Situational Awareness through Root Cause Analysis

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DAT300

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Control Room

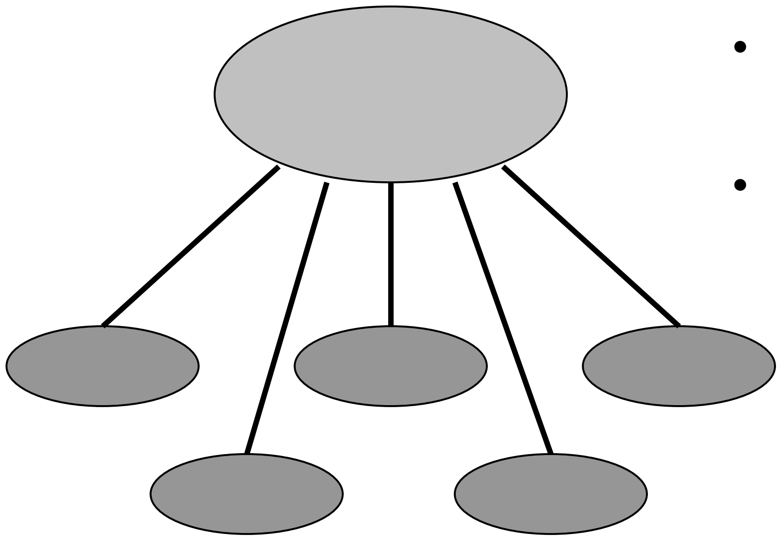
- Operator Task
  - Monitor and maintain
  - Remote readings
  - Remote control
  - Alarms indicate unexpected and dangerous readings
  - Quick and correct actions
- Problem
  - Alarms indicate symptoms
  - Single faults may result in many alarms
  - Correlations and consequences
  - Need to understand the faults
  - Situational awareness
- Solution
  - Root cause analysis
  - Present the fault, not the alarms

Old power plant control room

Actual, Modern TSO Control Room

- Maintain balance – *active power*
- Maintain voltages – *reactive power*
- Prepare for grid maintenance
- Deal with external factors – *storms, failing equipment*

Centralized Control Rooms



- Centralizing accentuates alarm problems

- Gives better overview of total state
- Alarm problems are multiplied

- Think ahead!

Alarm-Related Incidents

- Three Mile Island, 1979.
- Milford Haven Refinery, 1994.
- Vallvik Pulp Plant, 1998.
- Esso Longford, 1998.
- Texas City, 2005.
- Buncefield, 2005.






Vallvik Pulp Plant, 1998

- Pipe leak in mesa burner
- Cascade of 120 alarms in 1 minute
- Build up during 10 minutes
- Explosion destroyed burner

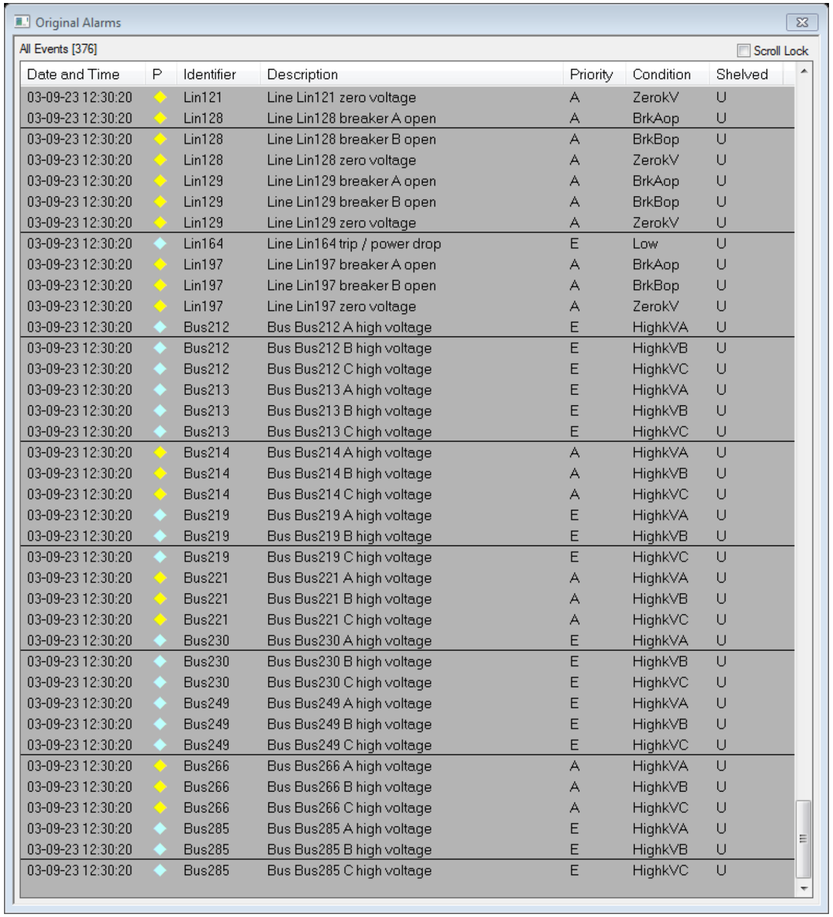
- Two independent faults
  - One less critical, *burner feed problem*, with lots of consequential alarms
  - One absolutely critical, *loss of steam pressure*, with few consequential alarms indicating imminent risk of explosion
- Critical fault drowned in cascade

