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Disclaimer and Credits

- All graphics and information used in this presentation are from various reports and presentations given by NERC – all are in the public domain.
- The opinions expressed in this presentation are those of Robert W. Cummings from 45 years of experience in the electric power industry:
  - 6 years – Central Vermont Public Service (System Planning – Gen. and Transmission)
  - 8 years – Public Service Company of New Mexico (Operations Engineering and Wide Area Planning)
  - 8 years – East Central Area Reliability Coordination Agreement (ECAR – Manager of Transmission Services)
  - 23 years – North American Electric Reliability Corp. (NERC – retired in 2020 as Senior Director of Engineering and Reliability Initiatives)

The 2003 Blackout – Twenty Years Later What Have We Learned Since Then?

NASPI Webinar Series

Robert W. Cummings 23 August 2023

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Summary of August 14 Blackout

- Impacts
  - 8 states/2 provinces
  - Over 50 million people
  - 60-65,000 MW
  - 30 hours to restore
  - Manufacturing disrupted
  - 531 generators tripped
    - 19 nuclear generators at 10 plants

- Statistics
  - Line trips began at 3:05 PM prior to reaching maximum temperature.
  - High Speed Cascading began at 4:06 PM by Zone 3 impedance relays
  - Transient Instability and cascading began at 4:10:38 PM
    - Lasted approximately 12 seconds
    - Thousands of discrete events

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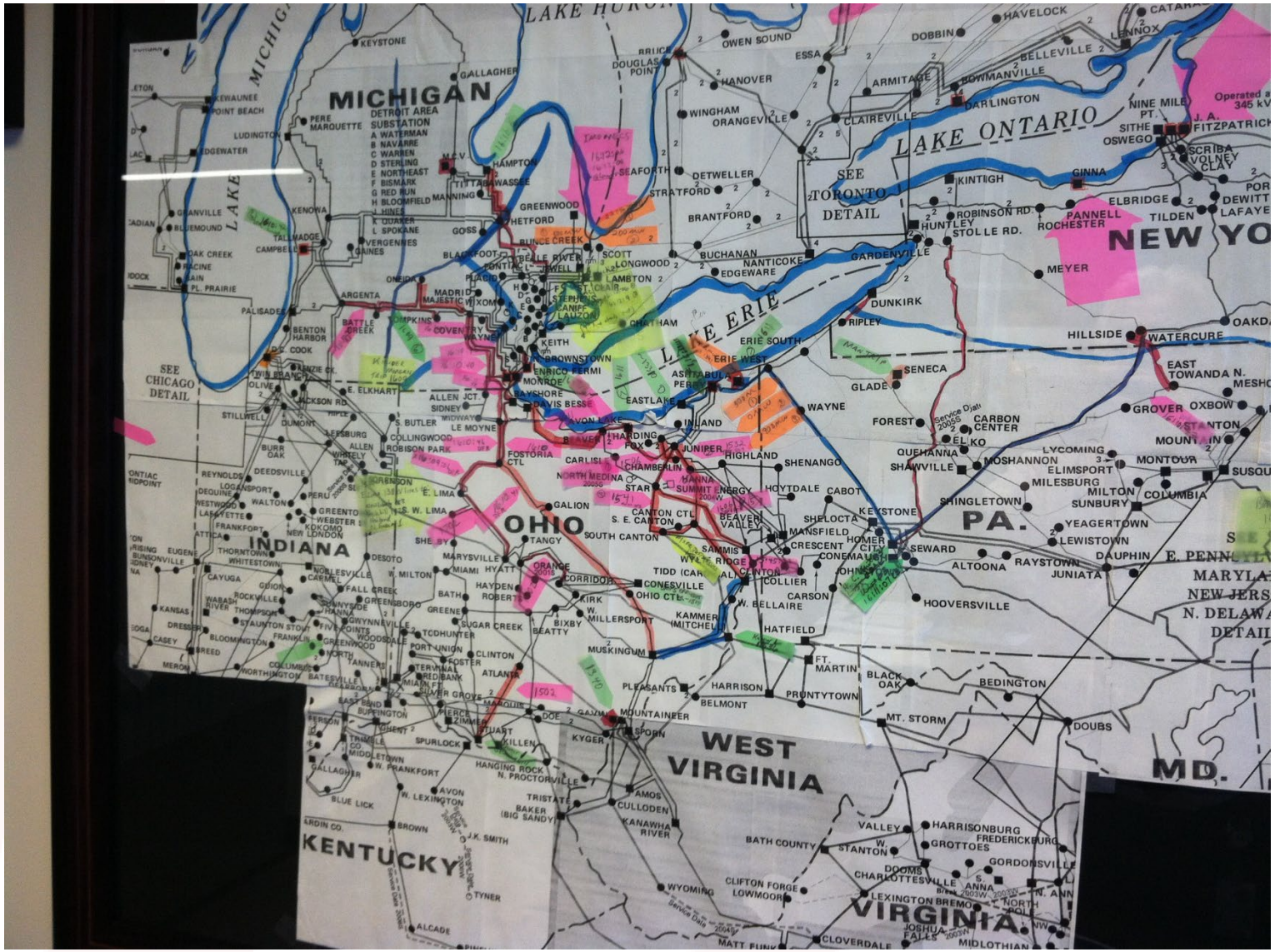
NERC – August 14, 2003

- About 30 employees
- Headquarters in Princeton, NJ
- Standards not mandatory
- Only 4 current employees were working for NERC
  - Can you name them?
- Everybody pressed into service
  - Handling the Press
  - Managing data
  - Analyzing data
- Coordination calls every 2 hours until restoration completed

Overnight Analysis



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Blackout Analysis

- US – Canada Power System Outage Task Force formed
  - NERC
  - FERC
  - DOE
  - National Energy Board of Canada
- Over 150 people worked on the analysis
- 36 Gigabytes of data (a large amount 20 years ago)
- A room full of paper
- Interim Report issued in November 2003
- Final Report issued April 2004

Blackout War Room

- 32 engineers, their laptops, 3 projectors
- 6-man team continued work for 2.5 years
- Not a PMU in sight!

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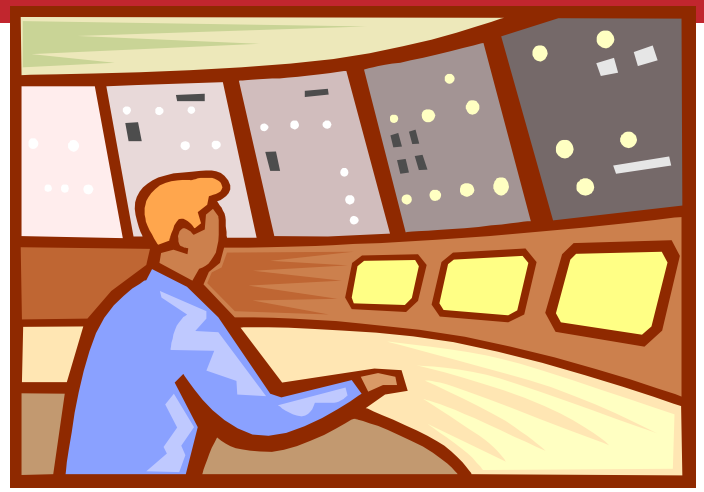
Caused by three "T's"

- The three "**T's**"
  - **Trees** – vegetation management to allow maximum conductor temperature.
  - **Tools** – for the operator to monitor and manage the system.
  - **Training** – provide training and drills to be prepared to respond to system emergencies



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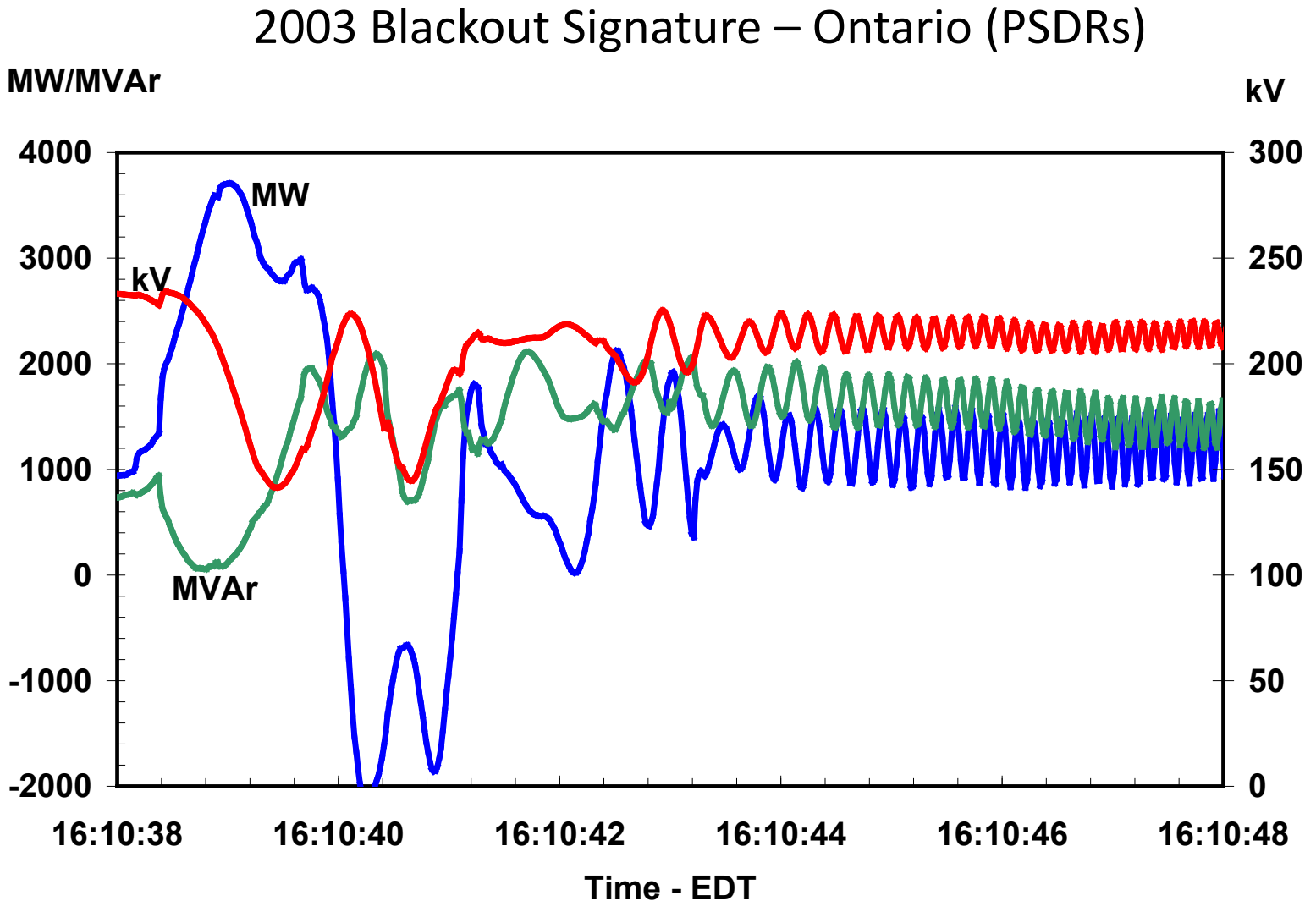
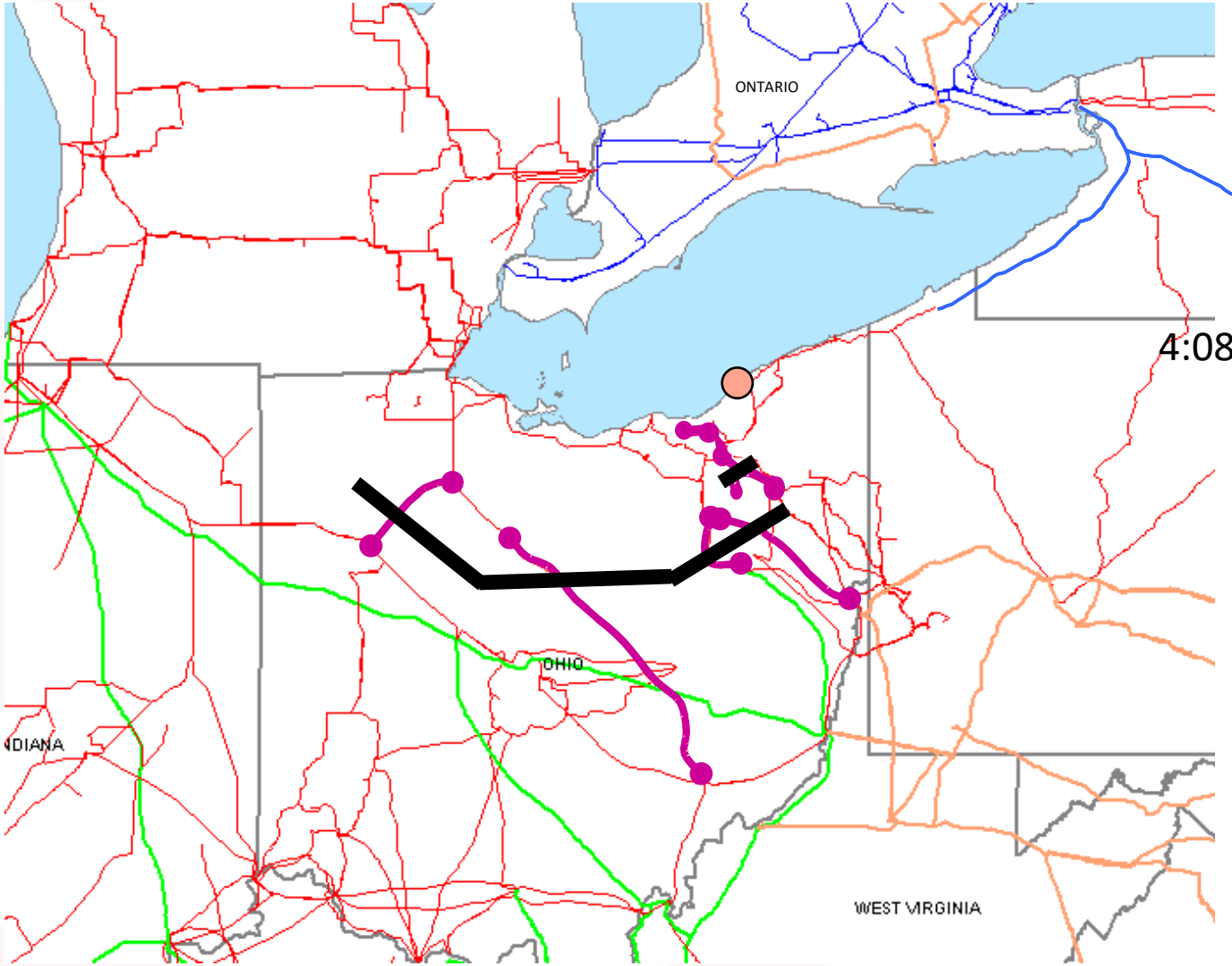
2003 Blackout Signature – Ontario (PSDRs)



