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Preventive Maintenance Optimization for Slovak Power Grid Using EOOS Risk Monitor

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Presentation Outline

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  - EOOS for scheduler

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Introduction

Within the project supported by Slovak Transmission grid operator - SEPS, a.s. a PSA project was initiated for the Slovak transmission grid (400 kV). The project has the following objectives:

- assessment of the overall system reliability of the transmission grid,
- identification of the transmission system components most likely to contribute to critical situations,
- identification of the specific components most susceptible to interruption,
- quantification of the frequency of partial and total blackout,
- development of a risk monitor to control the risk.

Introduction

- Traditional approach to control the grid configuration is based on **the deterministic rule (n-1)** which is formulated to ensure that maintenance outages are controlled in order to ensure, that the reliability has an adequate level.
- The current trend is to move towards an integrated decision making approach using the information provided by a **risk monitor** to ensure that the occurrence and duration of grid configurations are managed to keep the risk at or below an acceptable levels.
- The risk measures addressed by risk monitors usually include quantitative risk measures such as a frequency of partial blackout or total blackout. The numerical values associated with quantitative risk measures are quoted in a number of ways which include baseline risk, instantaneous risk and cumulative risk.

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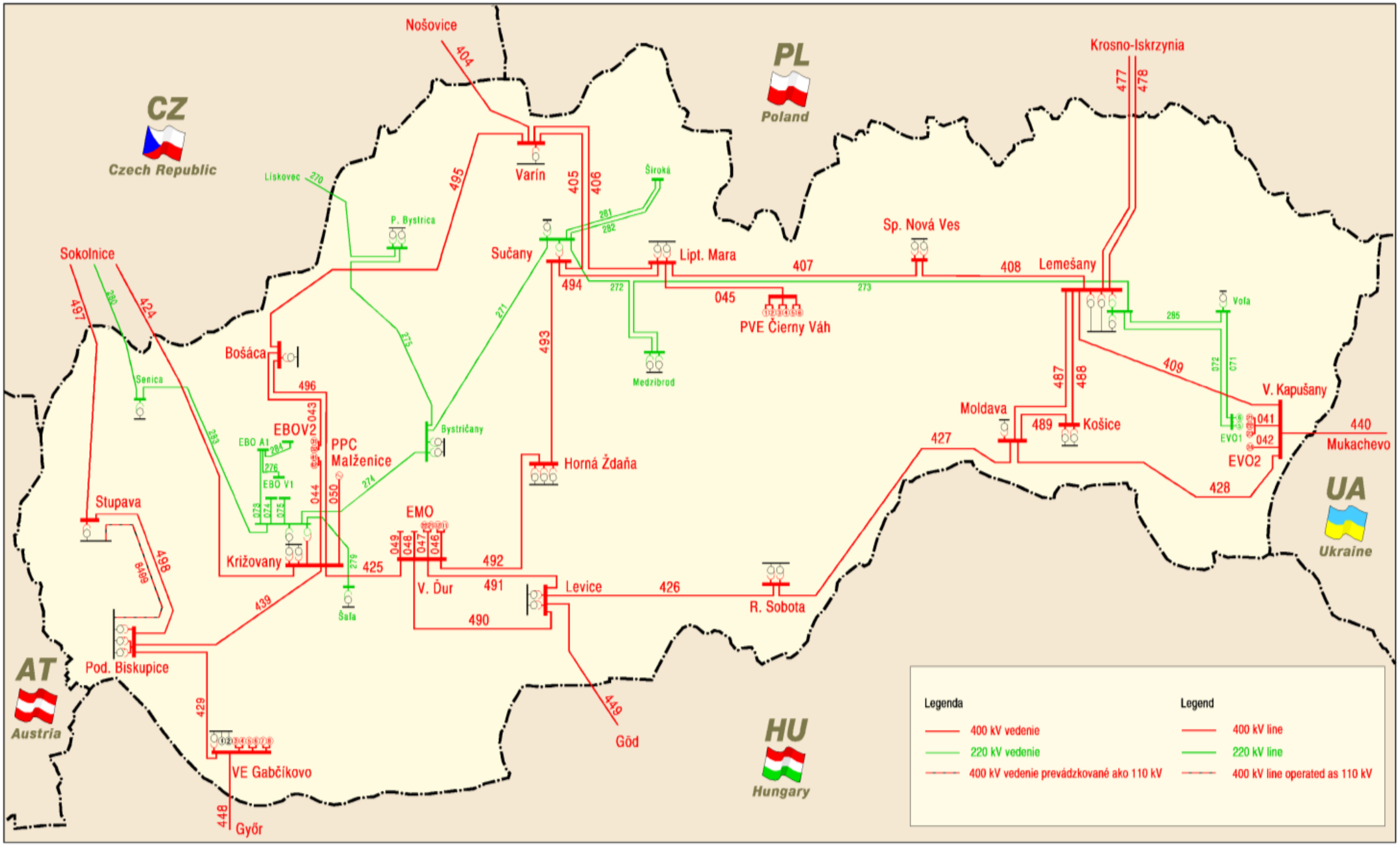
Introduction



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The initiating events

- The accident starts with an initiating event, the continuation of which is then modeled with event and fault trees.
- This approach is suitable also for modeling of power system protections, since the method is developed for analysis of the safety functions after an accident.
- This analysis of post-fault substation operations is therefore analogous to a nuclear power station PSA analysis.

The initiating events

- Initially the following list of initiating events are considered:

1) short connection of the lines,
2) short connection in the substations,
3) outage of power sources,
4) outage of lines,
5) outage of consumers.

- IEs 3,4 and 5 excluded based on accident simulations results

The initiating events

The following short connection causes were identified and analyzed:

Short connection of the lines:

- A unidentified,
- B operational failure and wear out,
- C environmental influence,
- D influence of nature,
- E abroad failure,
- F pollution - contamination.

Short connection in the substations:

- B operational failure and wear out,
- G human factor.

The accident simulations

- The grid simulations are made using a power system analysis software package (PSLF). The grid model in the software is the Slovak interconnected transmission system.
- The grid models of other countries were not as detailed as that of Slovak grid.
- Two levels of the load flow were simulated to model the power imports from different countries through the Slovak transmission grid.

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The accident simulations

- The results of the accident simulations are classified taking into account the stability, the voltage violations, and the thermal limits.
- Angle stability is classified into the categories: stable and unstable.
- When the angle stability of the power system is lost in 20 seconds the result is a major disturbance. There is nothing the control operation personnel can do to prevent the case.
- The power system consequences received from power system simulations are added into the end branches of the event trees.

