NERC Update

2015 WDC Disturbance and Protection Standards Overview

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IEEE PSRC meeting – Denver, Co

May 12, 2016

RELIABILITY | ACCOUNTABILITY




SPCS and Standards Activities

System Protection and Controls Subcommittee Activities

- Unit Auxiliary Transformer Protection
  - The *Unit Auxiliary Transformer Overcurrent Relay Loadability During a Transmission Depressed Voltage Condition* Report – Approved the NERC Planning Committee in March 2016
  - Investigated potential gaps in for UAT protective relays not covered by the PRC-025-1 Reliability Standard (specifically, the low-side overcurrent protection)
  - The Report recommended no further action

System Protection & Control Subcommittee (SPCS) Activities

Power Plant and Transmission System Protection Coordination

- Version 2 approved by NERC Planning Committee in June 2015

Single Point of Failure (FERC Order 754)

- Moved into Standards development
- Modifications to be made to Standard TPL-001-4
  - In SAR drafting phase

Protection-Related Standards Activities

Standards Applicability for Dispersed Power Producing Resources

- Collaborating with IEEE PSRC Standard 1547 Distributed Generation (resources) – Generally connected at distribution level voltages
- Dispersed Power Producing Resources – aggregated small-scale resource technologies such as: wind, solar, fuel cells, flywheels, geothermal, energy storage, & micro-turbines
- Launched a Distributed Energy Resources Task Force (DERTF) in association with the activity on Essential Reliability Services

Protection System Maintenance and Testing

- PRC-005-6 -- Protection System, Automatic Reclosing, and Sudden Pressure Relaying Maintenance
  - Approved by NERC Board November 2015
  - Filed with FERC November 13 2015
  - NERC submitted a motion requesting FERC to defer the implementation of PRC-005-3, PRC-005-3(i), and PRC-005-4 from January 1, 2016 until after FERC issues a final order on proposed PRC-005-6.
  - PRC-005-2i currently in effect.
  - Letter order by FERC approving PRC-005-6 on December 18, 2015.
- PRC-005-6 became effective on January 1, 2016 – with a phased Implementation Plan

System Protection Coordination (Phase 1)

- PRC-027-1 – Coordination of Protection Systems for Performance During Faults
  - Replaces R3 and R4 from PRC-001-1.1(ii) concerning coordination of Protection Systems
  - Approved by NERC BOT November 2015

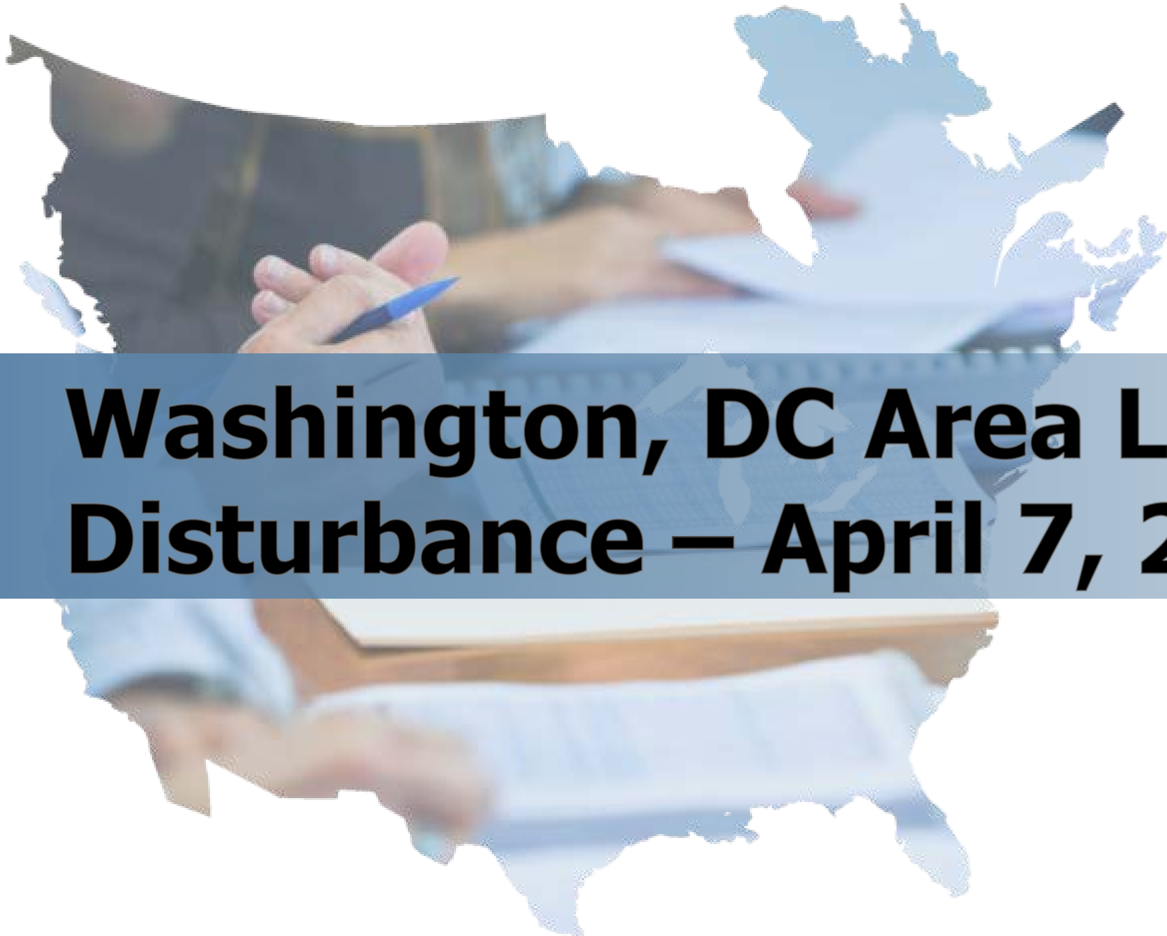
System Protection Coordination (Phase 2)

