Flexible Transmission Decision Support

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PSERC Webinar

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Outline

- Key Takeaway Points, Project Overview, Industry Practices
- Flexible Transmission Decision Support: Tool Development
- System Architecture
- Stability
- Results
- Summary
- Contact info

Key Takeaway Points, Project Overview, Industry Practices

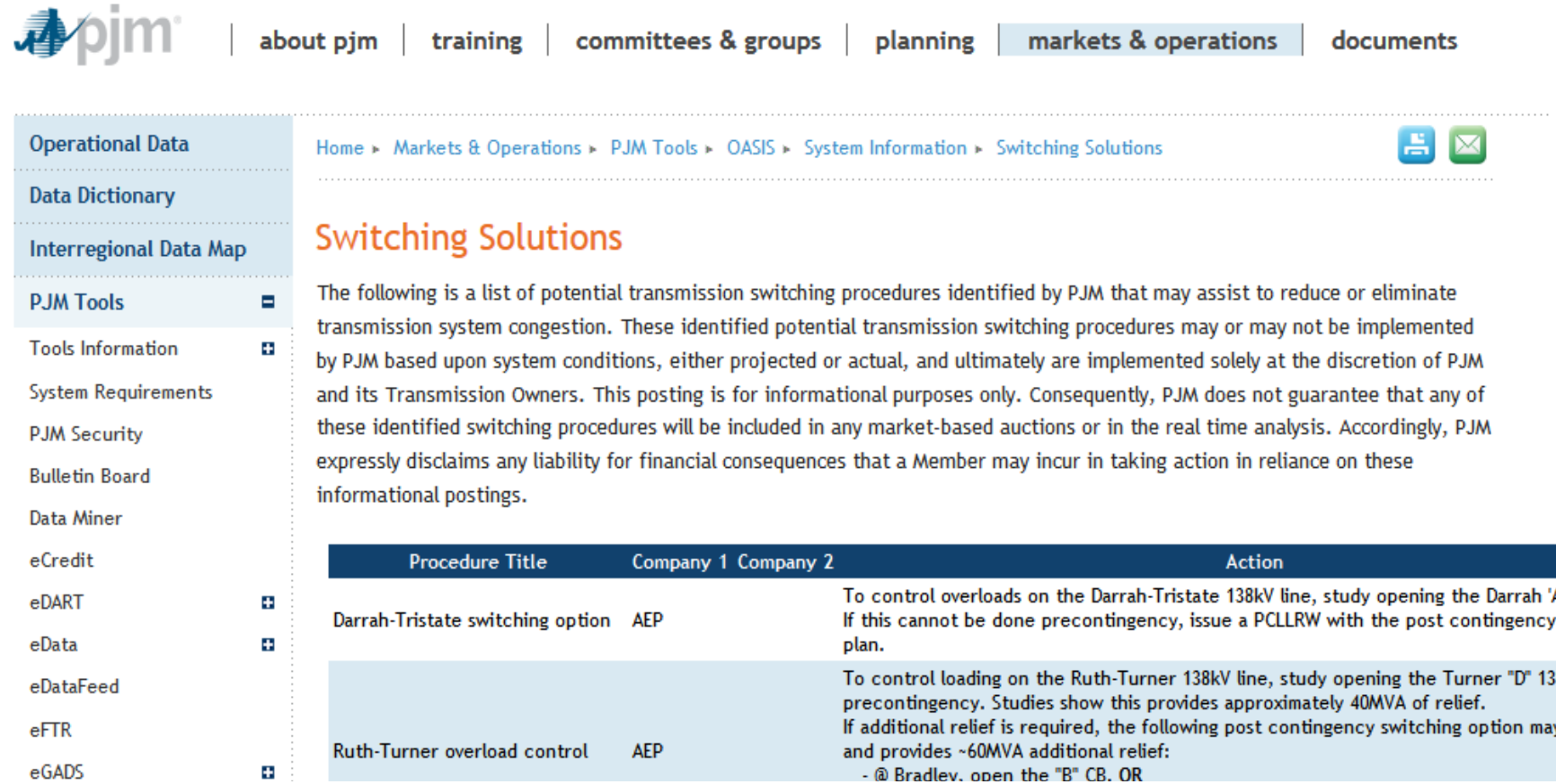
Key Takeaway Points

- Existing EMS & MMS neglect transmission asset flexibility (lines, transformers, FACTS, Smart Wires)
  - Handled outside optimization/power flow engines (e.g., SCUC, SCED, RTCA)
  - Actions determined on an ad-hoc basis
- **New hardware: expensive**
- **New software** that improves utilization of existing hardware: **cheap**
- ***Need: decision support software solutions for power flow control***

Flexible Transmission Decision Support

- Broader goals:
  - Optimal utilization of flexible transmission assets (FACTS, transmission switching, Smart Wires, etc.)
  - Integrate within EMS and MMS
- Short-term focus:
  - MPI based HPC real-time contingency analysis tool
  - Plug-and-play capability; run parallel to EMS
  - Identify corrective actions (post-contingency corrective transmission topology control) to eliminate post-contingency violations

Industry Practices: PJM



PJM Switching Solutions, https://www.pjm.com/markets-and-operations/etools/oasis/system-information/switching-solutions.aspx

Flexible Transmission Decision Support: Tool Development

FTDS based RTCA Tool Development

- Multi-threaded, MPI, HPC base AC Power Flow Real-Time Contingency Analysis (RTCA) Package with Corrective Switching

- Open Source

- Expanded IncSys' Open Source AC Power Flow tool to create multi-threaded RTCA package with corrective control

RTCA Assumptions

Brief overview (further discussion, if desired):

- N-1: Transmission (Line, Transformer, >69kV) Generator
- Few seconds post-contingency (t_{+0})
  - Single snapshot of time
  - MW compensation based on *participation factors* (various options are available)
  - Adjust PV set point (voltage control is fixed based on pre-contingency state **except when Q_G violates Q_{MIN} or Q_{MAX}**)
  - Consistent rules between vanilla RTCA & FTDS based RTCA

FTDS based RTCA

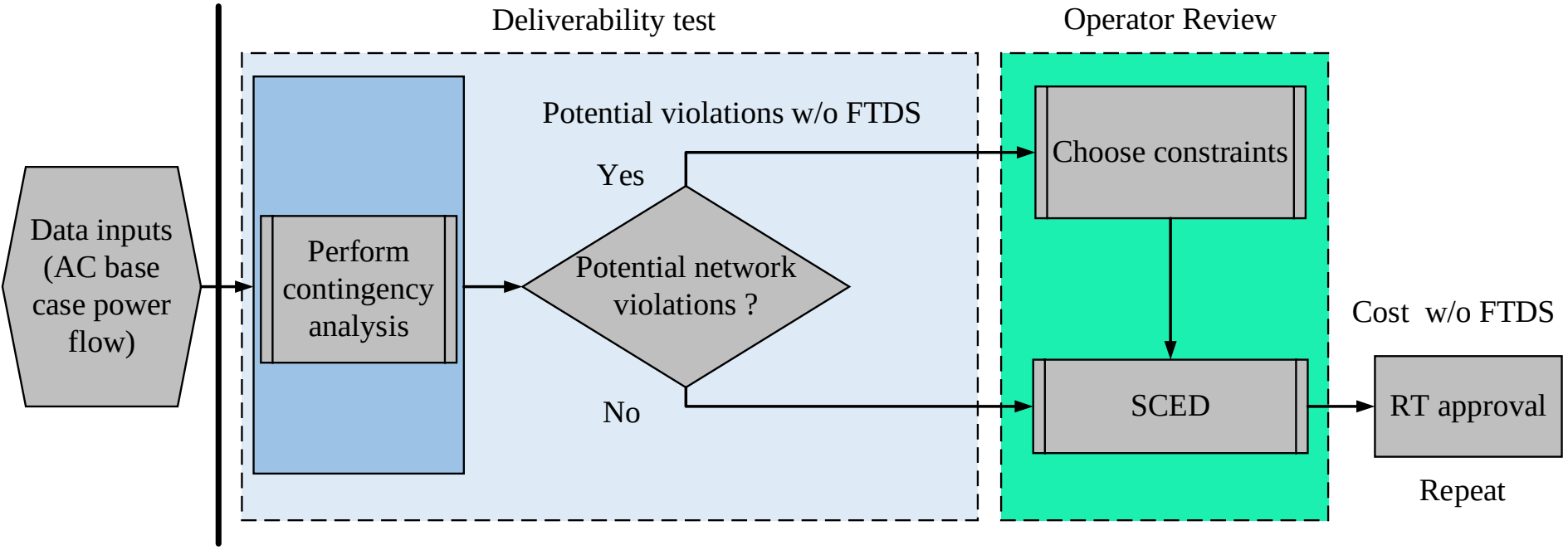
Post-contingency corrective transmission switching

- Shortly after a contingency, ***as a corrective action:*** *take a line out of service*
- Implement at most 1 corrective switching action
- But: identify multiple potential switching actions, in advance, per contingency to provide operators: **choice**
- Perform stability studies to confirm switching actions