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The accident simulations

- The following end states are defined for the event trees after the occurrence of the initiating event:
- D1- stable state
  - No power source is lost
  - No line is overloaded
  - No substation will be without power supply
  - No passive element is lost which can lead to limitation of power supply in Slovak Republic
- D2 - stable state with limitation
  - No power source is lost with power higher than 880 MW
  - Two or more substations will not be without power supply (the second substation will not be Krizovany, Levice or V. Dur) and the substation Krizovany will not be without power supply
  - No significant limitation in power supply in Slovak Republic

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The accident simulations

- D3 - dangerous state
  - Power sources are lost with total power higher than 880 MW or
  - Two or more substations will be without power supply (the second station is Krizovany, Levice or V. Dur) or the substation Krizovany will be without power supply or
  - Significant limitation in the power supply in Slovak Republic
- D4 – unstable state
  - Power sources are lost with total power higher than 880 MW
  - Two or more substations will be without power supply (the second station is Krizovany, Levice or V. Dur) or the substation Krizovany will be without power supply
  - Significant limitation in the power supply in Slovak Republic
- D5 – total blackout
  - Blackout is a power system state in which the power system has collapsed. In this state the system has collapsed and operators start the system restoration. The breakdown can be caused due to rotor angle, voltage or frequency instability after the fault. It also can be caused by insufficient operator actions after a fault that occurred during the states D1-D4.

The event trees

- The event tree describes the response of the grid to the initiating event.
- Event trees are constructed for short connections at 400 kV lines and at substations and for 2000MW and 2700MW power flow.

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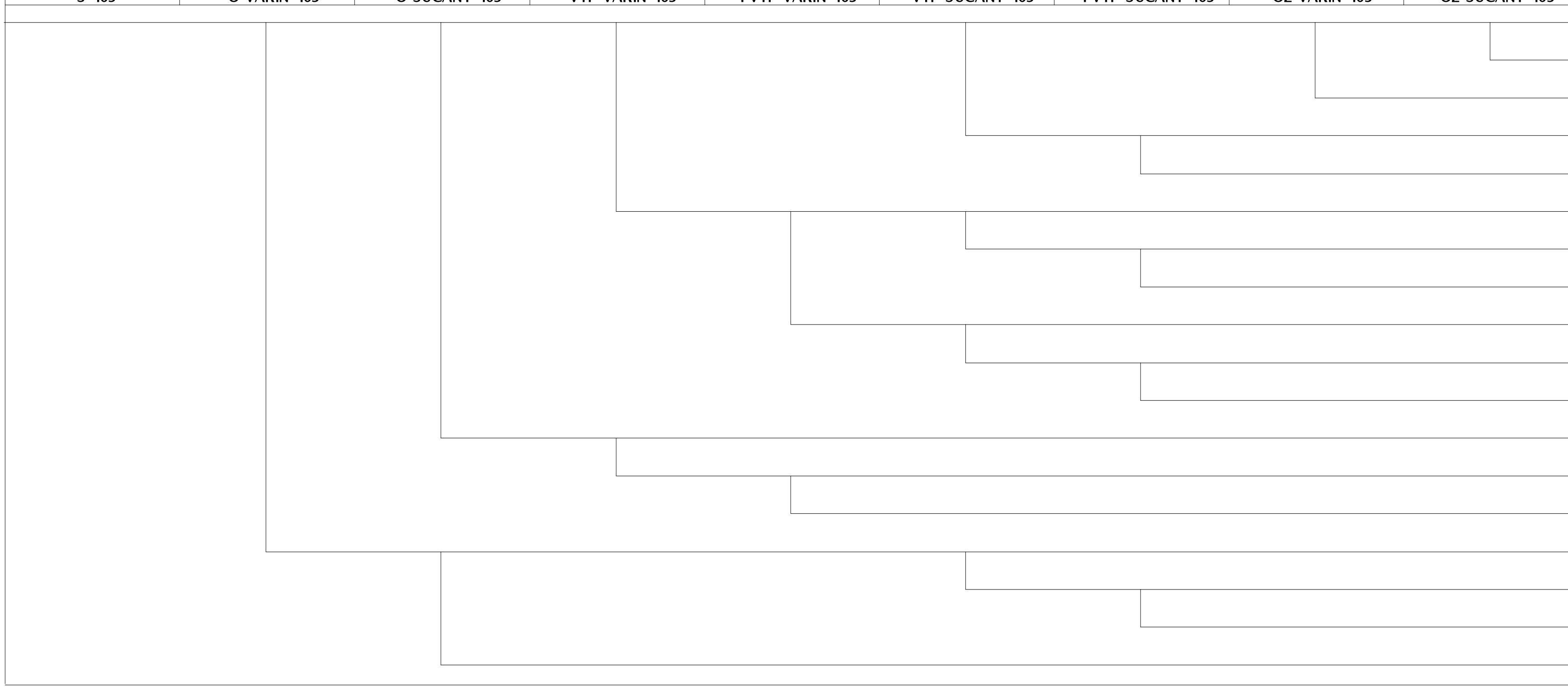
The event trees

Event tree for 400 kV line short connection

Short connection on the line 405	Protection trip signal in Varín (405)	Protection trip signal in Suèany (405)	Line breaker opening in Varín (405)	Substation breaker opening in Varín (405)	Line breaker opening in Suèany (405)	Substation breaker opening in Suèany (405)	Rapid automatic reclosing in Varín (405)	Rapid automatic reclosing in Suèany (405)	P.è.	Následky
S-405	O-VARIN-405	O-SUCANY-405	VYP-VARIN-405	PVYP-VARIN-405	VYP-SUCANY-405	PVYP-SUCANY-405	OZ-VARIN-405	OZ-SUCANY-405		



P.è.	Následky
1	OK
2	OK
3	OK
4	D2
5	D2
6	D2
7	D2
8	D3
9	D3
10	D3
11	D3
12	D2
13	D3
14	D3
15	D3
16	D3
17	D3
18	D3