345 kV Lines Trip Across Ohio



4:08:59 - 4:09:07 PM

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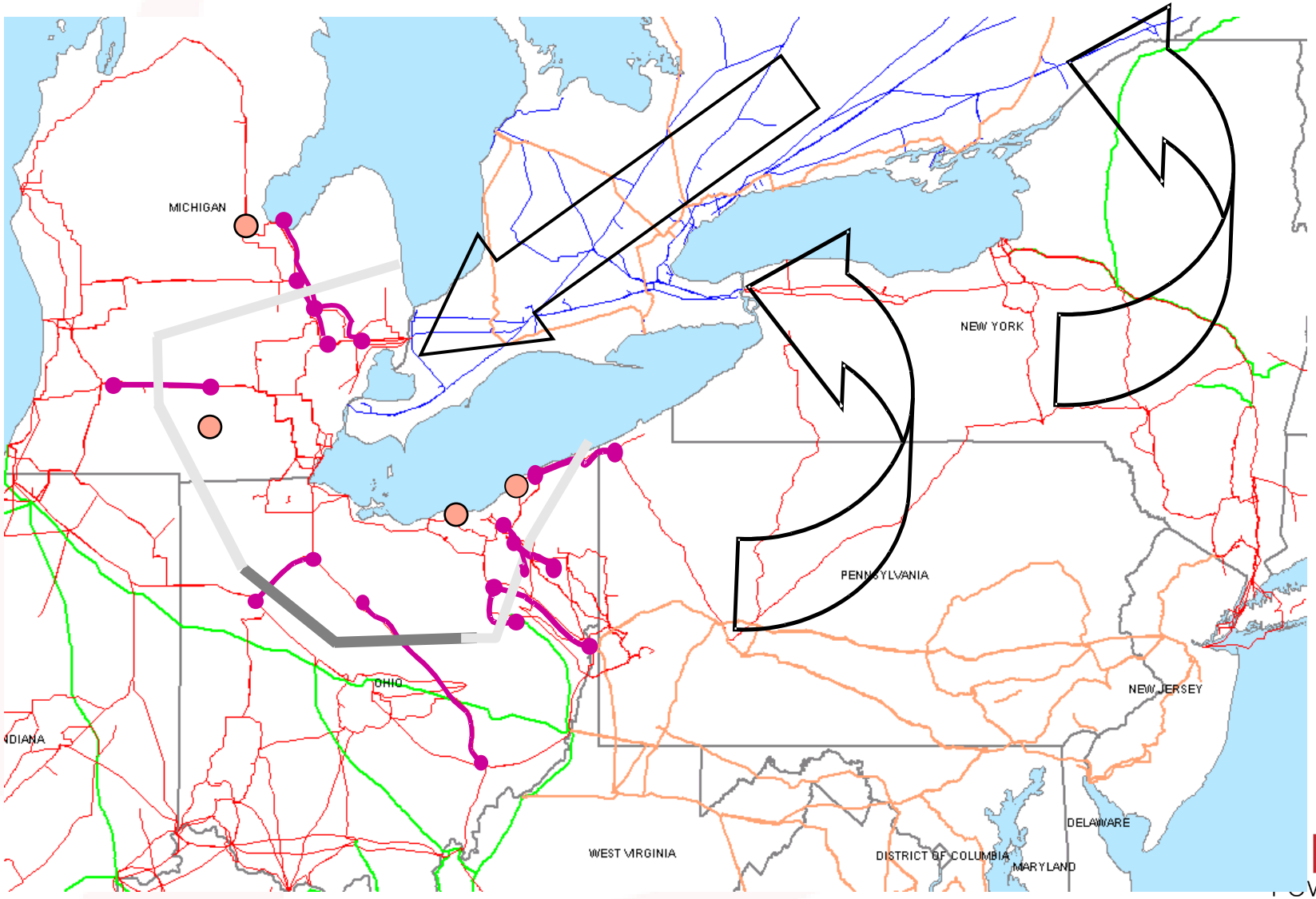
Power Transfers Shift 4:10:38.6 PM



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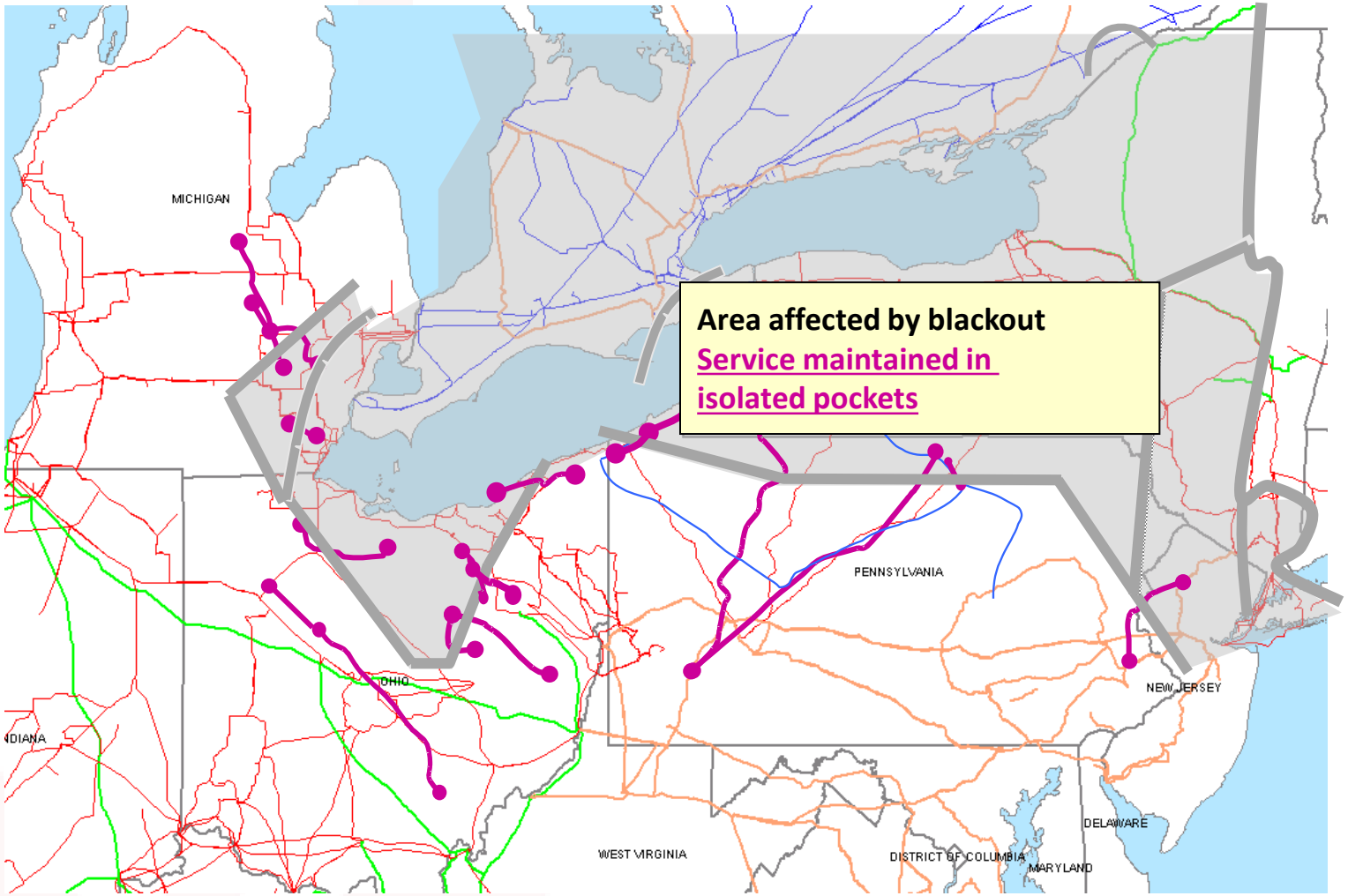
Northeast Island Separates from Eastern Interconnection



