NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Washington, DC Area Low Voltage Disturbance

April 7, 2015

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NASPI Working Group Meeting
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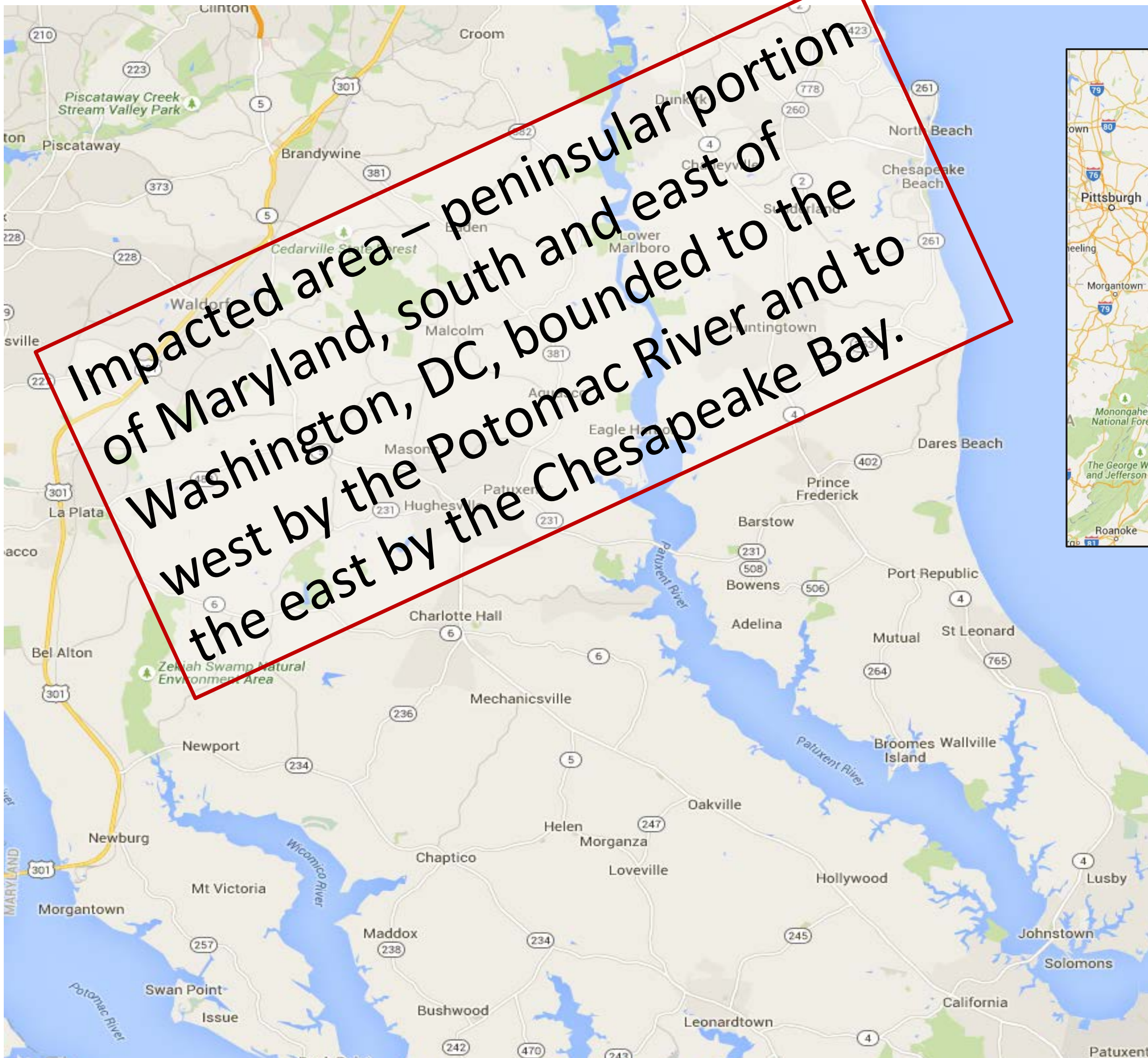
RELIABILITY | ACCOUNTABILITY



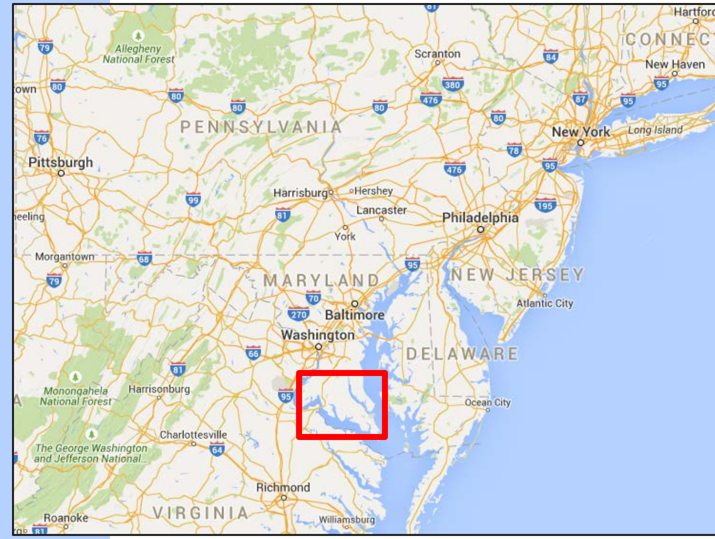

Overview

- April 7, 2015 - 12:39 EDT – Washington, DC area experienced a severe, prolonged voltage sag
- Initiating event – Failure of one 230 kV lightning arrester in Pepco portion of Ryceville Substation
- Protracted fault caused extreme low voltage
  - Protection system failure to isolate due to a failure of Pepco protection systems to isolate an electrical fault on a 230 kV transmission line.
- Disturbance resulted in 532 MW of load lost in Pepco and SMECO:
  - Customers' loads automatically switching to back-up power sources
  - Customer protection systems separating from the grid due to low voltage
- Generators tripped:
  - Panda/Brandywine combined cycle plant – 202 MW net
  - Calvert Cliffs nuclear units 1 and 2 – 1,779 MW net

Overview



Impacted area – peninsular portion of Maryland, south and east of Washington, DC, bounded to the west by the Potomac River and to the east by the Chesapeake Bay.



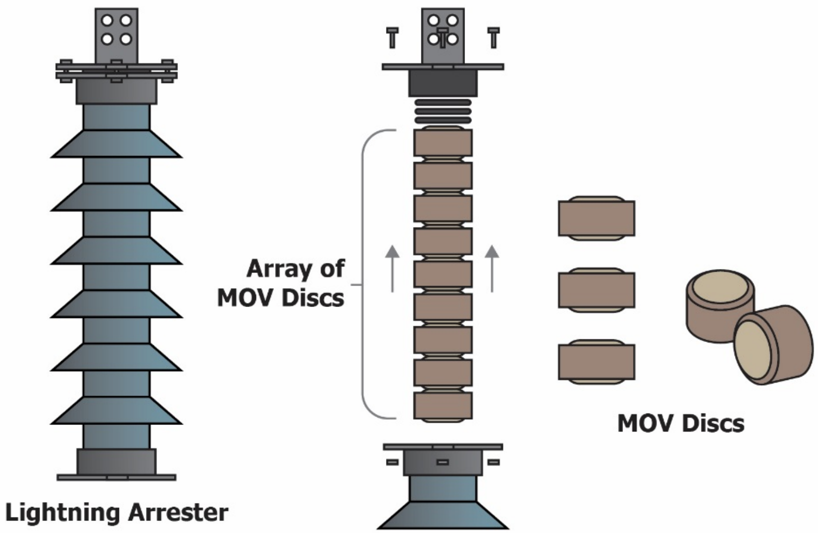
The nature of the interconnected system is that electrical disturbances in one area can often be impactful in adjacent areas. The initial electrical fault occurred over 40 miles south of DC.

