



# **Flexible Transmission Decision Support Systems**

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FERC Software Conference

June 24, 2015

- Key Takeaway Points, Project Overview
- Flexible Transmission Decision Support:  
Tool Development
- System Architecture
- Results: Analyzing 1 Week of PJM EMS  
Data
- Results: Analyzing PJM's Existing Switching  
Solutions
- Summary

# **Key Takeaway Points, Project Overview**

## Key Takeaway Points

- Existing EMS & MMS *often* neglect transmission asset flexibility (lines, transformers, FACTS)
  - Handled outside optimization/power flow engines (e.g., SCUC, SCED, RTCA), 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

# **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
- Assumptions are aligned with standard commercial grade RTCA packages

## FTDS based RTCA

Post-contingency corrective transmission switching

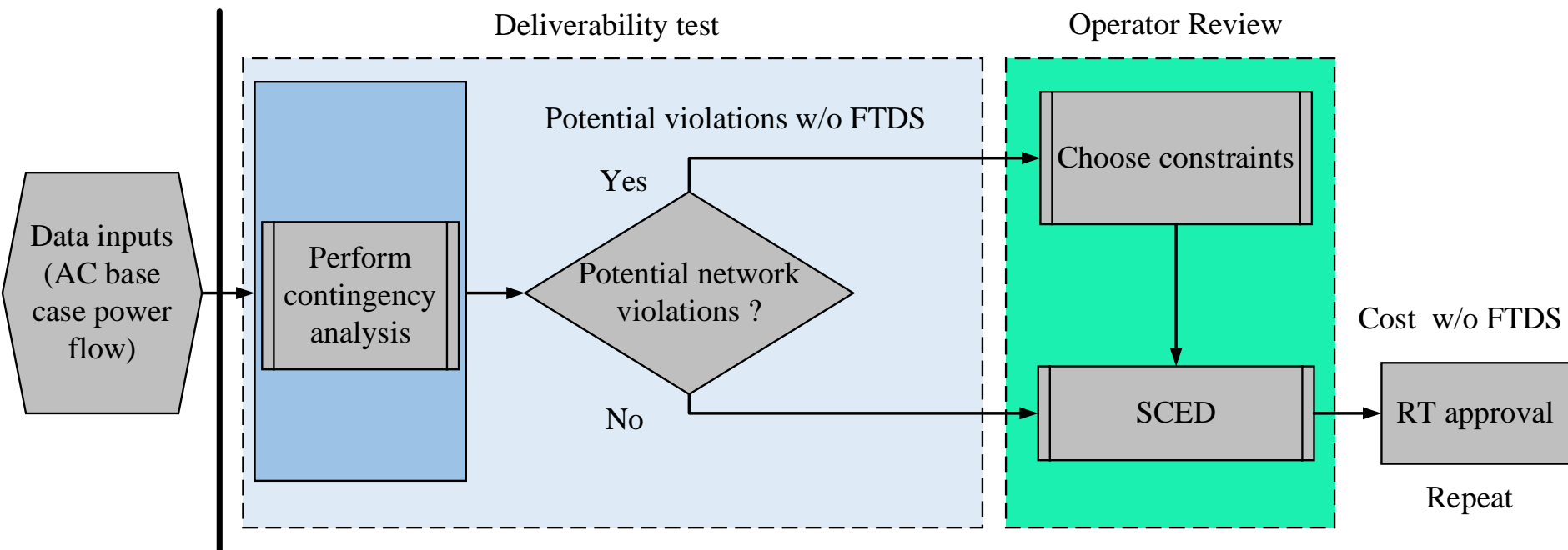
- Shortly after a contingency, ***as a corrective action:***  
*take a line out of service*
- Implement at most 1 corrective switching action
- But: identify multiple potential switching actions, in advance, per contingency to provide operators:  
**choice**
- Perform stability studies to confirm switching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