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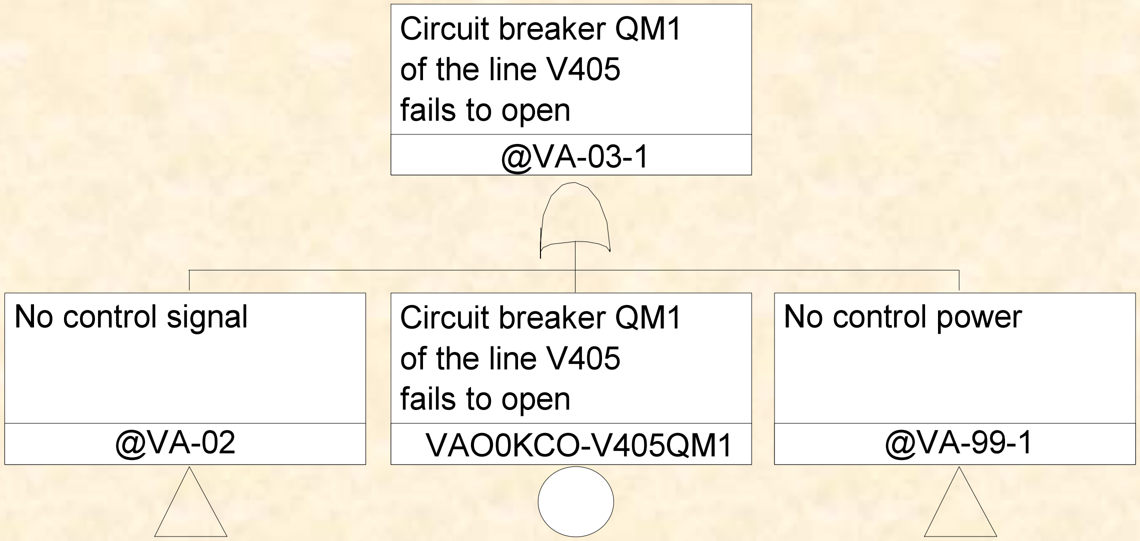
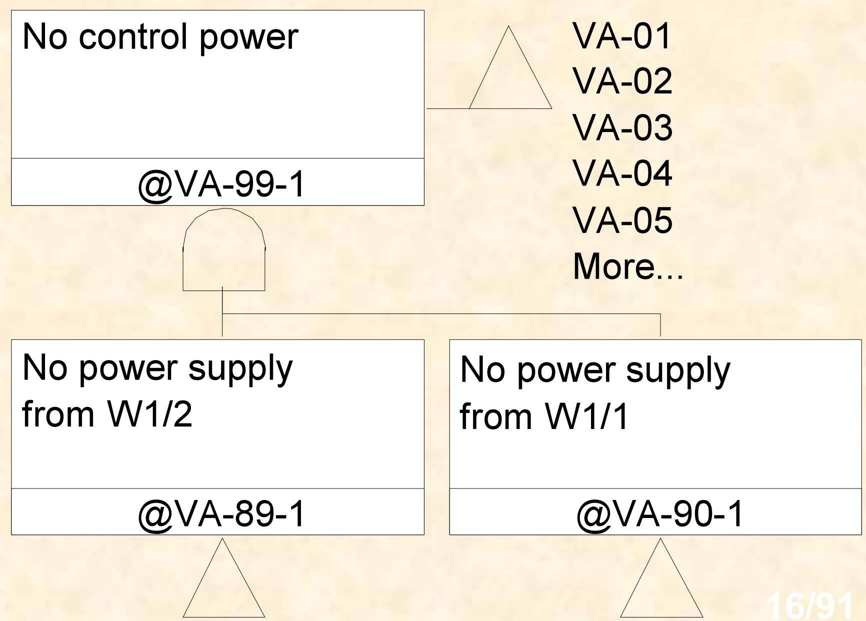
The event trees

Event tree for short connection in 400 kV substation

Skrat v 400kV rozvodni Levice	Zlyhanie rozdielovej ochrany Levice	Vypnutie vypínaèa Levice (490)	Vypnutie vypínaèa Levice (491)	Vypnutie vypínaèa Levice (426)	Vypnutie vypínaèa Levice (449)		
00S-LEVICE	ROZD.OCHR-LEVICE	VYP-LEVICE-490	VYP-LEVICE-491	VYP-LEVICE-426	VYP-LEVICE-449	P.è.	Následok
						1	OK
						2	D3
						3	D3
						4	D3
						5	D3
						6	D3

The fault trees





The PSA results

- The main results are frequencies of the partial and total blackout due to initiating events occurring during operation of the grid.
- The frequencies of the individual states are the following:
  - D1 = 1.75E-04/y
  - D2 = 1.37E-03/y
  - D3 = 4.34E-03/y
  - D4 = 1.98E-04/y
- The frequency of D5 is negligible.

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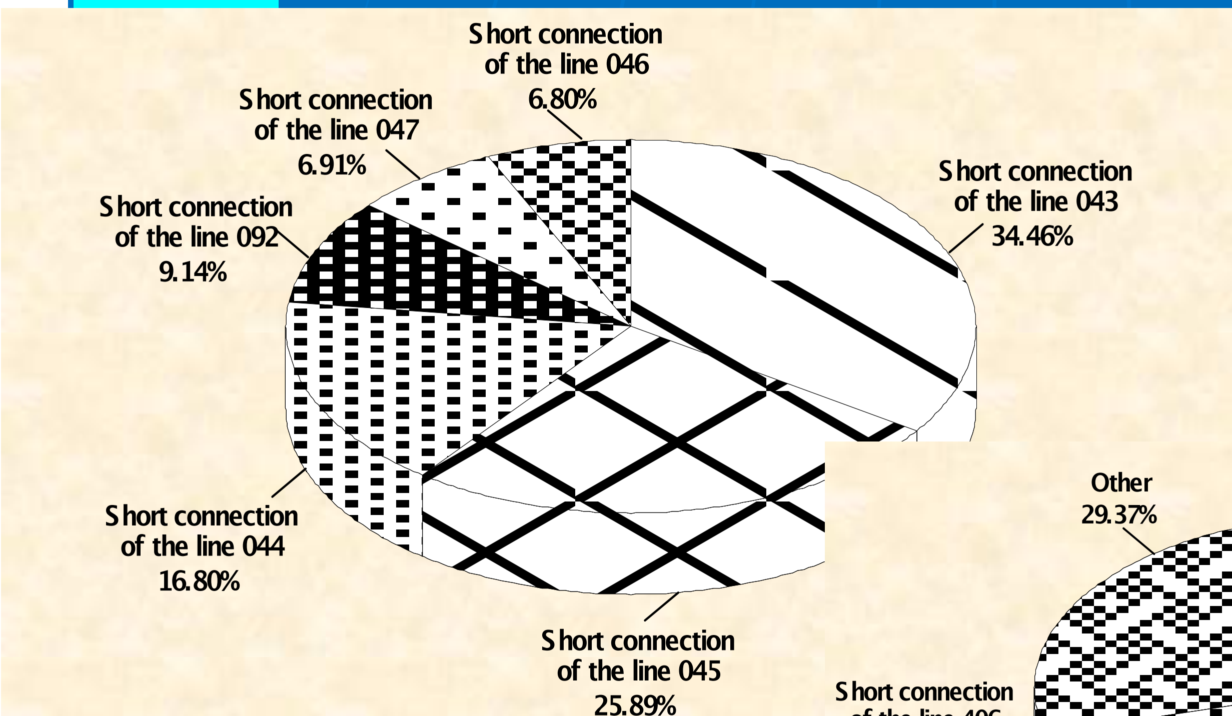
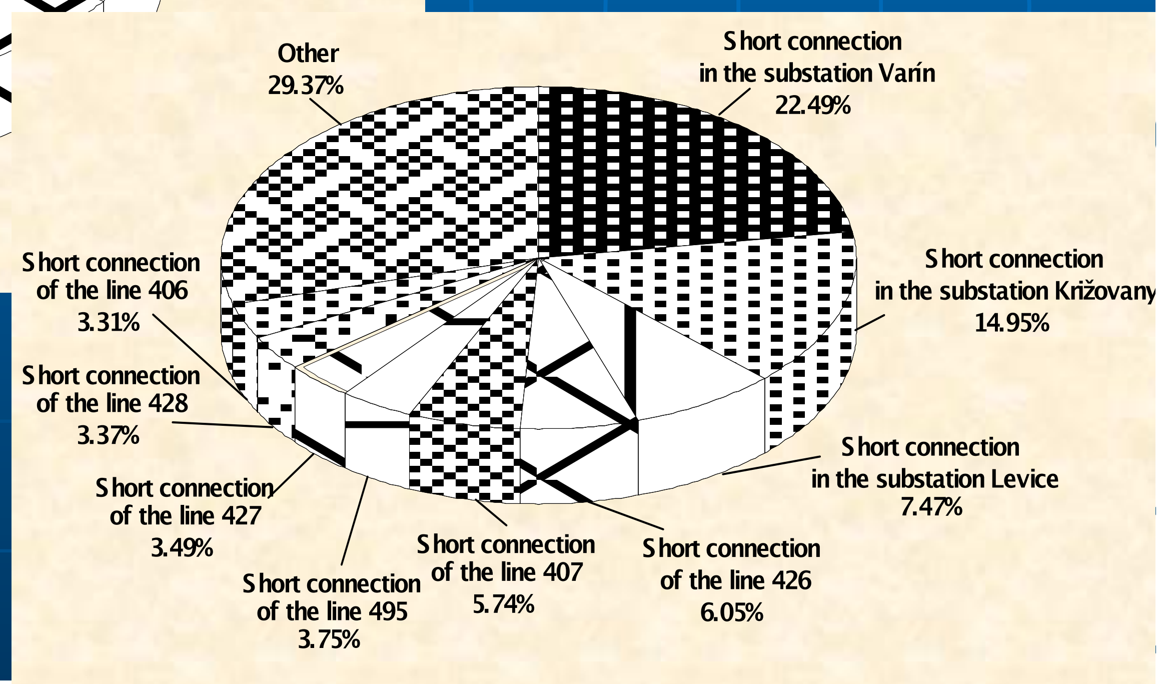
The PSA results