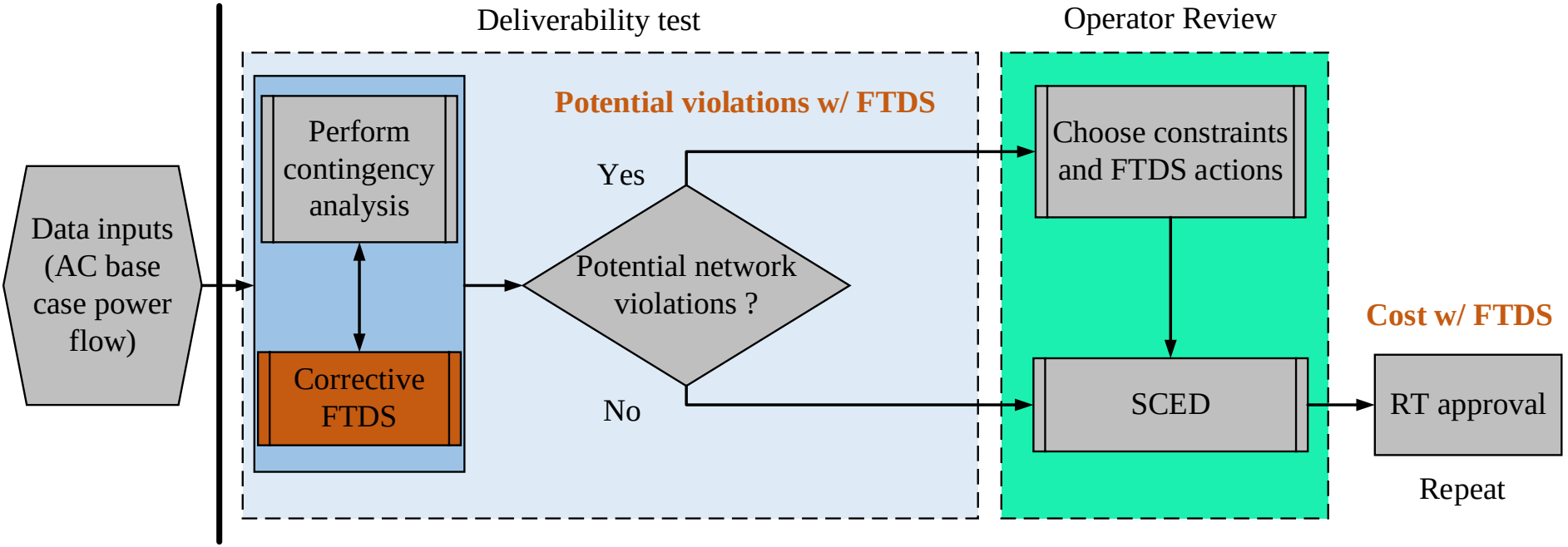
System Architecture

Develop FTDS based RTCA to work seamlessly with EMS

Real-Time Contingency Analysis and Security Constrained Economic Dispatch



Implementation of FTDS based RTCA and Impact on SCED



Operator Review Example

Approve FTDS, Send to SCED:	Post-Contingency Status	Approve FTDS, Send to SCED:	Post-Contingency Status
X	Contingency Line 5 Potential Violation: Line 8 – 120% Potential Line Flow: Line 10 – 96% FTDS: No Violations: Switch Line 9 Potential Line Flow: Line 8 – 97% Potential Line Flow: Line 10 – 82% Potential Line Flow: Line 11 – 95%	X	Contingency Line 52 Potential Violation: Line 62 – 116% FTDS: No Violations: Switch Transformer 54 Potential Line Flow: Line 62 – 91%
	Contingency Line 25 Potential Violation: Line 8 – 118% Potential Violation: Line 10 – 102% FTDS: Violations Reduced: Switch Line 9 Potential Violation: Line 8 – 102% Potential Line Flow: Line 10 – 90%	X	Contingency Line 89 Potential Violation: Line 90 – 102% Potential Line Flow: Line 92 – 98% FTDS Option 1: No Violations: Switch Line 93 Potential Line Flow: Line 90 – 94% Potential Line Flow: Line 92 – 97%
			FTDS Option 1: No Violations: Switch Line 95 Potential Line Flow: Line 90 – 97% Potential Line Flow: Line 92 – 96%

Stability

Discussion with Industry on Stability

- Concerns regarding stability of post-contingency corrective switching actions

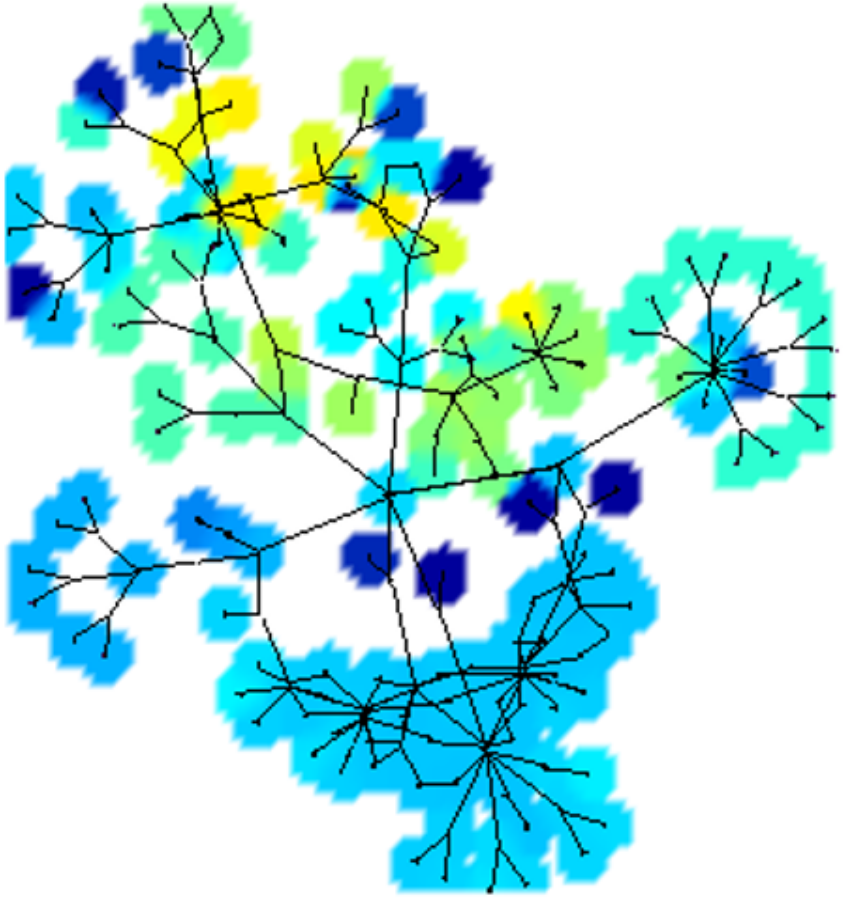
PJM Discussion

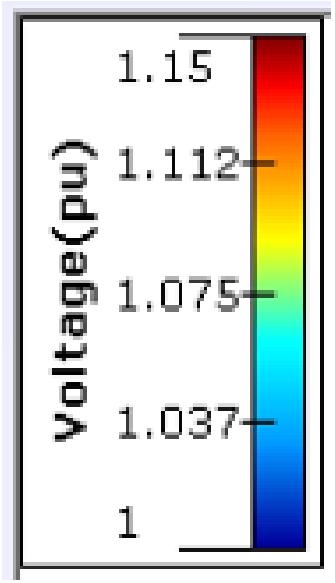
- PJM analyzes N-1-1 (static and dynamic)
- PJM: Highly unlikely that a post-contingency corrective switching action (after an N-1 event) will cause instability
  - The corrective switching action involves a line that does not have a **fault current**
- PJM results have been tested for stability

