltage collapse induced by sequential operations of on load tap changer. These tap changers operated on grid power transformers 220/110 kV in order to maintain the voltage in 110 kV grid.

Grid state at: 08:21:49 a.m.	Cascading events rolled further. New primary event happened and purple arrow appears on 110 kV line which was overloaded. This event was temporary presented. New lines and transformer were tripped and put in blue (no voltage). Đakovo substation was tripped during very short voltage collapse.	 PECS SUBOTI ERNESTINOVO N Đakovo LUKA Gradaèac S MITROVICA 2 UGLJEVIK TE Tuzla
Grid state at: 08:22:49 a.m.	Finale stage of cascading event. The bus-bar protection is identified as the root cause and the other 82 events are shown as consequences. 400 kV grid stayed in operation. IAP operated in timely manner.	 PECS SUBOT ERNESTINOVO Međuriæ Đakovo BANJA LUKA dor Gradaèac S MITROVICA 2 UGLJEVIK TE Tuzla Zenica

SCADA ALARM ANALYSES

A comparison of the data arrived at the SCADA system and the IAP is given in Table II, for the period from 08:18:48 to 08:26:25 a.m.

Table II. Number of disturbance events.

SCADA		IAP	
Event list	SOE list	Primary event	Consequences
2094	533	2	82

SCADA system collect and generate numerous events in Event list and detail events inflow in Sequence of Events (SOE) list. This last list is essential for later off line analyses.

Isolated fault in mountain part of transmission network

Description of the Event

In February 2014, due to snow and icing, a serious disturbance in transmission grid occurred in the region of Gorski Kotar. Due to a damaged 110 kV tie line Delnice-Vrata, the substation 110/35/20 kV Delnice was radially supplied through the 110 kV line Delnice-Moravica. On 12th of February 2014, at 10:36 am, the IAP system registered the primary event of a mutual failure on the 110 kV line Delnice-Moravica.

The primary event was triggered by relay protection on the transmission line at Delnice SS (permanent fault on the transmission line) and consequently three transformers tripped off. Figure 5 shows the primary event due to transmission line failure (arrow on white-shaded transmission line) and secondary events (small white dot in the SS Delnice facility).

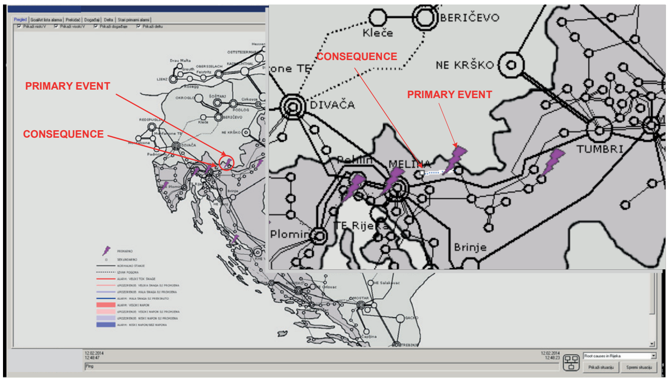
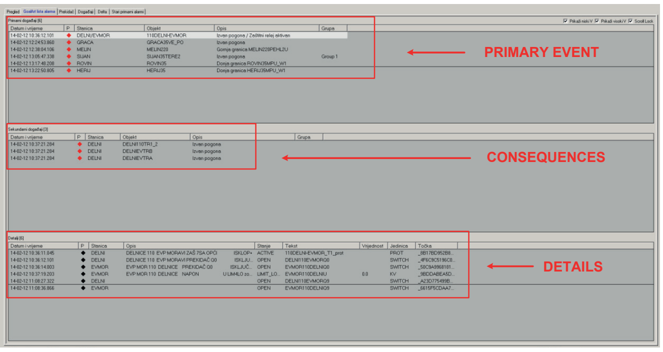


Figure 5. Graphical display of event on February 12, 2014 at 10:36 am

In the alarm list, as a result of the analysis, Figure 6 shows the primary event for the 110DELNI-EVMOR object out of operation and the protective relay active and the secondary events, transformers in SS Delnice out of operation: 110TR1_2, 110TRA and 110TRB. The details window shows us the signals from the SCADA system grouped into objects that are topologically related to the specified event.

During the analysis of this disturbance, the model worked properly and classified events by cause and effect. The result of the model analysis is one primary event and three secondary events, with a total of 64 process signals recorded in the SCADA system.



Primarni događaji [6]

Datum i vrijeme	P	Stanica	Objekt	Opis	Grupa
14-02-12 10:36:12.101	◆	DELNI/EVMOR	110DELNI-EVMOR	Izvan pogona / Zaštitni relej aktivan	
14-02-12 12:24:53.860	◆	GRACA	GRACA35VE_PO	Izvan pogona	
14-02-12 12:38:04.106	◆	MELIN	MELIN220	Gornja granica MELIN220PEHL2U	
14-02-12 13:05:47.338	◆	SIJAN	SIJAN35TERE2	Izvan pogona	Group 1
14-02-12 13:17:48.208	◆	ROVIN	ROVIN35	Donja granica ROVIN35MPU_W1	
14-02-12 13:22:50.805	◆	HERIJ	HERIJ35	Donja granica HERIJ35MPU_W1	

Sekundarni događaji [3]

Datum i vrijeme	P	Stanica	Objekt	Opis	Grupa
14-02-12 10:37:21.284	◆	DELNI	DELNI110TR1_2	Izvan pogona	
14-02-12 10:37:21.284	◆	DELNI	DELNIEVTRB	Izvan pogona	
14-02-12 10:37:21.284	◆	DELNI	DELNIEVTRA	Izvan pogona	