- Cost over 100 000 000 SEK

Different Kinds of Alarm Problems

- High average alarm rates
  - Remove alarms
  - Redesign alarm system
  - Alarm system revision
- Wrongly tuned alarm limits
  - Retune alarm limits
- Irrelevant alarms in certain states
  - Suppress irrelevant alarms
  - State-based alarm priority
- Alarm cascades
  - Find root cause (difficult)

Ordinary Alarm list



Original Alarms

All Events [376] Scroll Lock

Date and Time	P	Identifier	Description	Priority	Condition	Shelved
03-09-23 12:30:20		Lin121	Line Lin121 zero voltage	A	ZeroKV	U
03-09-23 12:30:20		Lin128	Line Lin128 breaker A open	A	BrkAop	U
03-09-23 12:30:20		Lin128	Line Lin128 breaker B open	A	BrkBop	U
03-09-23 12:30:20		Lin128	Line Lin128 zero voltage	A	ZerokV	U
03-09-23 12:30:20		Lin129	Line Lin129 breaker A open	A	BrkAop	U
03-09-23 12:30:20		Lin129	Line Lin129 breaker B open	A	BrkBop	U
03-09-23 12:30:20		Lin129	Line Lin129 zero voltage	A	ZerokV	U
03-09-23 12:30:20		Lin164	Line Lin164 trip / power drop	E	Low	U
03-09-23 12:30:20		Lin197	Line Lin197 breaker A open	A	BrkAop	U
03-09-23 12:30:20		Lin197	Line Lin197 breaker B open	A	BrkBop	U
03-09-23 12:30:20		Lin197	Line Lin197 zero voltage	A	ZerokV	U
03-09-23 12:30:20		Bus212	Bus Bus212 A high voltage	E	HighkVA	U
03-09-23 12:30:20		Bus212	Bus Bus212 B high voltage	E	HighkVB	U
03-09-23 12:30:20		Bus212	Bus Bus212 C high voltage	E	HighkVC	U
03-09-23 12:30:20		Bus213	Bus Bus213 A high voltage	E	HighkVA	U
03-09-23 12:30:20		Bus213	Bus Bus213 B high voltage	E	HighkVB	U
03-09-23 12:30:20		Bus213	Bus Bus213 C high voltage	E	HighkVC	U
03-09-23 12:30:20		Bus214	Bus Bus214 A high voltage	A	HighkVA	U
03-09-23 12:30:20		Bus214	Bus Bus214 B high voltage	A	HighkVB	U
03-09-23 12:30:20		Bus214	Bus Bus214 C high voltage	A	HighkVC	U
03-09-23 12:30:20		Bus219	Bus Bus219 A high voltage	E	HighkVA	U
03-09-23 12:30:20		Bus219	Bus Bus219 B high voltage	E	HighkVB	U
03-09-23 12:30:20		Bus219	Bus Bus219 C high voltage	E	HighkVC	U
03-09-23 12:30:20		Bus221	Bus Bus221 A high voltage	A	HighkVA	U
03-09-23 12:30:20		Bus221	Bus Bus221 B high voltage	A	HighkVB	U
03-09-23 12:30:20		Bus221	Bus Bus221 C high voltage	A	HighkVC	U
03-09-23 12:30:20		Bus230	Bus Bus230 A high voltage	E	HighkVA	U
03-09-23 12:30:20		Bus230	Bus Bus230 B high voltage	E	HighkVB	U
03-09-23 12:30:20		Bus230	Bus Bus230 C high voltage	E	HighkVC	U
03-09-23 12:30:20		Bus249	Bus Bus249 A high voltage	E	HighkVA	U
03-09-23 12:30:20		Bus249	Bus Bus249 B high voltage	E	HighkVB	U
03-09-23 12:30:20		Bus249	Bus Bus249 C high voltage	E	HighkVC	U
03-09-23 12:30:20		Bus266	Bus Bus266 A high voltage	A	HighkVA	U
03-09-23 12:30:20		Bus266	Bus Bus266 B high voltage	A	HighkVB	U
03-09-23 12:30:20		Bus266	Bus Bus266 C high voltage	A	HighkVC	U
03-09-23 12:30:20		Bus285	Bus Bus285 A high voltage	E	HighkVA	U
03-09-23 12:30:20		Bus285	Bus Bus285 B high voltage	E	HighkVB	U
03-09-23 12:30:20		Bus285	Bus Bus285 C high voltage	E	HighkVC	U