Results: Post-Contingency Corrective Transmission Switching Example

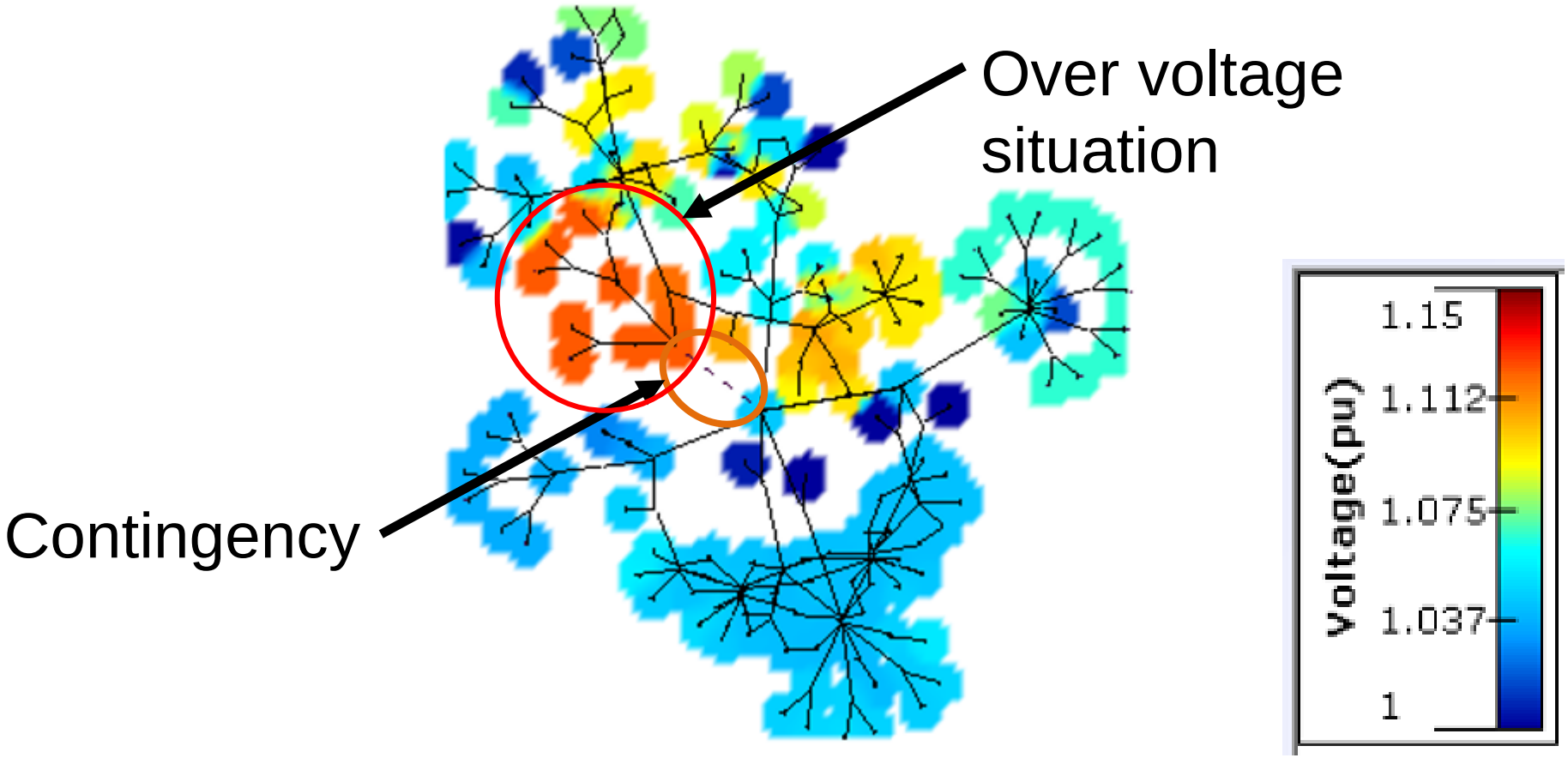
Pre-Contingency State

Subsection of an actual large-scale system



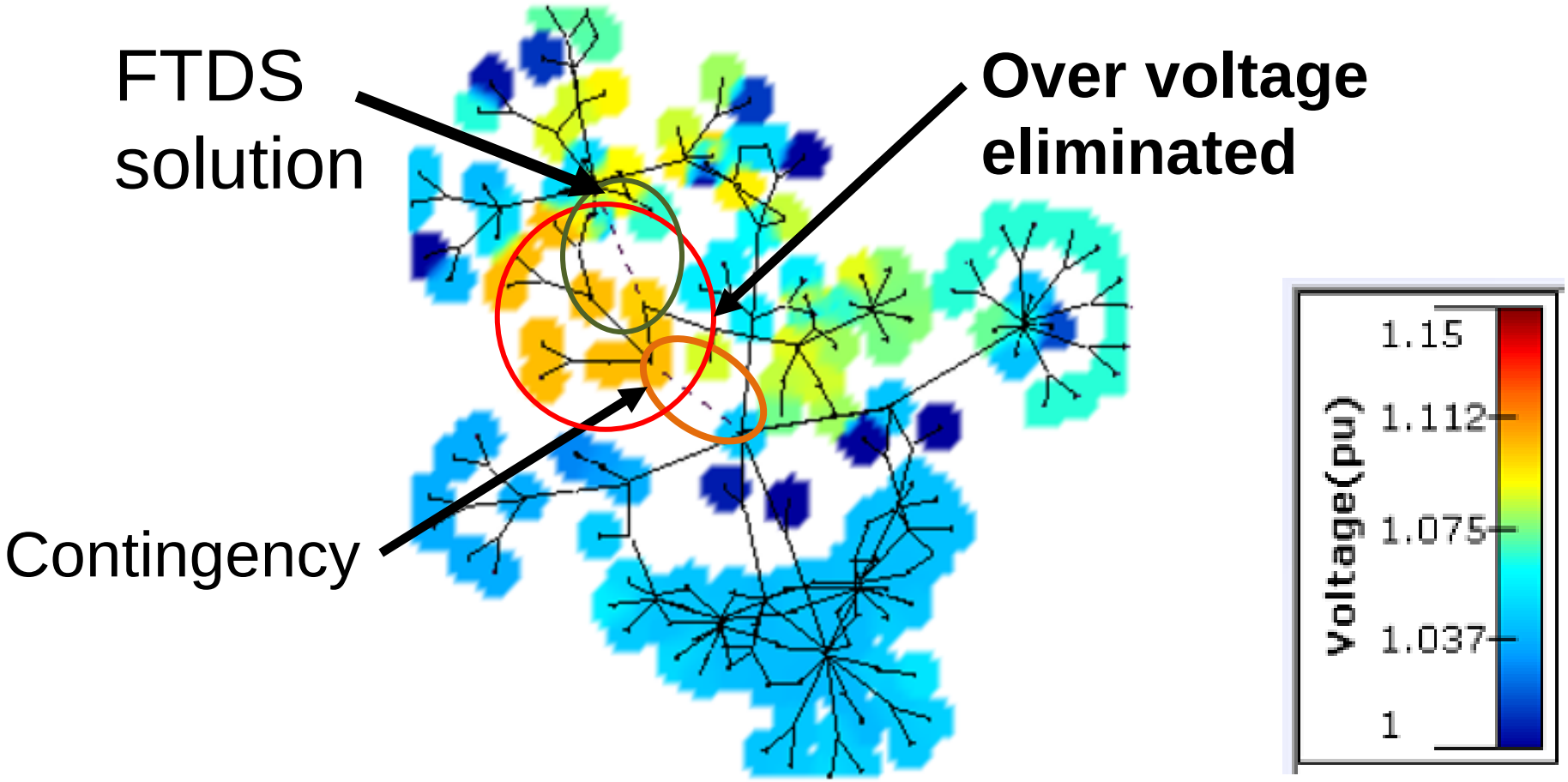


Post-Contingency State



All 500 kV buses affected

Post-Contingency State with FTDS



All 500 kV buses affected

Results:
PJM Test Case

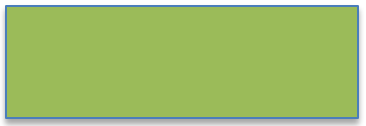
Test Data Source: PJM

- FTDS takes PSS/E .RAW files as inputs
- 167 PSS/E .RAW input files based on PJM data for testing (7 days)
  - **Actual real-time operational snapshots from PJM**
  - PJM saved a snapshot of its operations (from their EMS) every hour for one week in July 2013
  - Network: ~15k buses; ~21k branches; ~3k gen; ~1.6k switchable shunts; ~1.4M contingencies simulated
- **~4000 cases (critical contingencies that result in post-contingency violations)**

FTDS based RTCA Results

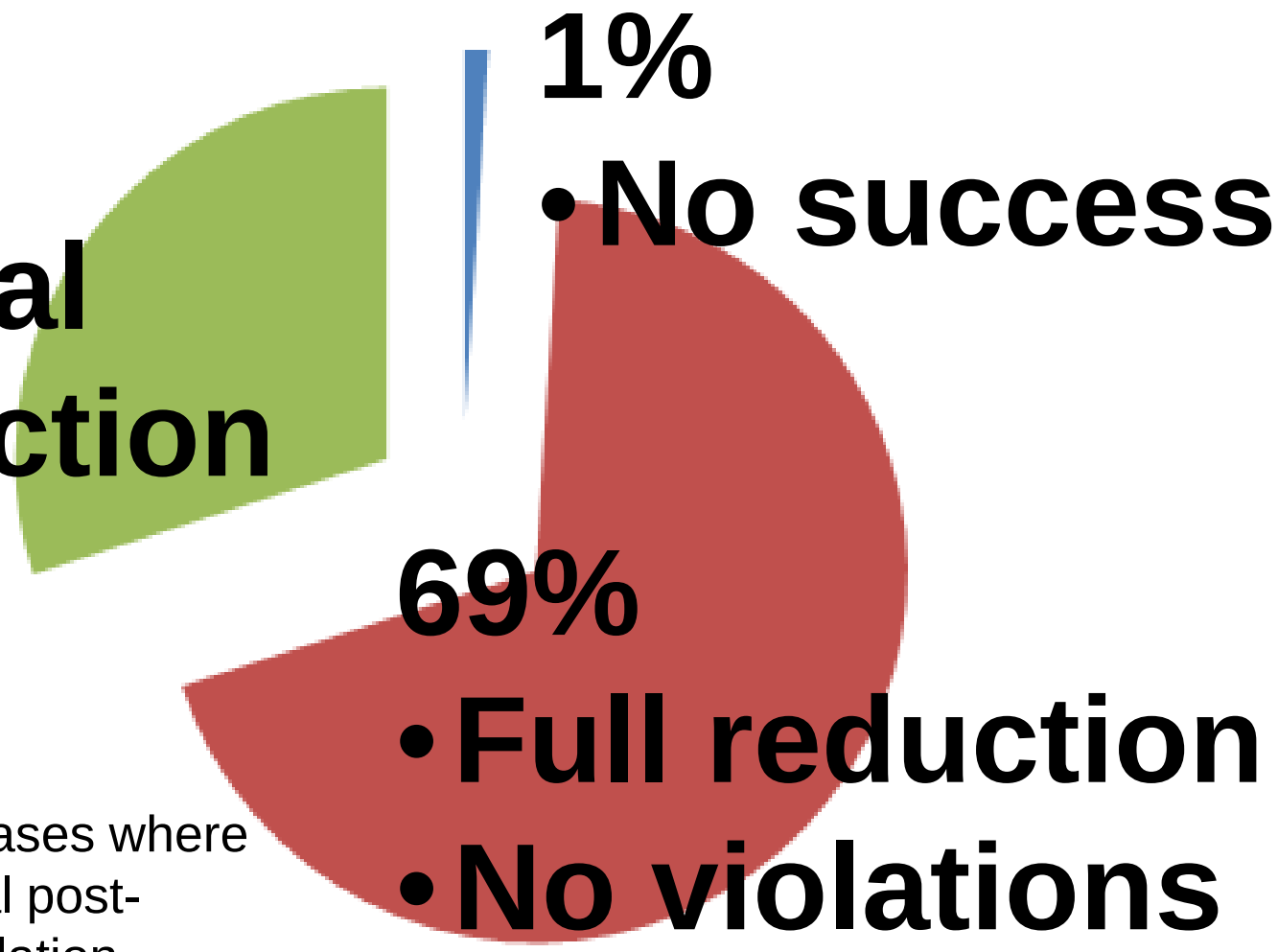
- Full success:
  - Post-contingency violations are fully eliminated

- Partial success:
  - Post-contingency violations are reduced but not fully eliminated