- Addressing Requirements R1, R2, R5, R6 of PRC-001-1.1(ii)
- PER-006-1 – Specific Training for Personnel
  - Posted March 10 – April 25 for comment and initial ballot
- Complete retirement of PRC-001-1.1(ii) is contingent upon the approval of PER-006-1 and definition modifications

Protection-Related Standards Activities

Protection Systems Phase 3: Remedial Action Schemes (RAS)

- Replacing existing RAS-related standards - PRC-012, PRC-013, PRC-014, PRC-015, PRC-016 and revises SPS definition
- PRC 012-2 – Remedial Action Schemes
  - Stakeholders approved PRC-012-2 and revised definition of SPS
  - Posted for final ballot in late April 2016
  - Approved the NERC Board of Trustees May 5, 2016

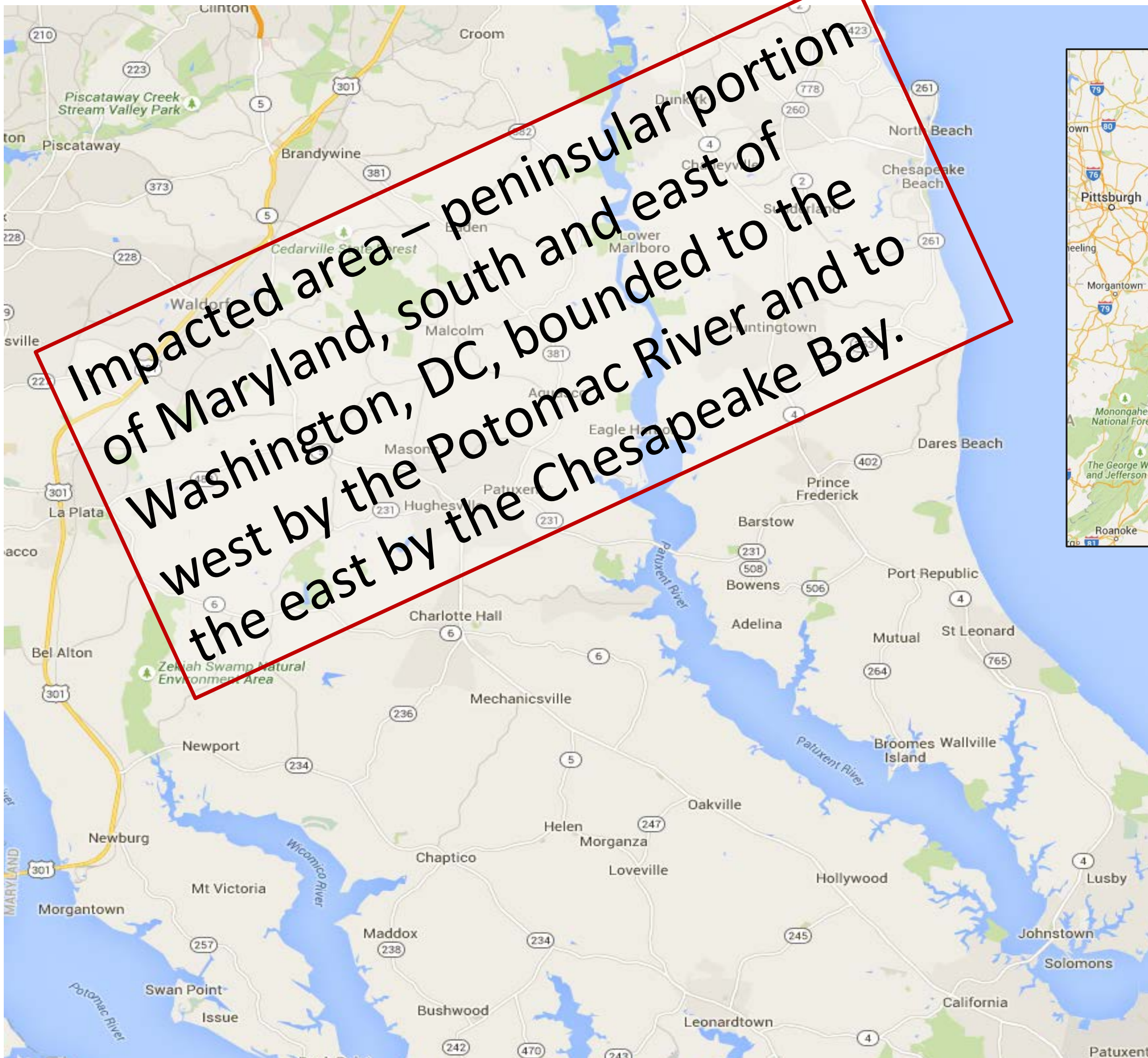


Washington, DC Area Low Voltage Disturbance – April 7, 2015

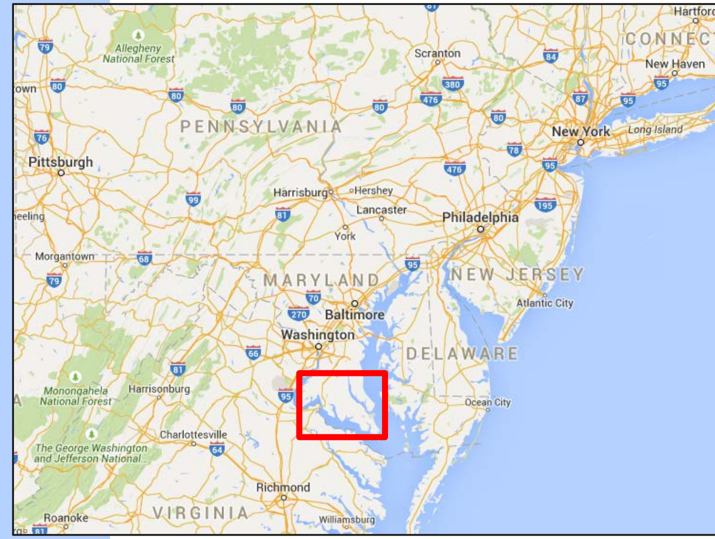
Overview

- 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 **58 second** 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.