- Too much information
  - Different types of alarms
  - Different levels of importance
  - Many alarms on the same thing
- Beyond human capacity to effectively understand the complete situation
- The alarm list becomes useless (really!) during incidents
- Look elsewhere to really understand what happened…

Grouping of Alarms

- Only active GDS alarms are visible in GDS – together with any underlying SCADA alarms

- Example: line connected (through separate breakers) to A and B bus bars
  - First breaker (on A bar) opens => no alarm, line still in service
  - Second breaker (on B bar) opens => alarm, line out of service
  - GDS shows one alarm, indicating **low flow** on the line (text says Out of Service)
  - If the GDS alarm is selected, both breaker SCADA alarms show up in the Details list

- Designed for "Situational Awareness"
  - We need to know if the line becomes out of service
  - We do not (primarily) care about documenting the state of individual breakers

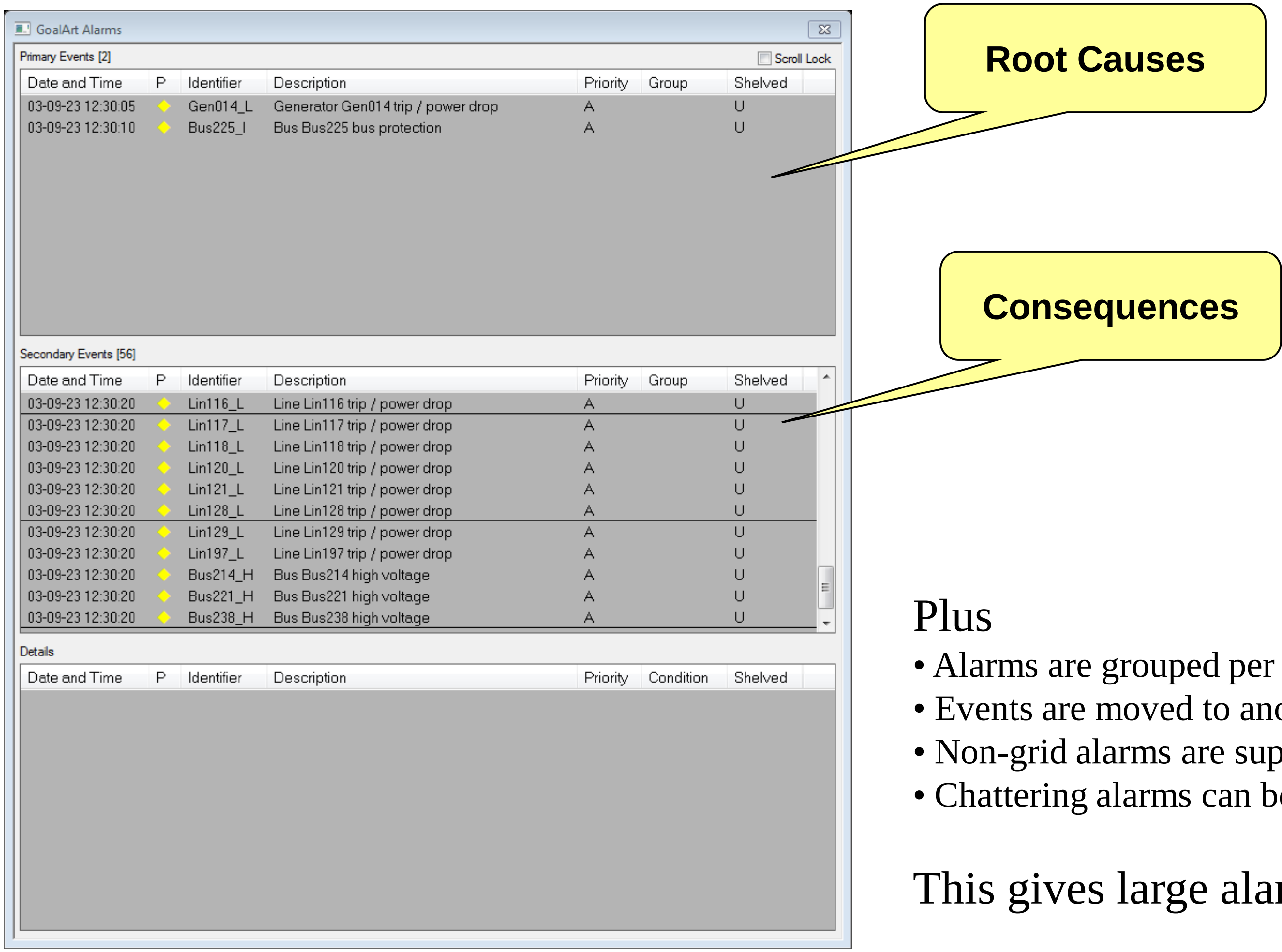
  - There is a separate list in the GDS with all active, individual breaker alarms