Anatomy of a Surge Arrester

www.hubbellpowersystems.com/arresters/sub/general/

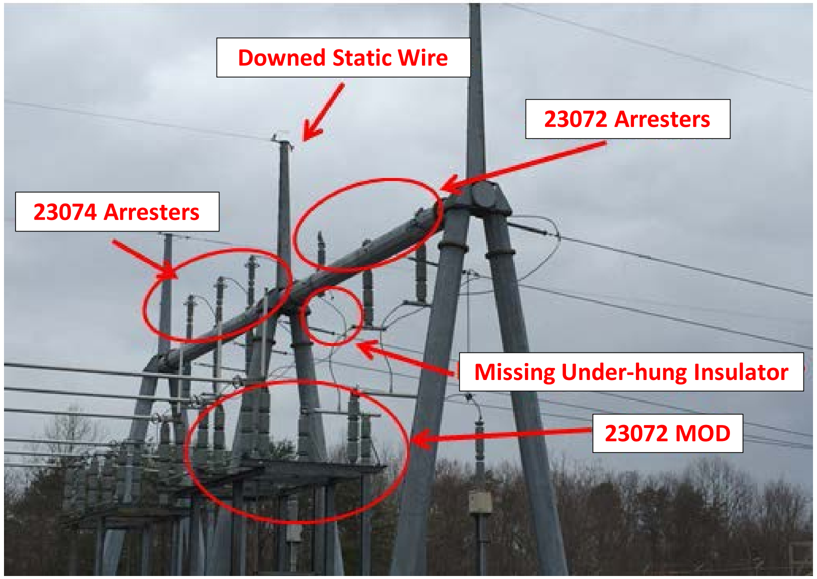
Lightning (surge) arrester is a device used on electrical power systems to protect the insulation and conductors of the system from the damaging effects of lightning. When a lightning surge (or switching surge, which is very similar) travels along the power line to the arrester, the current from the surge is diverted through the arrester, in most cases to earth (ground).

Lightning that strikes the electrical system introduces thousands of kilovolts that may damage the transmission lines, and can also cause severe damage to transformers and other electrical or electronic devices. Lightning-produced extreme voltage spikes in incoming power lines can damage electrical home appliances.

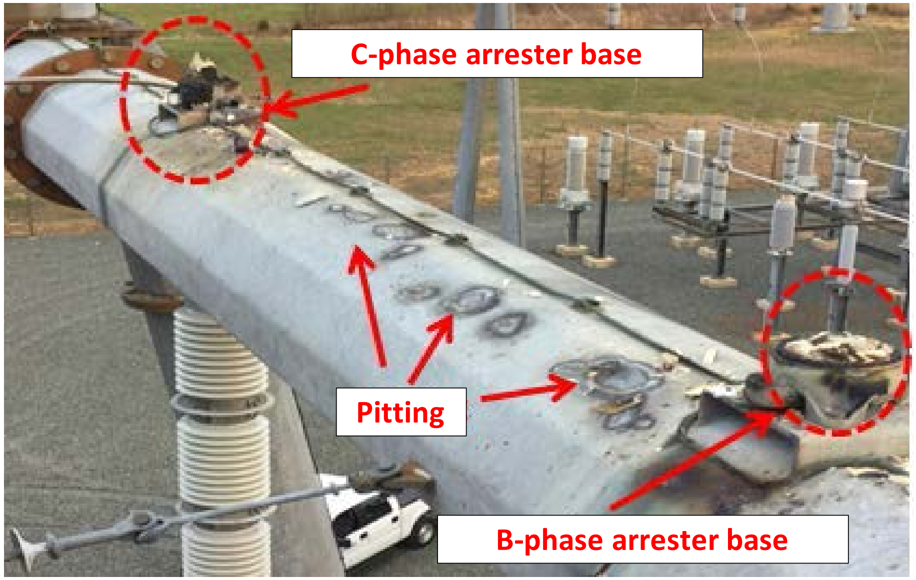


Lightning Arrester Failed

- Significant damage to the A-frame structure in the substation
  - Pitting near burned arresters
  - Downed static wire
  - A-phase conductor detached, found outside fence line