Detalji [6]

Datum i vrijeme	P	Stanica	Opis		Stanje	Tekst	Vrijednost	Jedinica	Točka
14-02-12 10:36:11.045	◆	DELNI	DELNICE 110 EVP MORAVI ZAŠ 7SA OPĆI	ISKLOP+	ACTIVE	110DELNI-EVMOR_T1_prot		PROT	_8B17BD952B8...
14-02-12 10:36:12.101	◆	DELNI	DELNICE 110 EVP MORAVI PREKIDAČ Q0	ISKLJU...	OPEN	DELNI110EVMORQ0		SWITCH	_4F6C9C5196C0...
14-02-12 10:36:14.003	◆	EVMOR	EVP MOR 110 DELNICE PREKIDAČ Q0	ISKLJUČ...	OPEN	EVMOR110DELNIQ0		SWITCH	_50C9A9968181...
14-02-12 10:37:19.203	◆	EVMOR	EVP MOR 110 DELNICE NAPON	U LIM4LO zo...	LIMIT_LO...	EVMOR110DELNIU	0.0	KV	_9BDDABEA5D...
14-02-12 11:08:27.322	◆	DELNI			OPEN	DELNI110EVMORQ9		SWITCH	_A23D775499B...
14-02-12 11:08:36.866	◆	EVMOR			OPEN	EVMOR110DELNIQ9		SWITCH	_6615F5CDAA7...

Figure 6. Alarm list of event on February 12, 2014 at 10:36 am

Use case as daily monitoring of situation

In order to describe the principles of grouping and presentation of the event in IAP in comparison to the SCADA system, a simple protection event will be described with only one power line tripped on 3th of January 2020 at 15:04:41. The event was caused by an unknown and undetected reason and distance protection tripped the power line. During the period from 15:01:11 to 15:04:51 there are 238 registered events from protection relays, switching states and auxiliary power supply in the SCADA event list. The intelligent alarm processing application presents the alarms under one primary event, which is presented in the event lists as shown in Figure 7:

- Time: 15:04:41.641.
- Station(s): *LUDBRE/HECAK*.
- Name of the network element: *110HECAK-LUDBR.*
- Text - event description: outage (*Izvan pogona*)/Protection event (*Zaštitni relej aktivan*)/Voltage state (*Nema napona*).

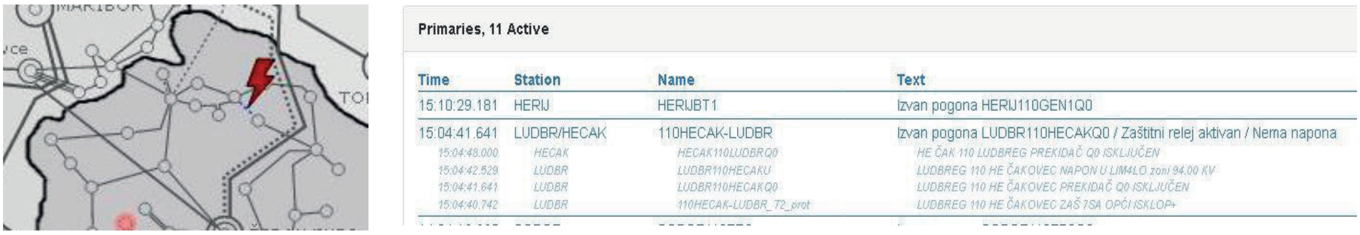
When the grouped event is expanded, the most important signals from the SCADA event lists are presented (breakers tripped, protection trip events, voltage limits).

The visual representation in the diagram in IAP is presented with the arrow pointing to the network element that was tripped, as shown in Figure 7.

CONCLUSION

IAP system in control room is powerful and useful tool during normal operation conditions and disturbances. Very efficient tool which output points out accurately and promptly on root cause transmission network element stressed with disturbances.

Although the main benefit of the IAP tool is to help the operator in detection of the root cause during cascading events, it can also be used to monitor the operational state during normal operation as well as for automated generation of outage reports. Due to the fact that such a grouping of information contains almost all relevant information (outage duration, protection trip or operator command) these lists can be used as an input for the operator diary as well as for different reporting purposes. Furthermore, the integration of such a tool with software for outage planning and software for weather and storm monitoring can be made, in order to detect the cause of the outage.



Primaries, 11 Active

Time	Station	Name	Text
15:10:29.181	HERIJ	HERIJBT1	Izvan pogona HERIJ110GEN1Q0
15:04:41.641	LUDBR/HECAK	110HECAK-LUDBR	Izvan pogona LUDBR110HECAKQ0 / Zaštitni relej aktivan / Nema napona
15:04:48.000	HECAK	HECAK110LUDBRQ0	HE ČAK 110 LUDBREG PREKIDAČ Q0 ISKLJUČEN
15:04:42.529	LUDBR	LUDBR110HECAKU	LUDBREG 110 HE ČAKOVEC NAPON U LIM4LO zoni 94.00 KV
15:04:41.641	LUDBR	LUDBR110HECAKQ0	LUDBREG 110 HE ČAKOVEC PREKIDAČ Q0 ISKLJUČEN
15:04:40.742	LUDBR	110HECAK-LUDBR_T2_prot	LUDBREG 110 HE ČAKOVEC ZAŠ 7SA OPĆI ISKLOP+

Figure 7. IAP presentation list for a simple protection trip event

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