Power Grid Monitoring and Alerting System

Adapting *The Morning Report* technology for monitoring the Electrical Power Grid

The Morning Report was originally developed as part of NASA's Aviation Safety Program. It has won several awards for its inventive and effective data analysis capability.

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May 2006

Overview

- Goals
  - Adapt *The Morning Report* approach to the electric power grid and demonstrate its usefulness to identify atypical events.
  - Create a Proof-of-Concept
  - Involve the power grid community experts to build interest.
- Funding:
  - PNNL is funding this as an IR&D project.
  - Very small seed funding
- Major Accomplishments
  - Access to a small set of archived data
  - Preliminary data processing
  - LiveMeeting with ~6 EIPP Power Grid Experts, April 11, 2006

Discussion

- Presentation on approach

- Data analysis preliminary results

Why invest in this area?

- Aviation Safety Program
  - Aviation is one of the safest ways to travel in the world.
  - Why does it warrant efforts to monitor and improve?
    - Number of flights is expected to double in the next few years, which means the number of accidents is likely to double (or worse).
    - Changes in the airspace can have subtle and unenvisioned but significant impact on safety.
  - Monitoring 1000s of flights every day is almost impossible, but we can monitor
    - ~20 typical patterns (with ~99% of the flights)
    - ~20 atypical flights
  - By studying all flights, we can find pre-cursor situations that increase the risk of incidents and accidents.

- Electrical Power Grid
  - Electrical Power Grid is one of the most reliable major systems in use today; largely as a result of significant efforts to make it reliable.
  - Demand will continue to increase.
  - Margin for recovering from incidents will continue to erode.

Hypothesis: Data analysis tools can identify typical patterns, atypical events, and pre-cursors.

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How to do it?
The key elements of the approach

- Aviation Safety Program uses:
  - On-board instrumentation to record hundreds of variables that monitor the aircraft throughout every flight.
  - Sophisticated statistical analysis programmed into a workstation that analyzes the data to find:
    - Typical patterns, that characterize ~99% of the flights
    - Atypical events, that are worthy of individual inspection
  - User-friendly software enables the aviation user to rapidly and effectively drill into the gigabytes of data to find the insight needed to:
    - Understand safety issues and formulate corrective plans if appropriate
    - Monitor typical patterns for trends
  - Aviation Experts inspired by new insight proactively identify and correct safety issues affecting aviation safety

- Electrical Power Grid
  - Instrumented system operation exists
  - Adapt statistical analysis: Proof-of-concept in work
  - User-friendly software: On-hold
  - Expert review of results: TBD

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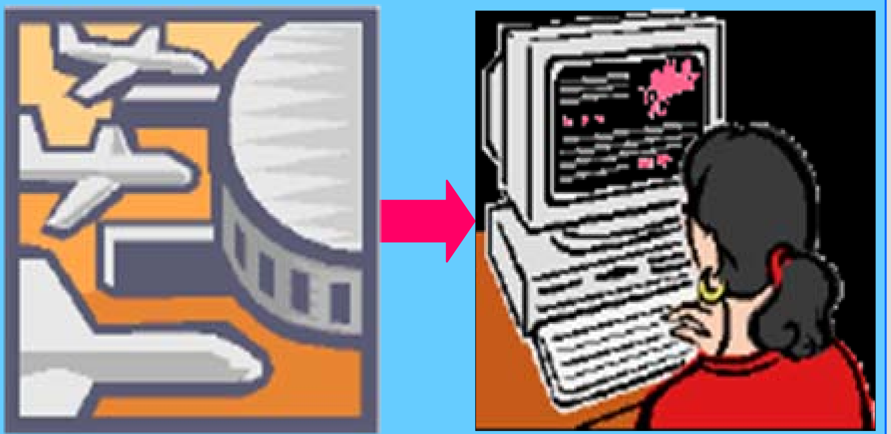
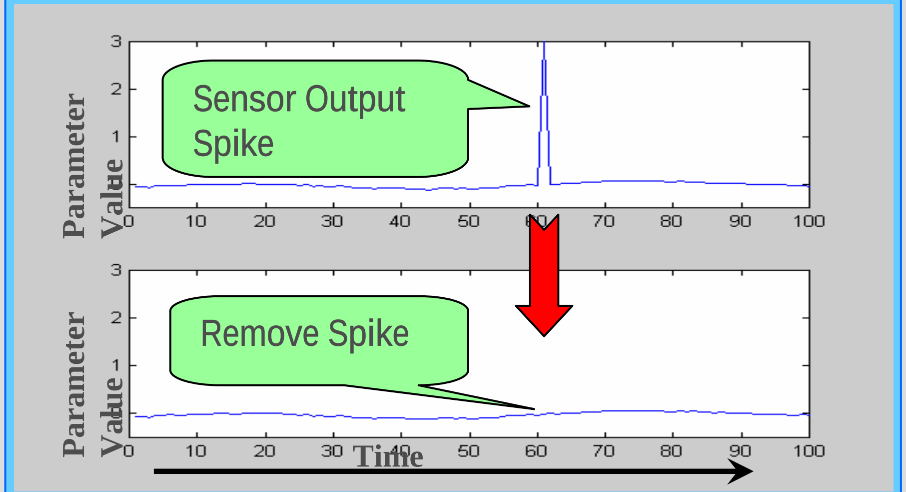
The Morning Report can be described in 12 Basic Steps