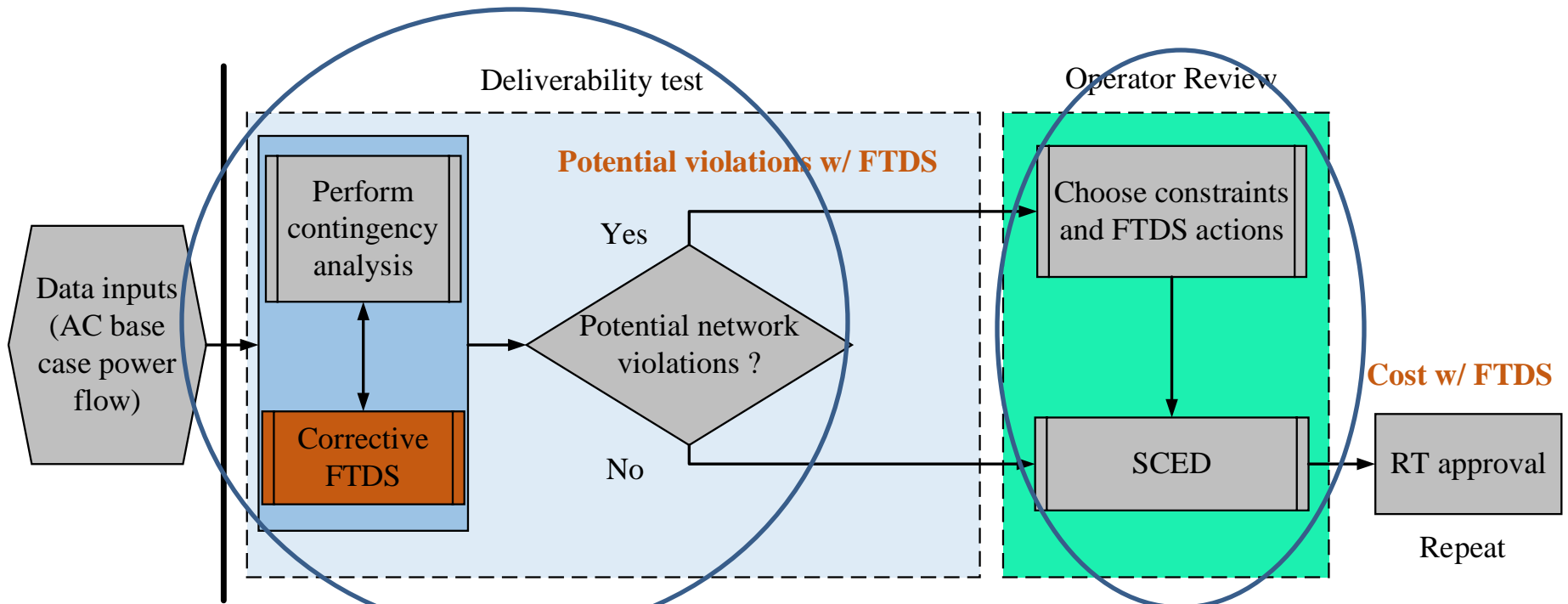
# System Architecture

Develop FTDS based RTCA to work seamlessly with EMS

# Real-Time Contingency Analysis and Security Constrained Economic Dispatch





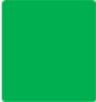


# Implementation of FTDS based RTCA and Impact on SCED



FTDS determines corrective transmission switching actions

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


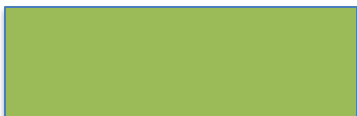

# Operator Review Example

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

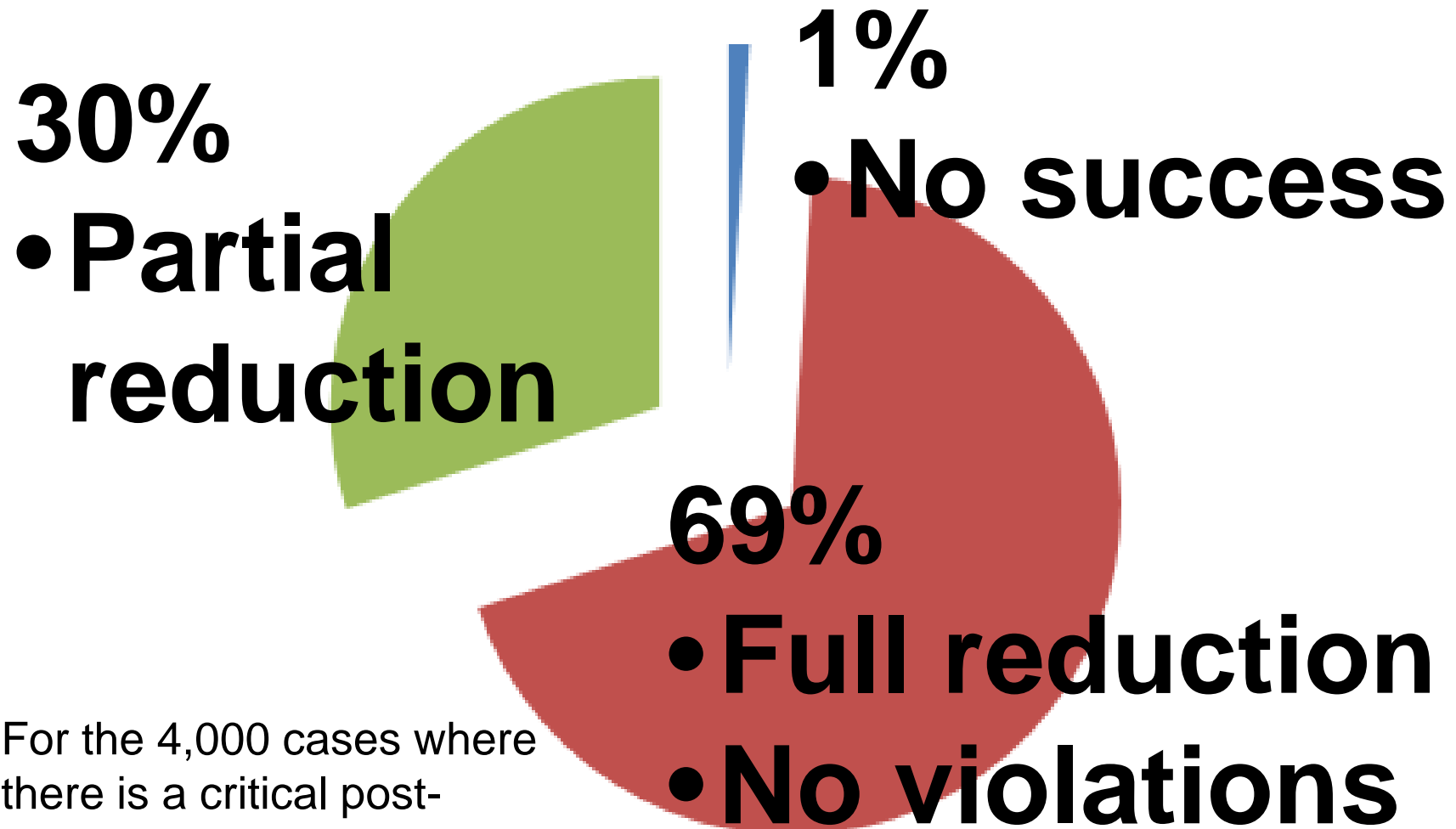
# **Results: Analyzing 1 Week of PJM EMS Data**

- 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; ~8k contingencies simulated each hour (1.4M contingencies simulated in total)
- **~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