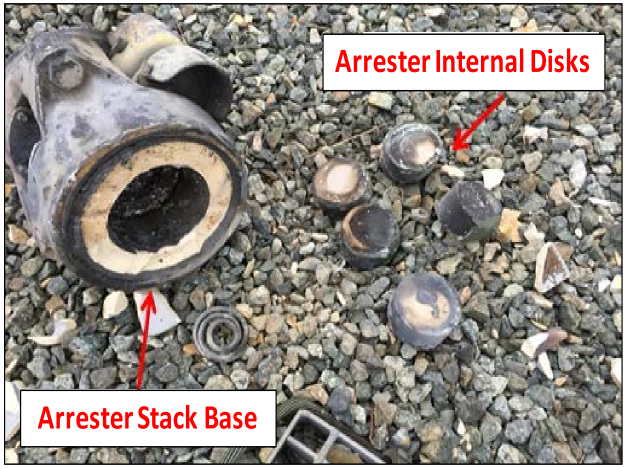
Damaged A-Frame



Pitting Near Arrester Bases

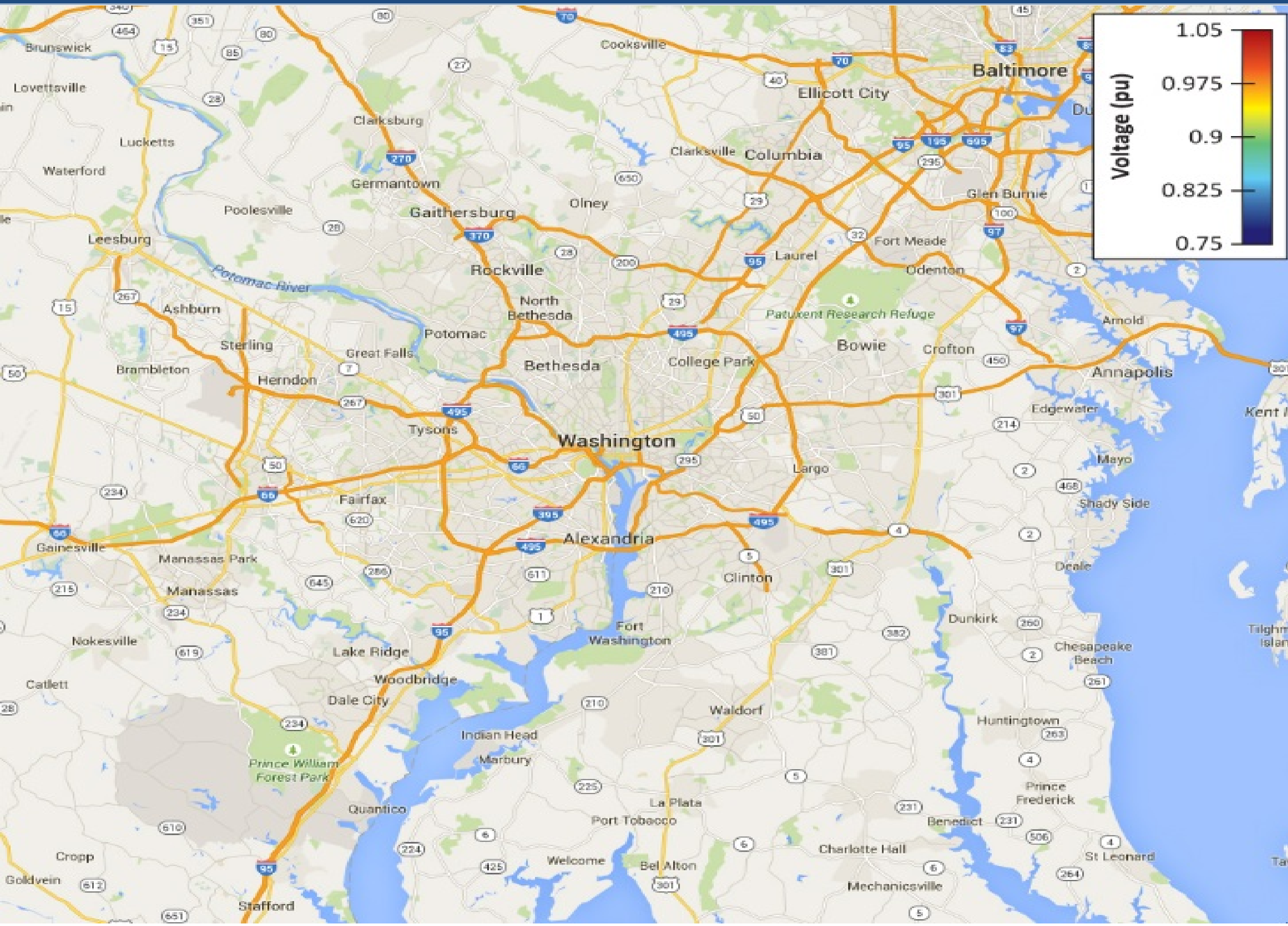
Forensic Analysis

- No evidence of vandalism, sabotage, or cyber-attack in the event – verified by post-event forensic analysis
- Revealed significant burning to the C-Phase arrester
  - Consistent with electrical damage
- No evidence of burning to A-phase arrester
  - Suggests mechanical failure as a result of the arc burning off the insulator and the weight of the line breaking the arrester free from the structure



Internal MOV Disks from C-phase (left) and A-phase (right) Arresters

Pre-Disturbance Voltage Levels

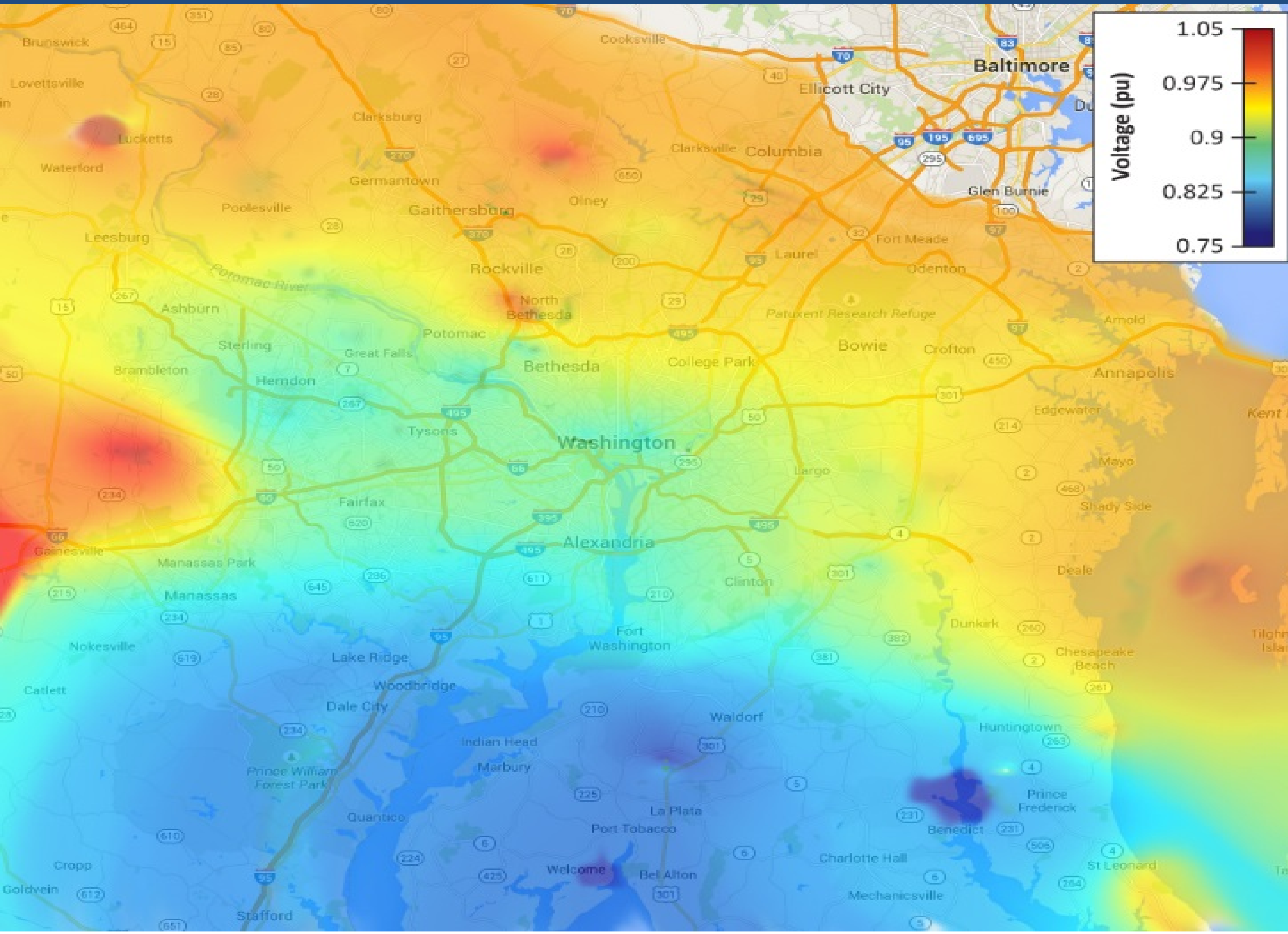


Fairly standard voltage profile indicating acceptable load on system with no issues.