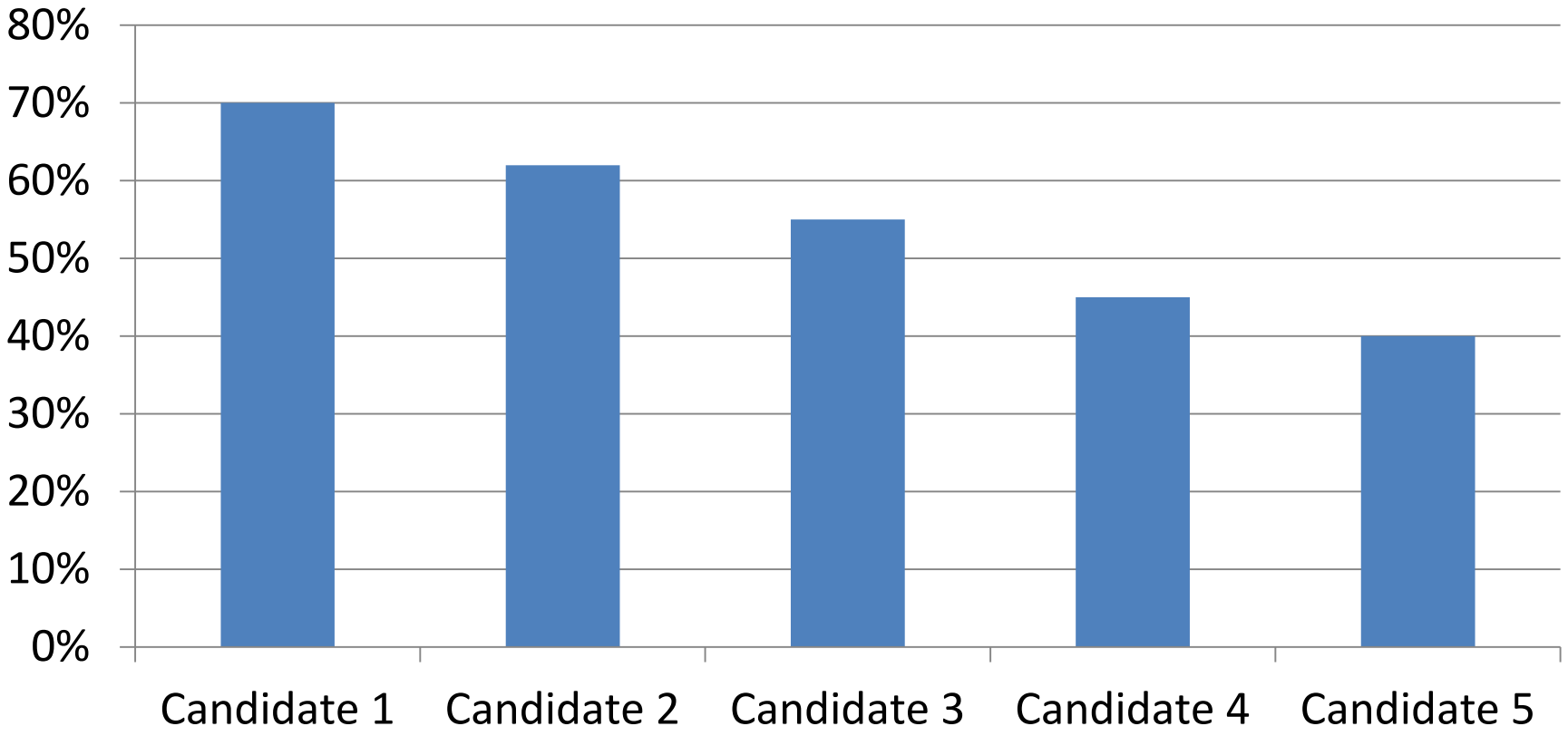
- No success:
  - No beneficial FTDS solution found

FTDS Benefit: PJM



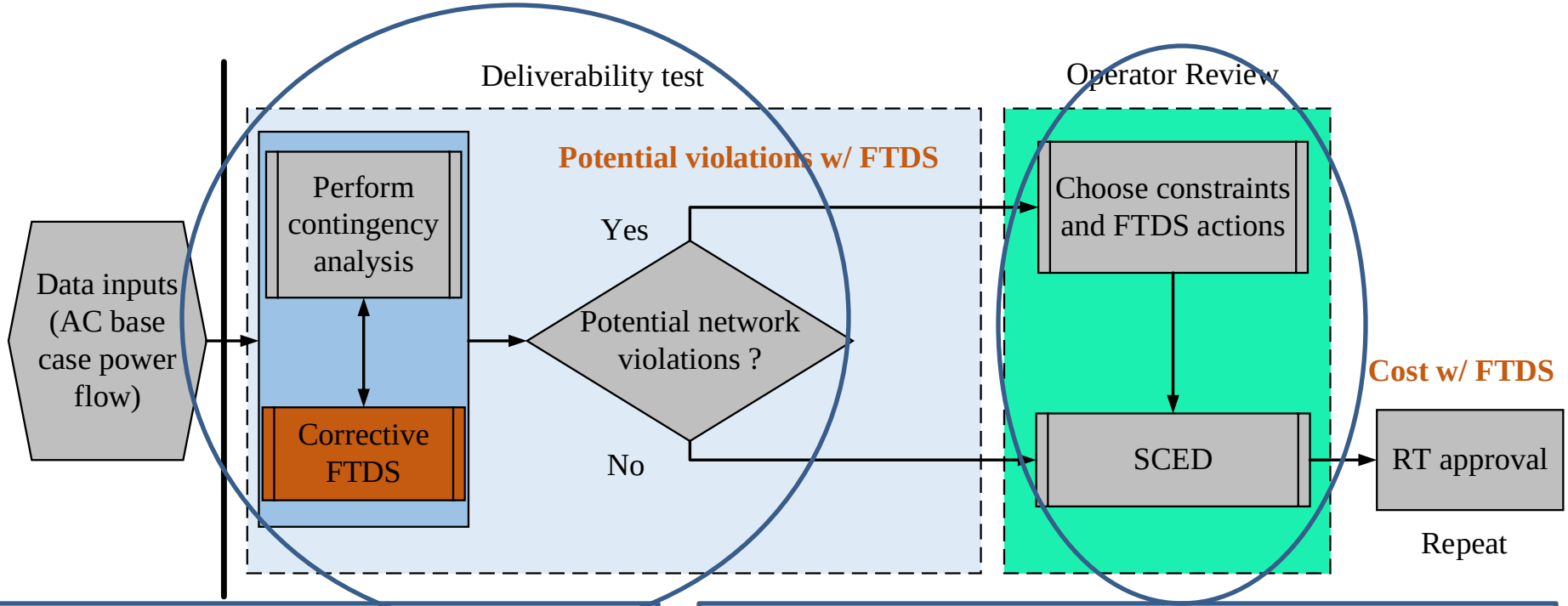
For the 4,000 cases where there is a critical post-contingency violation

Percent Corrective Action Eliminates All Post-Contingency Violations



FTDS algorithm suggests 5 candidate switching actions; all perform well

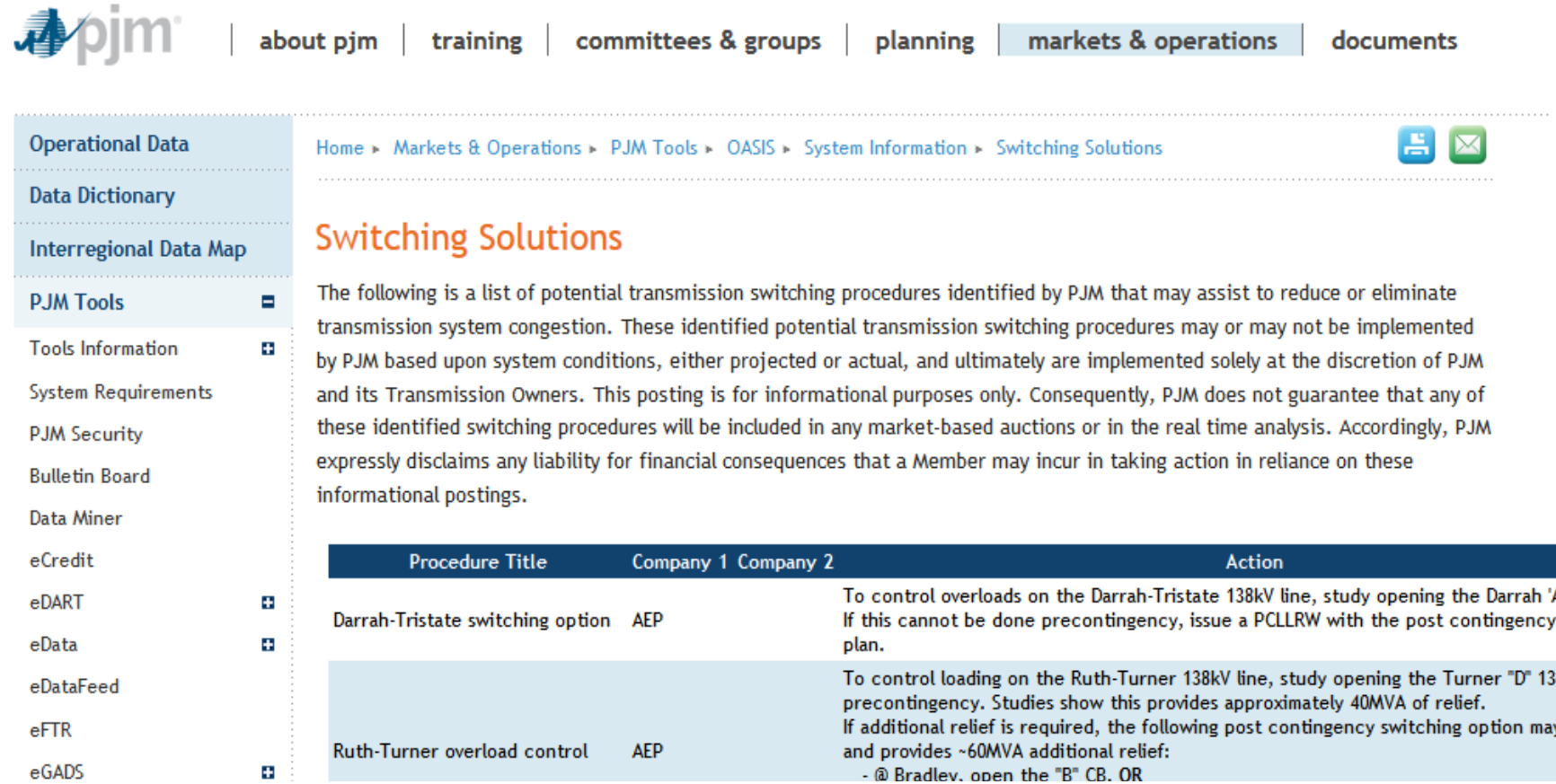
Implementation of FTDS based RTCA and Impact on SCED



FTDS determines corrective transmission switching actions

Constraints sent to SCED are reduced; operational costs decrease; reliability maintained

Industry Practices: PJM



PJM Switching Solutions, https://www.pjm.com/markets-and-operations/etools/oasis/system-information/switching-solutions.aspx

PJM Switching Solutions

- PJM has publicly released ~100 Switching Solutions (corrective switching actions)
- We analyze 1 week of PJM EMS data (July 2013):
  - 104 Incidences exist where a previously identified PJM Switching Solution could be implemented
  - These 104 correspond to only 7 of the 100 Switching Solutions
  - Example: In hour 15, there is a potential post-contingency overload on line 5; PJM's Switching Solution states to take out of service line 6

Switching Solution Example

PJM: Galion-Leside 138kV control (FE-ATS)

To control for actual or contingency overloads on the Galion-Leside 138kV line, study the following options:

1.) Transfer load from Longview to Galion on the 69kV for ~9MVA of relief.