Finding the Real Fault

- Root Cause Analysis
  - Model based
  - First time right
  - Efficient algorithm exists
  - Zero maintenance effort (grid model is already maintained for other purposes)

- Other Methods – *Not Really Working*
  - Static alarm priorities – *severity of the problem independent of what caused it*
  - First alarm to occur – *what if there are several faults / process delays*
  - Statistical methods / learning – *can't ensure meaningful results, disasters are rare*
  - Logic trees / Manual rule bases – *endless maintenance/update effort*

GoalArt Alarm List



Plus

- Alarms are grouped per equipment
- Events are moved to another list
- Non-grid alarms are suppressed
- Chattering alarms can be suppressed

This gives large alarm reduction

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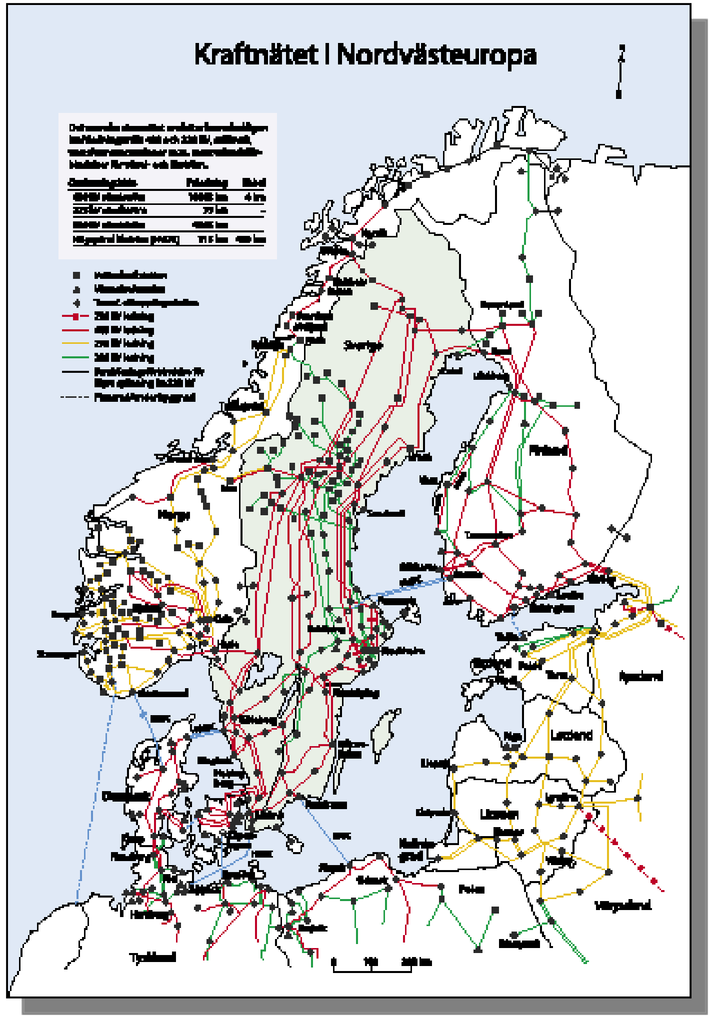
Blackout September 23rd 2003