Step 1: Download Data



- Download daily or weekly
- From tapes, disks, or solid state devices
- Use commercially available playback software
- Insert data into commercially vended database

Step 2: Check the Data Quality



- Apply knowledge-based filters
- Identify “bad” data
- Remove the “bad” data
- Inform user of QA problems

- PMU data continuously recorded
- Multiple variables (2 to 10000)
- Multiple 30 locations (1 to 100)
- Data could be:
  - From archives
  - Live / real time

Limited data checks to remove dramatically bad data.

Step 3:
Conduct Pre-defined Alerting Checks

- Airline experts define specific data comparisons to be made at specific routine events
  - Are the gear down while altitude is above 18,000 ft?
  - Are the flaps extended while airspeed is greater than 300 knots?
  - Etc.

Time (secs)	Param 1	Param 2	. . .	Param P	Routine Events
1	103.40	1		277.40	Start Takeoff
2	103.70	1		266.30	
…	…	…	…	…	
126	104.49	1		267.31	
127	104.98	1		268.19	
[illegible]	[illegible]	[illegible]		[illegible]	
129	105.45	0		269.12	Gear Up
[illegible]	[illegible]	[illegible]		[illegible]	
131	106.39	0		269.78	
…	…	…	…	…	
4021	106.82	0		270.71	
4022	107.33	0		270.78	
4023	107.89	0		270.85	10000 ft AFE
4024	108.40	0		271.14	
4025	108.53	0		271.53	
4026	109.38	0		272.03	
. . .	…	…	…	…	
N	110.68	0		273.70	Touchdown

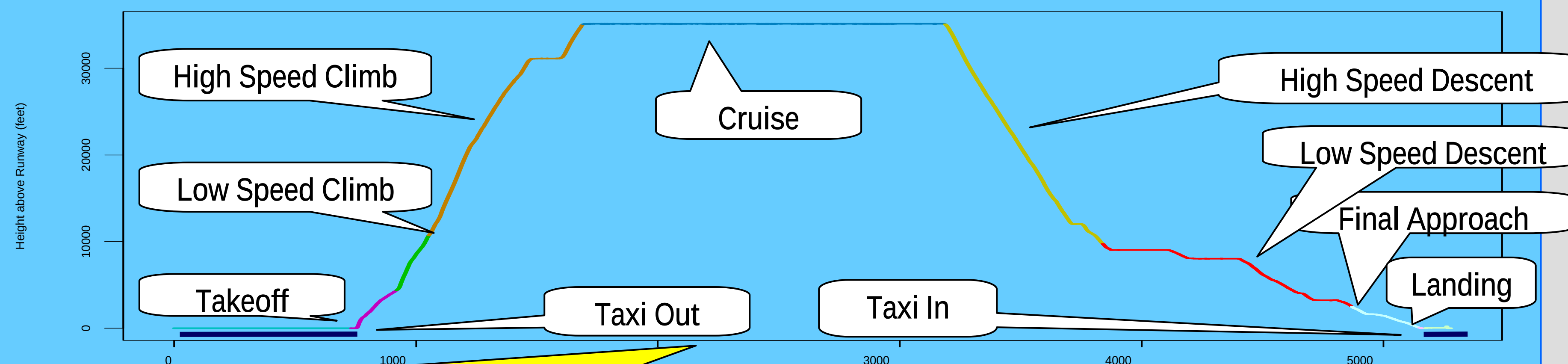
This requires that we envision the potential problems before they occur.