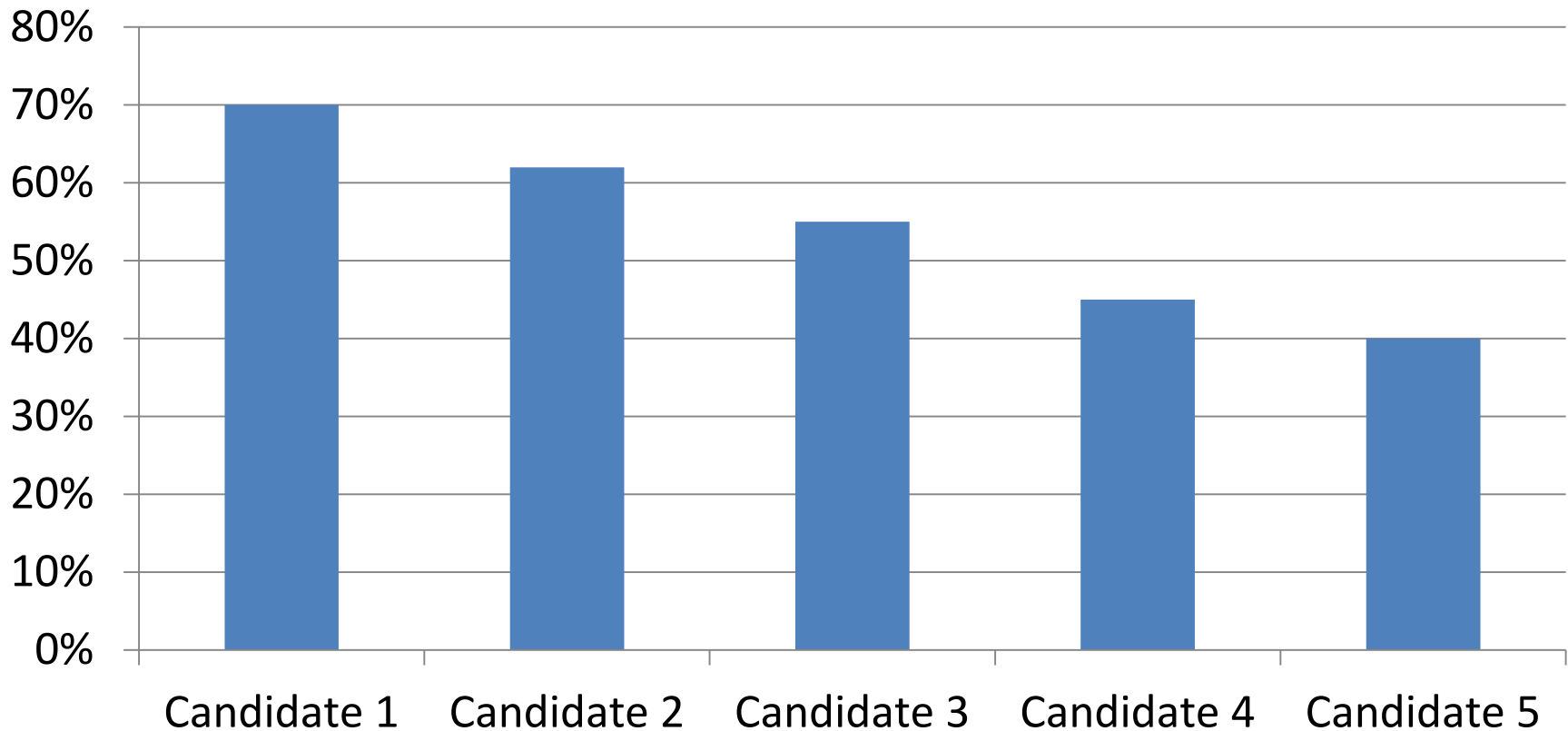


For the 4,000 cases where there is a critical post-contingency violation





# Percent Corrective Action Eliminates All Post-Contingency Violations



**FTDS algorithm suggests 5 candidate switching actions; all perform well**

# **Results: Analyzing PJM's Switching Solutions**



# Industry Practices: PJM

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## Switching Solutions

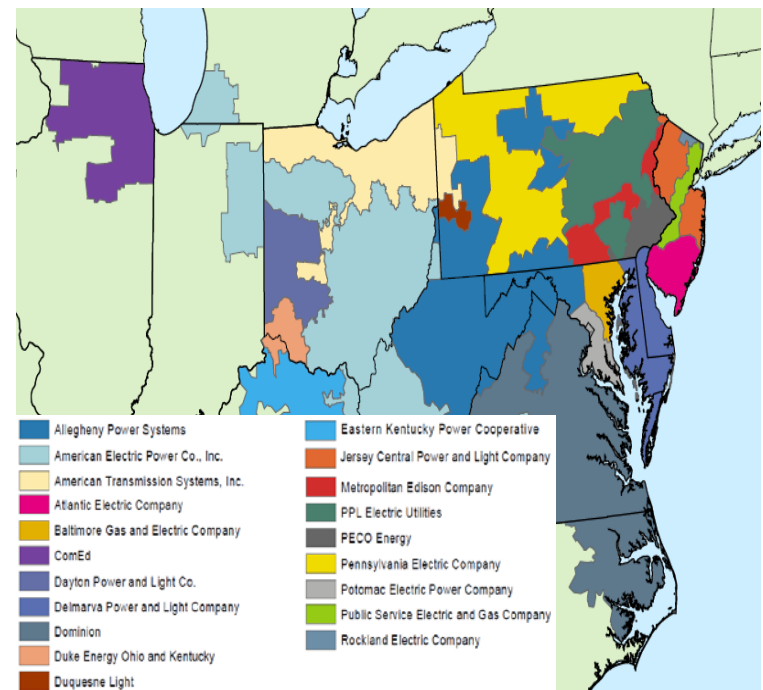
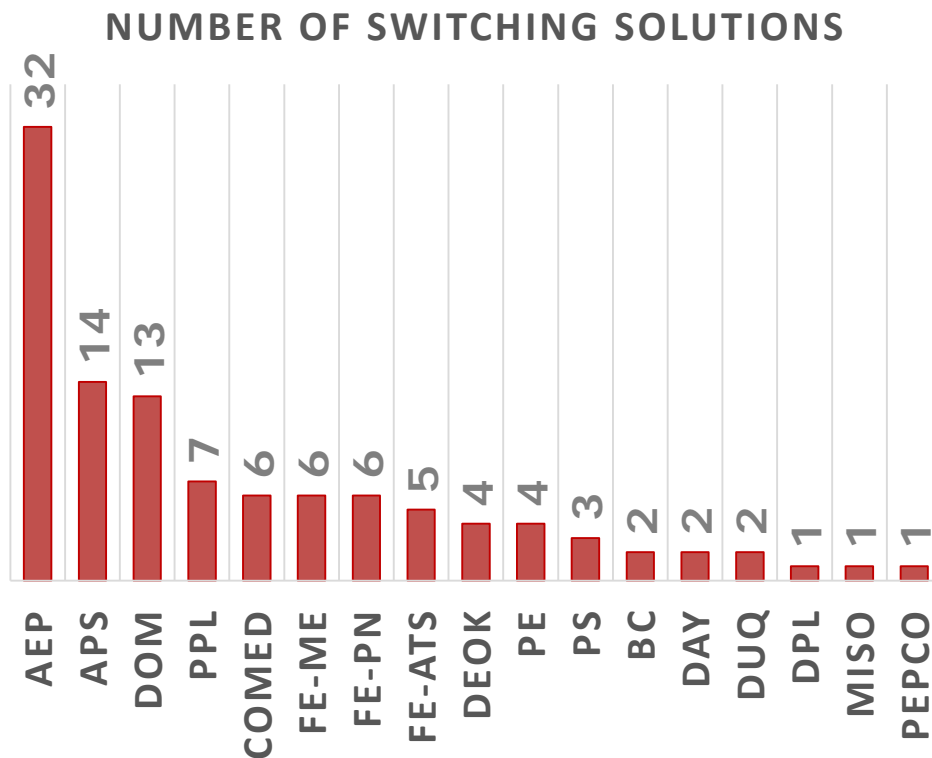
The following is a list of potential transmission switching procedures identified by PJM that may assist to reduce or eliminate transmission system congestion. These identified potential transmission switching procedures may or may not be implemented by PJM based upon system conditions, either projected or actual, and ultimately are implemented solely at the discretion of PJM and its Transmission Owners. This posting is for informational purposes only. Consequently, PJM does not guarantee that any of these identified switching procedures will be included in any market-based auctions or in the real time analysis. Accordingly, PJM expressly disclaims any liability for financial consequences that a Member may incur in taking action in reliance on these informational postings.