Initiating Event

- 12:39:03 – C-phase-to-ground fault at Ryceville substation due to lightning arrester failure
- Tripped properly at Chalk Point, Ryceville, and Morgantown
- Automatic reclosing (testing) of line from Morgantown, Ryceville, and Chalk Point terminals
  - Morgantown and Ryceville ends both re-tripped
- 12:39:23 – Breaker at Pepco's Chalk Point substation fails to re-trip
- Two separate and redundant protection systems:
  - First failed due to loose connection to auxiliary trip relay circuit
  - Second failed due to intermittent discontinuity in auxiliary trip relay circuit

C-Phase-to-Ground Fault Voltage Levels



Noticeable depression in voltage due to Chalk Point breaker remaining closed

Fault Expands

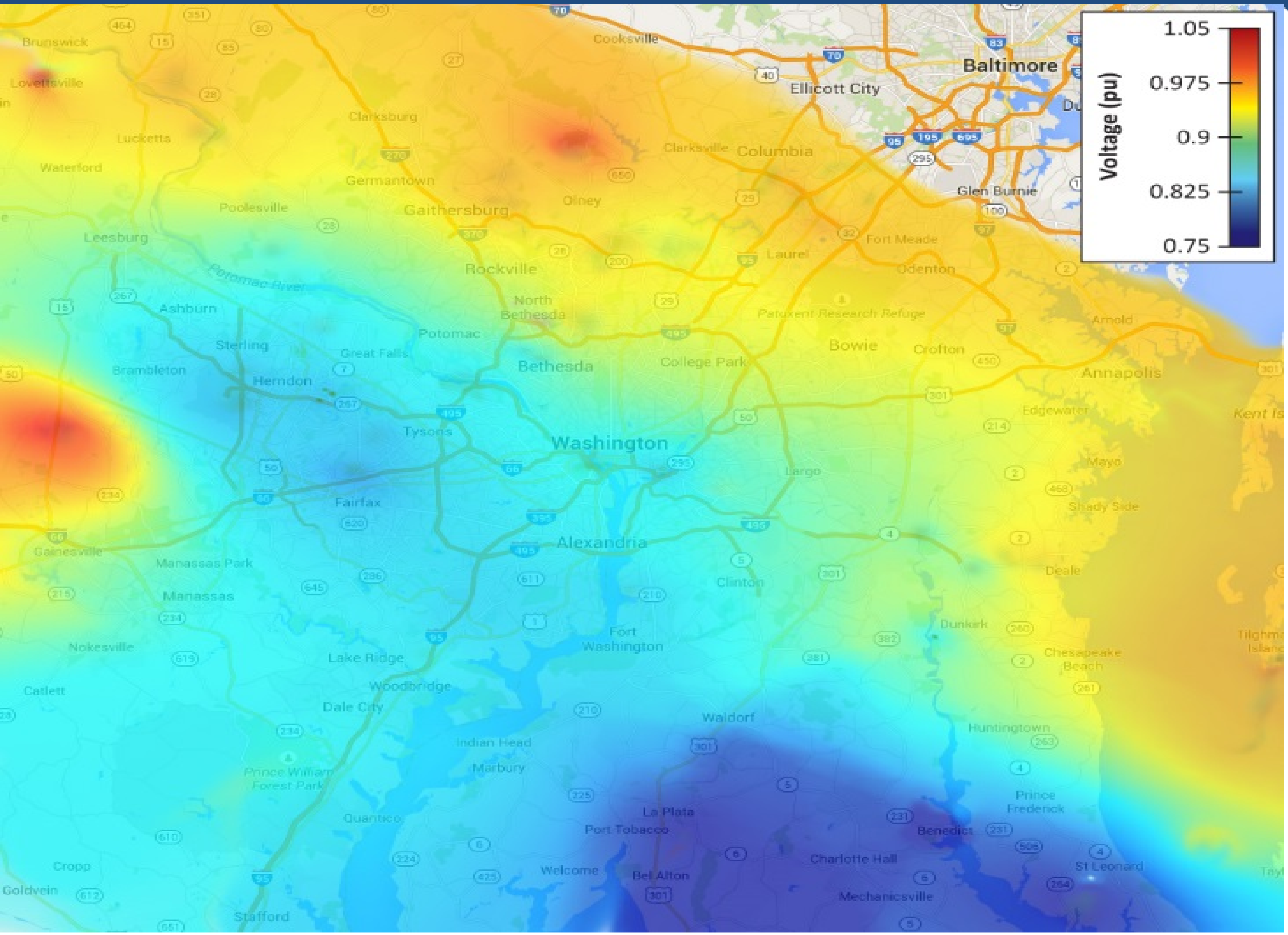
Two-Phase Fault

- Local breaker failure protection system fails to initiate at Chalk Point
  - Same auxiliary trip relay that failed to trip circuit breaker also provides breaker failure initiate signal
- 12:39:24 – 0.768 seconds later, fault expands to B-phase creating a two-phase-to-ground fault
- 12:39:25.045 – ~1.5 seconds later, Panda Brandywine combined cycle generators tripped

Three Phase Fault

- 12:39:31.003 – ~7 seconds later, fault expands to A-phase,
  - A-phase dead-end insulator mechanical failure – line on the ground
- 12:39:39 – ~8 seconds later, Calvert Cliffs Units Tripped

Three-Phase-to-Ground Fault Voltage Levels



Further voltage depression following Brandywine and Calvert Cliffs generator trips