Power Grid Domain Experts could create Boolean expressions for automatic monitoring.
This effort is not part of the Proof-of-Concept investigation.

Step 4:
Structure the Data

- Data are parsed into flight segments
- Flight Segments based on Event Markers, e.g.
  - Gear-up
  - Cross outer-marker
  - Descent through 1000 ft AFE
- Customizable to each air carrier phase definitions

Time (secs)	Param 1	Param 2	. . .	Param P	Event Marker	ACR Phase
151						
152	103.40	1		277.40	Rotate	Takeoff
153	103.70	1		103.70		
…	…	…	…	…		
335	105.13	1		105.13		
336	105.45	0		105.45	Gear Up	
337	105.73	0		105.73		
…	…	…	…	…		climb
1225	106.82	0		106.82		
1226	107.89	0		107.89	10000 ft AFE	
1227	108.10	0		108.07		
…	…	…	…	…		
3236	108.51	0		109.04		
3237	109.33	0		109.12	Max Altitude	Cruise
3238	110.25	0		109.74		
…	…	…	…	…		
6259	109.04	0		108.60		
6260	109.85	0		109.57	10000 ft AFE	
6261	109.87	0		110.39		
…	…	…	…	…		Approach
6673	110.70	0		110.53		
6674	111.19	0		110.68	Gear Down	
6675	111.90	1		111.29		
…	…	…	…	…		
7786	112.13	1		112.10		Landing
7787	112.91	1		112.43	Touchdown	
7788	113.63	1		112.90		



Data maybe partitioned into “60 second” observations. Observations may be grouped for comparison as function of Time-of-Day and Day-of-Week.

Step 5: Create Derived Parameters to Capture Physics Based Insights

- Aircraft heading with respect to runway
- Aircraft location with respect to runway
- Derived Energy Parameters
  - Total energy
  - Kinetic energy
- Others

e.g.: Deltas among various Bus locations
Others: Physics based/Insightful Variables

Step 6: Calculate Preliminary Flight Parameter Signatures

- Continuous Variable
  - Air speed, roll, altitude, vibration, etc.
- Discrete Variables
  - Gear position, autopilot mode, reversers status, etc.
- Data Compression Signature

Expect to use temporal, spatial, and multivariate characteristics

Step 7: Store the Signatures into the Database

For Proof-of-Concept, use R&D convenient storage.

Step 8: Select the Data

- Select a subset of data:
  - Aircraft type
  - Airports
  - Flight Phase
  - Time Frames
  - Other Parameters

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May look at
- Full grid
- Subset of the grid;
- Single organization/utility
- Individual bus or line.

Step 9: Transform the Signatures

- Multivariate mathematical statistical techniques used enable:
  - Time series analysis
  - Characterization independent of phase duration
  - Flight mode transitions
  - Quantification captures values, trends, & noise