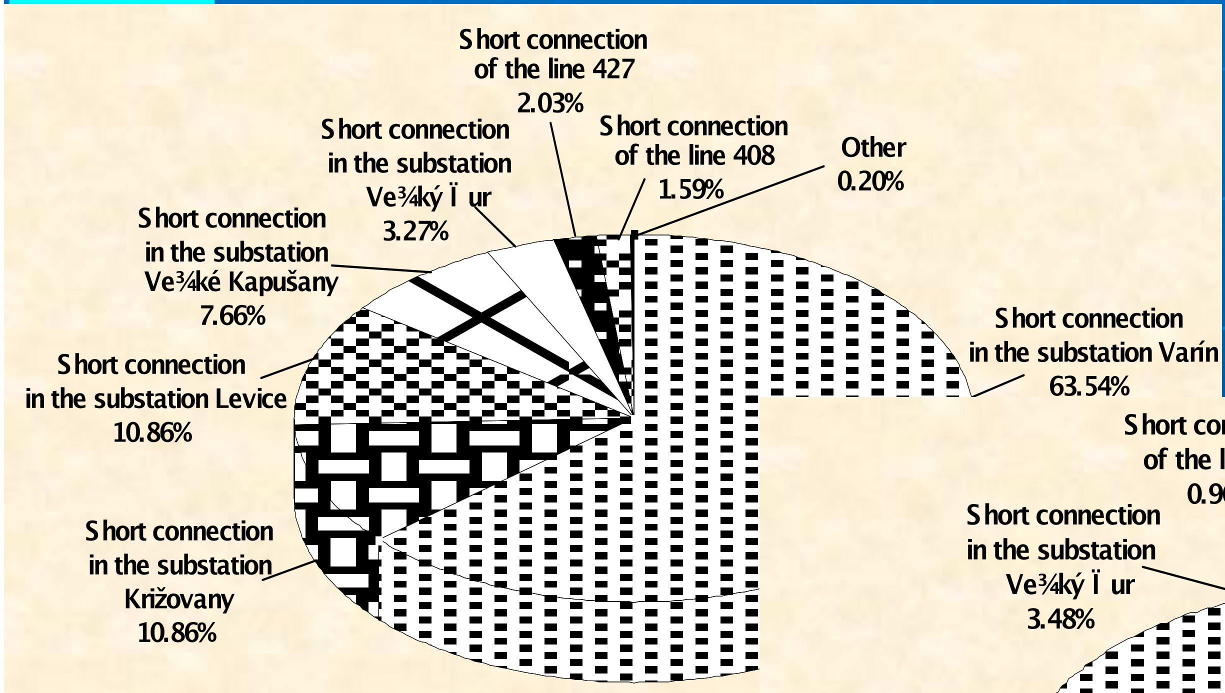
Dominant contributors to the state D1 and D2

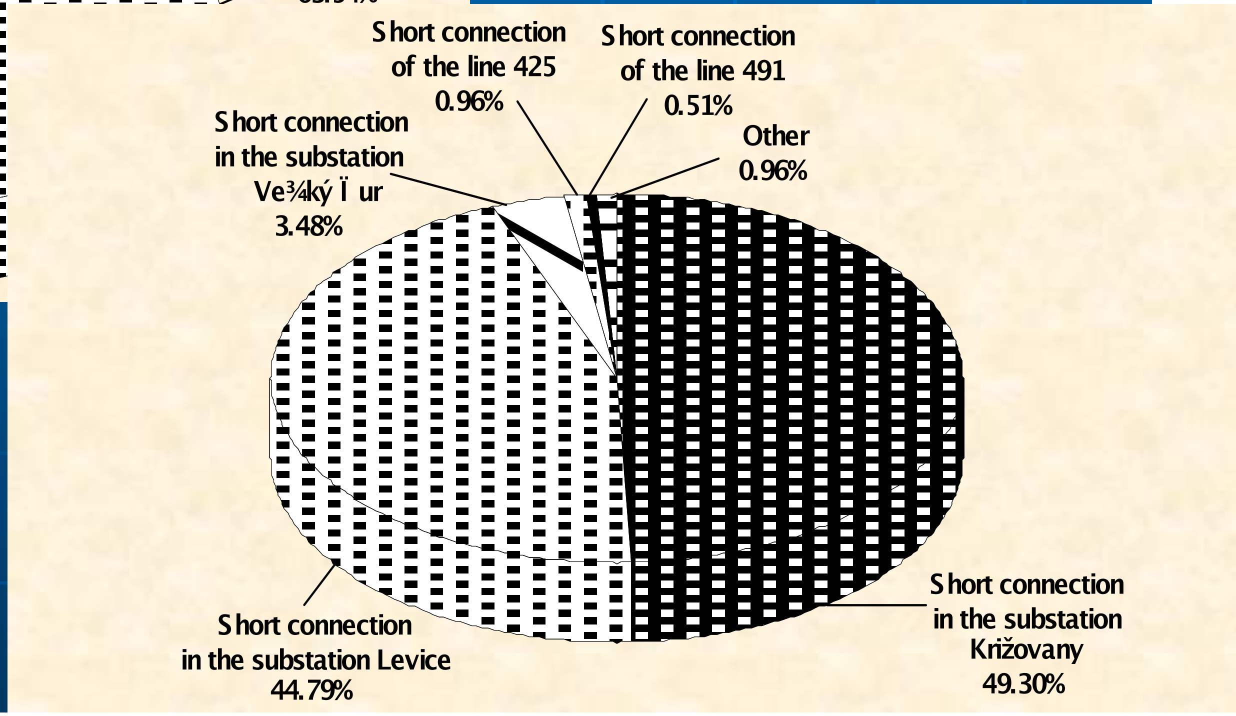




The PSA results

Dominant contributors to the state D3 and D4





The PSA results

- In addition, other indicators are available from the PSA results:
  - the minimal cut sets (simultaneous failure of components and the initiating events leading to the given state)
  - an index for the relative importance of each component in relation to states D1-D4, this can be done by ranking the grid-level importance measures,
  - local indices for each initiating event, etc.