Procedure Title	Company 1	Company 2	Action
Darrah-Tristate switching option	AEP		To control overloads on the Darrah-Tristate 138kV line, study opening the Darrah 'A' 138kV CB. If this cannot be done precontingency, issue a PCLLRW with the post contingency switching plan.
Ruth-Turner overload control	AEP		To control loading on the Ruth-Turner 138kV line, study opening the Turner 'D' 138kV CB precontingency. Studies show this provides approximately 40MVA of relief. If additional relief is required, the following post contingency switching option may be available and provides ~60MVA additional relief: - @ Bradlev. open the "B" CB. OR

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

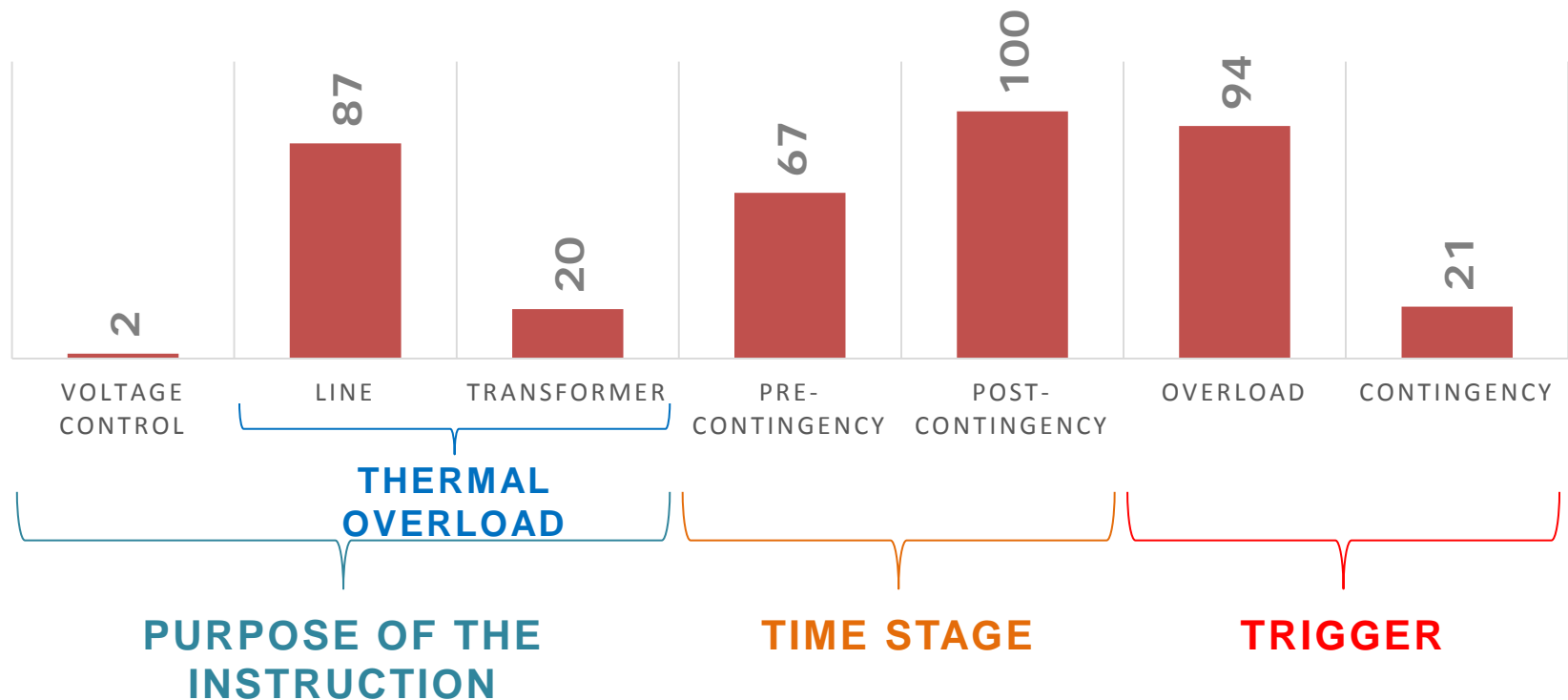
# Switching Solutions per Utility Zone

- Total number of switching solutions: 109



# Switching Solutions Statistics

- Total number of switching solutions: 109



# Switching Solutions: Lessons Learned

- 107/109 of PJM's instructions are for *thermal limit violation* control.
- 2/109 of PJM's instructions are designed for *voltage control*.
- PJM acknowledges transmission switching as a *fast* and *cheap* solution compared to its alternatives.
- PJM's switching solutions are often based on a *node-breaker* model.
  - Most of them can be translated into a *bus-branch* action.
- A few of PJM's switching solutions involves *bus-tie* switching, which would be a *bus-splitting* action.