4:10:43 – 4:10:45 PM

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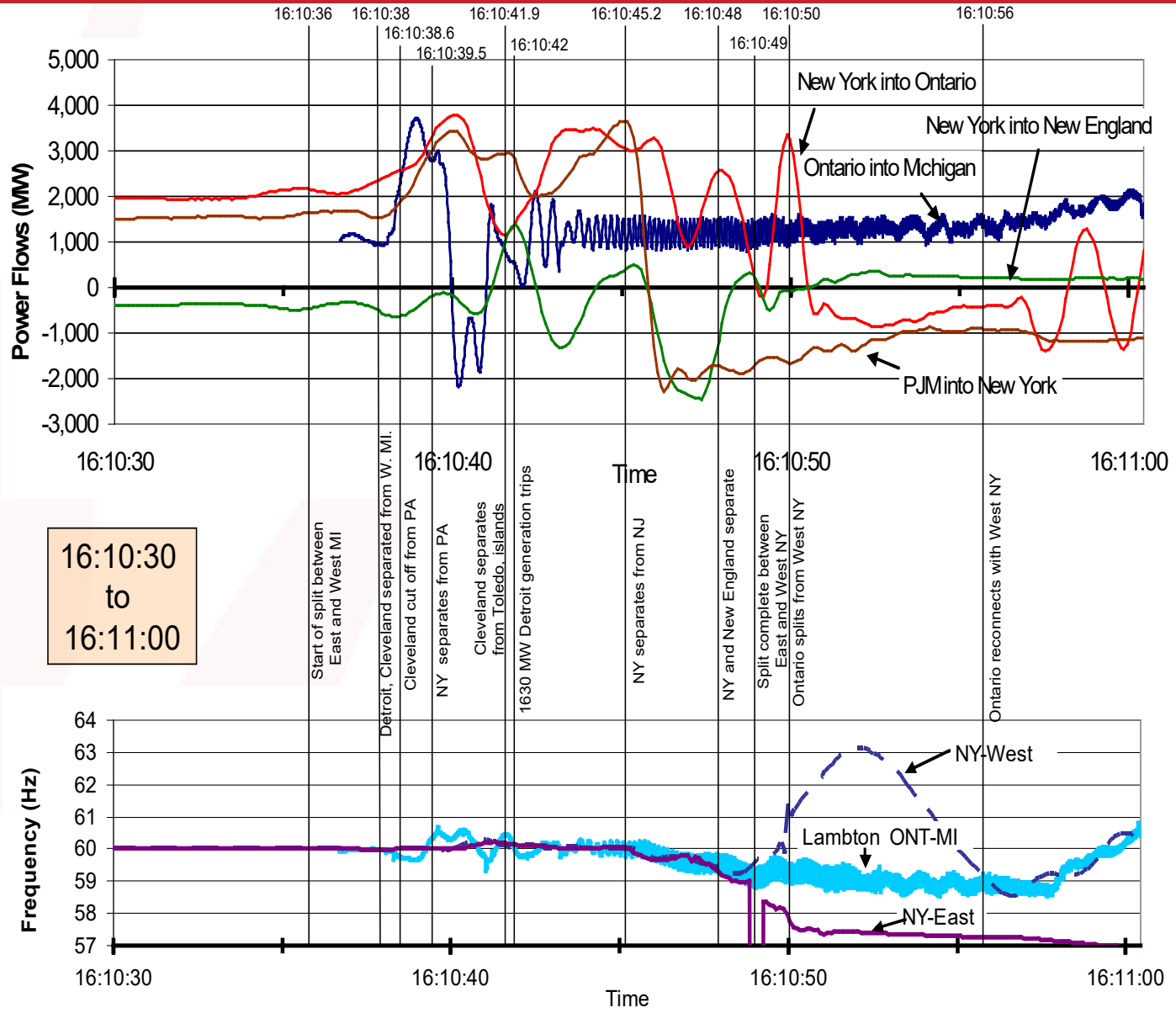
2003 Blackout Analysis



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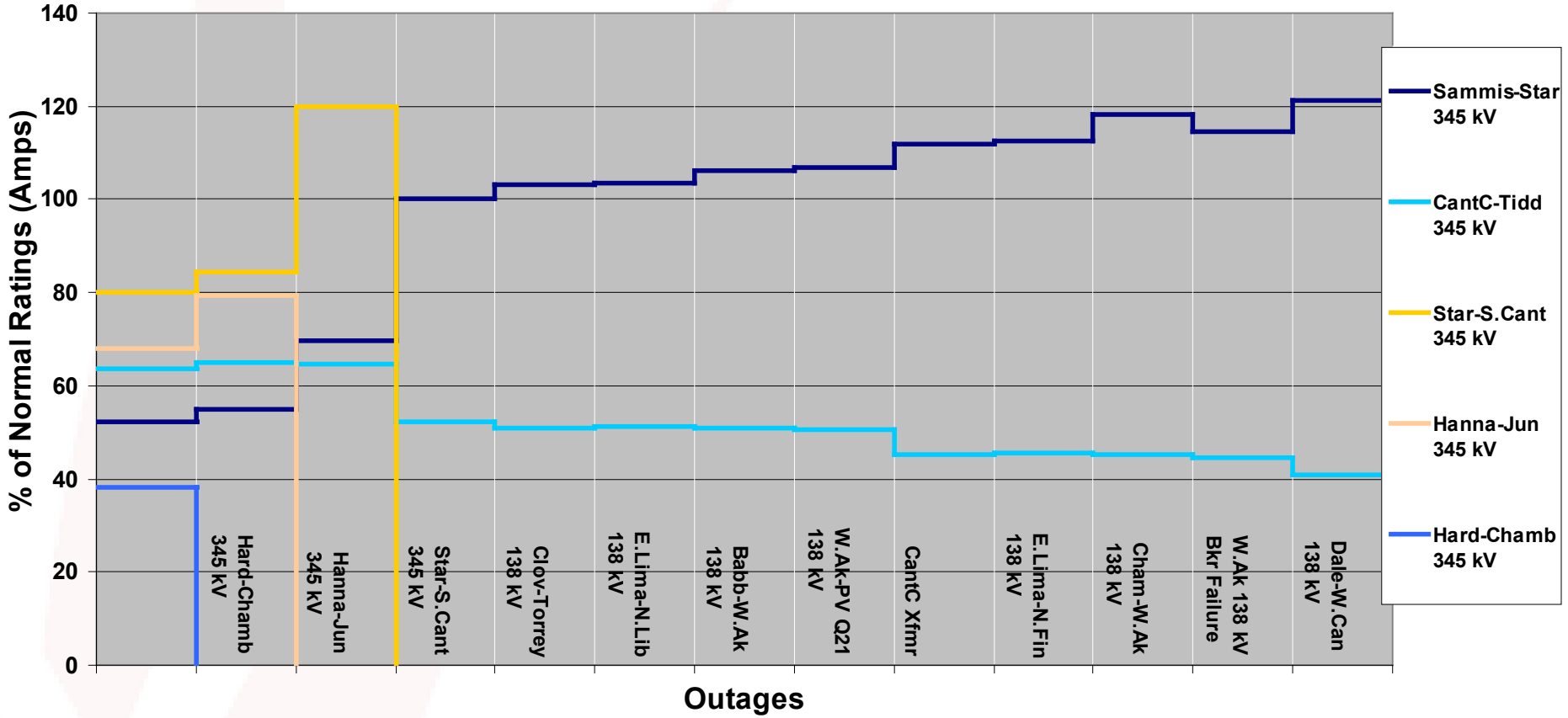
2003 Blackout Powerflow Simulations

35 engineers – took 3 Months to Build



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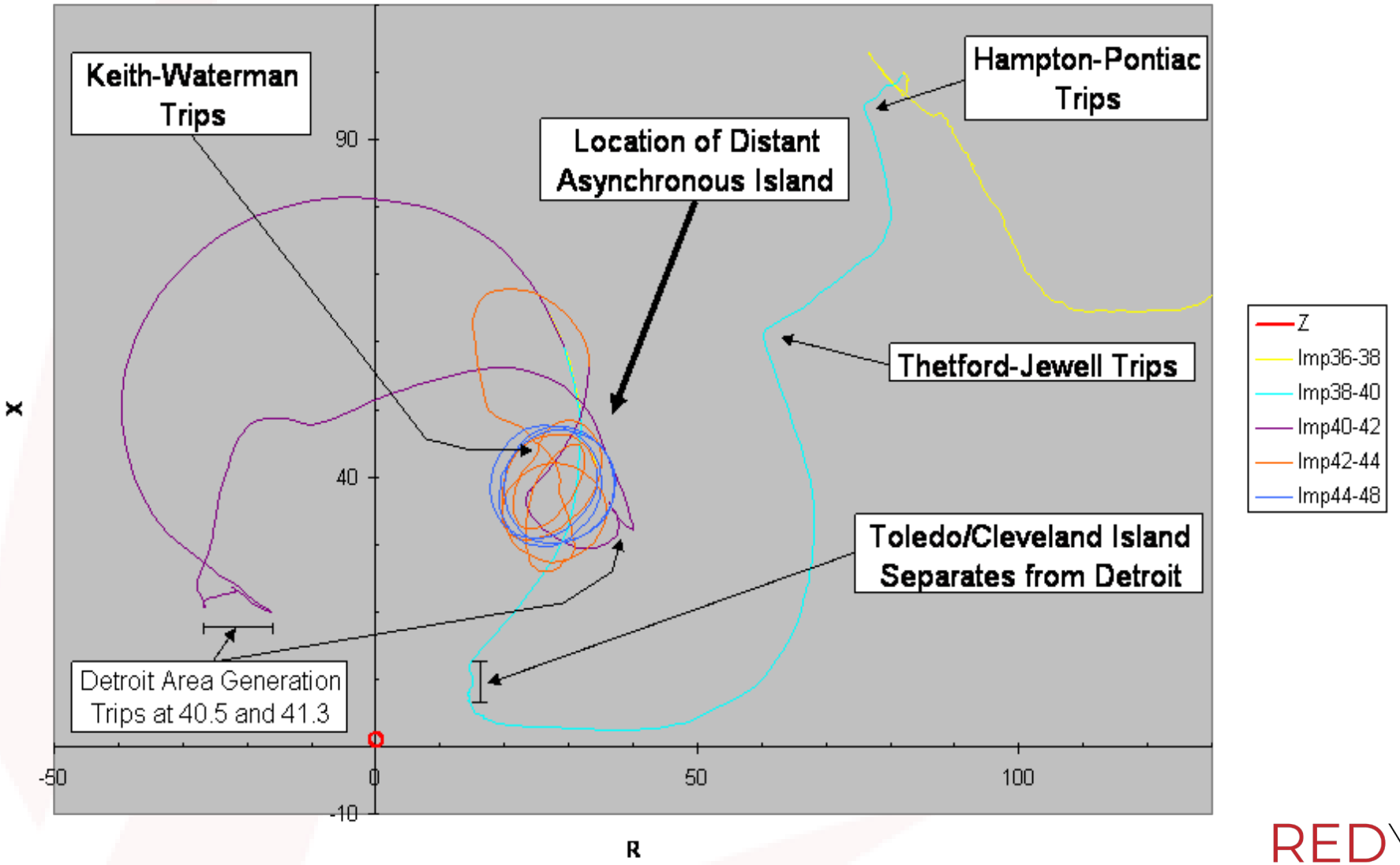
View Into Detroit from Lambton



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Time Synchronized SOE Database First Used

ID	Source	SourceFileName	Event Time
85	IID	Disturbance Data Form Sep08-2011-IID.	15:28:17.265

Event
Coachella Valley 230/92kV Bank #1 No Longer Carrying Load

☑ **Phase-Initiating Event?** InfoLevel 3 EventType Transform

DetailedEvent
Coachella Valley 230kV KSNO breaker open. This breaker is a High side breaker on the 230kV Ring Bus arrangement. The other high side H1O breaker was opened at 15:28:17.264, resulting in the disconnection of Bank #1. The overcurrent tripping relay (51) recorded 843 A on the 230 kV winding at the time of trip.

	Start	Stop	Time Zone
Raw	15:28:17		PDT
Agreed	15:28:17		PDT

Agreed ms: 265

TimeQuality: NIST

☑ **Reconciled?**

HowDateWasReconciled
Confirmed within 0.1 seconds by Devers 230kV PMU voltage and frequency.