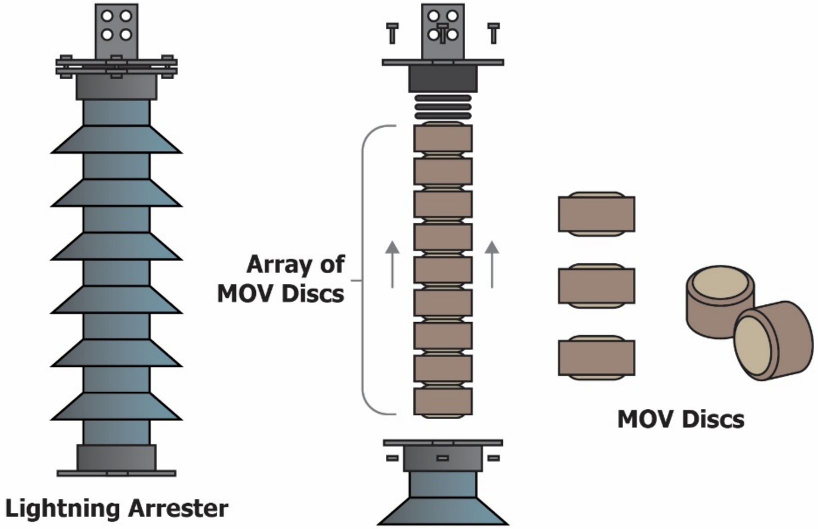
The nature of the interconnected system is that electrical disturbances in one area can often be impactful in adjacent areas. The initial electrical fault occurred over 40 miles south of DC.

Anatomy of a Surge Arrester

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

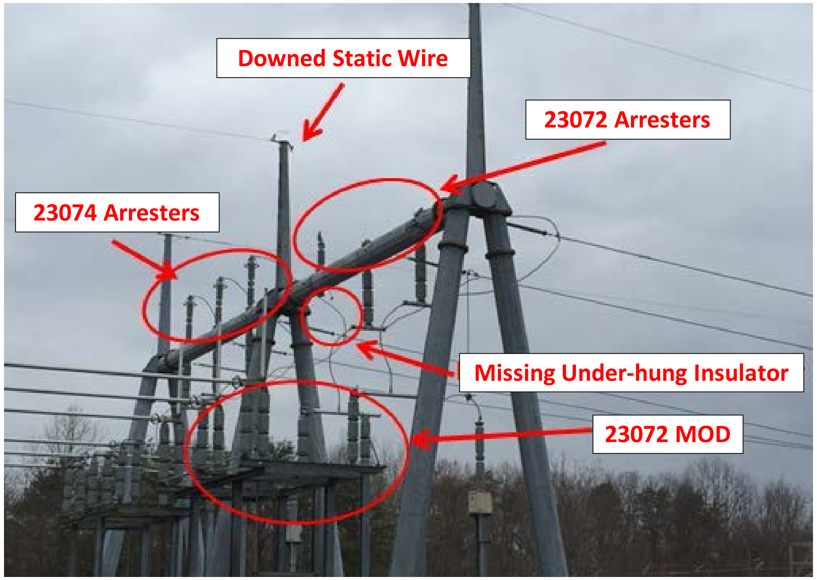
Lightning (surge) arrester is a device used on electrical power systems to protect the insulation and conductors of the system from the damaging effects of lightning. When a lightning surge (or switching surge, which is very similar) travels along the power line to the arrester, the current from the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