# 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

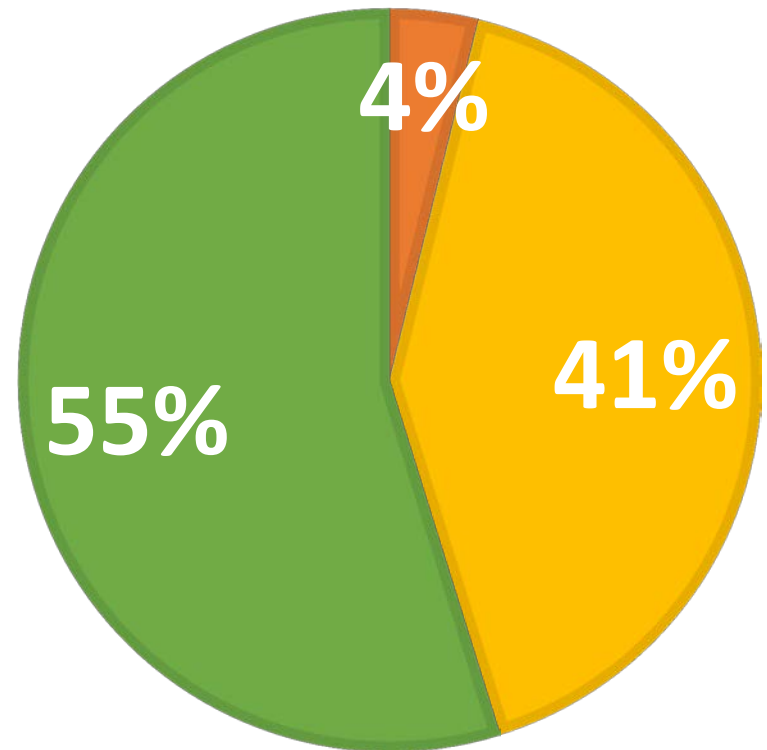
If the switching can't be performed pre-contingency, issue a PCLLRW with the post contingency switching plan.



## 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**





# PJM Switching Solutions

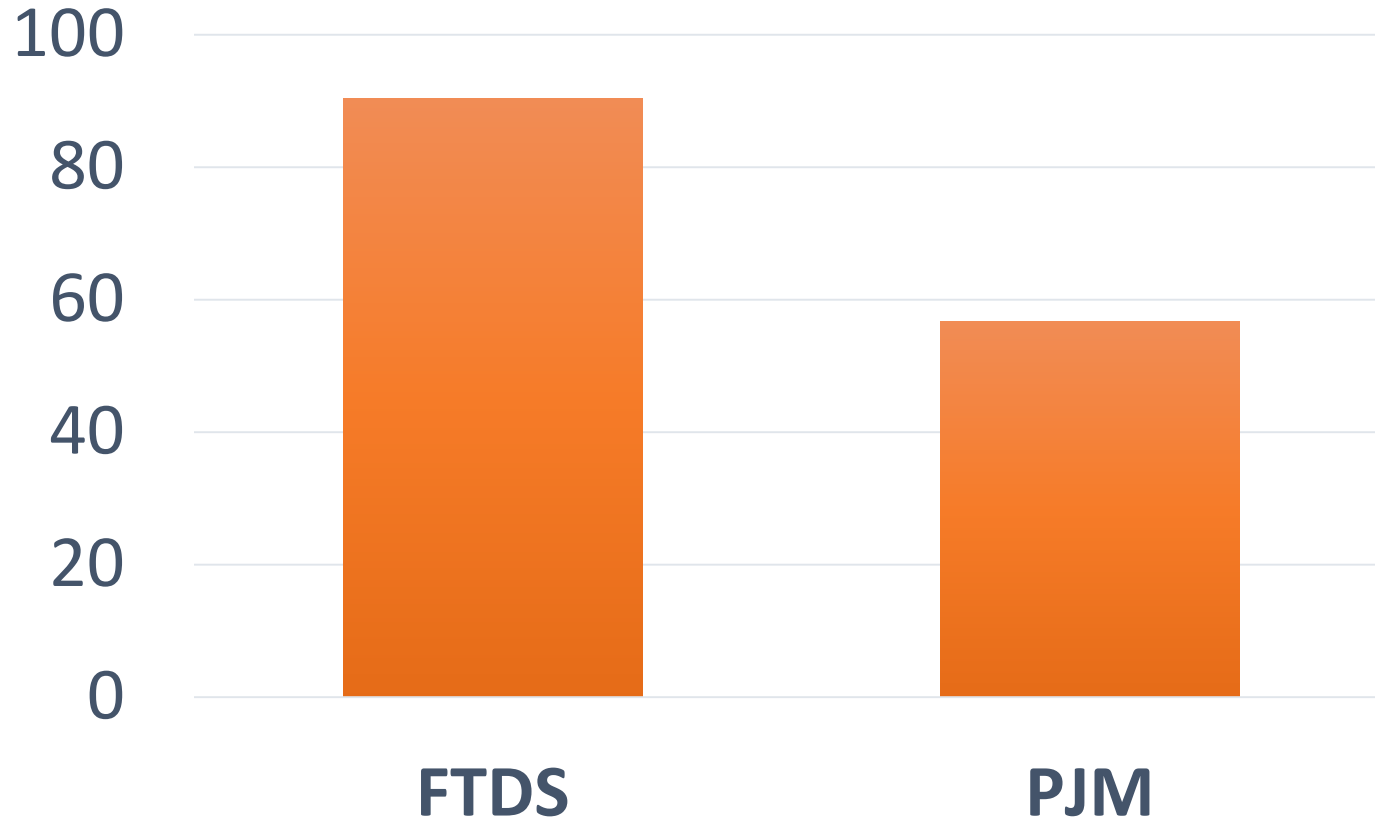
ETDS VS. PJM PERFORMANCE

**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



## Complete Elimination of the Violations (%)

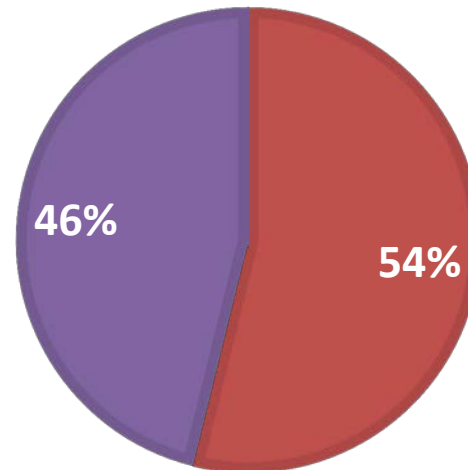


# Contingency / Violation matches PJM's solution

- 56 cases: FTDS identifies PJM's solution within the first five candidate
- 48 cases: PJM's solution is not within the first five candidates identified by FTDS
  - 46 of these 48:
  - FTDS completely eliminates the violation or does better than PJM's solution