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EOOS Risk monitor - Introduction

- The grid-risk monitor is developed using the EPRI software EOOS (Equipment Out Of Service). The software was one of EPRI's Risk and Reliability Analysis Workstation products and is a computer program for monitoring safety. It provides an interface that makes the fault tree usable by non-PSA experts. An operator (dispatcher) panel, which can be readily adapted to an individual utility's requirements, allows easy user input to the fault tree.
- EOOS helps operator focus on safety and stability. The combined effect of many simultaneous work activities can have a significant impact on grid reliability. With each new task, dispatchers make a complex decision to act based on their perception of how it affects grid reliability.

EOOS Risk monitor - Introduction

- The EOOS grid risk monitor screen helps dispatcher to make these decisions by showing:
  - a numerical measure of grid safety that reflects changes in equipment status.
  - the maximum time allowed in a particular grid configuration.
  - the status of grid systems affected by various test and maintenance activities (providing measures of “defense-in-depth”).
  - a list of current activities that affect grid equipment.
  - lists of in-service and out-of-service items, ranked by their importance to safety
  - quick recalculating of safety measures for a variety of “what-if” tests.

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EOOS Risk monitor - Introduction

- In the current grid risk monitor the dispatchers can choose one of two transit power flows – **2000 MW** or **2700 MW**.
- They are also able to set any configuration of the grid by taking out of service any of 45 400 kV distribution lines, any component within 19 substations or entire substation.
- Furthermore, dispatchers can model the real situation of the grid also using **environmental effects function.**

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EOOS Risk monitor - Introduction

- ✓ For the grid safety measure the Plant Safety index (PSI) was chosen. The value of PSI ranges from 0 – 10 and it is derived from frequency of occurrence of desired end state (D3 or D4).
- ✓ A high PSI value implies a high level of safety: “10” is good, “0” is bad. The analog display is a vertical bar to the left of PSI number. Like a thermometer, this bar fills from the bottom up. The fill color is red, orange, yellow, or green.
- ✓ Red appears with low PSI values, green with high PSI values, and orange and yellow with intermediate values. The boundaries for color change are derived from base-line (no unavailability in the grid) frequency of occurrence of end states D3 and D4.

$$PSI(t) = 10.\frac{\log(Current\ \ risk)}{\log(Baseline\ \ risk)}$$

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EOOS Risk monitor - Introduction

PSI Risk Indicator

Baseline risk values:

$$D3_{2000} = 4{,}34E\text{-}03/r,$$
$$D4_{2000} = 1{,}98E\text{-}04/r,$$
$$D3_{2700} = 4{,}35E\text{-}03/r,$$
$$D4_{2700} = 2{,}01E\text{-}04/r.$$

PSI Threshold Values

Region	Range	Threshold values for $D3_{2000}$	Threshold values for $D4_{2000}$	Threshold values for $D3_{2700}$	Threshold values for $D4_{2700}$
Green	00Di < Di < (00Di * 10)	4.34E-3 ≤ D3 < 4.34E-2	1.98E-4 ≤ D4 < 1.98E-3	4.35E-3 ≤ D3 < 4.35E-2	2.01E-4 ≤ D4 < 2.01E-3
Yellow	(00Di * 10) < Di < (00Di * 20)	4.34E-2 ≤ D3 < 8.68E-2	1.98E-3 ≤ D4 < 3.96E-3	4.35E-2 ≤ D3 < 8.70E-2	2.01E-3 ≤ D4 < 4.02E-3
Orange	(00Di * 20) < Di < 1.0E-2 (1.0E-1)	8.68E-2 ≤ D3 < 1.00E-1	3.96E-3 ≤ D4 < 1.00E-2	8.70E-2 ≤ D3 < 1.00E-1	4.02E-3 ≤ D4 < 1.00E-2
Red	Di ≥ 1.00E-2 (1.00E-1)	D3 ≥ 1.00E-1	D4 ≥ 1.00E-2	D3 ≥ 1.00E-1	D4 ≥ 1.00E-2

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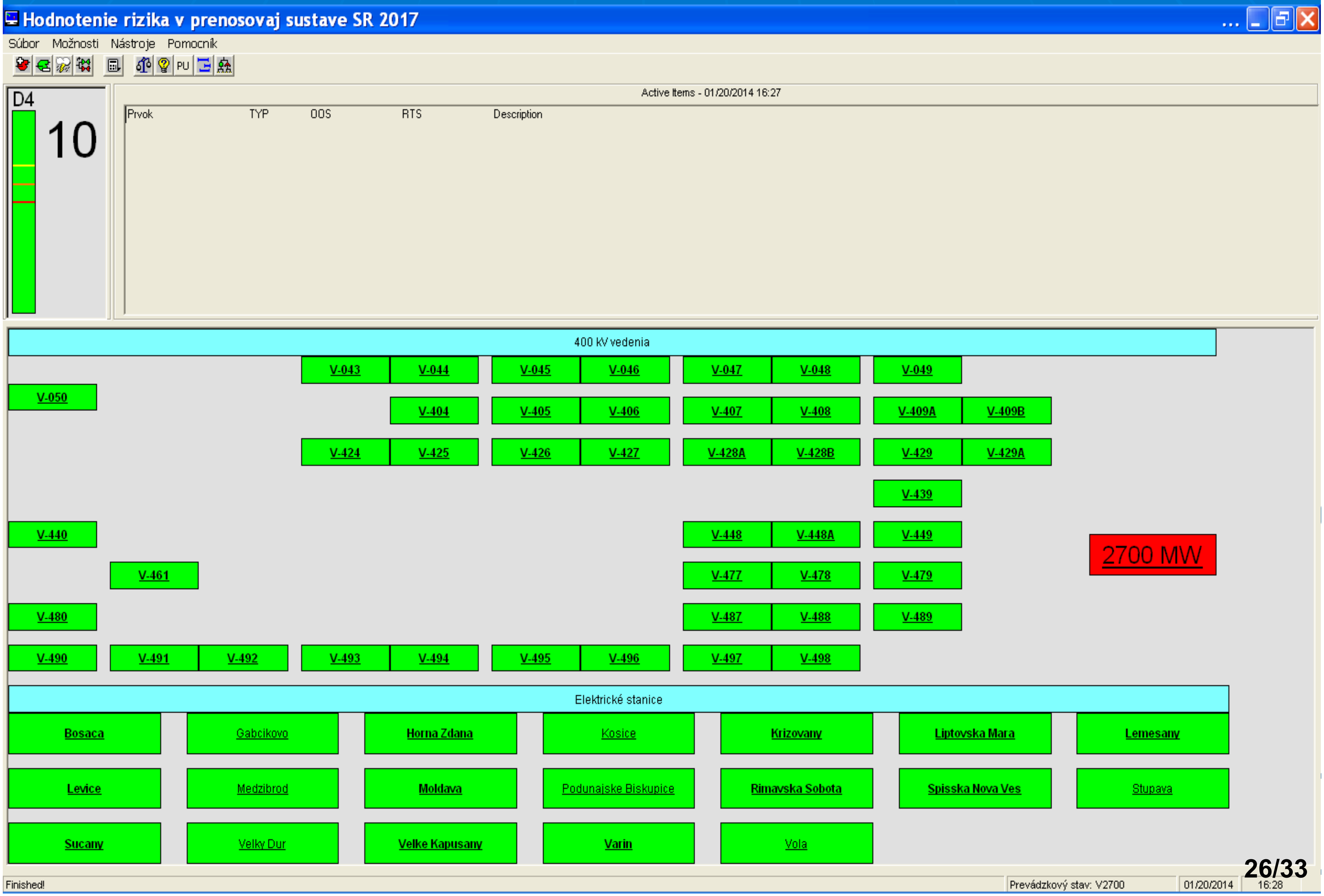
EOOS Risk Monitor for Dispatcher