2.) Open the Leside-Longview 69kV line for an additional ~5MVA of relief

3.) Open the Galion #3 345/138kV Transformer provided the transformer will not go into an actual or contingency overload.

4.) Close the N.O. Alta 'A2' 69kV disconnect

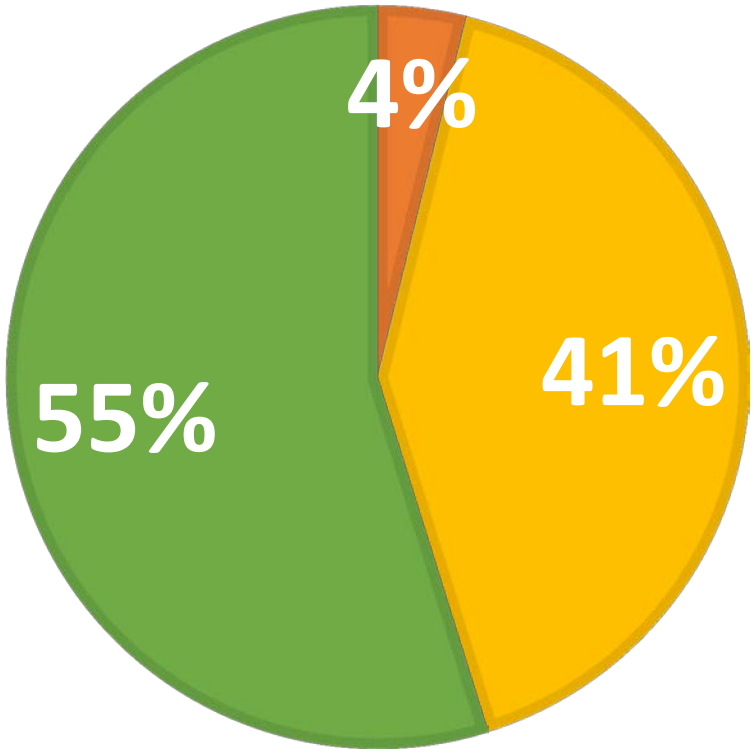
If the switching can't be performed pre-contingency, issue a PCLLRW with the post contingency switching plan.

PJM Switching Solutions, https://www.pjm.com/markets-and-operations/etools/oasis/system-information/switching-solutions.aspx

PJM Switching Solutions

FTDS VS. PJM PERFORMANCE ALL CASES

- PJM outperforms FTDS
- FTDS outperforms PJM
- Similar

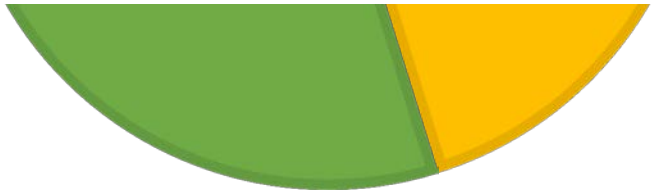


For the cases that are similar: FTDS either proposes the same solution as PJM's switching solution or FTDS proposes a different solution that performs equally well

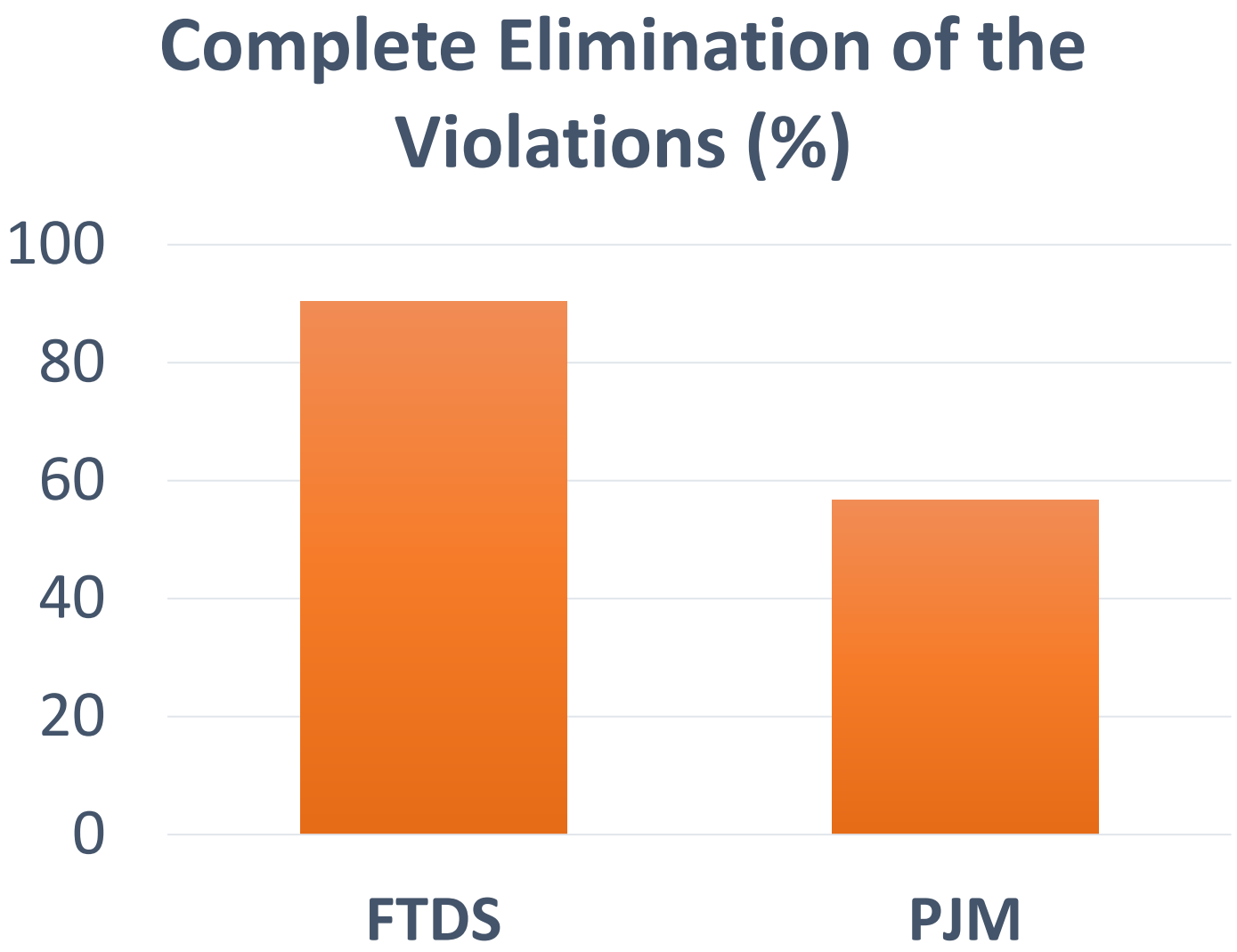
FTDS VS. PJM PERFORMANCE

96% of the time: FTDS does the same or better than PJM's identified switching solution

switching solution or FTDS proposes a different solution that performs equally well

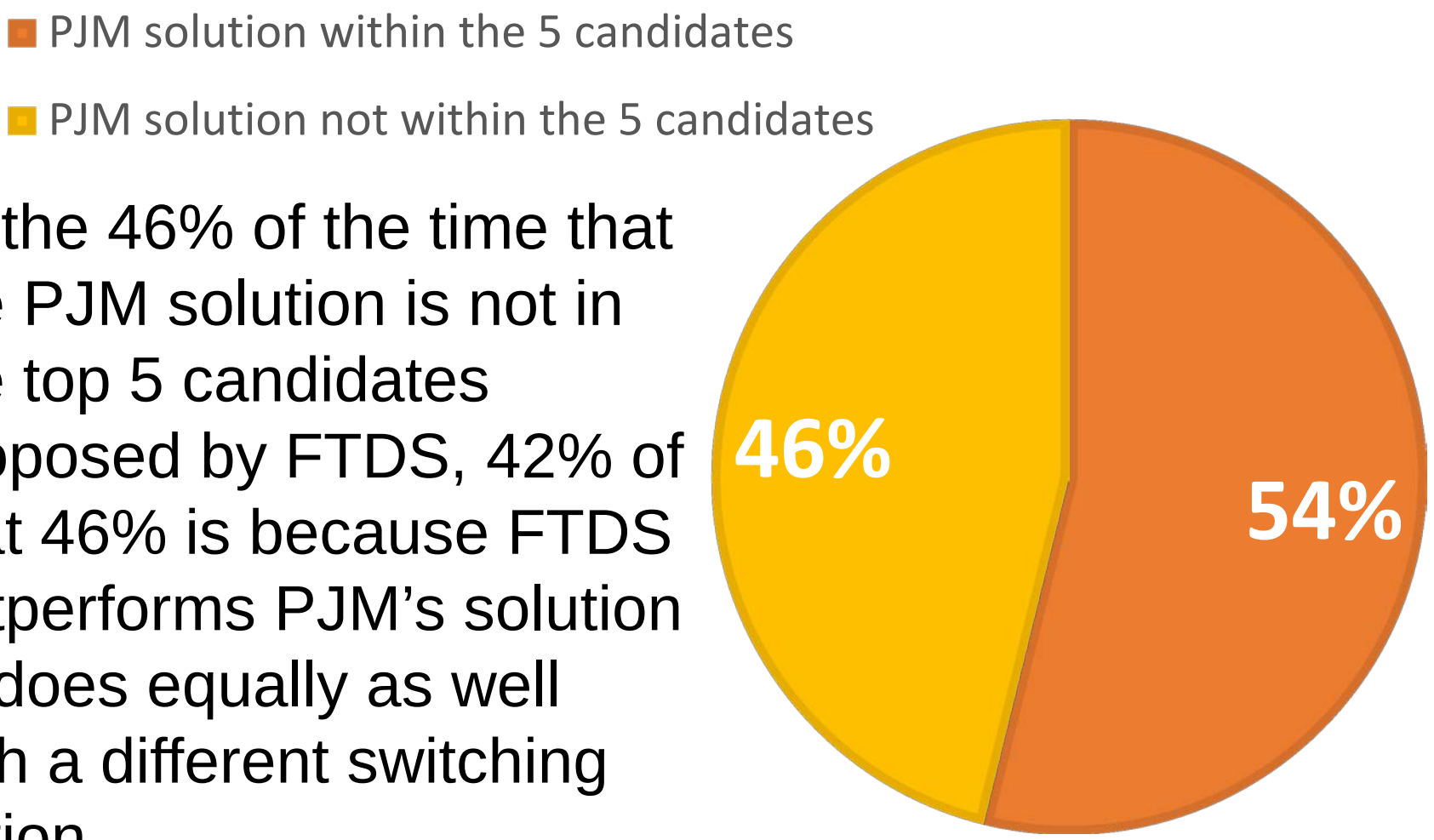


PJM Switching Solutions



PJM Switching Solutions

MATCHING PJM'S SWITCHING SOLUTION



Of the 46% of the time that the PJM solution is not in the top 5 candidates proposed by FTDS, 42% of that 46% is because FTDS outperforms PJM's solution or does equally as well with a different switching action