Fault Clears

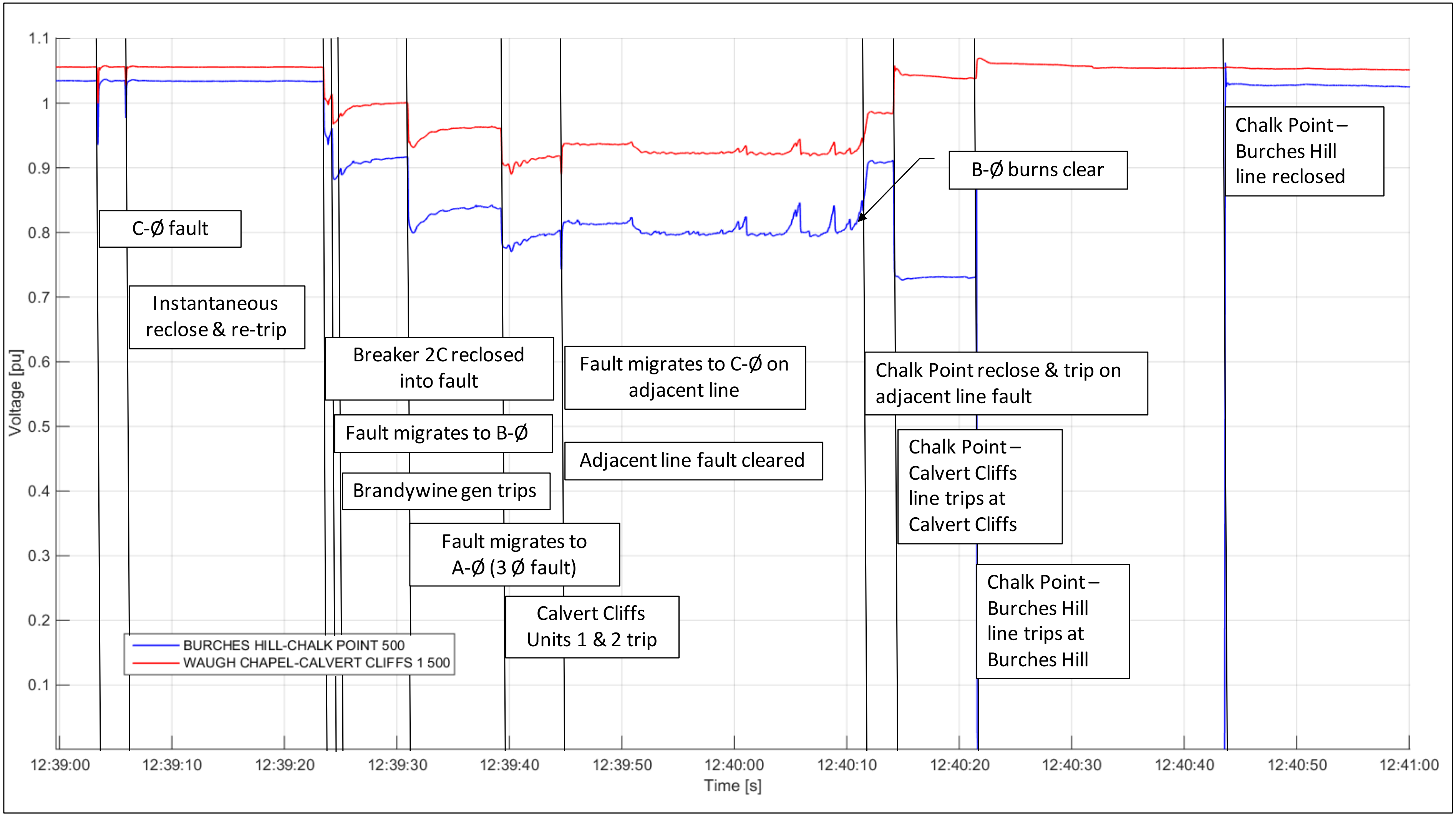
Fault Continues to Migrate

- 12:39:44.582 – ~12 seconds later, fault migrated to C-phase of adjacent Pepco 230 kV line
  - Tripped properly at Chalk Point, Ryceville, and Morgantown

Fault Clears

- 12:40:11 – ~48 seconds after reclosing into fault, B-phase burned clear
  - Causes significant enough current imbalance to trip 500 kV line breakers
- 12:40:14 – Chalk Point–Calvert Cliffs 500 kV line tripped
- 12:40:21 – Chalk Point–Burches Hill 500 kV line tripped
  - Fault becomes fully isolated and is de-energized
- Fault lasted 58 seconds from reclosing

Disturbance Overview – 500 kV Voltages



Equipment and Load Restoration

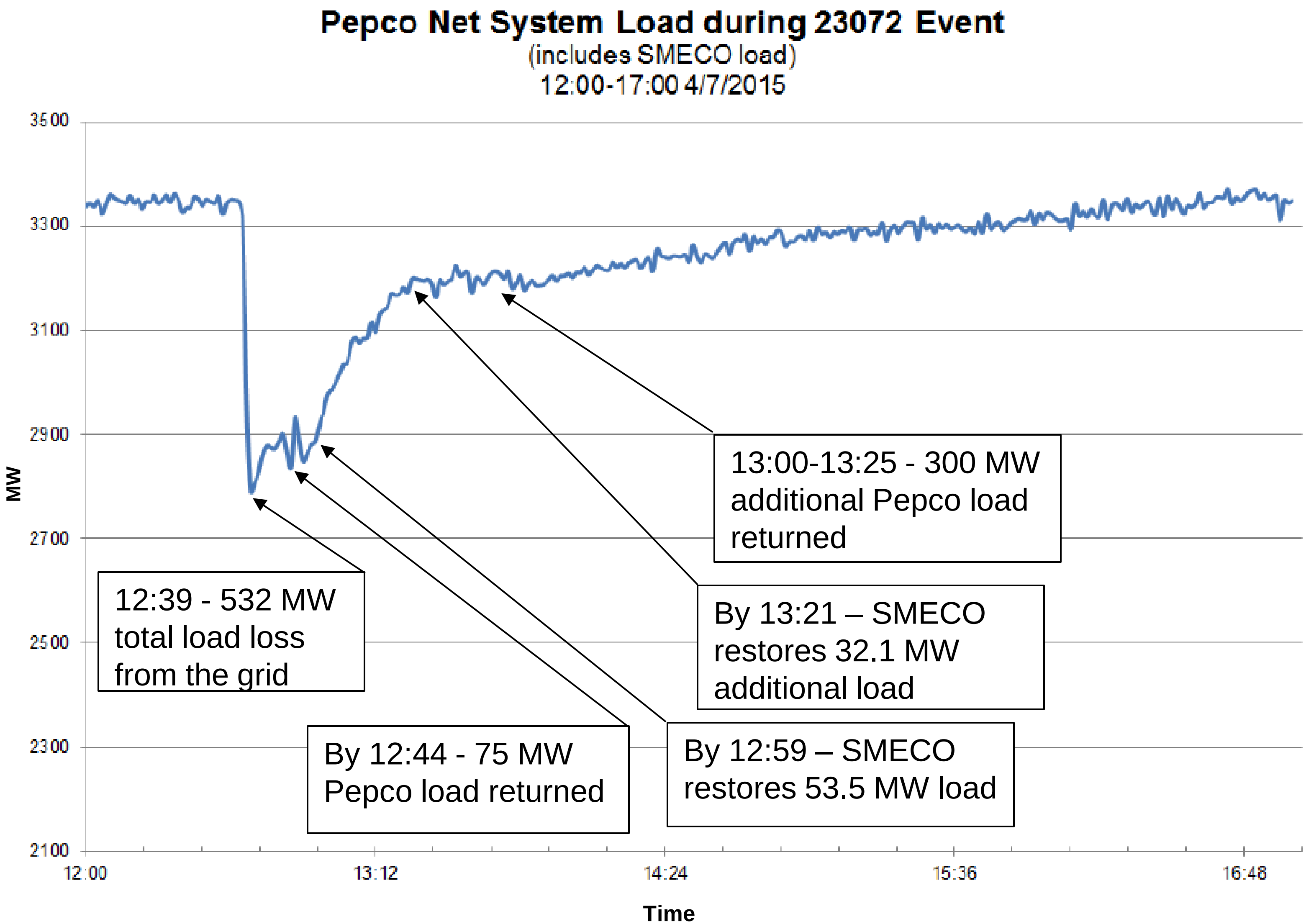
Equipment Restoration

- Panda Brandywine generators returned at 13:34 - ~1 hour outage
- Remaining equipment restored by 18:53 - ~6 hours from initial fault
- Calvert Cliffs Units 1 & 2 returned to service on April 9
- Chalk Point – Ryceville – Morgantown 230 kV line restored May 23

Load Restoration – 532 MW total load lost

- Pepco – 445 MW load lost, 71 customers power lost
  - 75 MW returned by 12:44, due to automatic systems
  - An additional 300 MW returned by 13:25
  - Remaining load was restored to meet demand
- SMECO – 87 MW load lost, 74,086 customers power lost
  - 53.5 MW returned by 12:39 via remote switching
  - An additional 32.1 MW returned by 13:21
  - Fully restored at 14:21

