An Advanced Visual Analytic Decision Support Tool for Electricity Infrastructure Operations

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Presentation Outline

- Background on Electricity Infrastructure Operation
- Need for Advanced Decision Support Tool
- Features of the Advanced Visual Analytic Decision Support Tool
- Conclusion and Future Work
Background – Complexity of Electricity Infrastructure Operations

- Human Errors
- Ice & Lightening Storms
- Dig-Ins
- Vehicular Collisions
- Physical Attacks
- Cyber Attacks
Consequences of Poor Situational Awareness

August 1996
30,000 MW
8M customers
~24M people

August 2003
62,000 MW
~16M customers
50M people

The need to improve situational awareness became clear.
The need to improve situational awareness and decision-making became clear.

- Contributing factors identified:
  - Human error
  - Poor display design
  - Lack of operator situation awareness

- Wide Area Situation Awareness (SA) is recognized as a critical requirement

- Improved interfaces and decision support is one of the five fundamental technologies that will drive the Smart Grid
Background – Inadequacy in Network Operations

▸ Today’s Network Operation Tools
  ▪ Mainly experience-based
  ▪ Raw/Tabular presentation dominates
  ▪ Data volume and complexity can overwhelm operators
  ▪ Inadequate support for real-time situational awareness and decision making

▸ There is a technical gap between data and actionable information
What Kind of Decision Support Tool We Need?

A tool can help operators on solving following questions:

- What is the current system status?
  - Detect problems
- Is the network becoming compromised?
  - Recognize developing problems
- What would the problem cause to the network?
  - Predict consequences of failures
- How effective would our response be to the problem?
  - Evaluate potential operator actions

“Enabling predictive Electricity Infrastructure operations”
Overall Technical Approach

1. Improve situational awareness by turning large amount of data into a geographical domain in a color scheme
   • Signature/risk analysis

2. Identify system trends by performing trending analysis
   • Statistical trending analysis

3. Predict consequences of problems by analyzing the pattern of the impact
   • Statistical analysis and pattern recognition

4. Assess effect of alternative actions via interactive risk analysis
   • Interactive evaluation of candidate control actions
   • Rank and provide guidance

Operator
1. Visual Analytics for Risk Assessment (1)

- **Risk Index Definition**
  - Bus risk index: 
    \[ R_{ik} \% = \frac{(V_{ik} - V_{i_{min}}) - (V_{i_{max}} - V_{i_{min}})/2}{(V_{i_{max}} - V_{i_{min}})/2} \times 100\% \]
  - Transmission Line Risk index: 
    \[ R_{ik} \% = \frac{P_{ik}}{P_{i_{max}}} \times 100\% \]

- **Multi-Layer Risk Index**
  - Superimpose risk indices for multiple possible configurations
    \[ R\% = \max(R\%_i) \]
1. Visual Analytics for Risk Assessment (2)

Visual Representation of Risk Indices

- Gaussian color mapping with green/gray/red scale

\[ R_{ik} \% \in \begin{cases} [0, R_T \%), & \text{safe} \\ [R_T \%, 100\%), & \text{alert} \\ [100\%, \infty), & \text{violation} \end{cases} \]
1. Visual Analytics for Risk Assessment (3)

- Time Series Analysis
  - Scenario: western power grid with increasing stress and lost element

![Graph showing stress level over time with a lost large nuclear power plant at 8:00]
2. Visual Trending Analysis (1)

Case Studies – western US power grid

System trending

Lost a large nuclear power plant
2. Visual Trending Analysis (2)

- Automatic Recognition of Merging and Separation of Security Regions
3. Clustering Analysis (1)

- Identify relationship between configurations and affected assets
- Enable operators to focus on important information

[Diagram showing affected assets and configurations]
3. Clustering Analysis (2)

- Easy to recognize system patterns
4. Interactive Assessment of Remedial Actions (1)

- Provide further decision support for power grid operators
- Test candidate options in model simulation, visualize the new situation of the grid on the color-contoured map
- A collective severity level (CSL) is used to quantify the effect of the actions
  - Derived based on performance index: 
    \[ PI = \sum_{i=1}^{N} \left( \frac{P_i}{P_{i_{\text{max}}}} \right)^2 \]
  - \[ CSL = \sum_{i=1}^{N} \left( \frac{\max(P_{i_k})}{P_{i_{\text{max}}}} \right)^2 \]
  - \( i \): denotes the \( i^{\text{th}} \) transmission line
  - \( k \): denotes the \( k^{\text{th}} \) contingency case containing violations
  - \( P_{i_{\text{max}}} \): the capacity of the \( k^{\text{th}} \) transmission line
  - \( P_{i_k} \): the real power carried on the \( i^{\text{th}} \) transmission line for the \( k^{\text{th}} \) contingency case
4. Interactive Assessment of Remedial Actions (2)

Provide guidance for preventing and mitigating failures

**All Action Options** (Sorted From Best To Worst)

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>CSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Reduce 8.4% loads off</td>
<td>0.000</td>
</tr>
<tr>
<td>B</td>
<td>Reduce 7.7% loads off</td>
<td>53.304</td>
</tr>
<tr>
<td>C</td>
<td>Reduce 4.9% loads off</td>
<td>74.028</td>
</tr>
<tr>
<td>D</td>
<td>Reduce 3.0% loads off</td>
<td>90.281</td>
</tr>
<tr>
<td>E</td>
<td>Reduce 1.0% loads off</td>
<td>117.231</td>
</tr>
</tbody>
</table>

Proudly Operated by Battelle Since 1965
5. Evaluation in Last August

- The prototype of this tool has been evaluated by NERC-certified control room operators in the Electricity Infrastructure Operation Center (EIOC) visualization experiment in PNNL.

- Operators wish to have this tool in their control centers.
Conclusion

- Today’s operation tools only provide inadequate support for real-time situational awareness and decision making.
- The advanced visualize analytics decision support tool can play a key role in Electricity Infrastructure operations.
- Generic framework, can be applied to other power system applications and other complex network operations.
Future Work

- Conduct a series of usability studies to validate the usefulness of the tool in real life
- Integrate the tool with current commercial power operation tools in control center to adapt the tool to operators’ environment.
- The tool is being evaluated in collaboration with the Western Electricity Coordinating Council, the organization overseeing the West American power grid.
Questions?