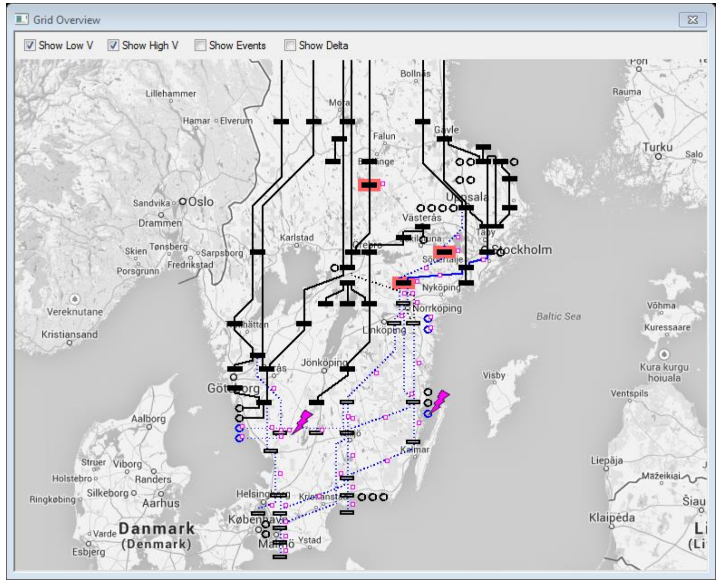
- Large blackout in Scandinavia
- September 23rd 2003, 12.35 PM
- Root causes
  - 12:30 OKG 3 nuclear reactor trip (east)
  - 12:35 Internal station short-circuit (west)
- Consequences
  - Two lines for all of southern Sweden
  - Southern Sweden collapsed (5-15 min)
  - Eastern Denmark collapsed
  - Lasted 1-5 hours
- Actions
  - Second root cause unknown for 4 hours
  - Helicopters looking for line faults
- Cost
  - Lost ~ 10 000 000 kWh
  - Cost ~ 500 000 000 USD
  - Largest disturbance in 22 years



Time to look at Reality – Demo time!

Graphical Overview

- Dynamic alarm presentation
  - Primary alarms shown as “Lightning Strikes”
  - Line colors represent flow
  - Background colors represent voltage
  - Red is high, Blue is low
- Situational awareness at a glance



The Real Root Cause

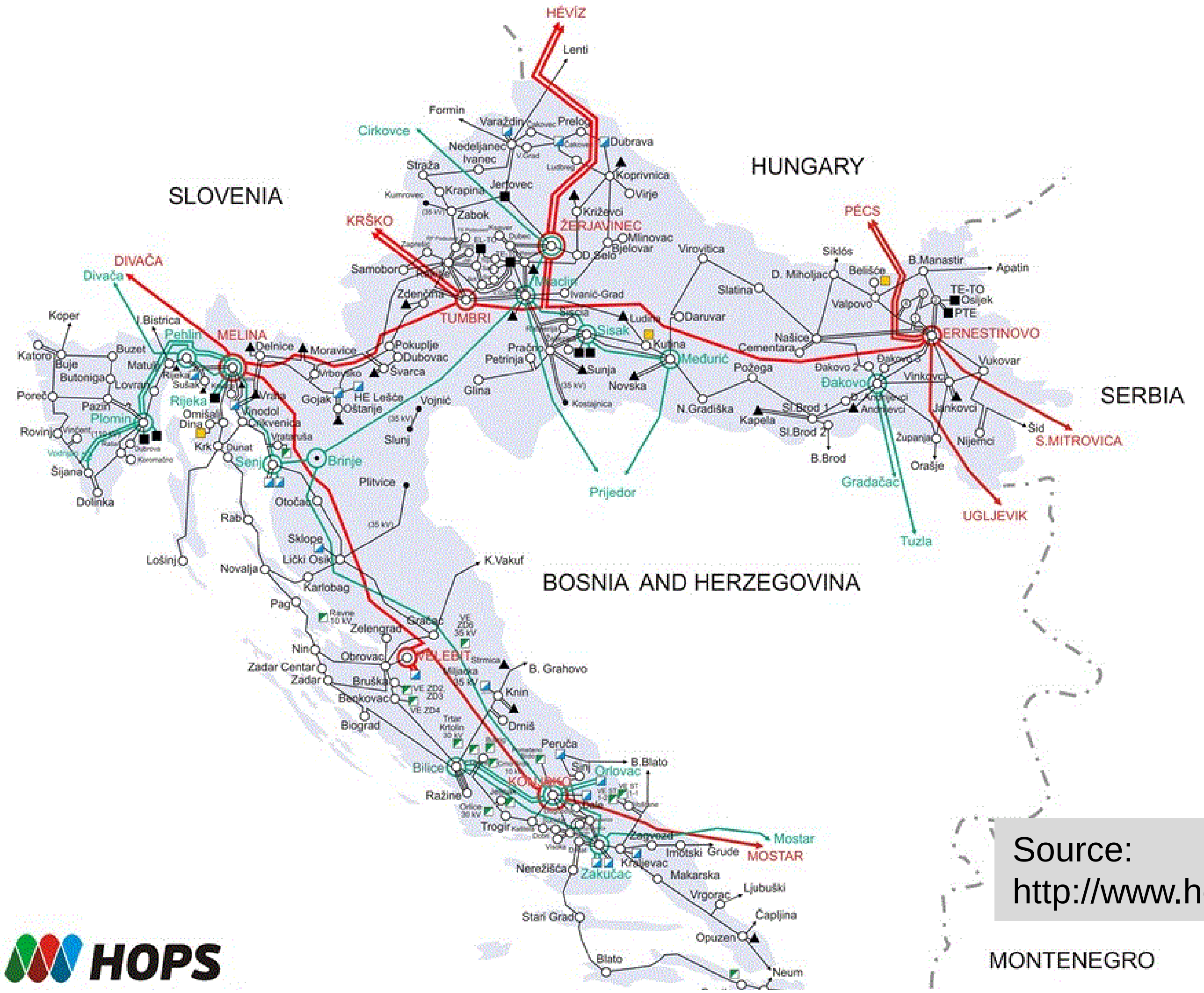
Please Note!