Load Restoration

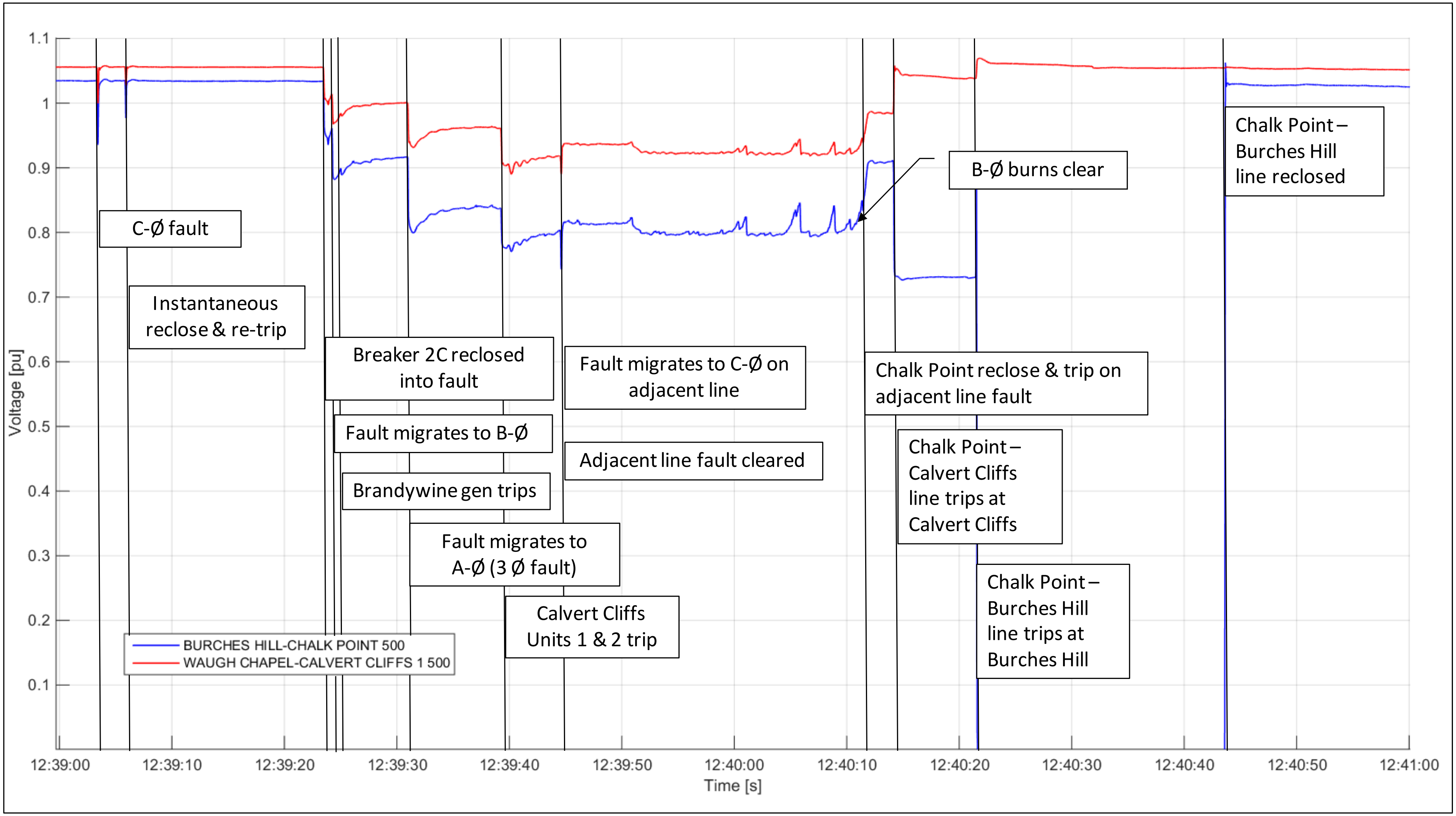


We Learn from Every Event

- Affected entities performed individual and joint root cause analysis (RCA)
- Pepco
  - Conducted extensive testing of all failed equipment, including the replacement of adjacent line's arrestors (for extensive forensic testing)
  - Replaced damaged line equipment
  - Replaced or redesigned failed protection systems
- NERC will actively collaborate with the industry to publish lessons learned from the event.
  - Enhancement of the auxiliary trip relay circuit achieved by wiring the breaker auxiliary contacts in parallel rather than series.
  - Enhancement of the design of the breaker failure initiate function by providing an independent signal source to initiate breaker failure scheme.