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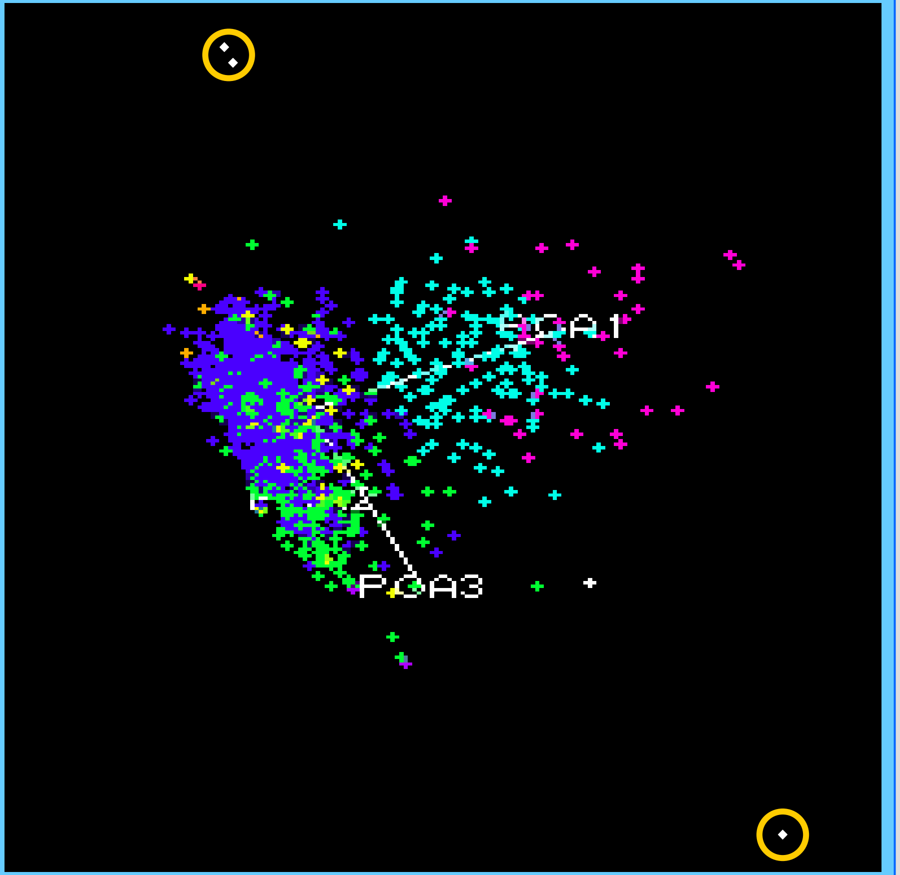
May combine adjacent time periods (e.g.; 8-9am and 9-10am maybe combined)

Step 10: Cluster the Transformed Signatures

- Use several alternative clustering methods
  - Then, generate a consensus
- Typical patterns
  - Clusters of similar flights
  - Summarized in plain English
- Atypical flights
  - Singletons, clusters of one or two
  - Summarized in plain English
- Performed for each user-defined and selected flight phase



• Each dot represents a observation (maybe1 minute of grid operation; 1440 obs./day

• Dots are mapped to patterns with similar characteristics.

• Some observations may be mapped to very small clusters or even singletons.

Step 11:
Find the Atypical Flights

- Atypical flights are defined to be
  - Singletons
  - Very small clusters (atypical clusters)
- Differs from classic exceedance analysis
  - Which look for triggers of Boolean expressions
- Can be the impetus for further investigation
  - By operationally knowledgeable persons

Finds the
<u>unenvisioned.</u>

End-users don’t have to know what they are looking for !!

The analysis finds atypical events never dreamt of !!

- Atypical behavior of the Power Grid will be identified by the methodology.
- Domain Experts will assess the significance of the atypical behavior.
- If it represents insightful finding: EUREKA !!!!