PJM Switching Solutions

- 104 potential cases based on PJM's Switching Solutions over 1 week
- FTDS identifies many more cases that are more significant in violations and not known by PJM
  - FTDS fully eliminates post-contingency violations ~70%
- With 200 violation cases per week that can be fully eliminated by FTDS, assuming a $10k savings per case: **$100M/year**

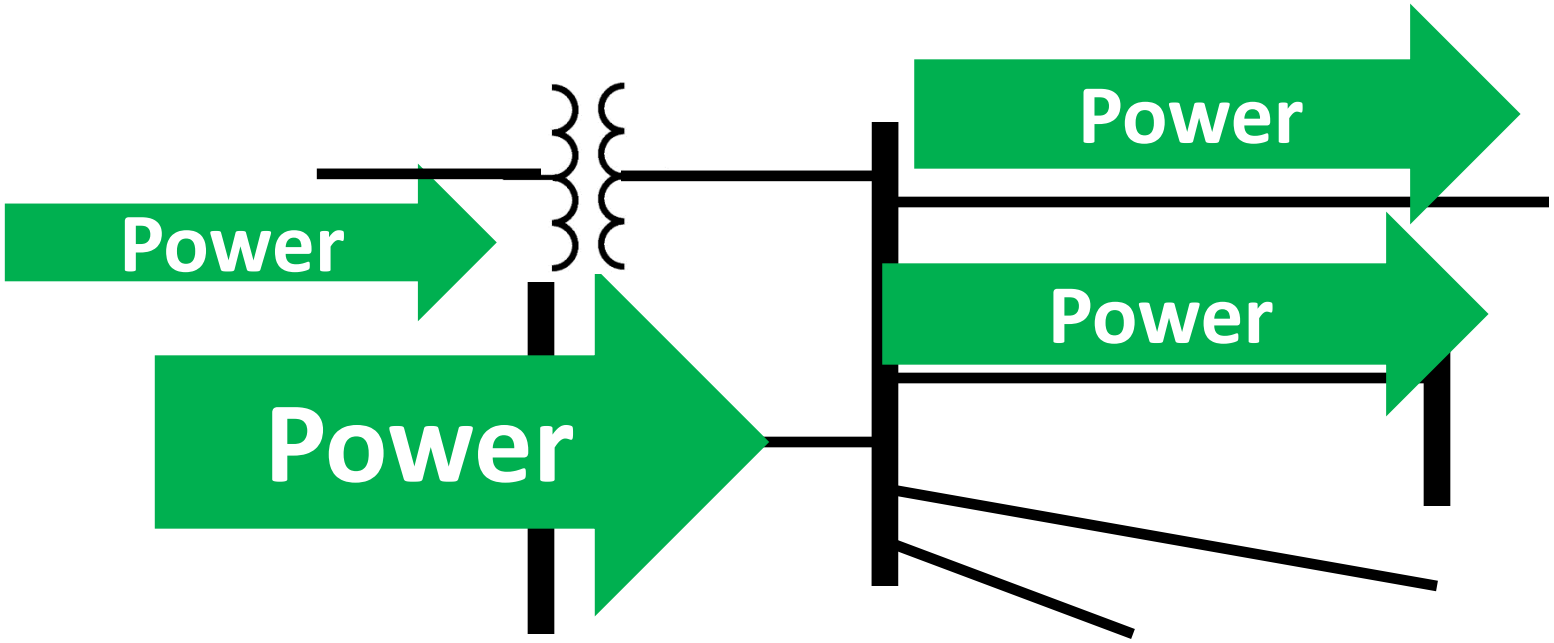
Example 1

Flow Violation

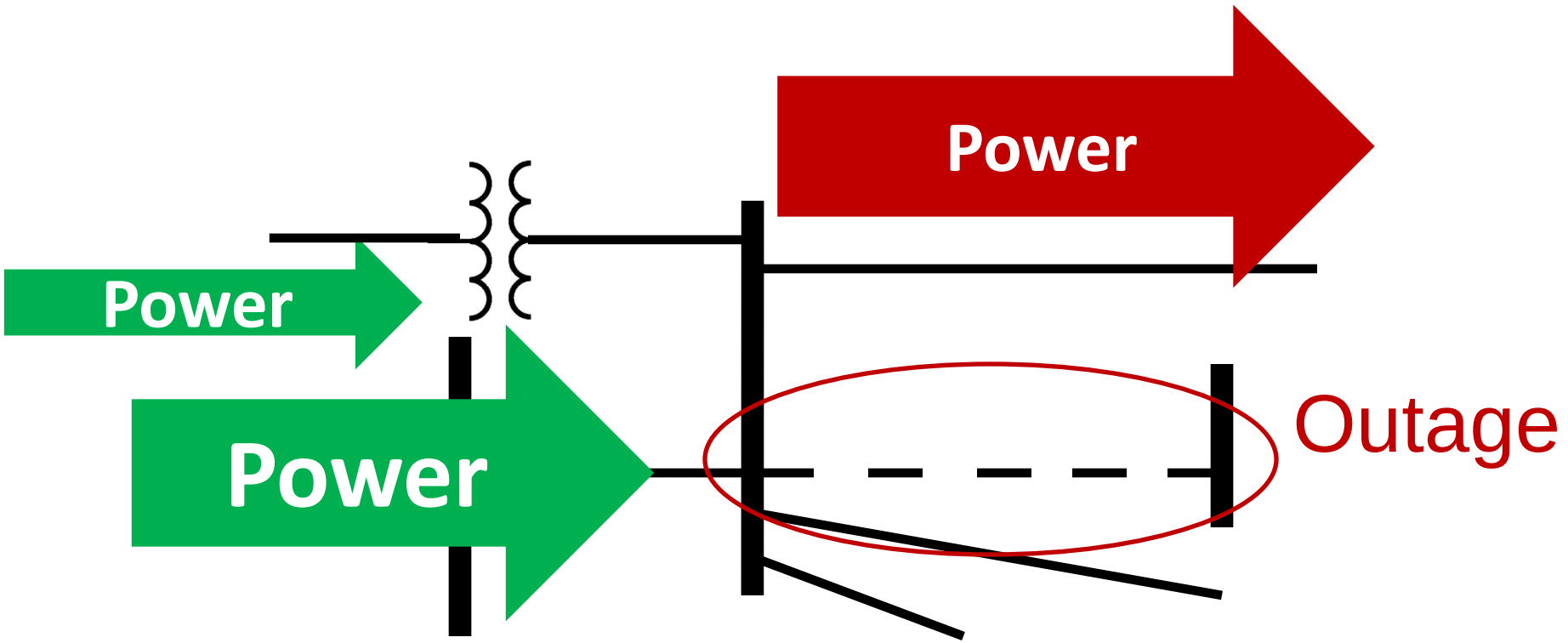
5 Lines are overloaded

FTDS Success: 100%

Pre-Contingency



Post-Contingency

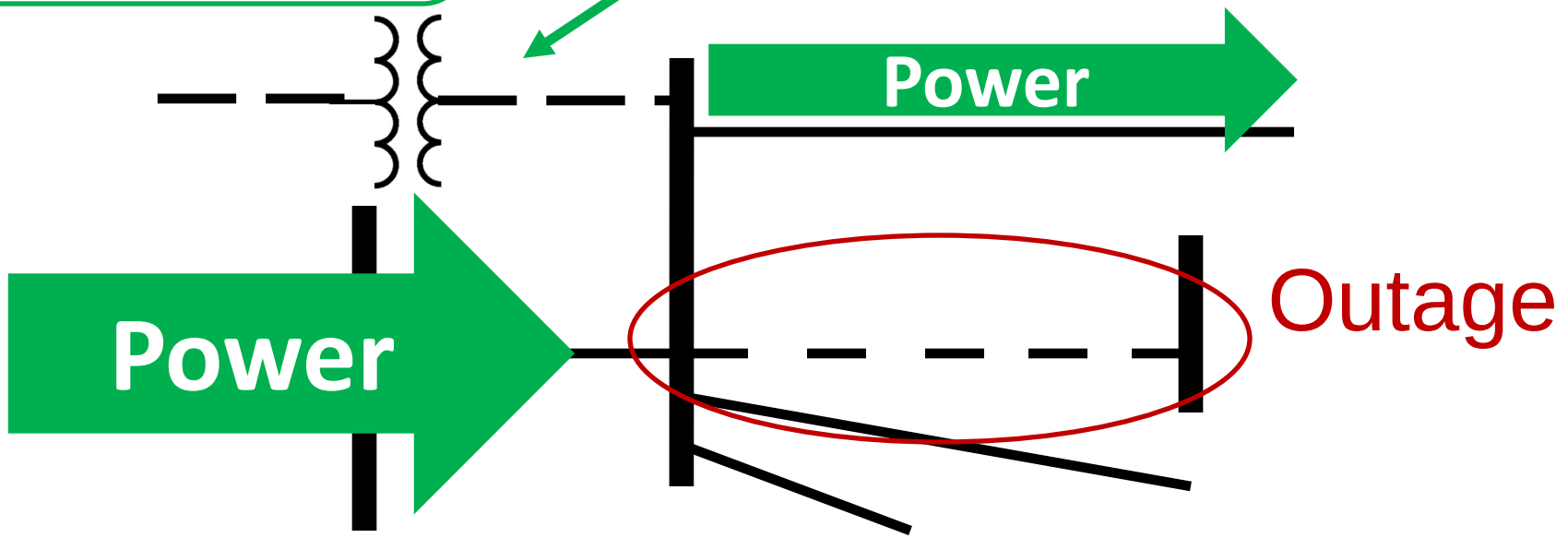


5 Line are overloaded; additional lines downstream are overloaded

Post-FTDS

- 6th candidate from the top of the list based on LODF
- Corrective Action

FTDS Corrective Transmission Switching Solution



All Post-Contingency Violations Eliminated

After FTDS, there are no post-contingency violations anywhere in the system

Example 2: Worst Case Flow Violation

- Worst case flow violation; No voltage violation
- Number of lines with flow violation = 1
- **First candidate: Improvement = 100%**
- **Second candidate: Improvement = 87.4%**