Notes Comments

From Bus #	To Bus #	Station	Circuit #
21007	21008	Coachella Valle	1
COACHELV	COACHELV		MVAR
230	92		

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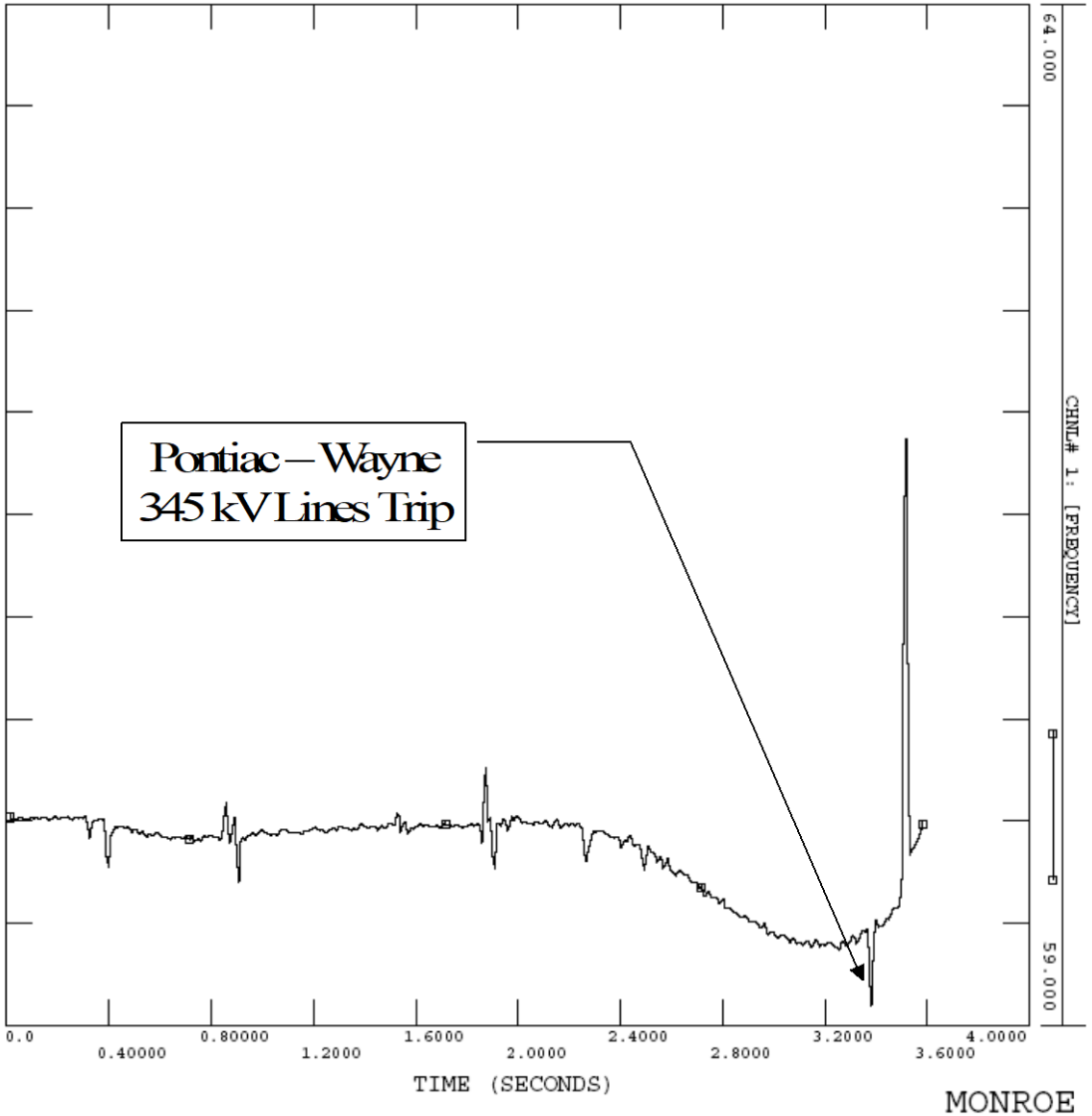
Use of Non-synchronized Data

- Over 1,700 digital fault recorder records analyzed
- Frequency, frequency spikes, and step changes in voltage and current used to identify events in a synchronized data record
- These spikes and step changes then matched to non-synchronized data records to determine the skew of the non-synchronized clock
- Identification of events in recordings aided by the dynamic simulation
- “Daisy-chaining” of multiple recorders

Events Identified in Frequency Domain

- Frequency, frequency spikes, and step changes in voltage and current used to identify events in a synchronized data record



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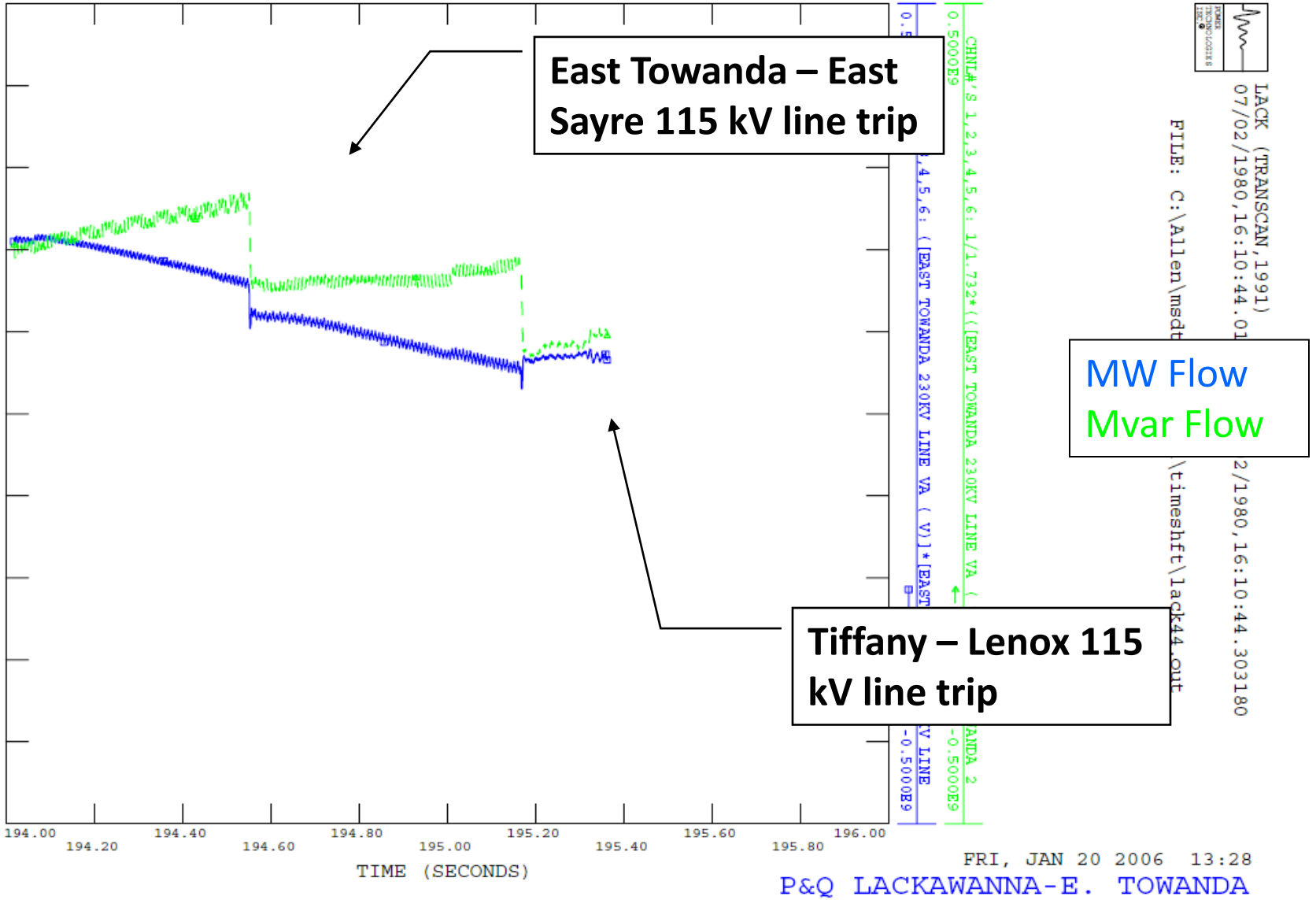
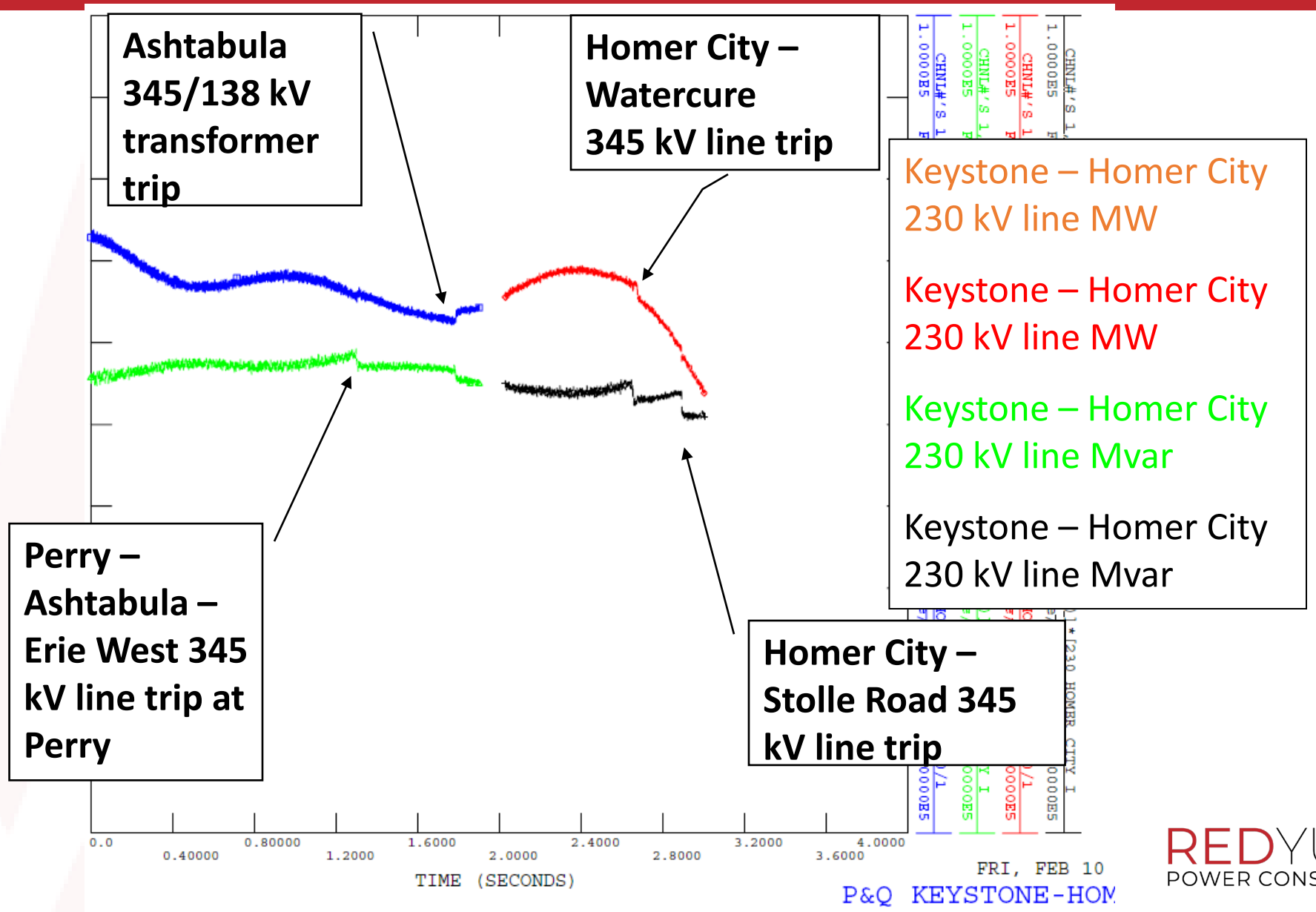
Multiple Trips on a Single Record



Daisy Chaining of Multiple Records



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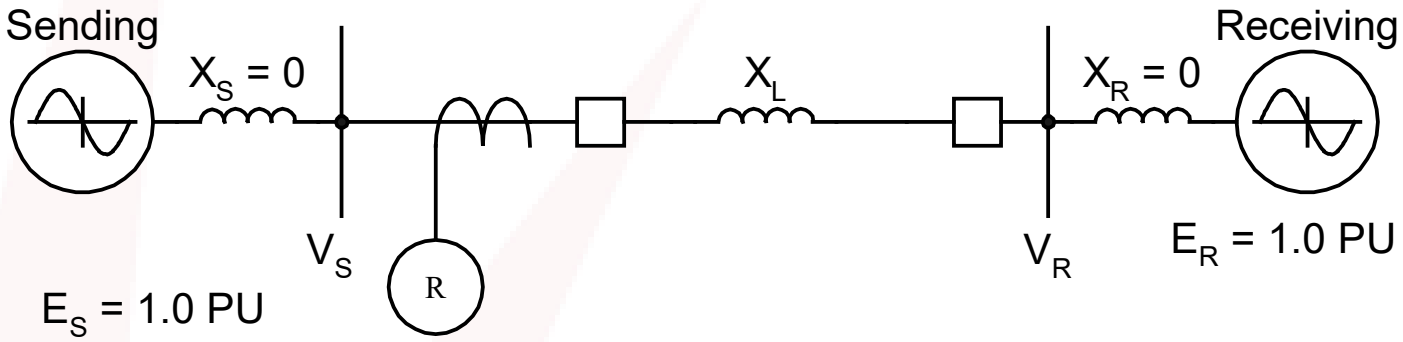
Dynamic Analysis Finding