- GoalArt is not (and does not replace) an alarm/event list
  - Track all alarms and events
  - Information about (the state of) all equipment
  - Acknowledge that the operator has observed all information – accountability ☺
  - Track all (also no longer valid) information about events/incidents
- GoalArt is support for the operator
  - Quick answer to the question ”What happened, really?”
  - Trace back to the origin of the problem
  - Only present relevant alarms/information
  - Give operator extra confirmation that the situation is well understood

Actual Outage in Real Time

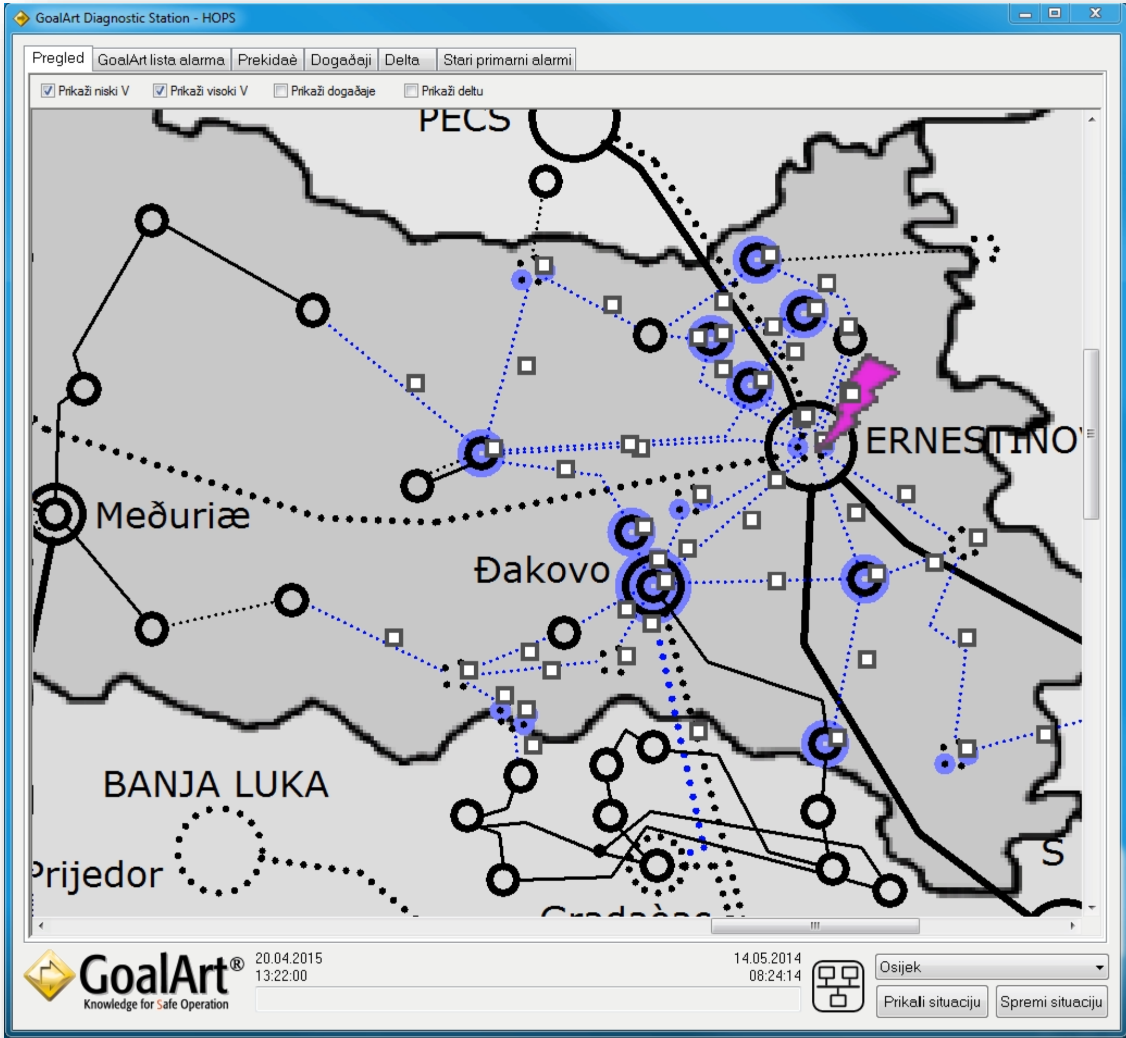
- System running at HOPS, Croatian Transmission System Operator Ltd.
- Regional black out occurred on May 14th, 2014, about 9 a.m.
- Transformer Magazine: “The entire city of Osijek, a large part of Slavonija and almost the whole of Baranja lost power supply”
- Much more than 100 SCADA Alarms
- The entire event is attributed to a single root cause, the Ernestinovo bus bar protection, with 77 grouped, consequential alarms