Example 3: Voltage Violation

- Voltage violation (No flow violation)
- Number of buses with voltage violation = 17
- Violation with FTDS = 0 pu
- **Improvement = 100%**

Results:
TVA Test Case

TVA Data

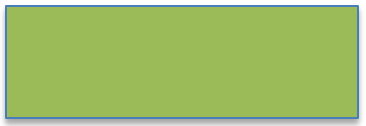
- 72 PSS/E .RAW input files based on TVA data for testing (3 days)

- Network (neighboring systems: equivalent)
  - ~1,800 buses; ~2,300 branches; ~350 gen;
    ~126,000 contingencies simulated
- **~4,200 cases (critical contingencies result in post-contingency violations)**

FTDS based RTCA Results

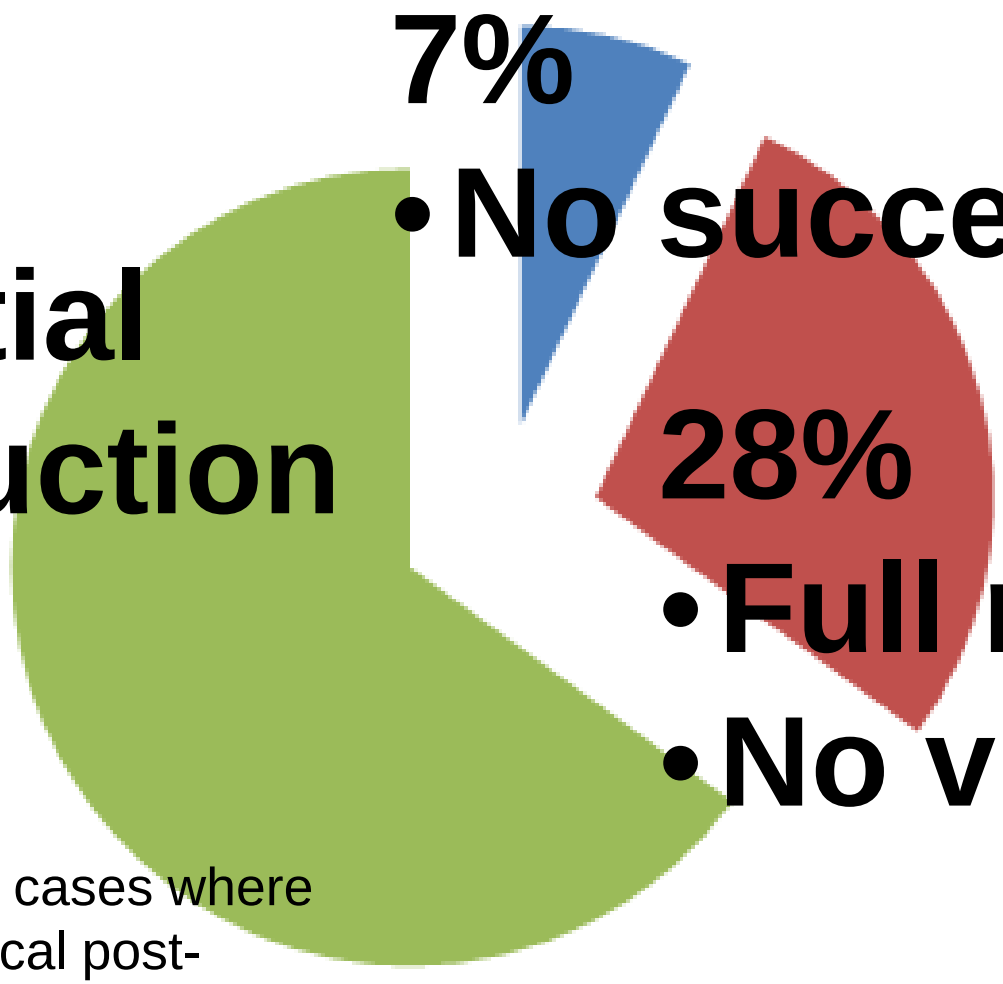
- Full success:
  - Post-contingency violations are fully eliminated

- Partial success:
  - Post-contingency violations are reduced but not fully eliminated



- No success:
  - No beneficial FTDS solution found

FTDS Benefit: TVA



For the 4,200 cases where there is a critical post-contingency violation

Results:
ERCOT Test Case

ERCOT Data

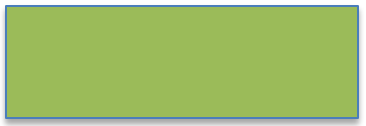
- 3 PSS/E .RAW input files based on ERCOT data for testing (3 hours)

- Network (neighboring systems: equivalent)
  - ~6,400 buses; ~7,800 branches; ~700 gen;
    ~13,000 contingencies simulated
- **~40 cases (critical contingencies result in post-contingency violations)**

FTDS based RTCA Results

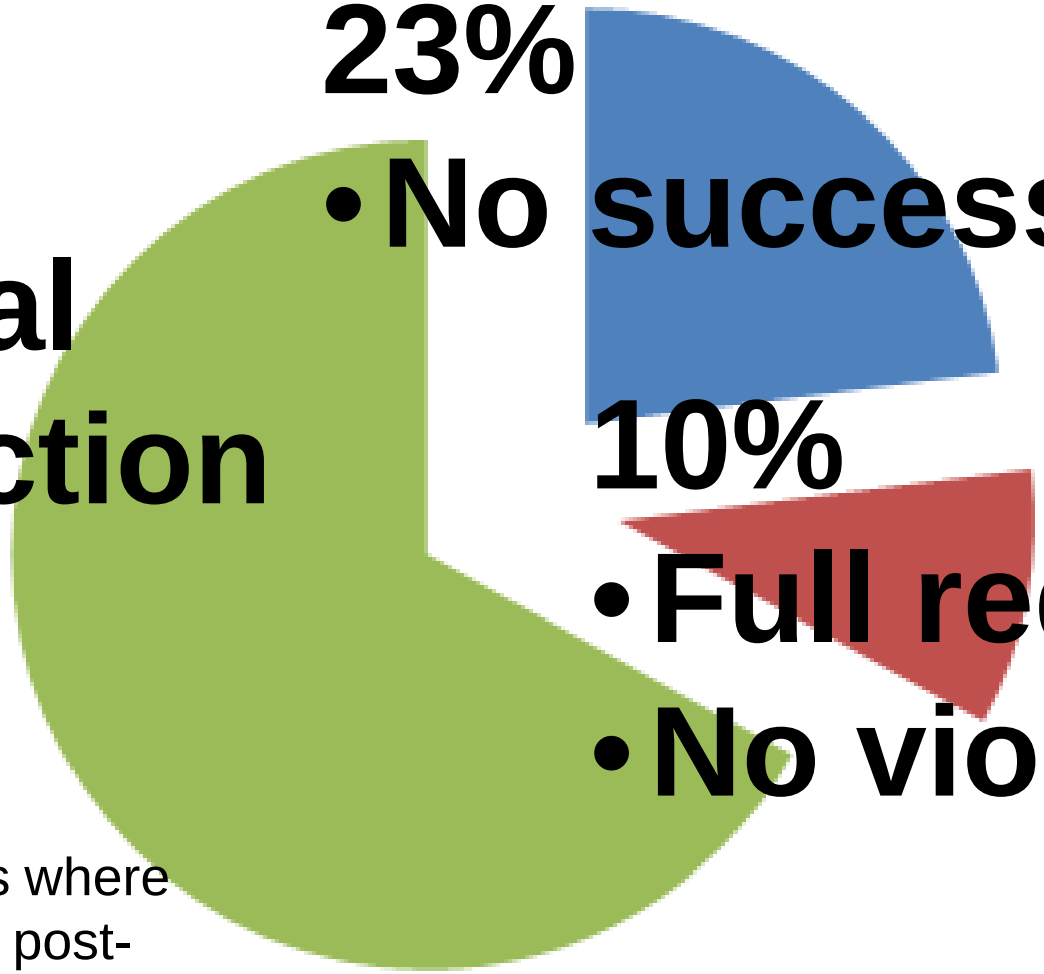
- Full success:
  - Post-contingency violations are fully eliminated

- Partial success:
  - Post-contingency violations are reduced but not fully eliminated