- The 2003 Cascade could have been stopped by dropping all of Cleveland load before the Argenta – Battle Creek and the Argenta – Tompkins 345 kV lines tripped
  - Nothing was measurable then to suggest taking such action
  - Angular separation analysis showed potential for phasor measurements to be used for:
    - Wide area alarms
    - Triggers for future protection systems

Generalize the Power Transfer Equation



$$P = \frac{V_S \times V_R \times \sin\Theta}{X_L}$$

$$\Theta = Arc\sin\left(\frac{X_L}{|V_S||V_R|}\right)$$

Apply Power Transfer Equation to a Zonal Approach

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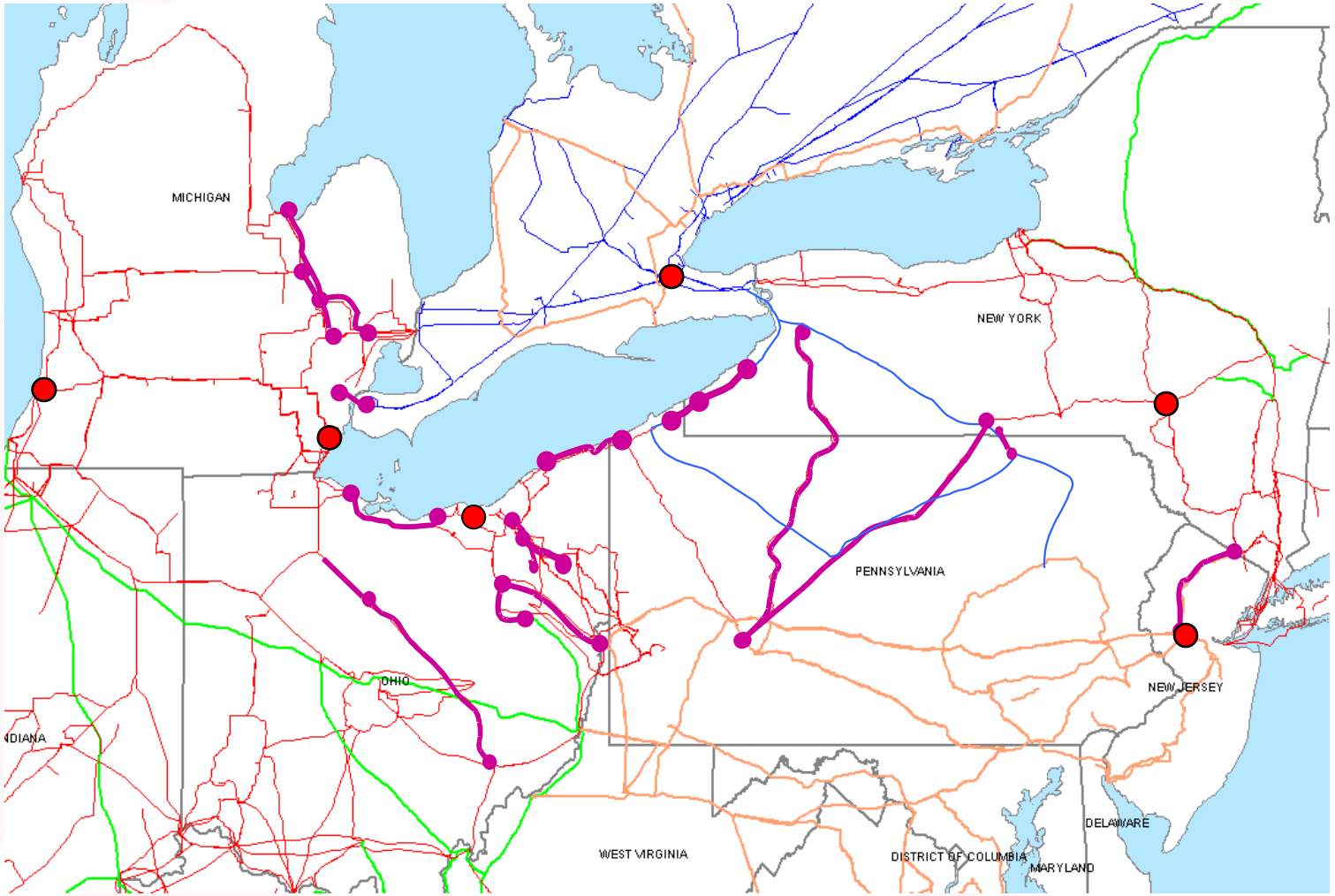
Simulation Angular Measurement Points



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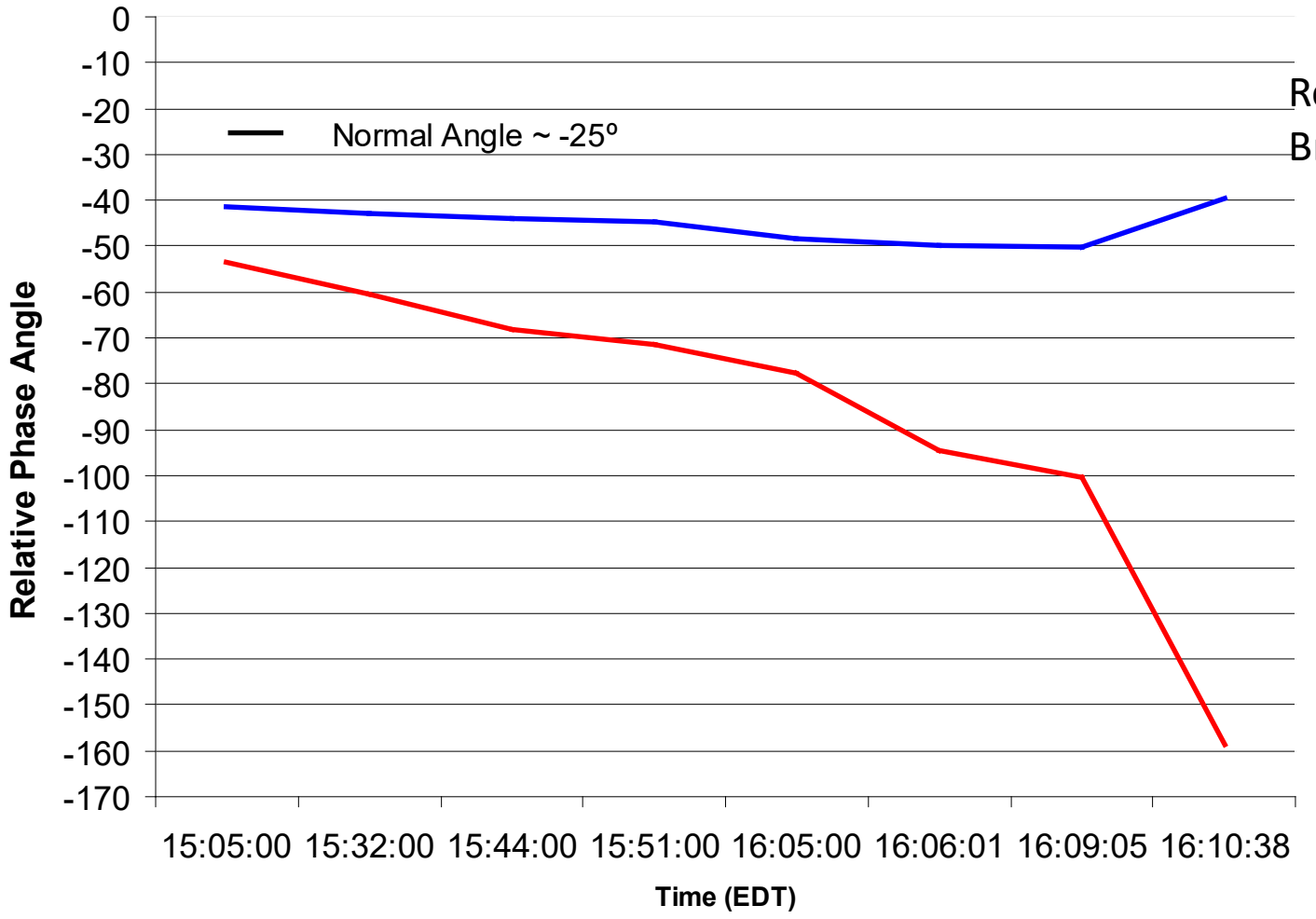
Angular Separation Theory and Analysis



Reference:
Browns Ferry

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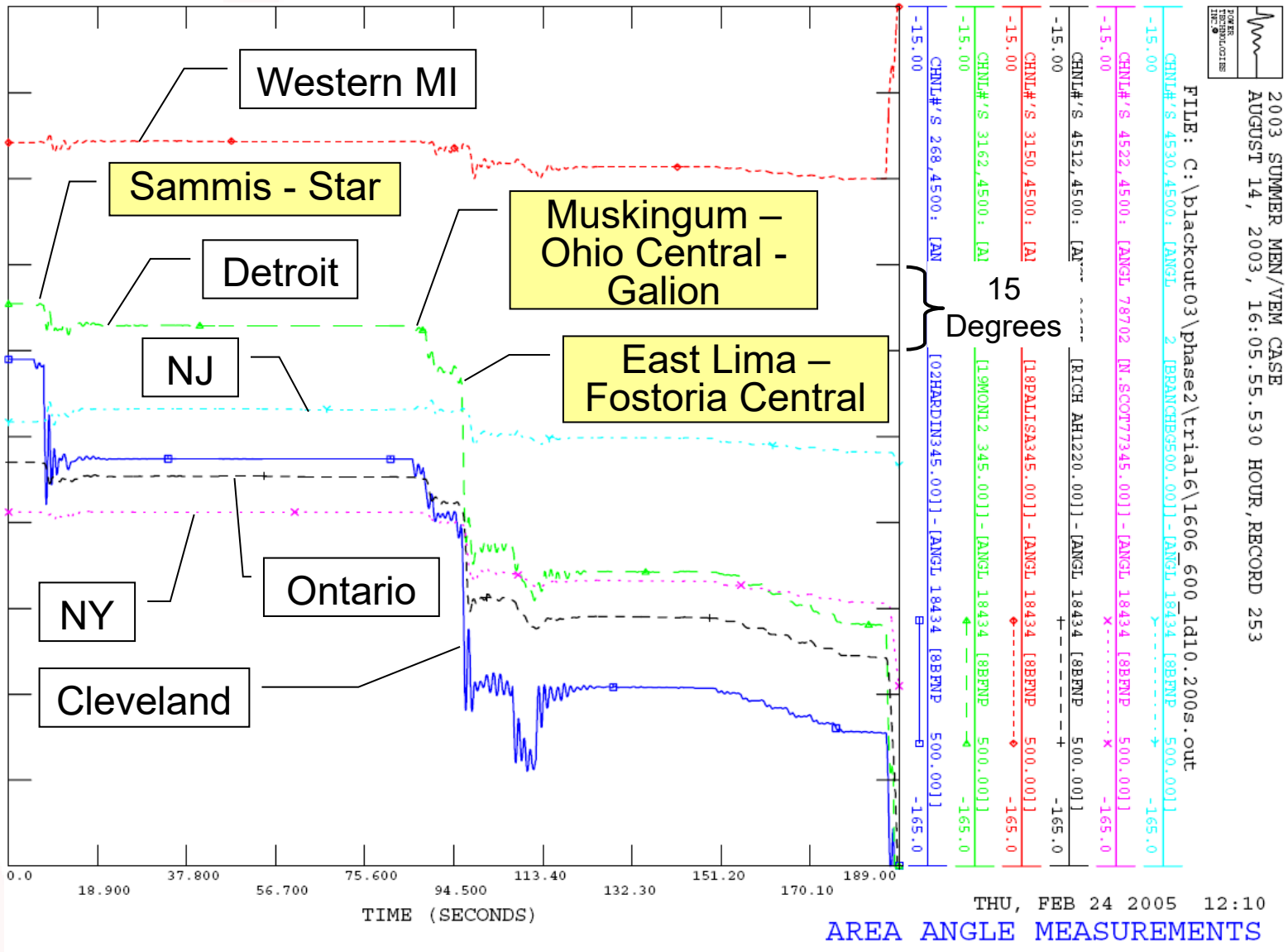
16:05:50 to 16:08:52