PMUs in Event Analysis

Disturbance Overview – 500 kV Voltages



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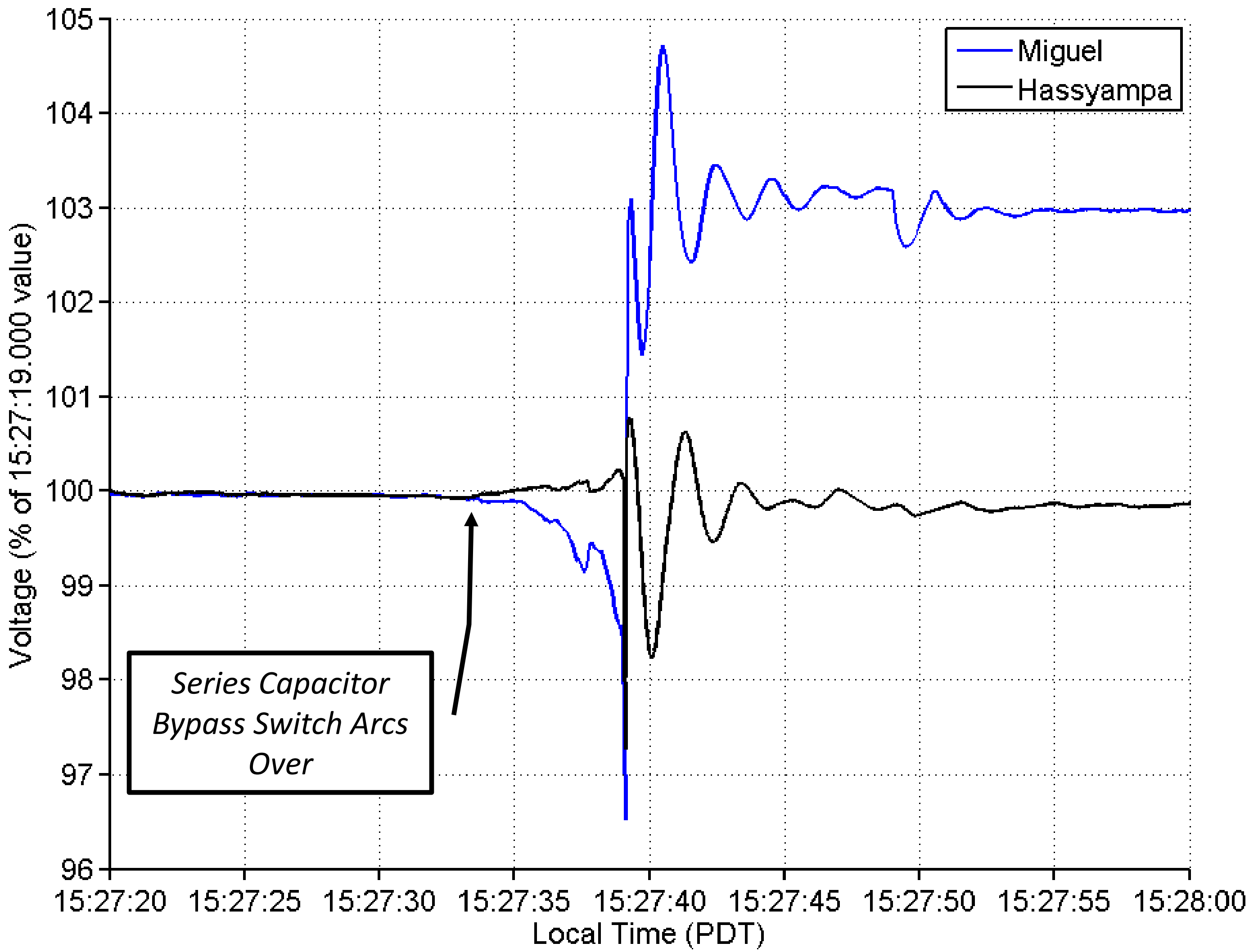
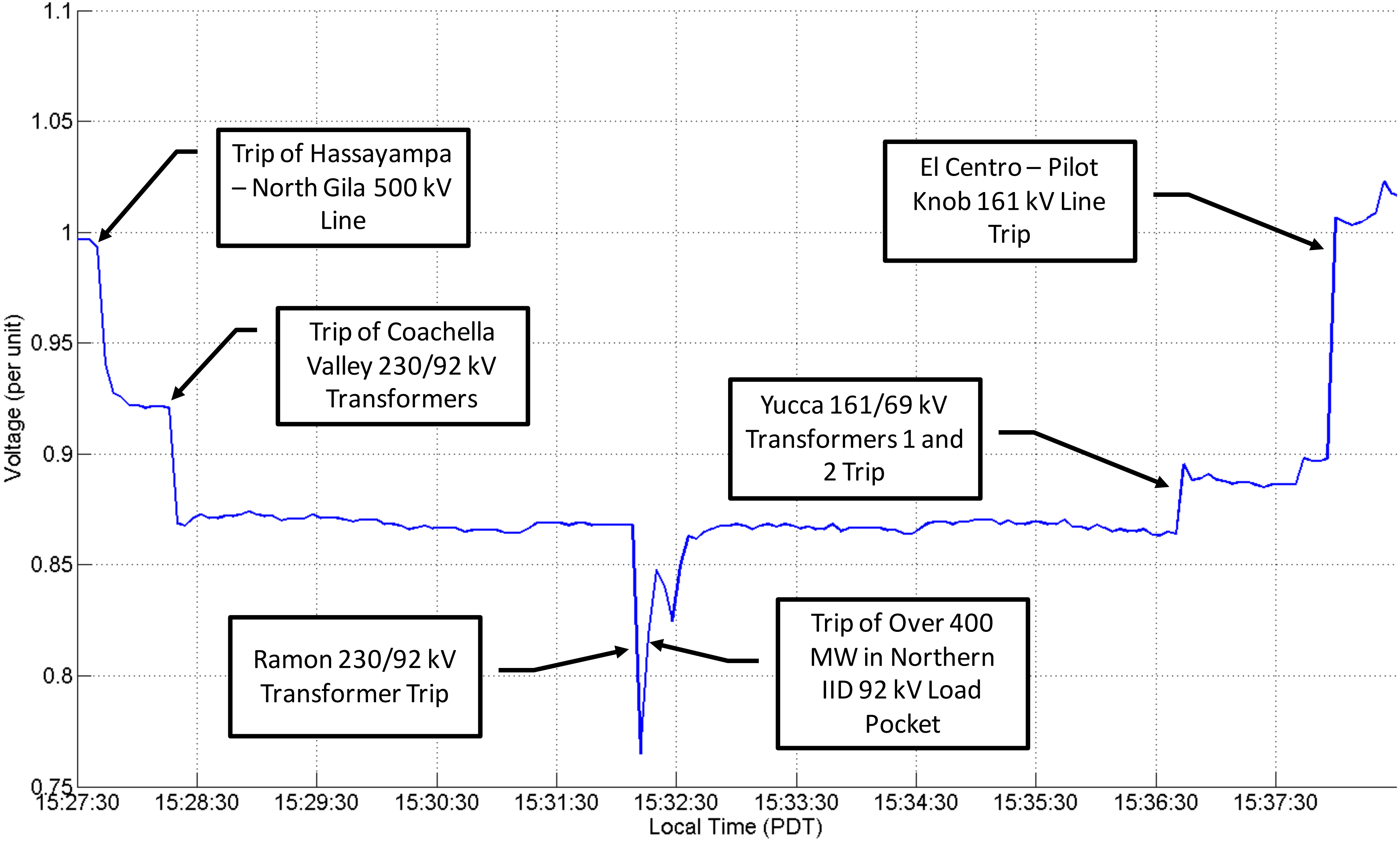
Uses of PMUs In Event Analysis

- Overview timeline capabilities
- Ability to look at several dimensions at once:
  - Frequency domain
  - Voltage domain
  - Flow domain
- Pinpointing timing of specific events in the disturbance
- Recognize PMU limitations
  - 30 samples/second = 33 millisecond resolution
  - Not capable of point-on-wave analysis
- Part of a suite of tools – works best when coupled with:
  - Digital relay records
  - Digital fault recorders
  - Other DME devices