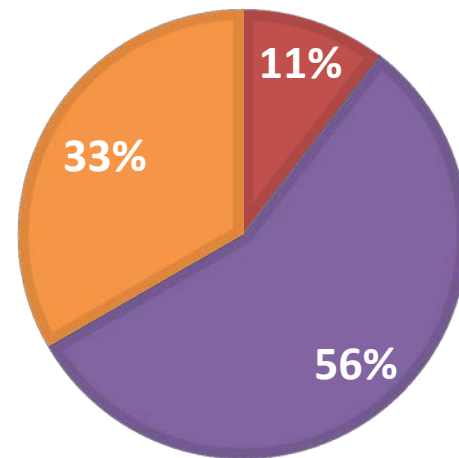
## MATCHING PJM'S SOLUTION

- PJM solution within the 5 candidates
- PJM solution not within the 5 candidates



## FTDS VS. PJM PERFORMANCE NOT MATCHING CASES

- PJM outperforms FTDS
- FTDS outperforms PJM
- Similar



## 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 24<sup>th</sup> (afternoon) and Thursday, June 25<sup>th</sup> (morning)**
- Contact Kory Hedman for more information

# Questions?

Contact Information:

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(480) 965-1276

# Appendix



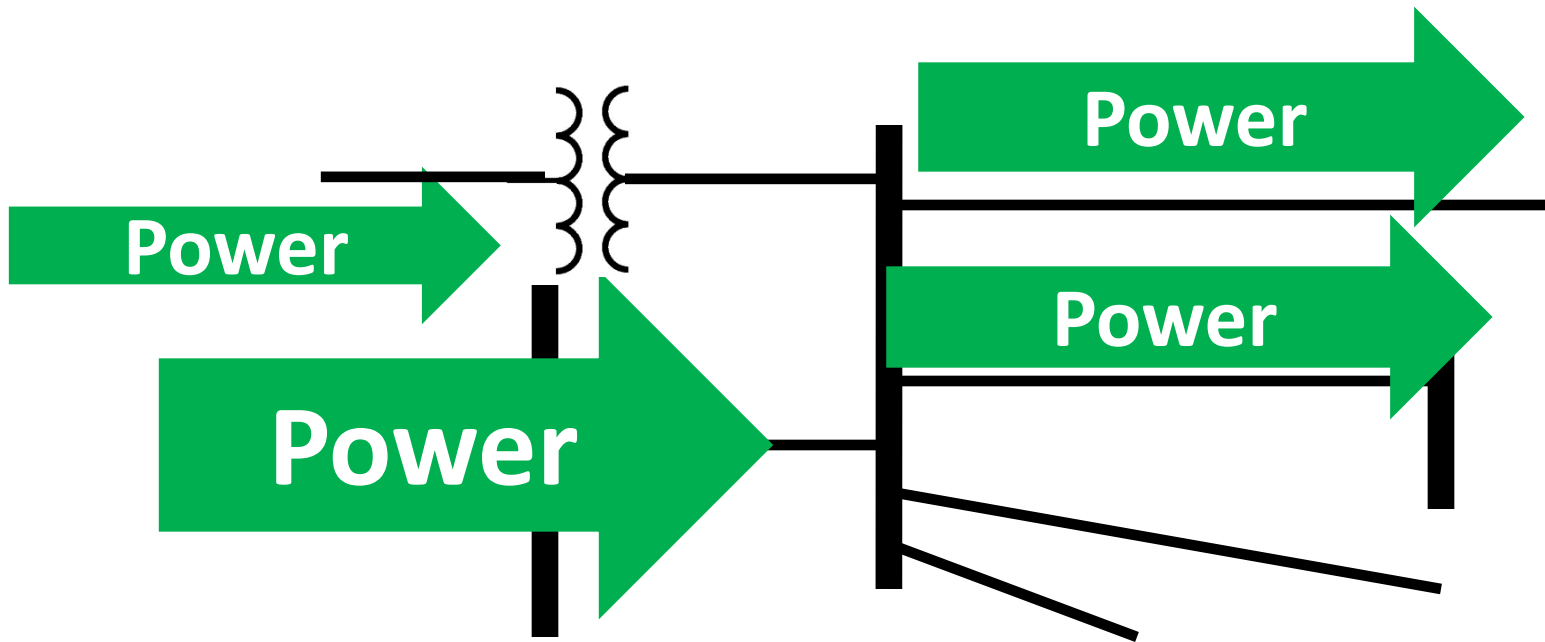
# Example 1

Flow Violation

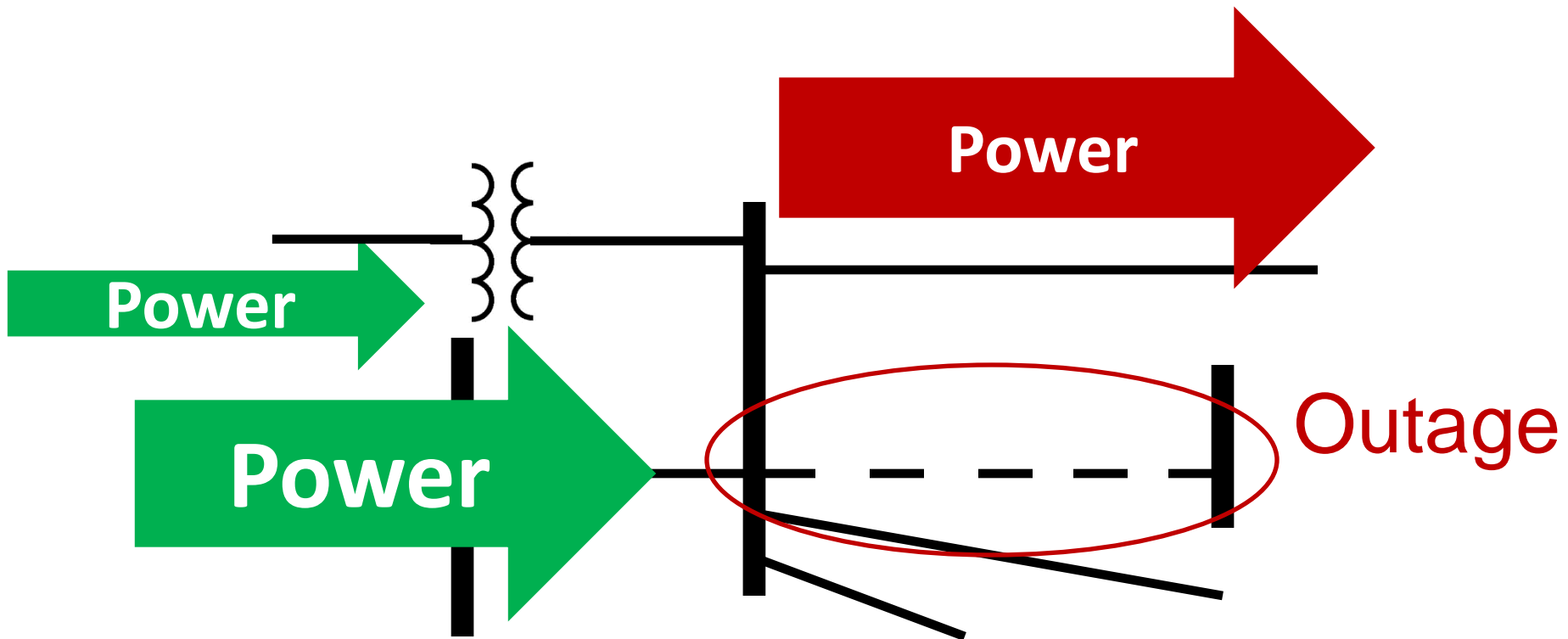
5 Lines are overloaded

FTDS Success: 100%

# Pre-Contingency



# Post-Contingency

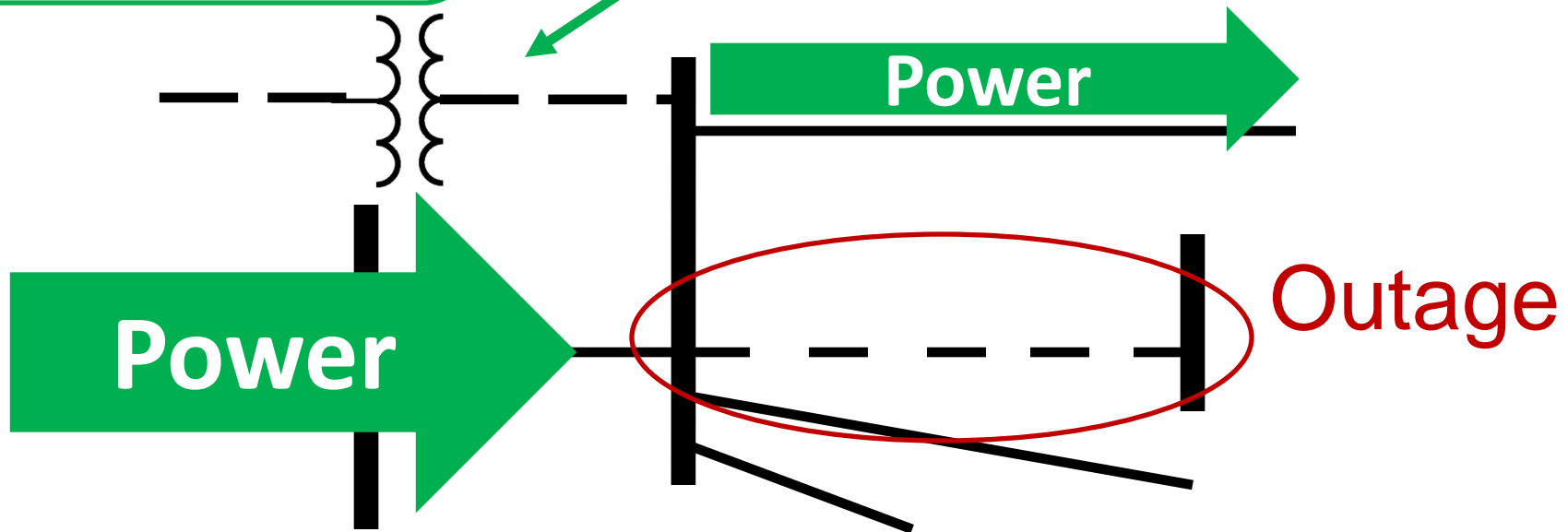


5 Line are overloaded; additional lines downstream are overloaded

# Post-FTDS

**FTDS Corrective  
Transmission  
Switching Solution**

- 6<sup>th</sup> candidate from the top of the list based on LODF
- Corrective Action