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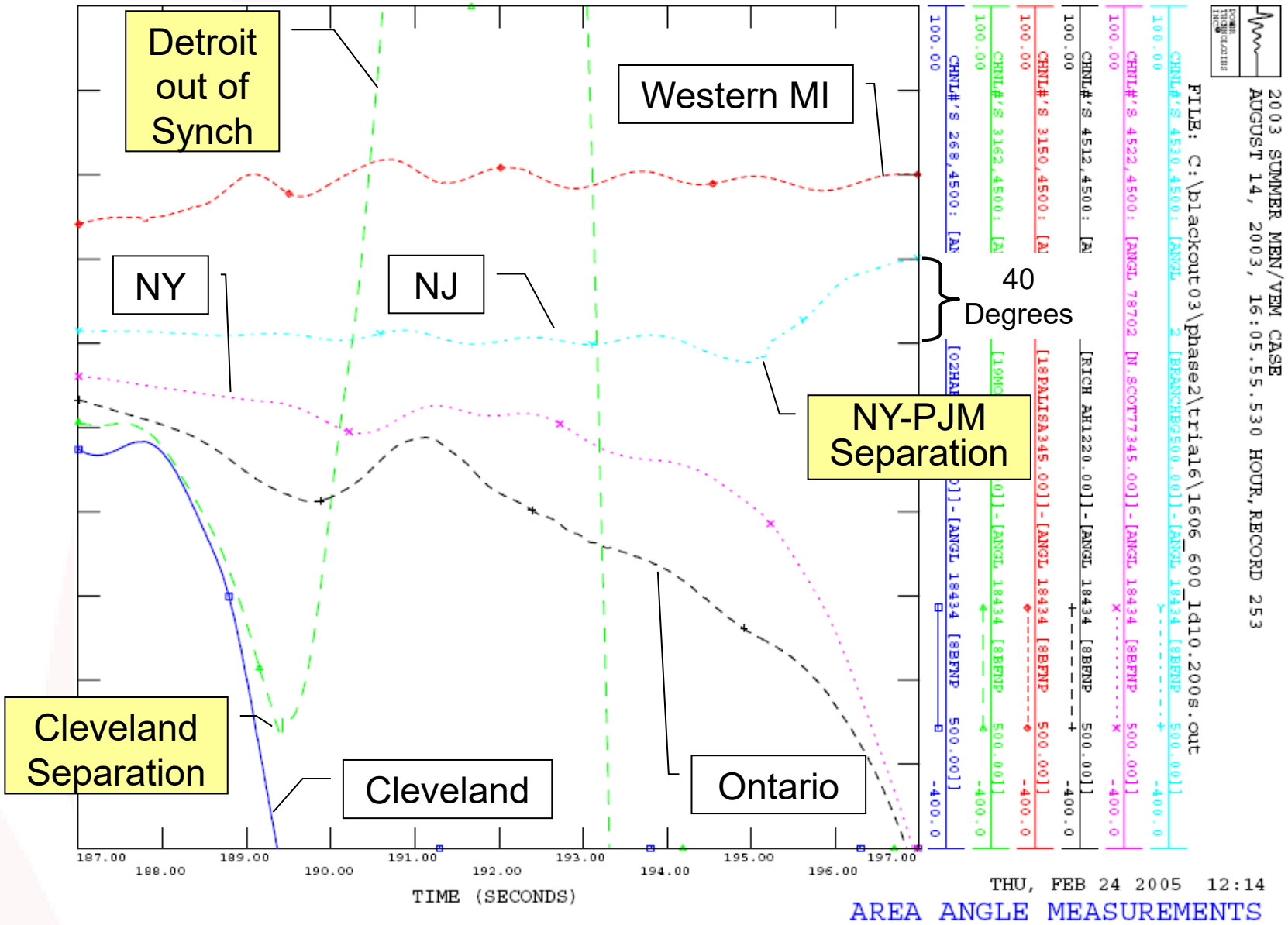
16:08:50 to 16:10:50



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The Beginning of The Eastern Interconnection Phasor Project

- Phasor measurement units (PMUs) collect high-speed, synchronized system measurements of voltages, currents, etc.
  - As high as 120 samples per second
- Multiple PMUs connect to Phasor data concentrators (PDCs)
- PDCs networked to Super PDC
  - Data sharing
  - Wide area visibility
- Initial funding by DOE
- Managed by Consortium for Electric Reliability Technology Solutions (CERTS)
- Similar to existing Wide-Area Measurement System (WAMS) in WECC
  - Working cooperatively with EIPP

Pacific Southwest Outage Analysis

Disturbance of 8 September 2011

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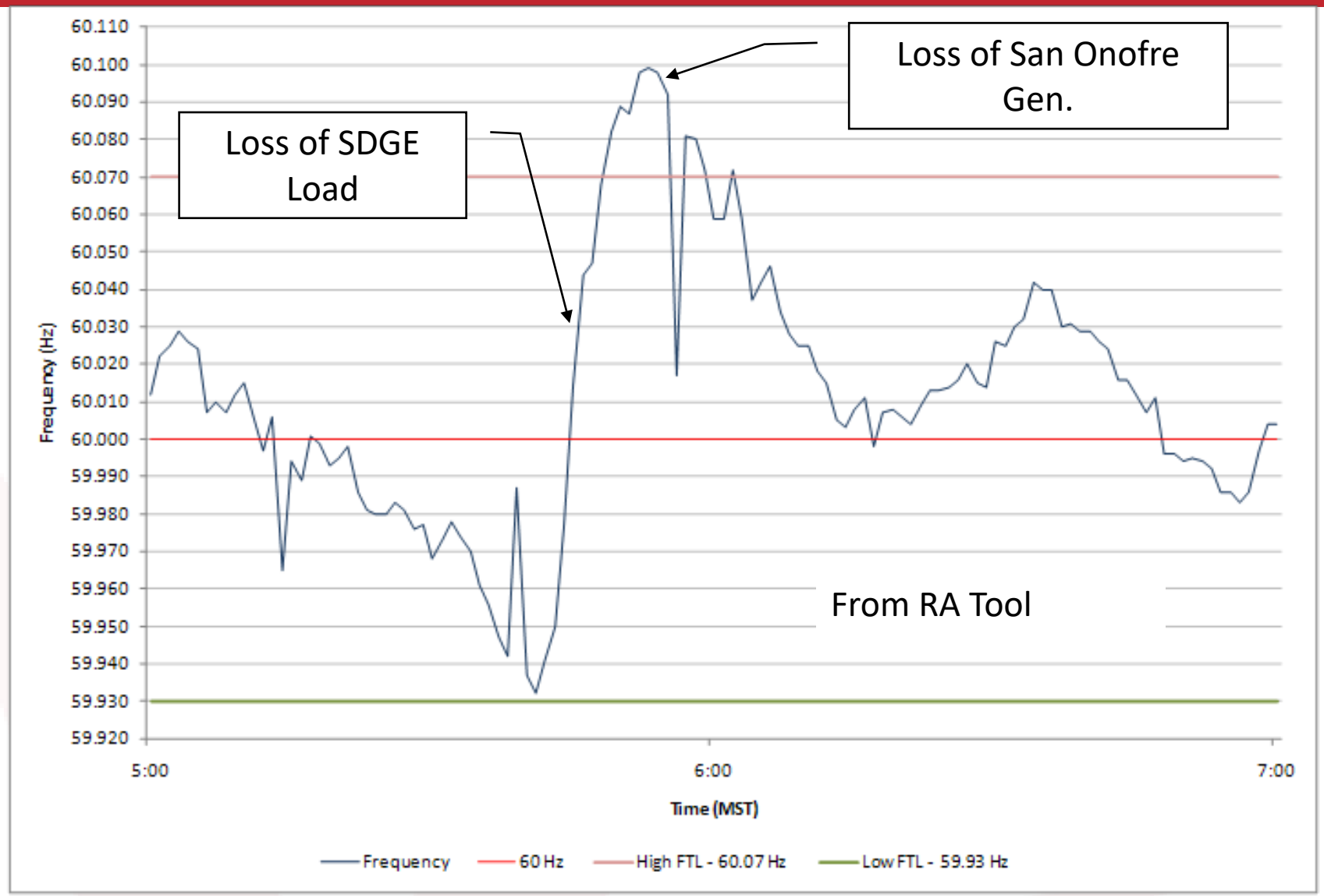
2011 PSW Outage Overnight Analysis



- **Loss of San Onofre generation did NOT cause the blackout of San Diego**

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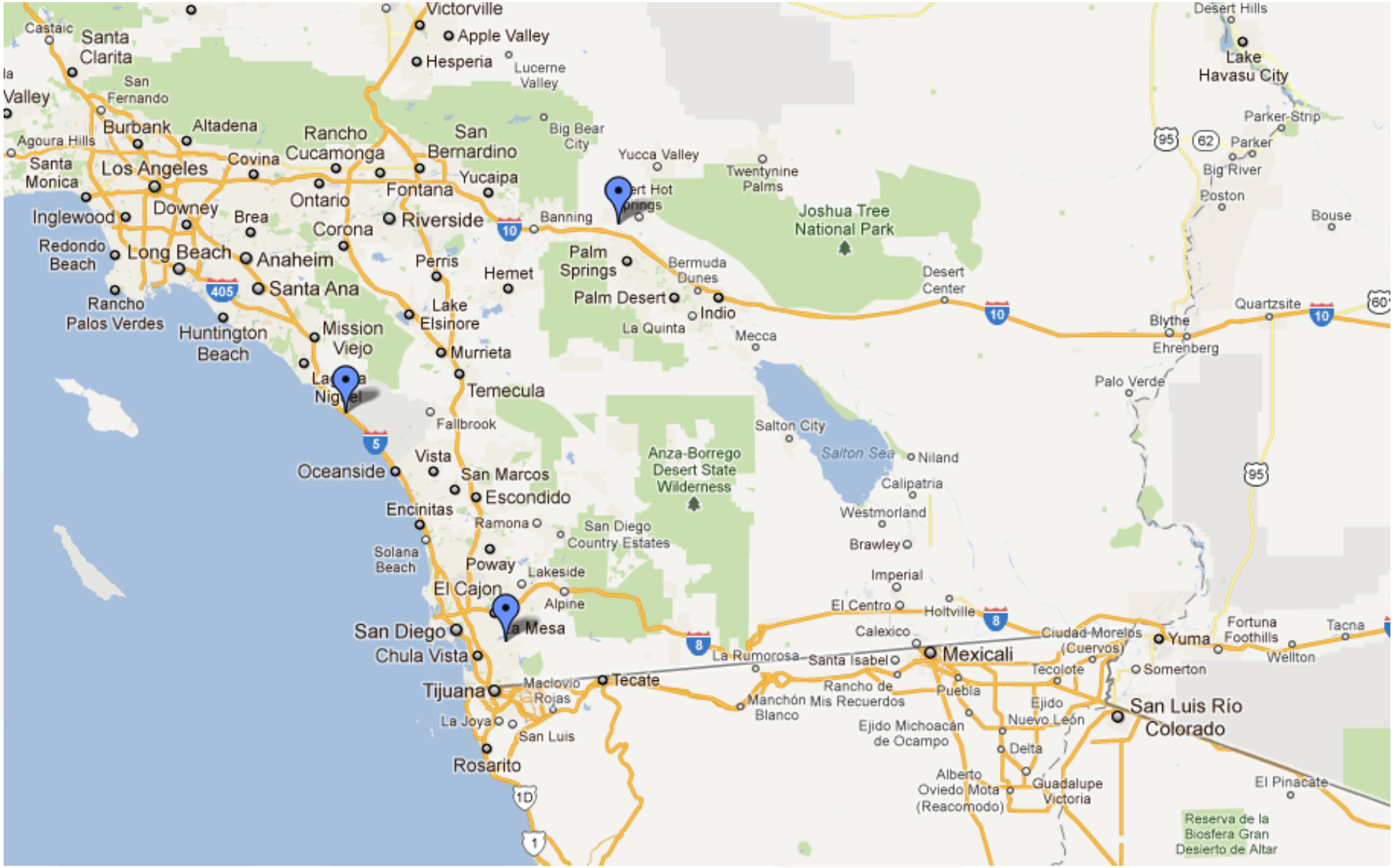
The Difference – Critical PMU Locations