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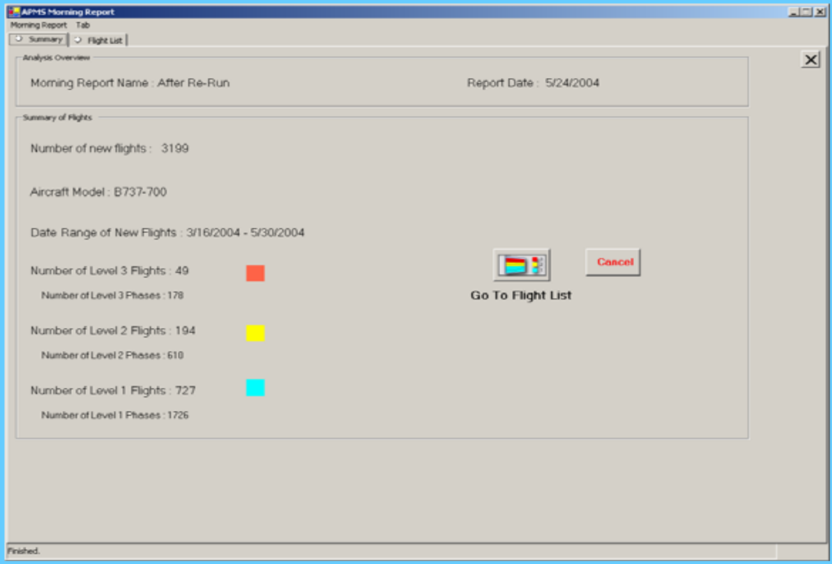
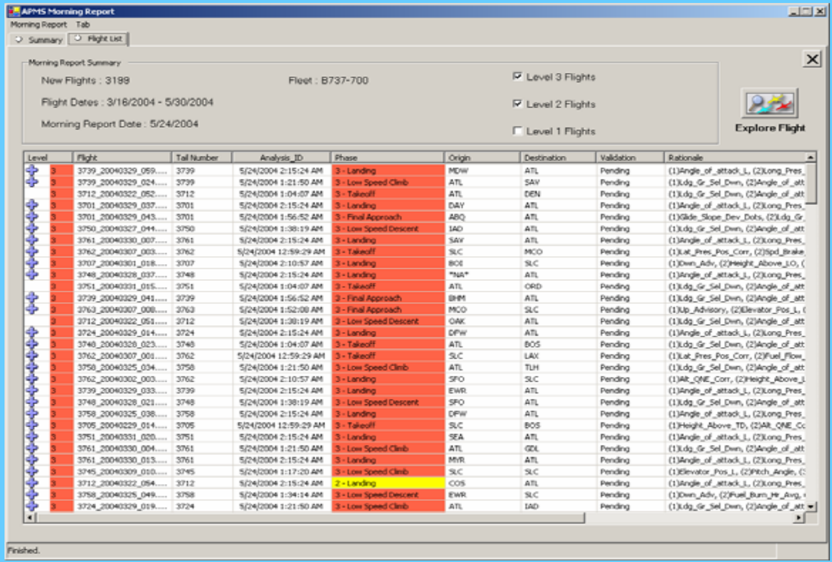
Step 12:
Present the Findings

- Data processing occurs over night
- Morning report is ready by 7am every morning.
- Identifies most atypical flights
  - Excludes flights previously reviewed and dispositioned
  - Enables drill down to flight details
  - Allows capture images in Microsoft PowerPoint files for communication ease.





- Nature of the displays are TBD.
- Frequency of the displays are TBD.
- Display focuses on atypical events.

This may evolve to

<u>The Minute Report.</u>

In Summary

- The Morning Report uses:
  - Multivariate statistical analysis and
  - User-friendly software
- It enables the user to understand:
  - Typical patterns observed in the operation of 1000s of flights
  - Atypical events
  - Identify flights and their flight characteristics associated with safety issues
  - Share the information with a community of aviation experts, thus enabling them to formulate improved aviation policies and action plans.
- A very important characteristic about the Morning Report is the basic approach is extendable to numerous other domains, including:
  - Air traffic control (in work)
  - Cyber Security (in work)
  - Electrical Power Grid (in work)

- **PNNL is "betting" its internal R&D funding that this will work for the Electrical Power Grid.**
- **We are betting that we will be able to:**
  - **Monitor hundreds of hours of operation and identify typical patterns**
  - **Identify atypical events very quickly with helpful insight as to the nature of the source of the atypicality**
  - **Identify pre-cursors**
  - **Share the information in a timely and useful manner.**

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Next Steps

- The Morning Report so excited the aviation community (Air carriers, FAA, Pilots association, NASA, etc.) that they have formed an Information Sharing Initiative
  - The air carriers will not share their data
  - We have devised a way to aggregate characteristics of the National Airspace without ever possessing the data.
- In FY06/07, System Level Morning Report will monitor aggregate performance of air carriers
- In FY06/07, maintenance interests will be investigated.

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A very early look at
Proof-of-Concept Analysis
intermediate results

This illustrates the approach with real power grid data.

The purpose is not to look at data or assess the behavior of the power grid, today.