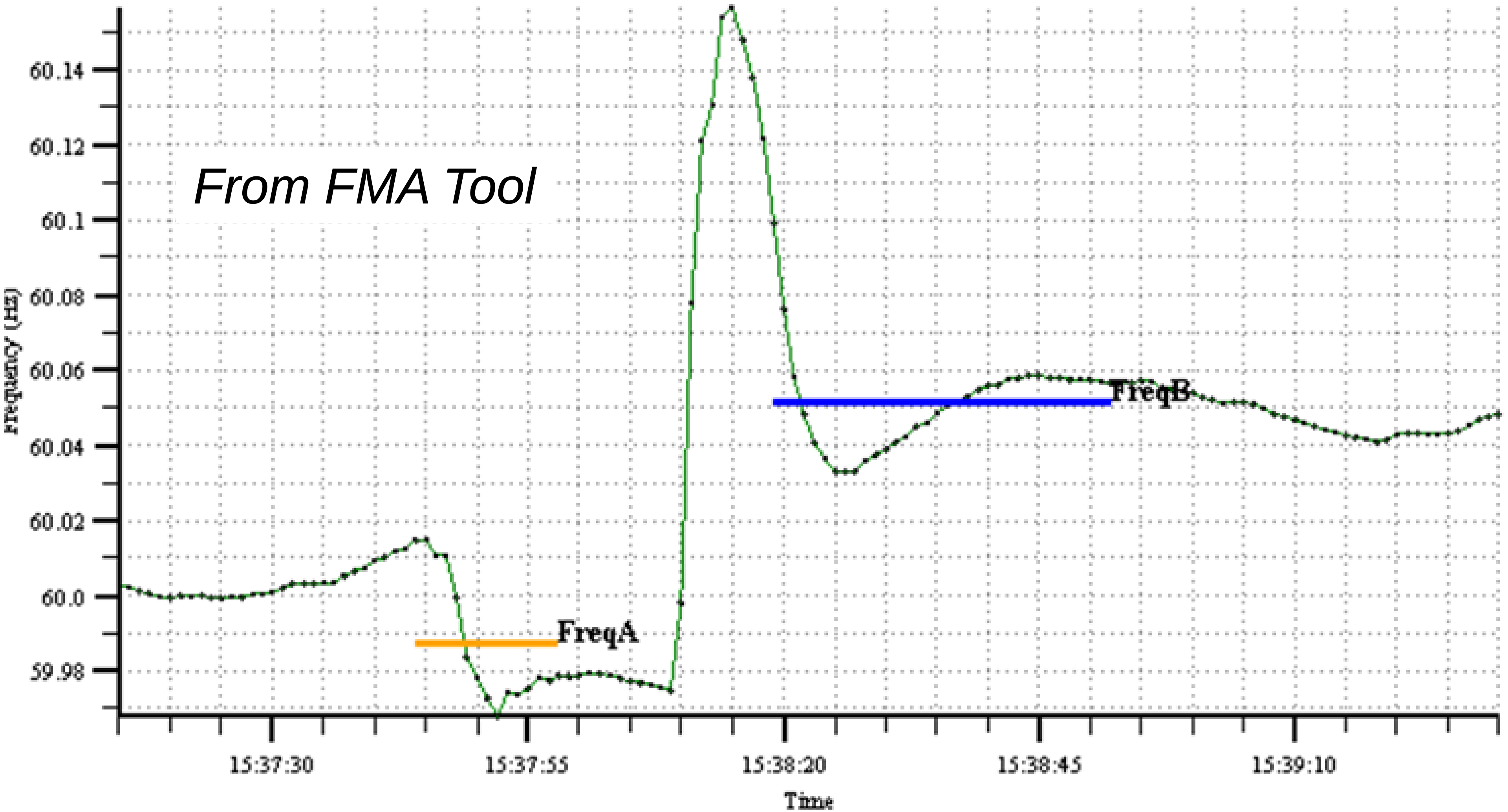
2011 San Diego Dist. – Voltage Divergence Hassayampa – North Gila 500 kV Line Trip



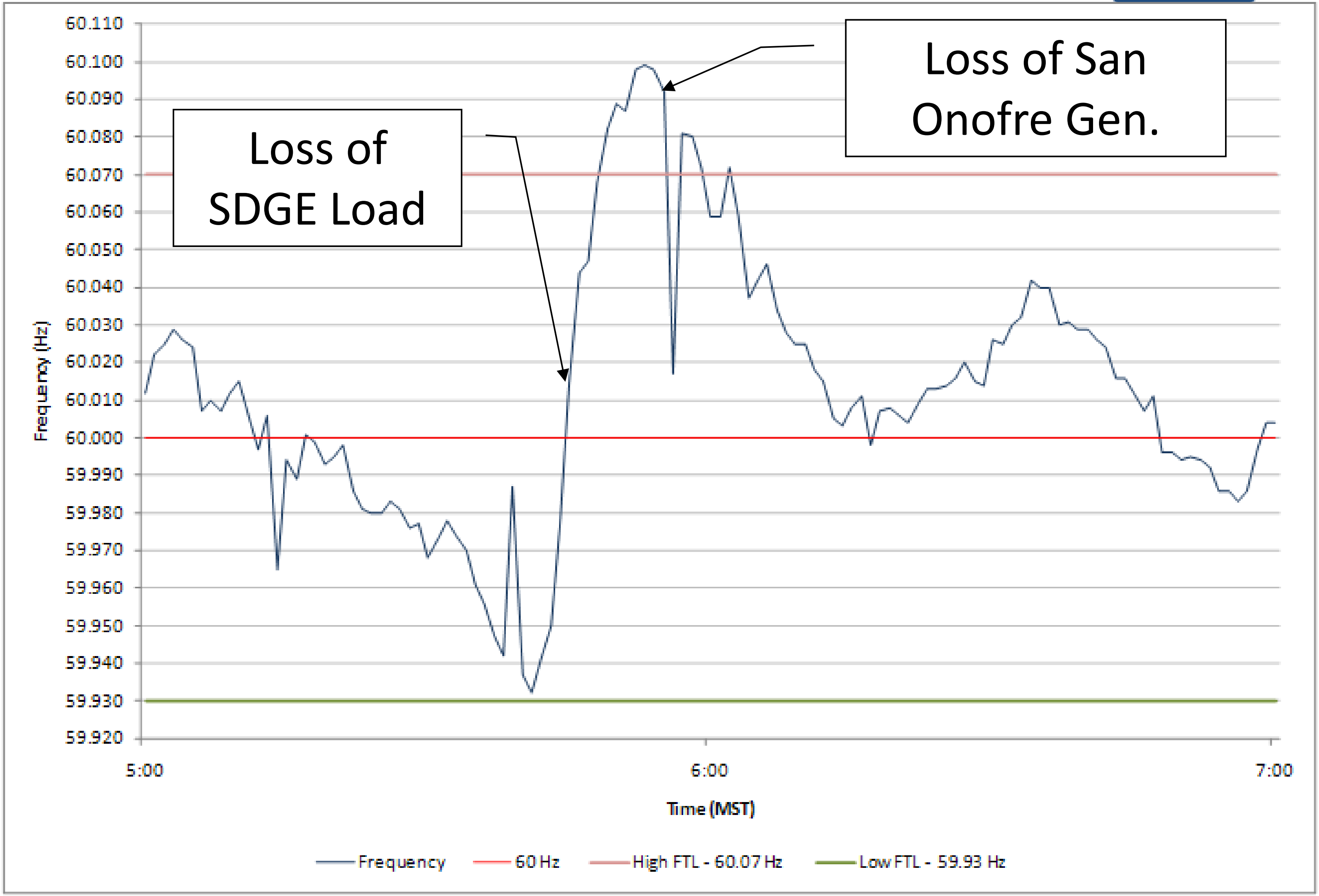
2011 San Diego Dist. Blythe 161 kV Voltage



2011 San Diego Dist.
WECC Freq ~1538 – SDGE Sep.



2011 San Diego Dist. System Separation & SONGS Trip



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Importance of Timely Data Provision

- 2003 Blackout – very few synchronized devices
  - Overview Simulations – 3- months
  - Daisy Chaining – 3 to 6 months
  - Sequence of Events (detailed) – 9+ months
- 2011 San Diego Blackout – Several PMUs used with synchronized DFRs and digital relay records
  - Overview Measurements – 2.5 hours once data supplied
  - Sequence of Events (detailed) – 2 weeks
- 2015 Washington Event – Two PMUs used with multiple synchronized DME devices
  - Overview Measurements – ~2 hours
  - Sequence of Events (detailed) – 2 weeks

PMU Tools Used

- MatLab
  - COMTRADE (preferred – per Standard PRC-002-1)
  - CSV format
- Universal Reader
  - COMTRADE (preferred – per Standard PRC-002-1)
  - Native DME formats

Questions and Answers