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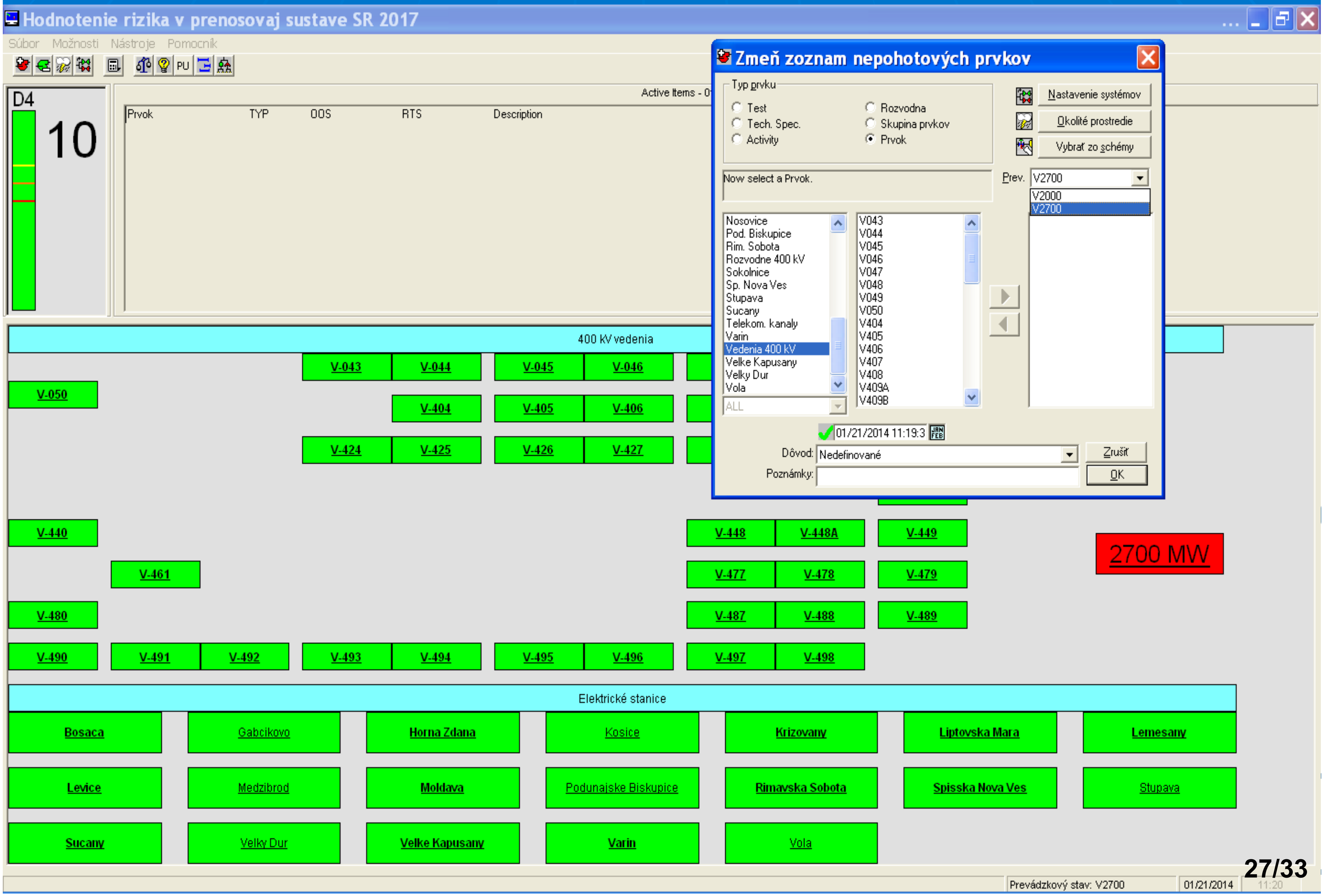
EOOS Risk Monitor for Dispatcher