Proof-of-Concept Analysis intermediate results

- Data
  - Data from historic archives
  - Data has been de-identified: no location, no date, no units
  - Data consisted of
    - Voltage Magnitude
    - Phase Angle
    - Frequency
  - Data came from multiple locations
- Analysis
  - Processed data to generate atypicality index
  - Identified components contributing significantly to the atypicality
- Much to be done
  - Incorporate more data and more derived variables
  - Refine methodology further
  - Refine atypicality rationale – what made this observation atypical?
  - *Compare operation logs with data analysis results!!*

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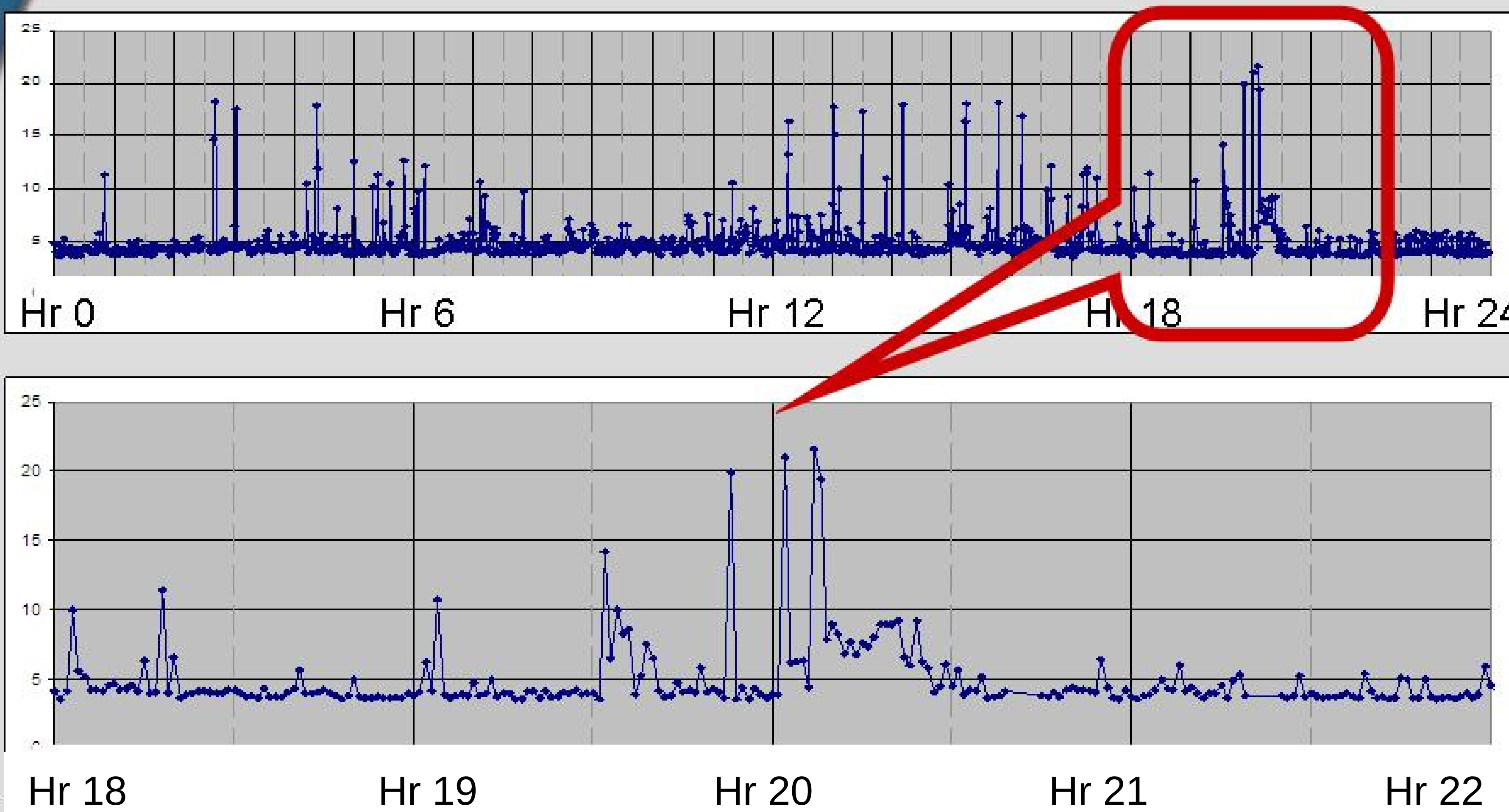
Atypicality Index for 1 day