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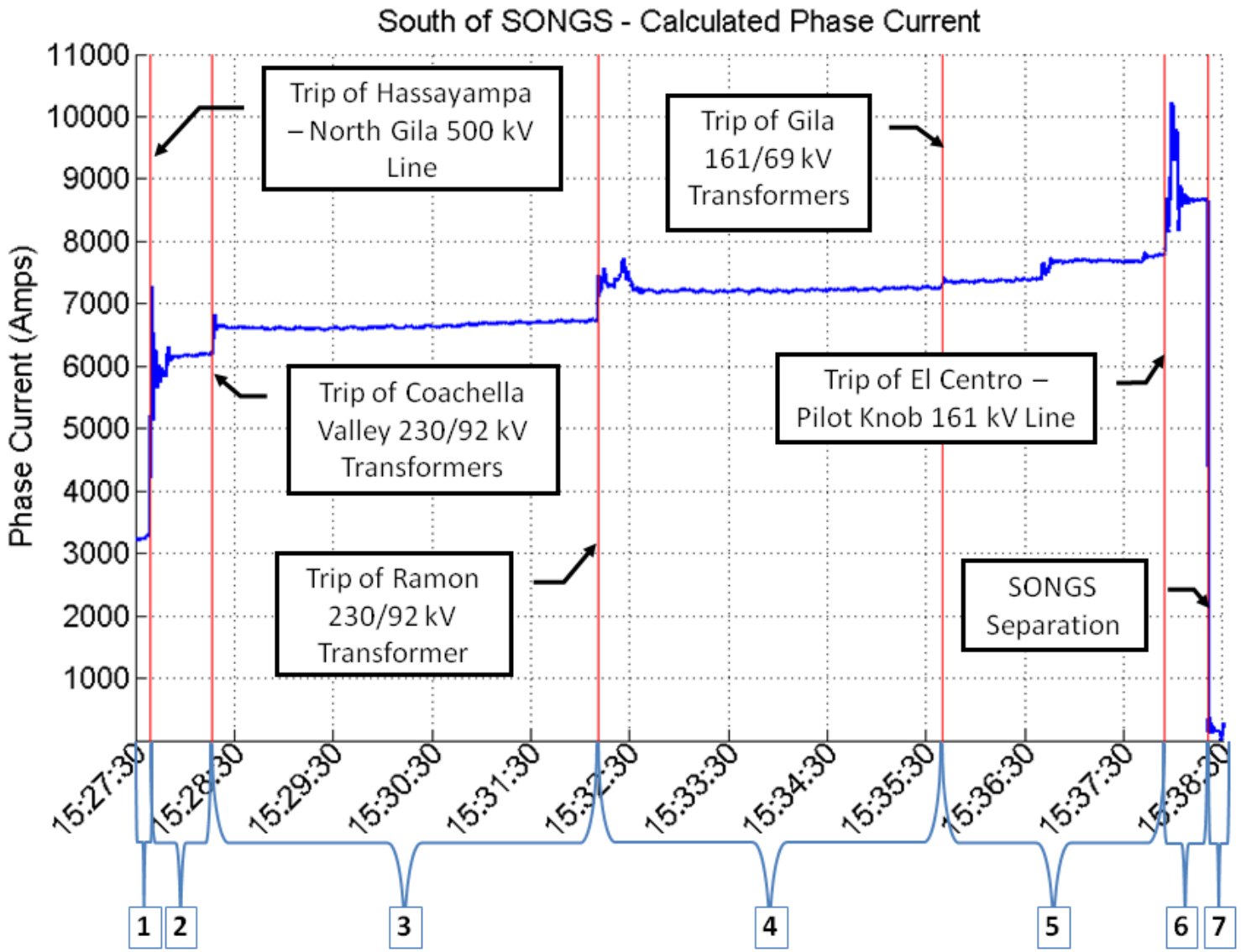
2011 PSW PMU Data

5 engineers Took 2.5 Hours to Build



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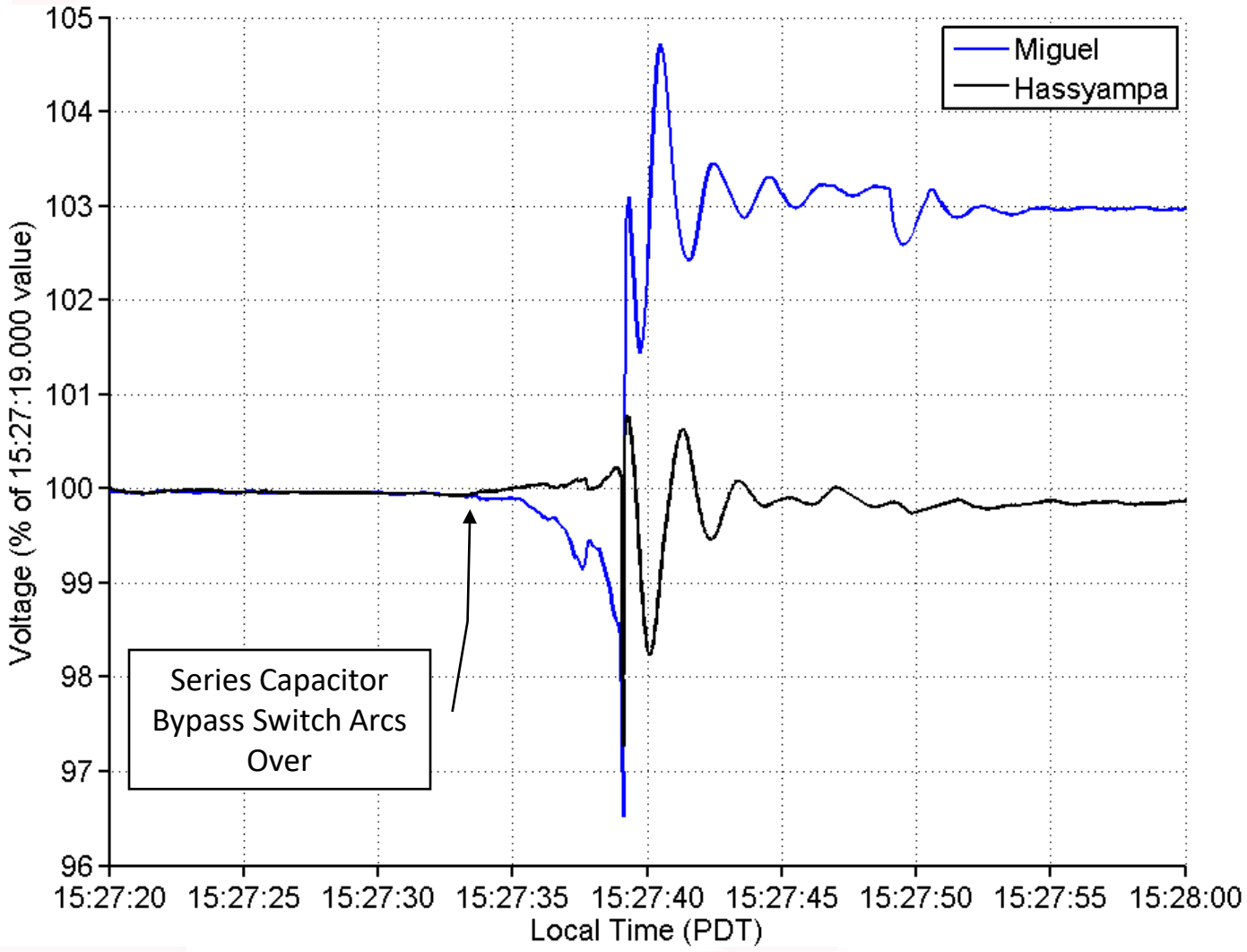
Initiating Event – Voltage Divergence
Hassayampa – North Gila 500 kV Trip



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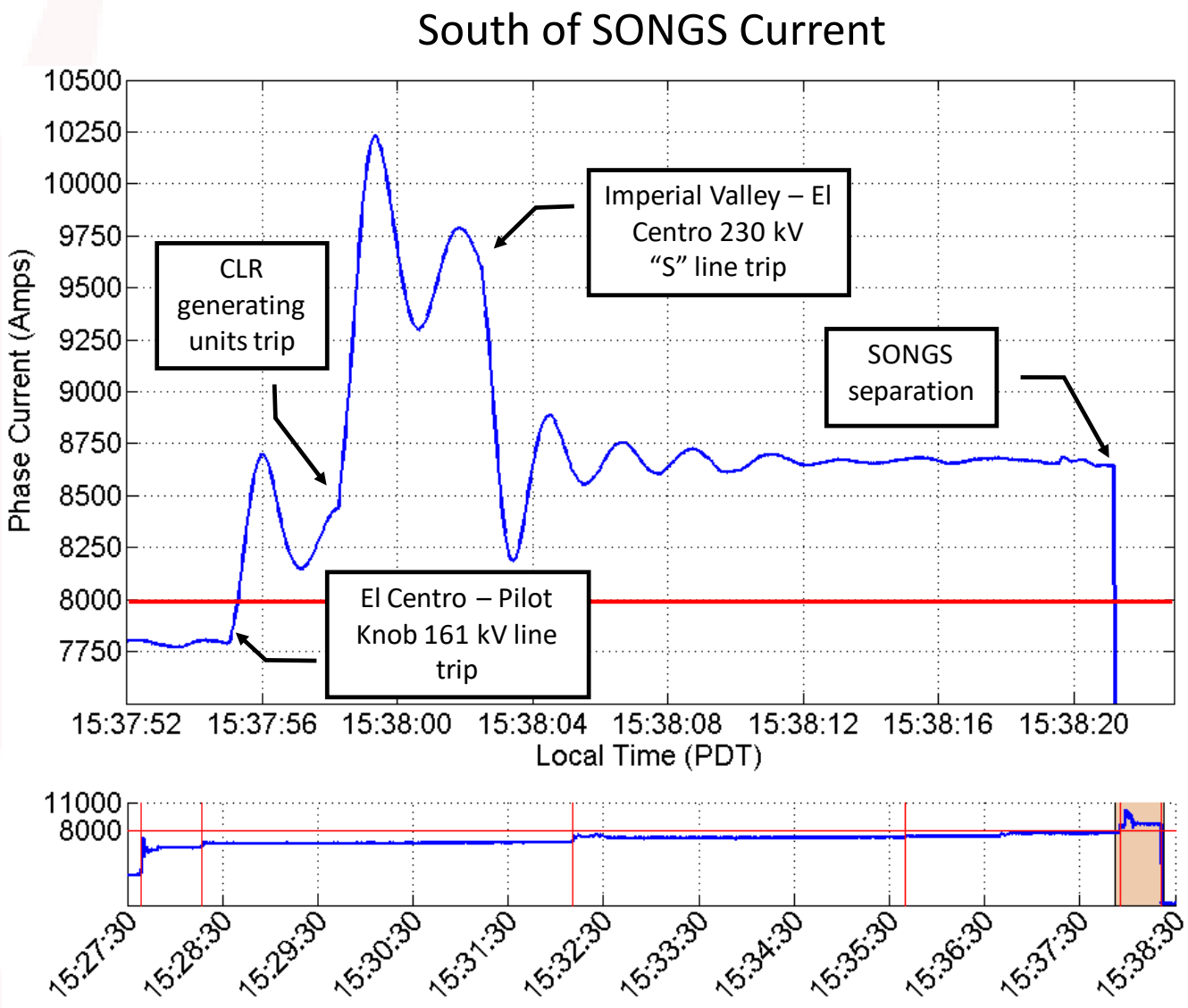
Phase 6 – High-Speed Cascade