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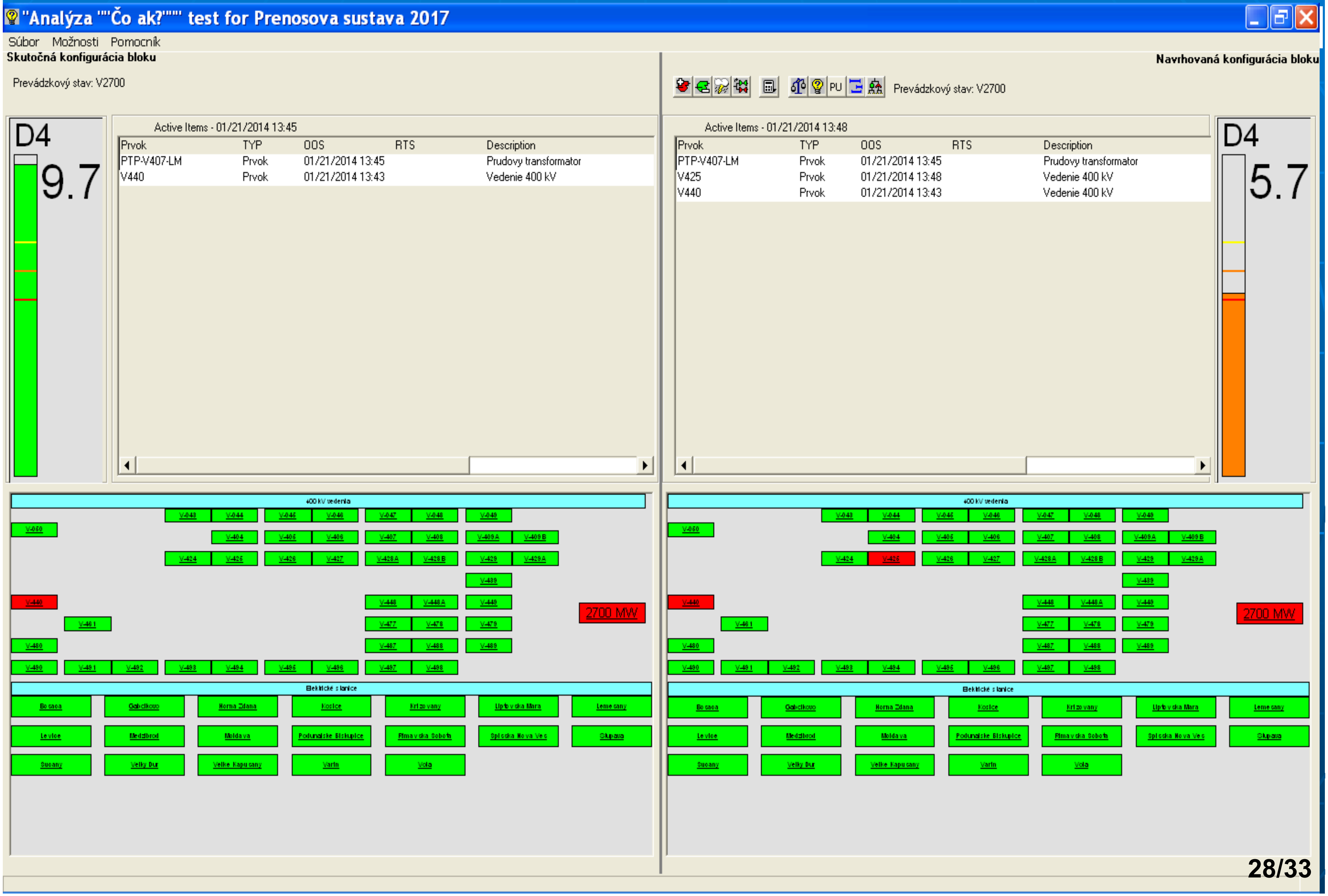
EOOS Risk Monitor for Dispatcher



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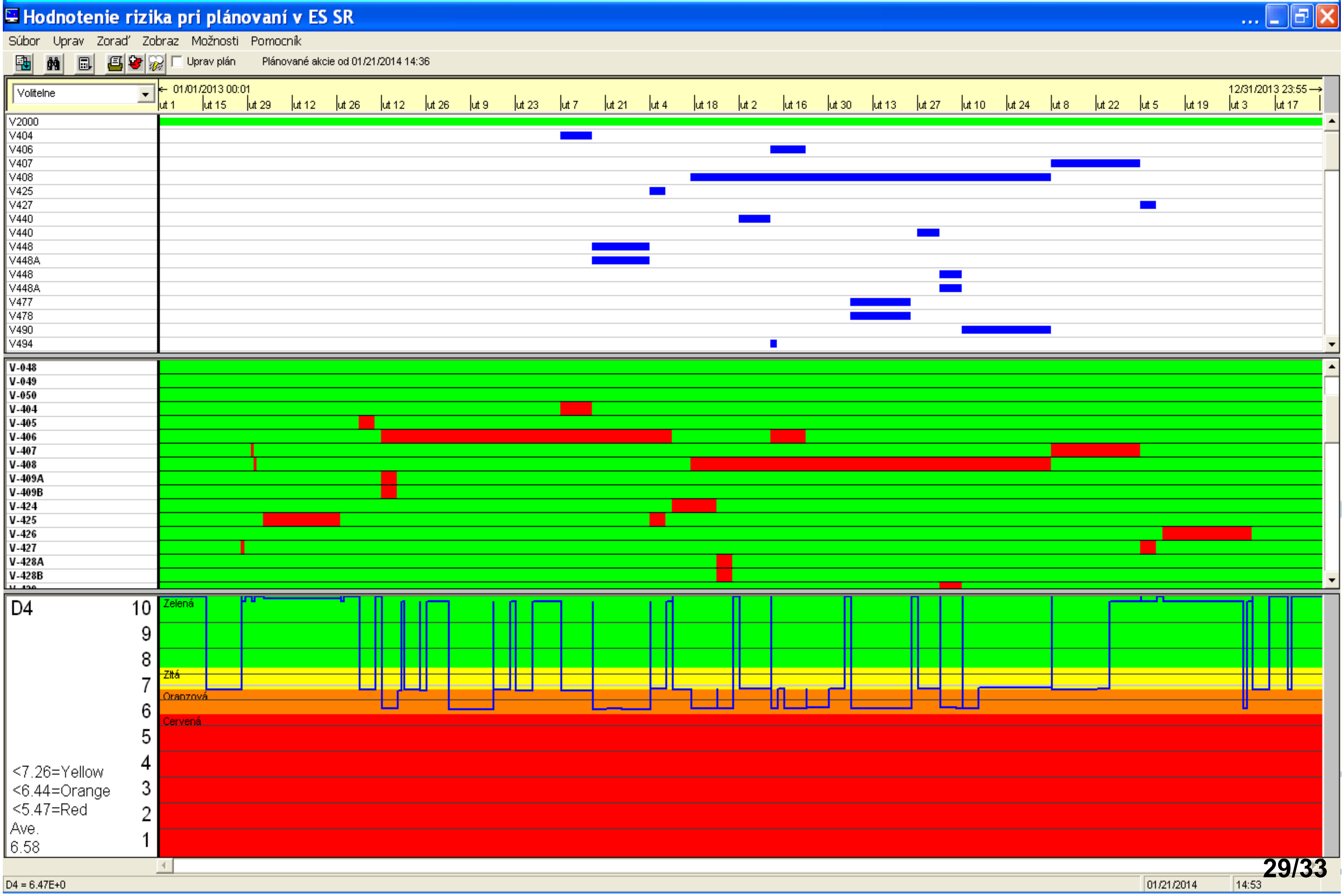
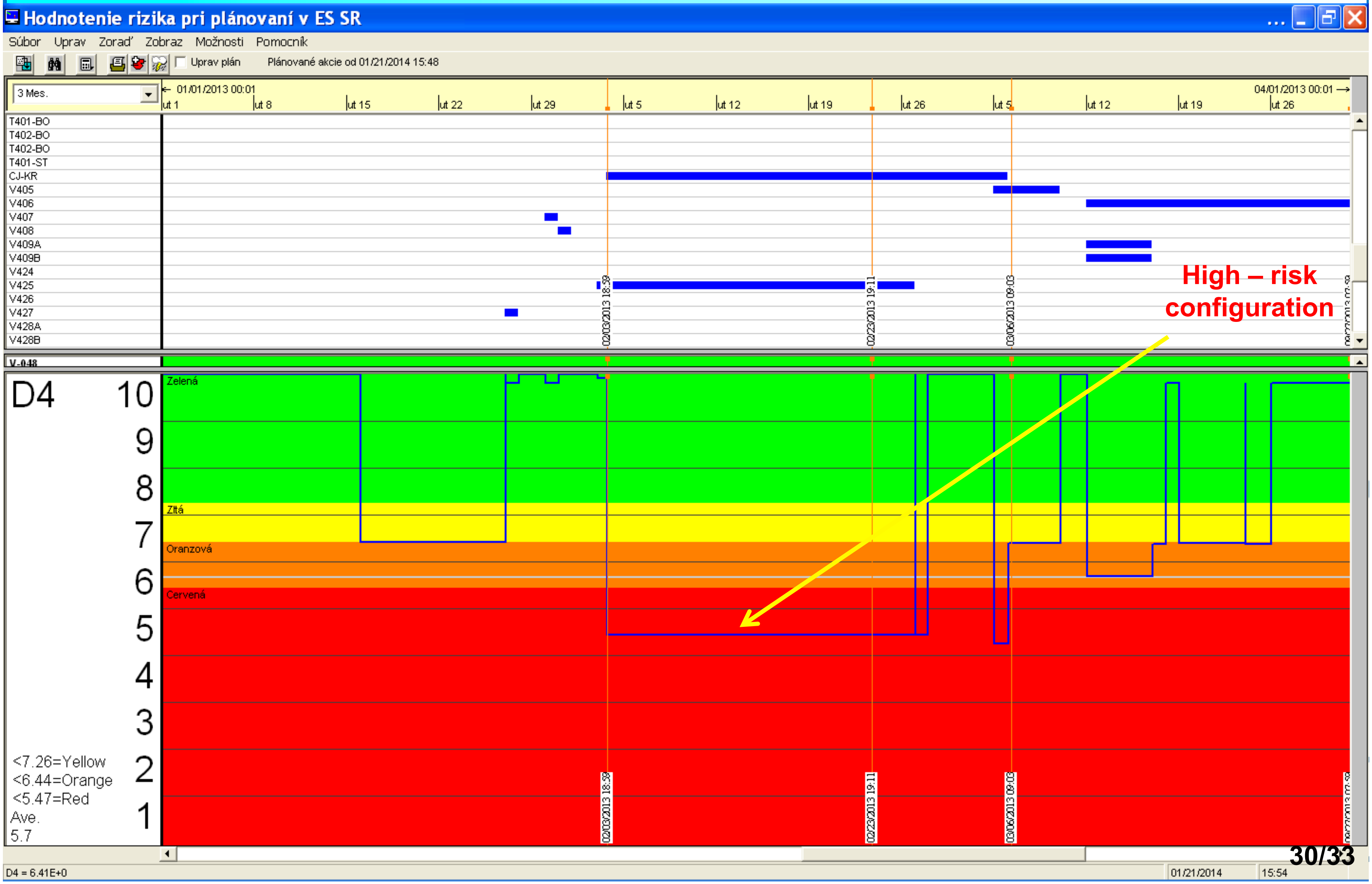
EOOS Risk Monitor for Scheduler