- HOPS representative: “We are very satisfied with the [GoalArt] results from the incident. This will boost operator confidence in the tool.”
- White Paper available at http://www.goalart.com/publications/2014-HOPS.pdf

Croatian Grid



Source:
http://www.hops.hr

Live Screen Capture

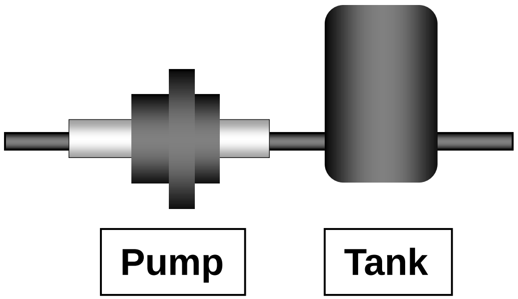


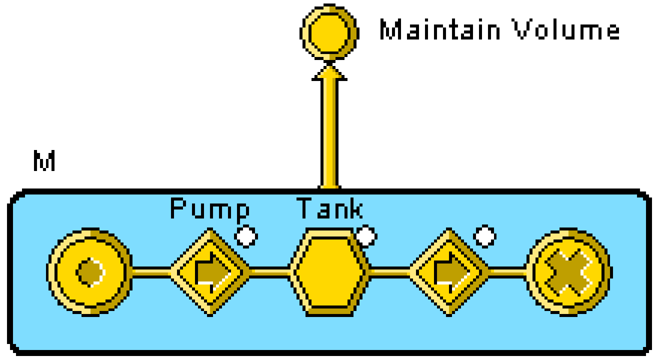
What Knowledge is in the GDS?

- Grid data from the EMS system
  - Exported from EMS in CIM/XML format
  - Complete set of one-line diagrams for the entire grid and all substations
  - All analog measurements (voltages, flows etc.) and related alarms
- Protection relay signals
  - Bus bar protection, Breaker fault protection and Ground fault protection relays
  - Based on the alarm naming conventions
- Graphics overview
  - Manually updated

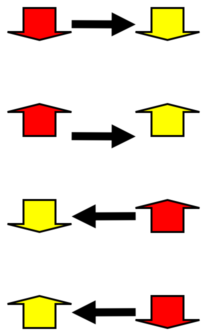
- Compiled to create the internal GDS knowledge base
  - Quick and simple process
  - No learning or statistical methods
  - No further tuning after installation

How Does It Work?