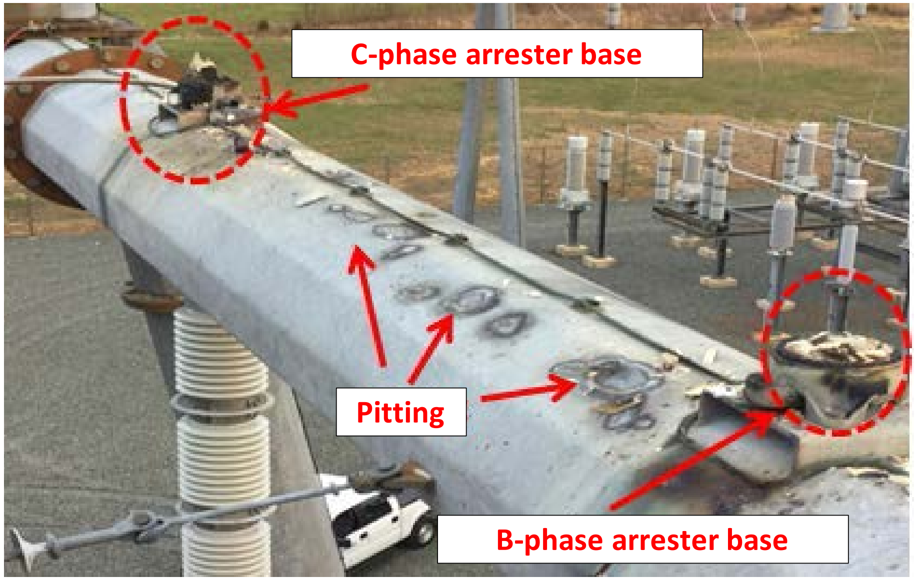


Lightning Arrester Failed

- 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



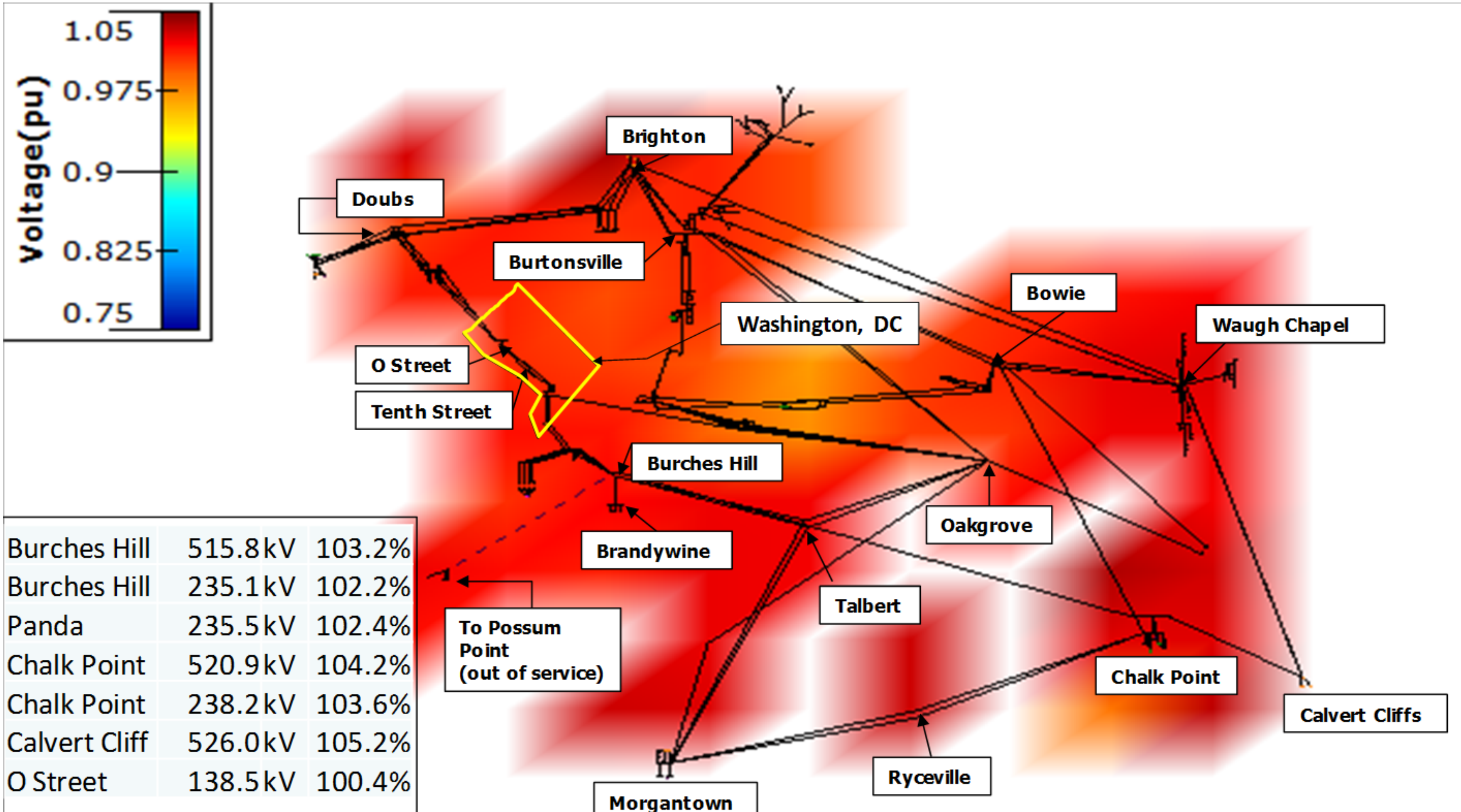
Pitting Near Arrester Bases

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