EOOS Risk Monitor for Scheduler



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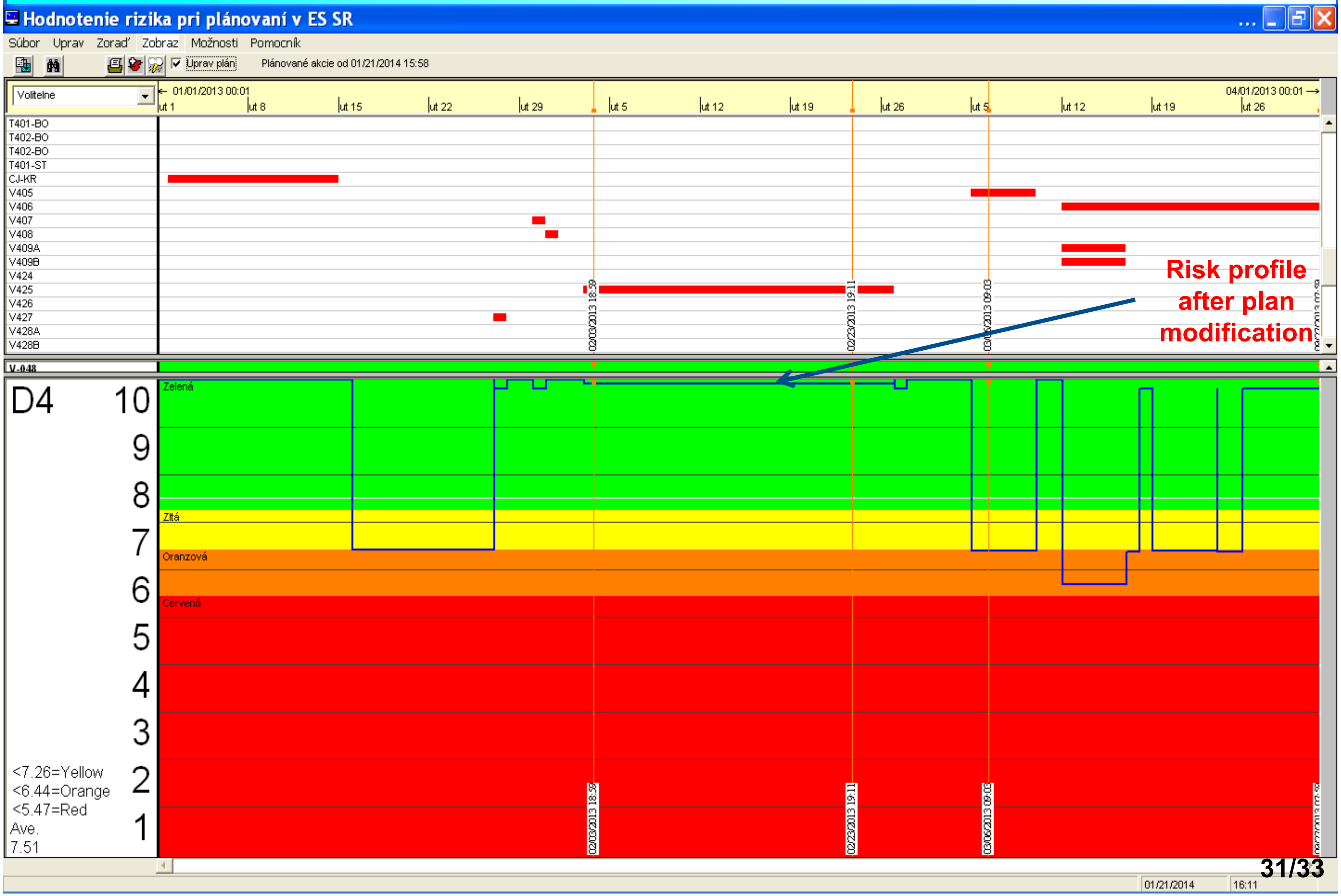
EOOS Risk Monitor for Scheduler



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Conclusions

In particular, the use of a risk monitor will:

- allow the grid operators the controlling the grid configurations, thus ensuring that the overall risk from the grid will be lower,
- provide risk information in a form that is readily understandable and can be used to demonstrate the level of safety of the grid,
- make it easier to address the maintenance activities, to assess the risk prior to entering a planned maintenance configuration and immediately after entering a non-voluntary configuration for all the modes of operation of the grid and
- provide a basis for a wide range of risk-informed applications.

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