- No success:
  - No beneficial FTDS solution found

FTDS Benefit: ERCOT



23%
- **No success**

67%
- **Partial reduction**

10%
- **Full reduction**
- **No violations**

For the 40 cases where there is a critical post-contingency violation

Onsite Testing of FTDS Concept at ISONE

Collaboration with Dr. Eugene Litvinov and Dr. Slava Masslenikov

ISONE Testing

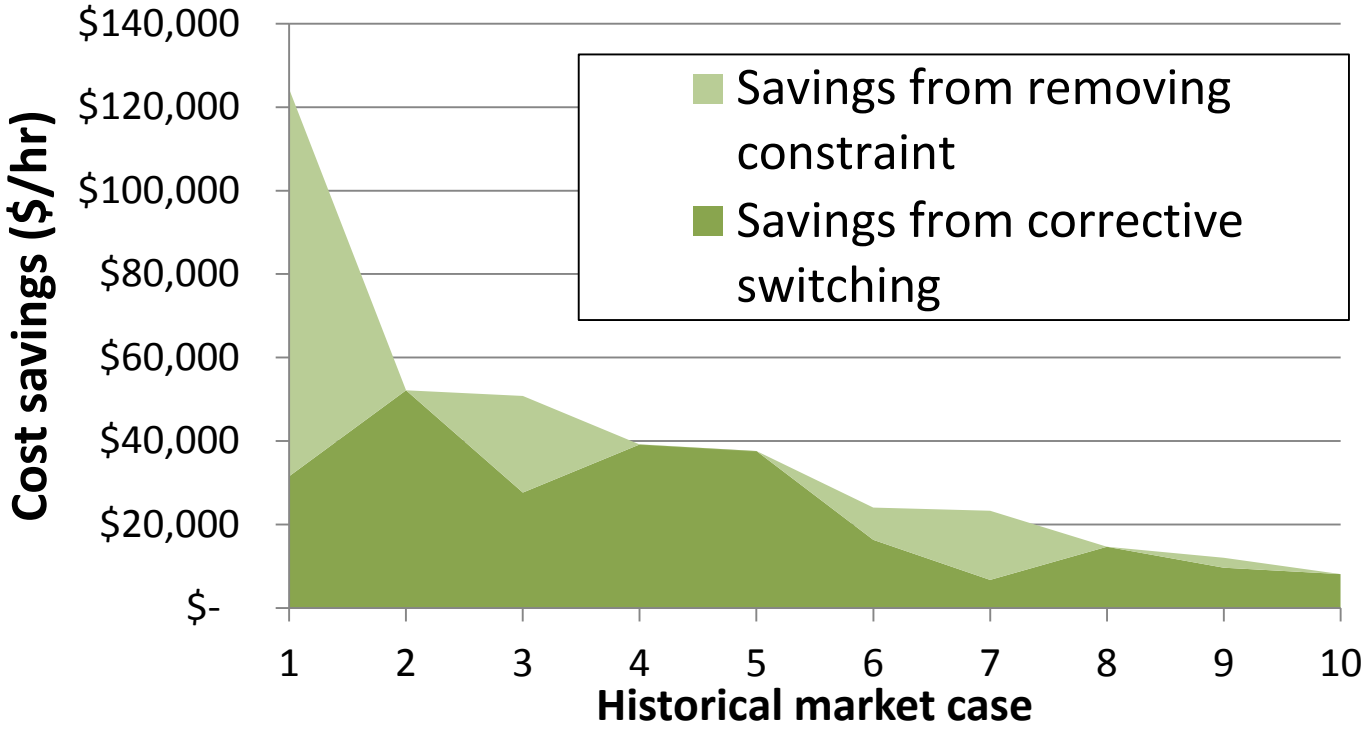
- Concept of FTDS replicated in house at ISONE
- Utilized actual historical market cases
- Re-solved real-time security constrained economic dispatch with FTDS
- Utilization of proprietary market data
- Report on cost savings

ISONE Applications

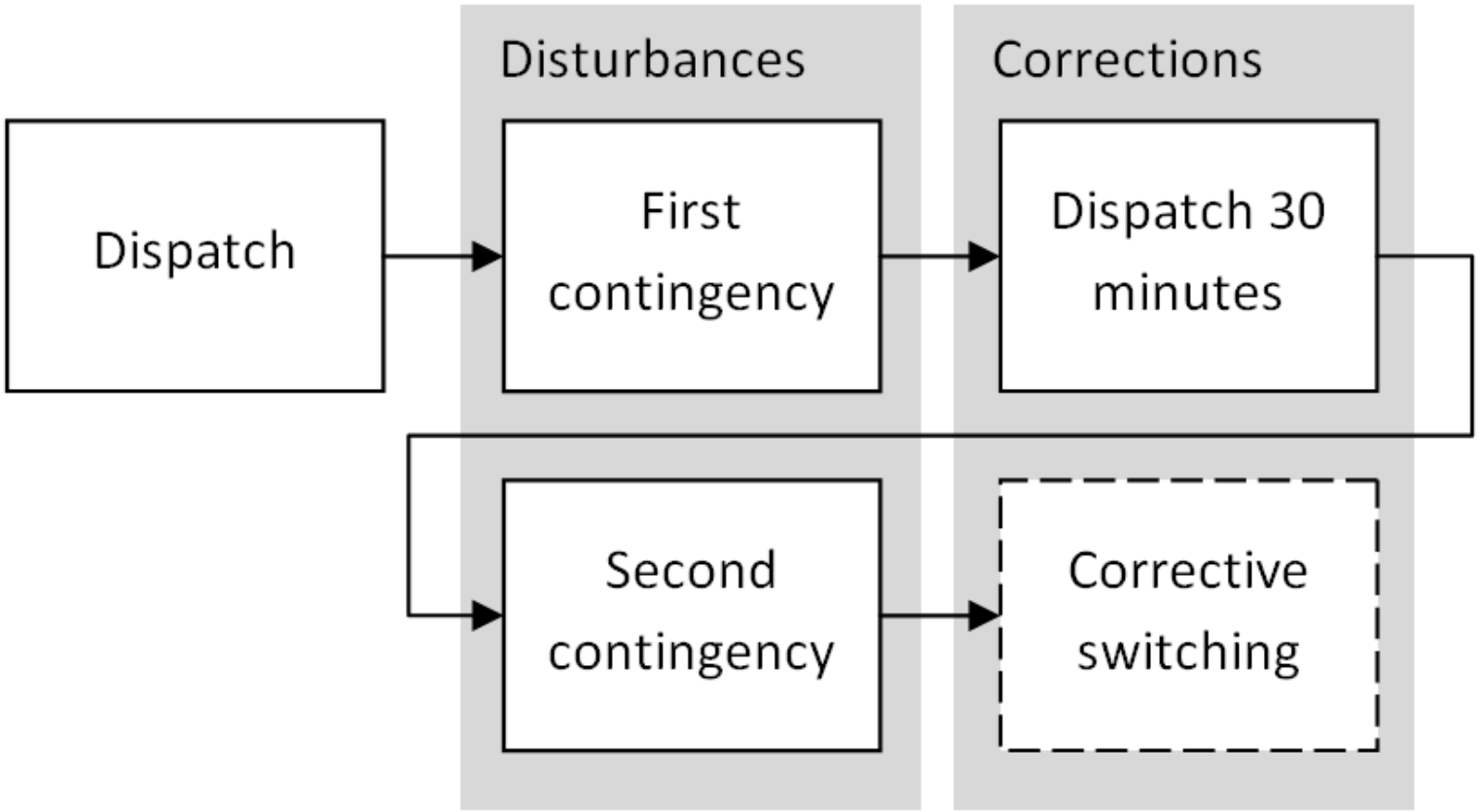
- **FTDS based RTCA:** Integrate post-contingency corrective topology control within RTCA and change SCED constraint set
- **FTDS with Interface Limits:** Integrate post-contingency corrective topology control within the process to determine interface limit constraints, which are fed into the market model

Real-Time SCED with FTDS

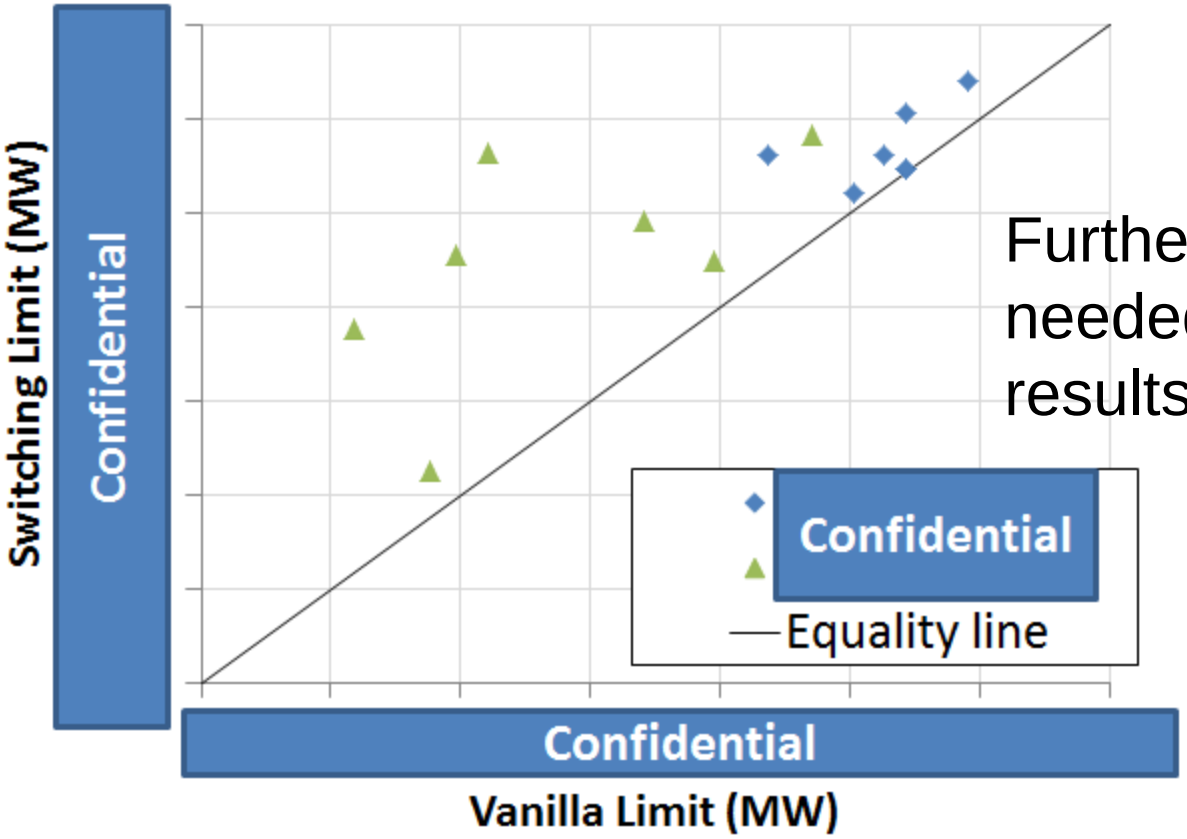
- Corrective switching often captures most of the potential benefit in ISO-NE



Interface Limits



Interface Limit Improvement with FTDS



Further work is needed to verify results

Summary

- Power flow control provides economic savings and reliability enhancements
- Transmission switching is a low-cost power flow control solution
  - Hardware already exists; need: decision support tools
- FTDS paves the way to transition EMS and MMS from neglecting flexible transmission to optimally utilizing transmission assets

FTDS User Forum

- FTDS was created under the RATC (Robust Adaptive Topology Control) ARPA-E Project

- We will further discuss the FTDS technology at **FERC on Wednesday, June 24th (afternoon)**

- Contact Kory Hedman for more information

Questions?

Contact Information:

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