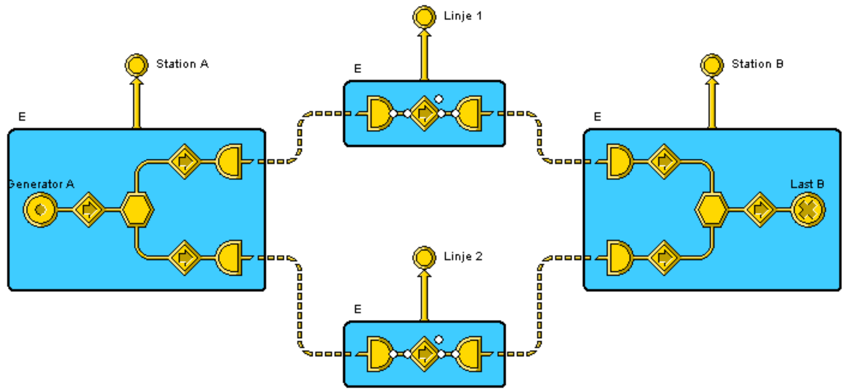


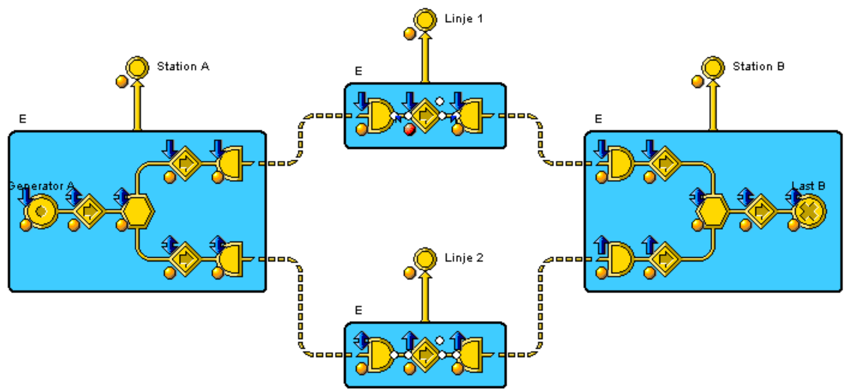
- Simple example
  - Pump and closed tank
- Described as transport and storage
- Four consequence propagation rules are valid for this connection



Simple Example

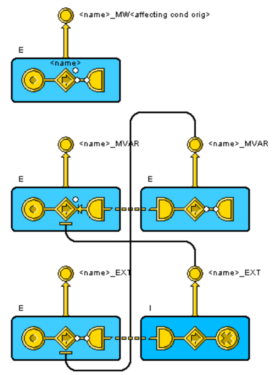
- Line 1 trips from internal fault
- Line 2 overloads
- Analysis
  - Line 1 is a root cause
  - Line 2 is a consequence
- Root cause analysis can reduce large alarm cascades to single root cause alarms

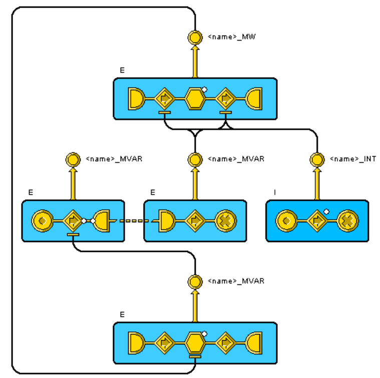


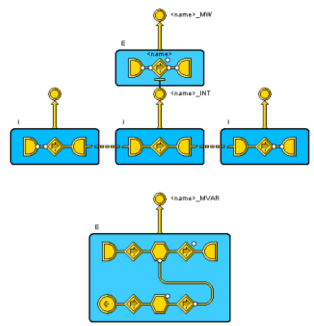


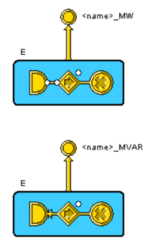
Basic MFM Model Constructs

- MFM model objects
  - Goals, functions, relations, conditions
- All grids created from model fragments in library
  - Generator
  - Line
  - Bus bar
  - Load
- Automatic generation from topology database possible
- Plug-and-play knowledge based system solution









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Thank You!

Any Questions?