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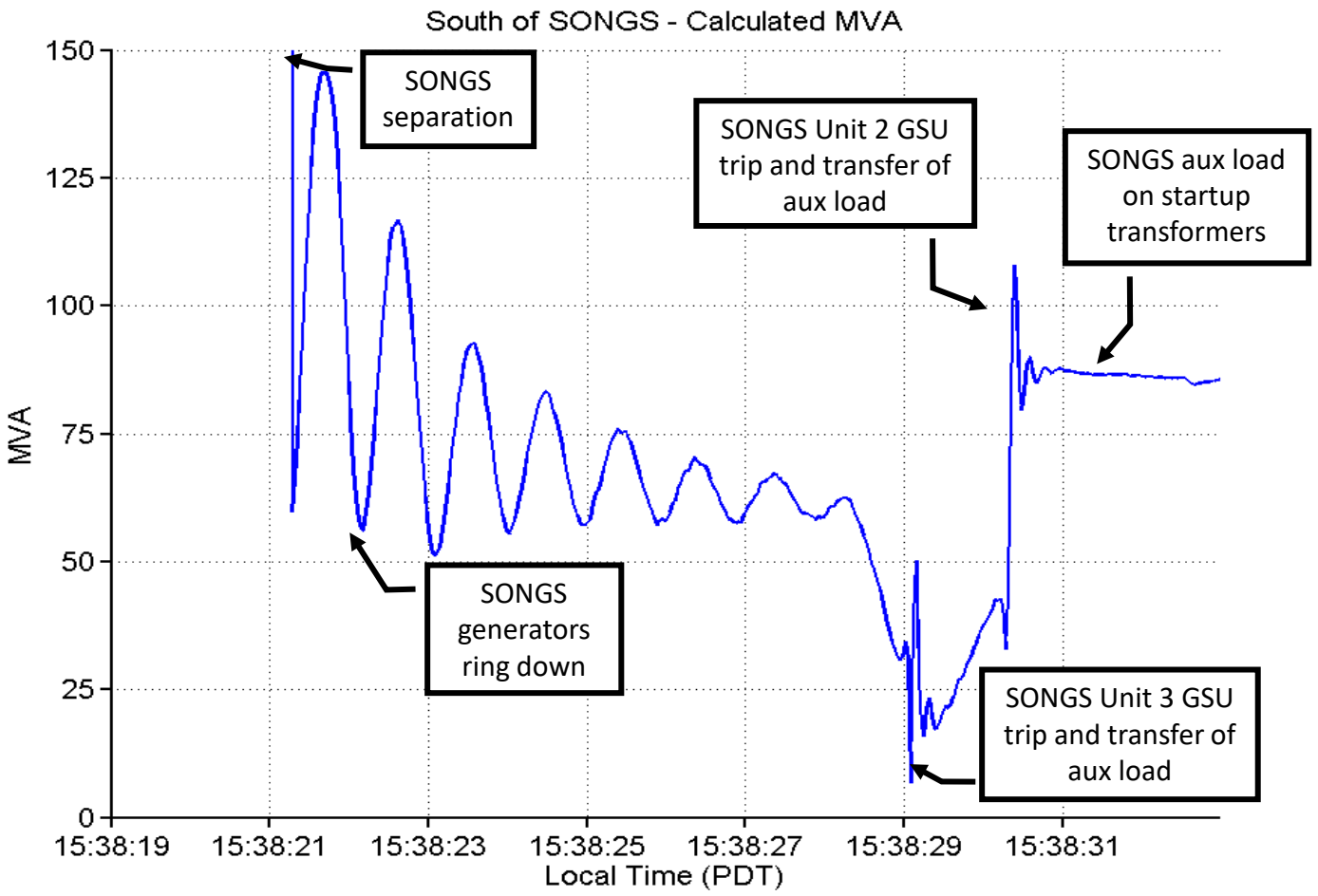
SONGS Generators Trip



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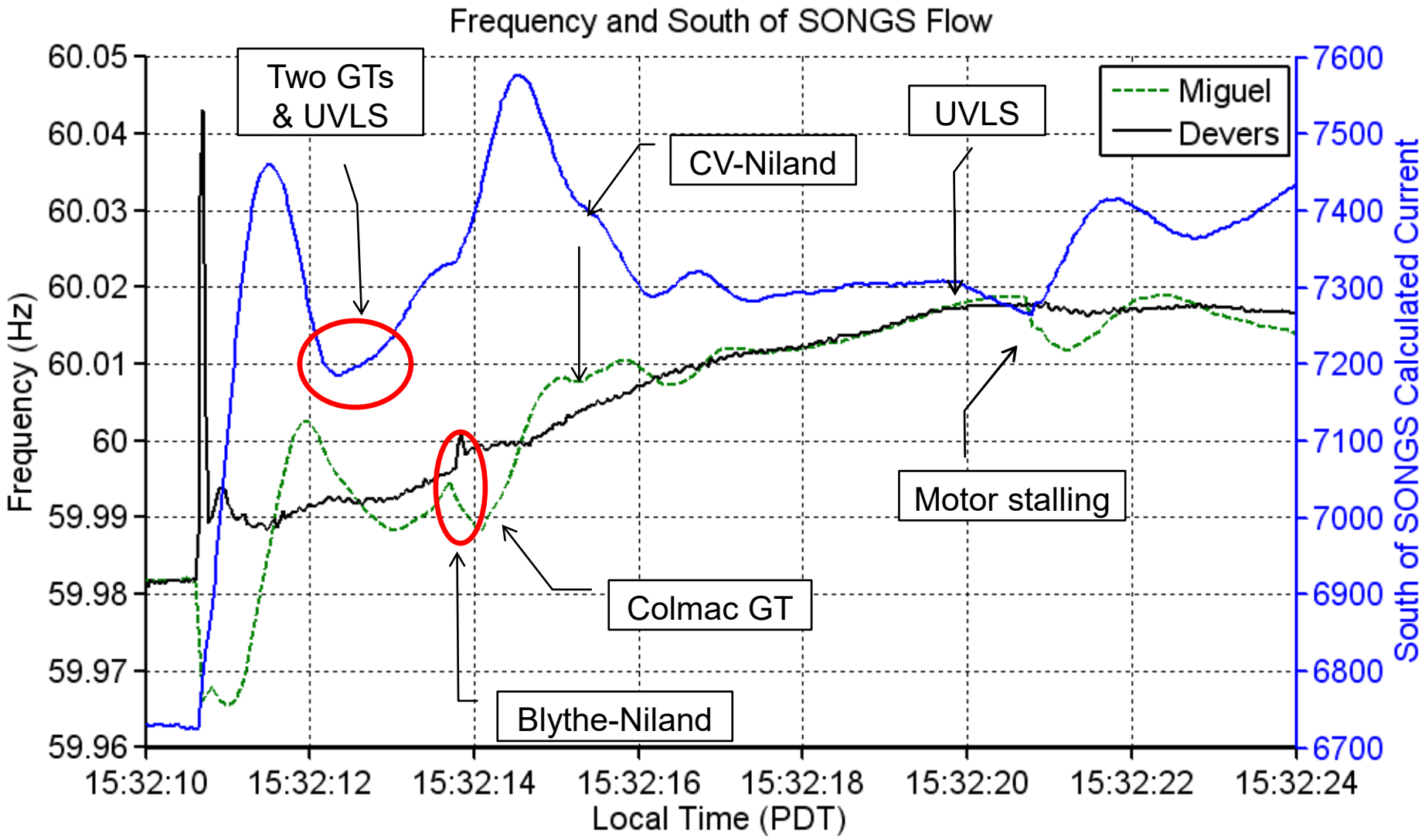
Multi-Domain Analysis



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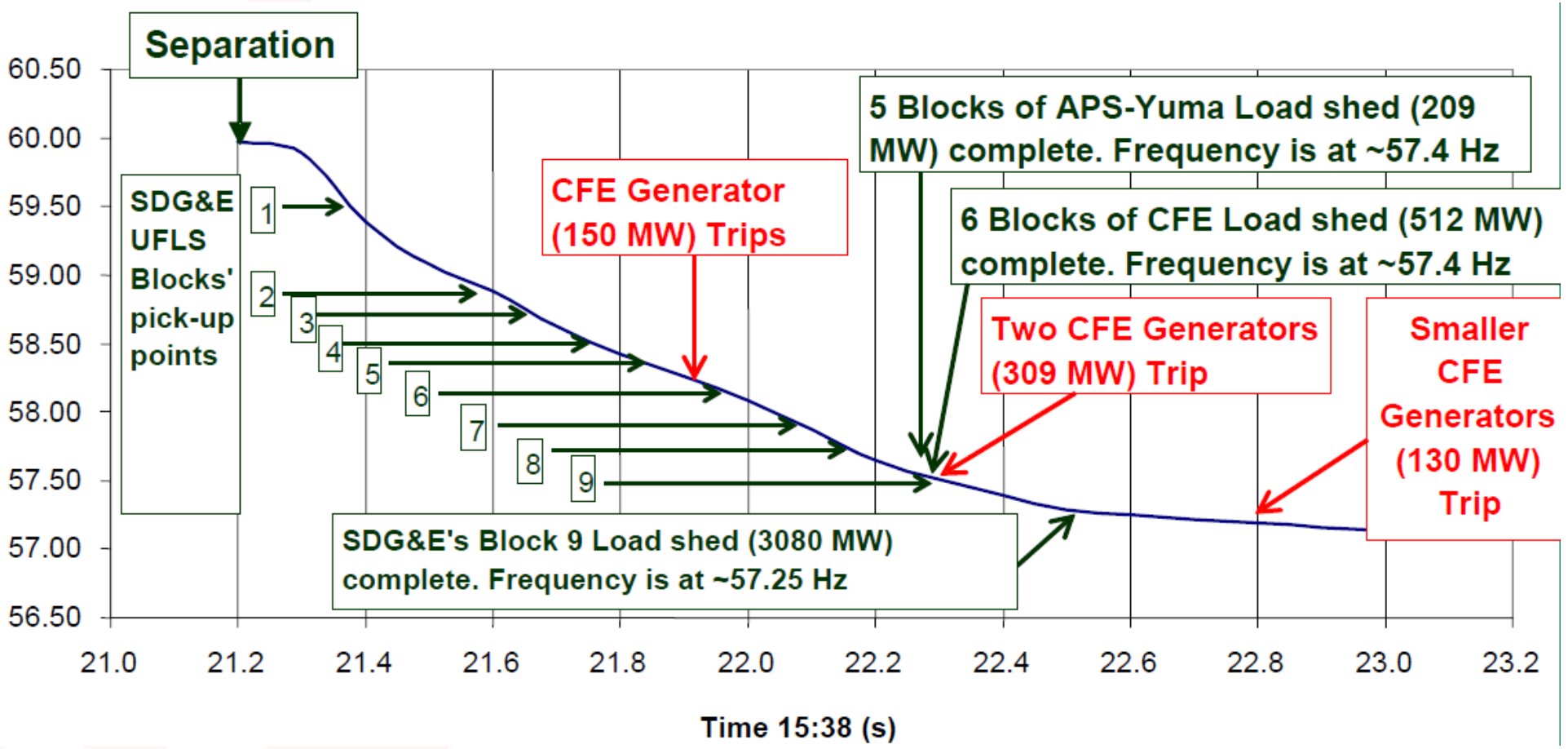
Insufficient Coverage to Determine Causes of Generation Trips

UFLS in SDGE Island



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What Have We Learned?

- PMUs have become ubiquitous – they are everywhere!
  - But they are not “the” silver bullet!
- They are GREAT for event detection and location in multiple domains
  - Voltage, Current, Phase angle, and Frequency
- They are wonderful for observing and monitoring inter-area oscillations
  - Help in determining Modes and Mode Shapes
- Changes to system topology and resources moved oscillations out of the familiar synchronous machine behavior – Oscillations can be at any frequency!
- We are still learning how to use them for finding sources of forced oscillations
- **BUT…They are TOO SLOW in the world of Inverter-Based Resources!!!!**
  - Point-on-wave data is needed to see the speed of IBR actions and interaction!

How Can We Put PMUs to Work for Us?

- Proven for detecting and analyzing inter-area oscillations
  - Detecting known modes and mode shapes – less effective if not looking for known frequency signatures
  - Used by several Reliability Coordinators for that purpose, but limited to their system unless data is shared
- Capable of being used for detecting forced oscillations
  - Unless Interconnection-wide data sharing is in place, limited capability
  - Proven in locating source of 0.25 Hz forced oscillation (near natural mode of the EI) on 11 January 11 2019
    - Interconnection-wide FNet frequency disturbance recorders (FDRs) showed origin to be in the Tampa FL area – source unknown to ISONE using internal PMUs only

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Wide-area Means Just That!!

- Sharing PMU data real-time is the key to success!

- I had this 1969 Opal Rallye in the ’70s…it had a hole in the passenger floorboard!
- Great view of the road, but it did not help me drive the car!

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PMUs in an IBR World

- Blue Cut Fire IBR Disturbance – SCADA records indicated loss of about 1,200 MW
- A line-to-line 500 kV fault, cleared normally in 2.49 cycles (~0.04 sec)
- PMU transmittal/recording of 30 samples per second – one sample is about 2 cycles
- Momentary cessation blocked inverter output at several IBR plants faster than the fault cleared, some returned, some did not
- Application of Kundur equation for inertia at time of the fault indicated about 2,500 MW lost during momentary cessation

Questions??

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