**All Post-Contingency  
Violations Eliminated**

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

# **Onsite Testing of FTDS Concept at ISONE**

**Collaboration with Dr. Eugene  
Litvinov and Dr. Slava Masslenikov**

# ISONE Testing

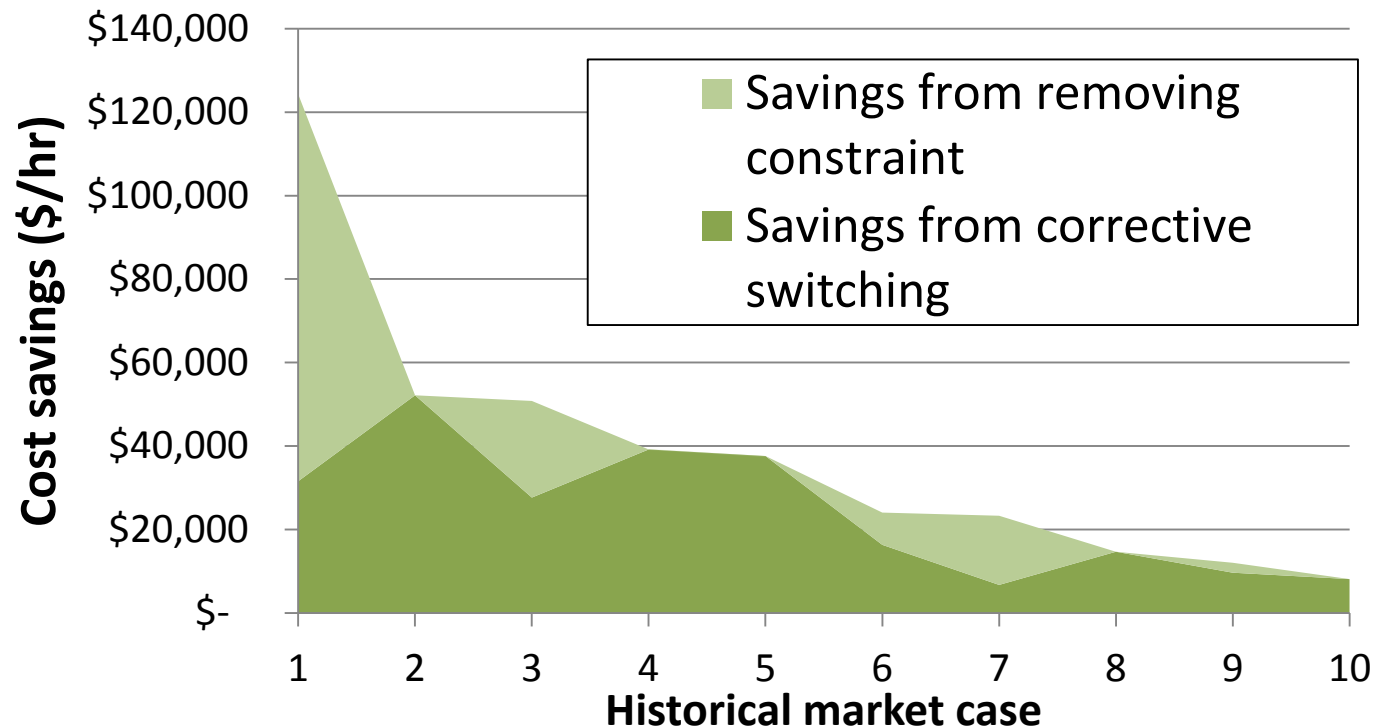
- Concept of FTDS replicated in house at ISONE
- Utilized actual historical market cases
- Re-solved real-time security constrained economic dispatch with FTDS
- Utilization of proprietary market data
- Report on cost savings

## 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

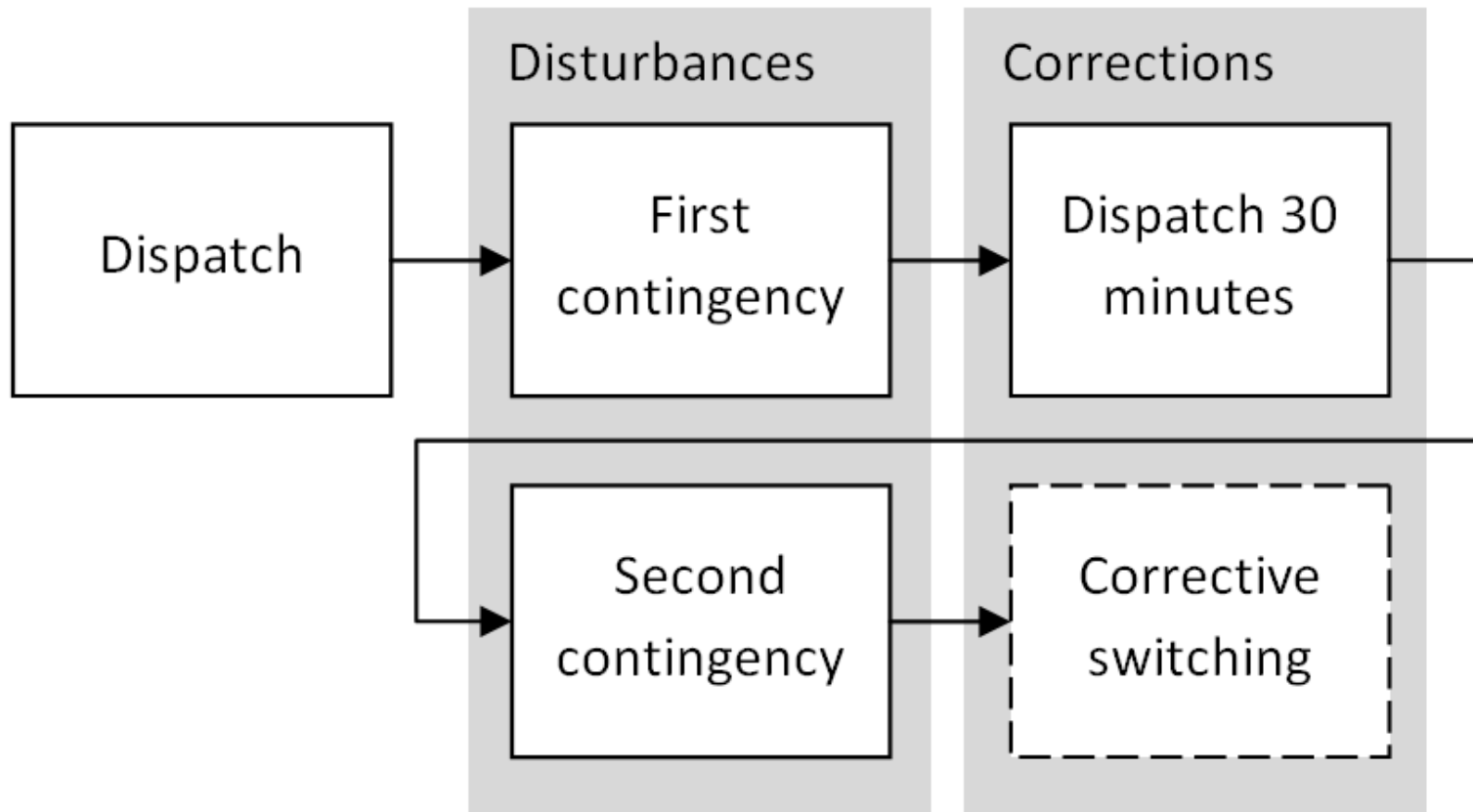
# Real-Time SCED with FTDS

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





# Interface Limits





# 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

# **RTCA Assumptions**

## 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