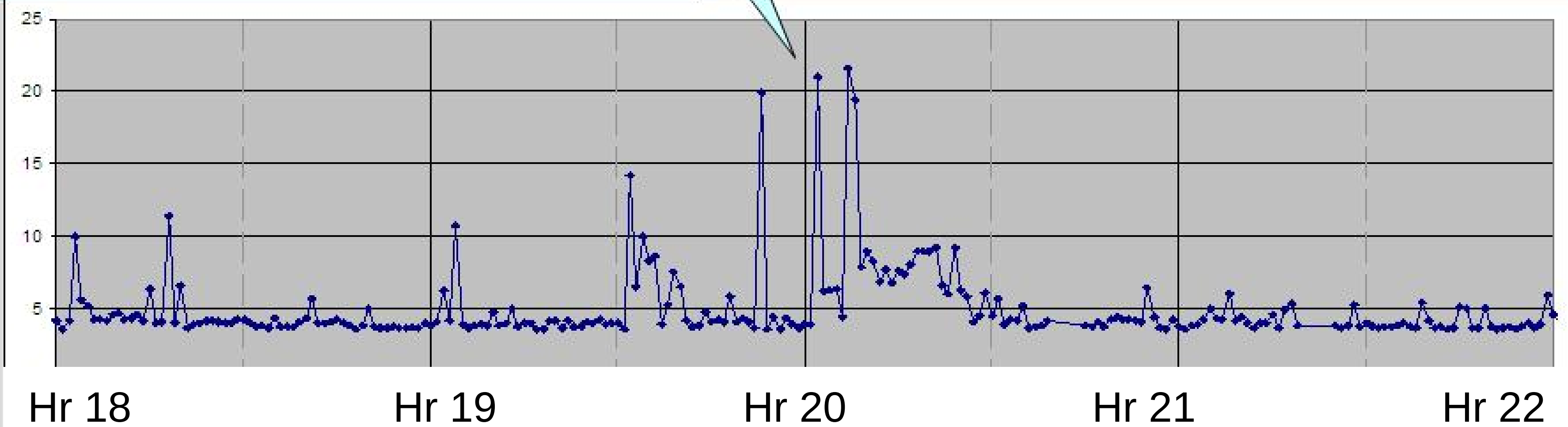


Atypicality Index for 4 hours

XX:02
Loc0029 VoltMag mean is very low.
Loc0030 VoltMag mean is very low.
Loc0029 PhaseAngle noise is high.
Loc0030 PhaseAngle noise is very high.
Loc0039 Freq noise is high.
Loc0041 Freq noise is high.

Rationale identifies variables that contribute significantly to the Atypicality Index and presents summary in plain English; e.g.:

- Variable W is very low.
- Variable X is low.
- Variable y is high.
- Variable Z is very high.



Long Term Vision

Once the proof-of-concept demonstration is achieved, when could this capability go???

- Identification of
  - Typical patterns
  - Atypical events
  - Trends over time (long term and cyclic)
  - Precursor identification
  - Associations
- Application approach
  - Stage 1. Off-line study of archives
  - Stage … Testing, refinements, improvements, testing
  - Stage n. On-line real-time decision support??
- Support for
  - National Power Grid
  - Individual organizations/utilities
  - Individual power generation system or distribution system maintenance and prognostics

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Plans

- Data analysis extensions
  - Refine atypical event identification
  - Explore pre-cursor event identification
  - Process additional data
- Build interest in Power Grid Community
  - Scheduled meeting May 10-11 to EIPP
  - Establish contacts and stimulate follow-on interactions
    - Disturbance Monitoring Working Group (West Coast)
    - EIPP On-Line Analysis Task Team
    - ???

Are you interested in participating?
What do you think about this concept?
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