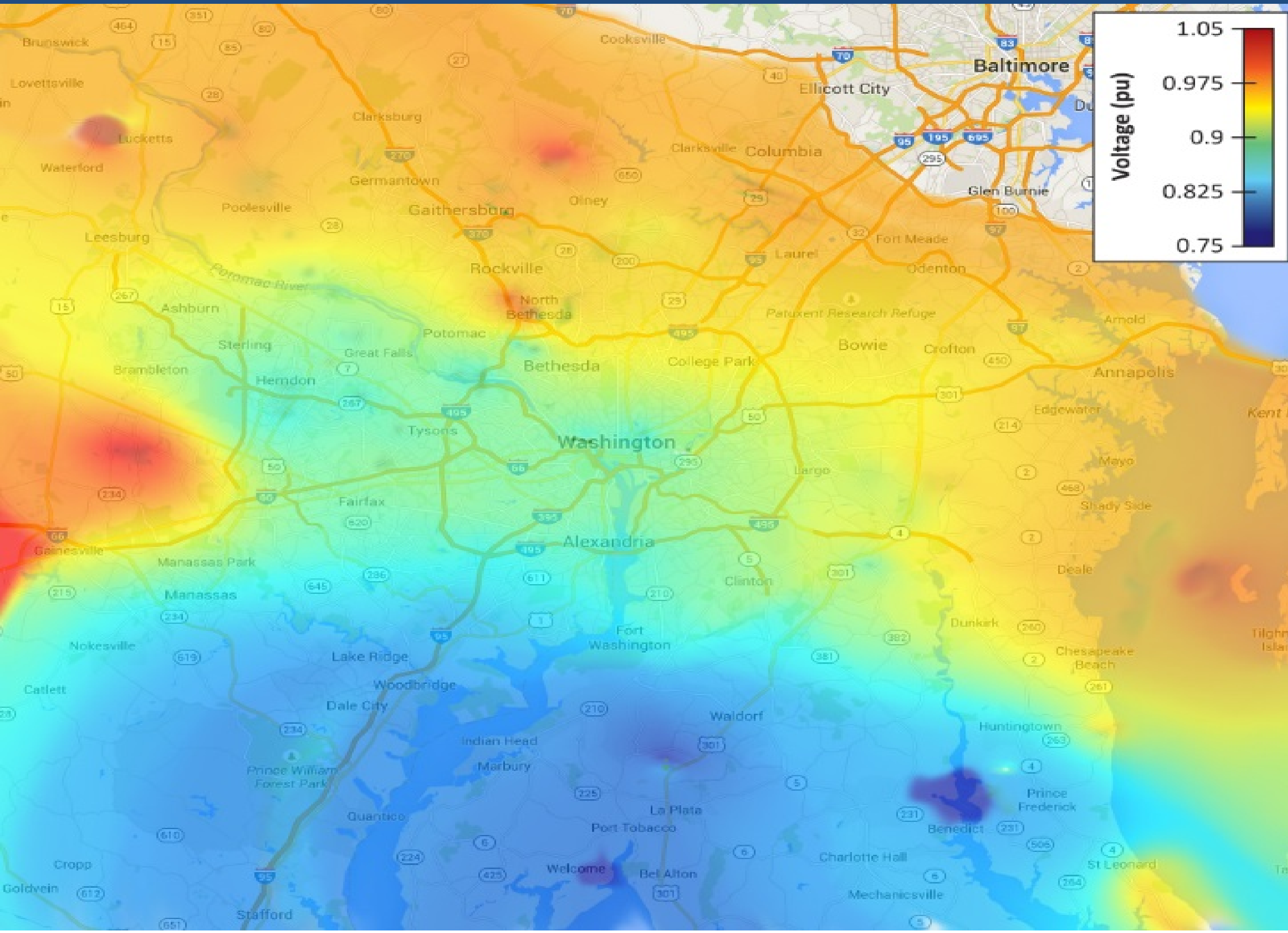
Burches Hill	515.8 kV	103.2%
Burches Hill	235.1 kV	102.2%
Panda	235.5 kV	102.4%
Chalk Point	520.9 kV	104.2%
Chalk Point	238.2 kV	103.6%
Calvert Cliff	526.0 kV	105.2%
O Street	138.5 kV	100.4%

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

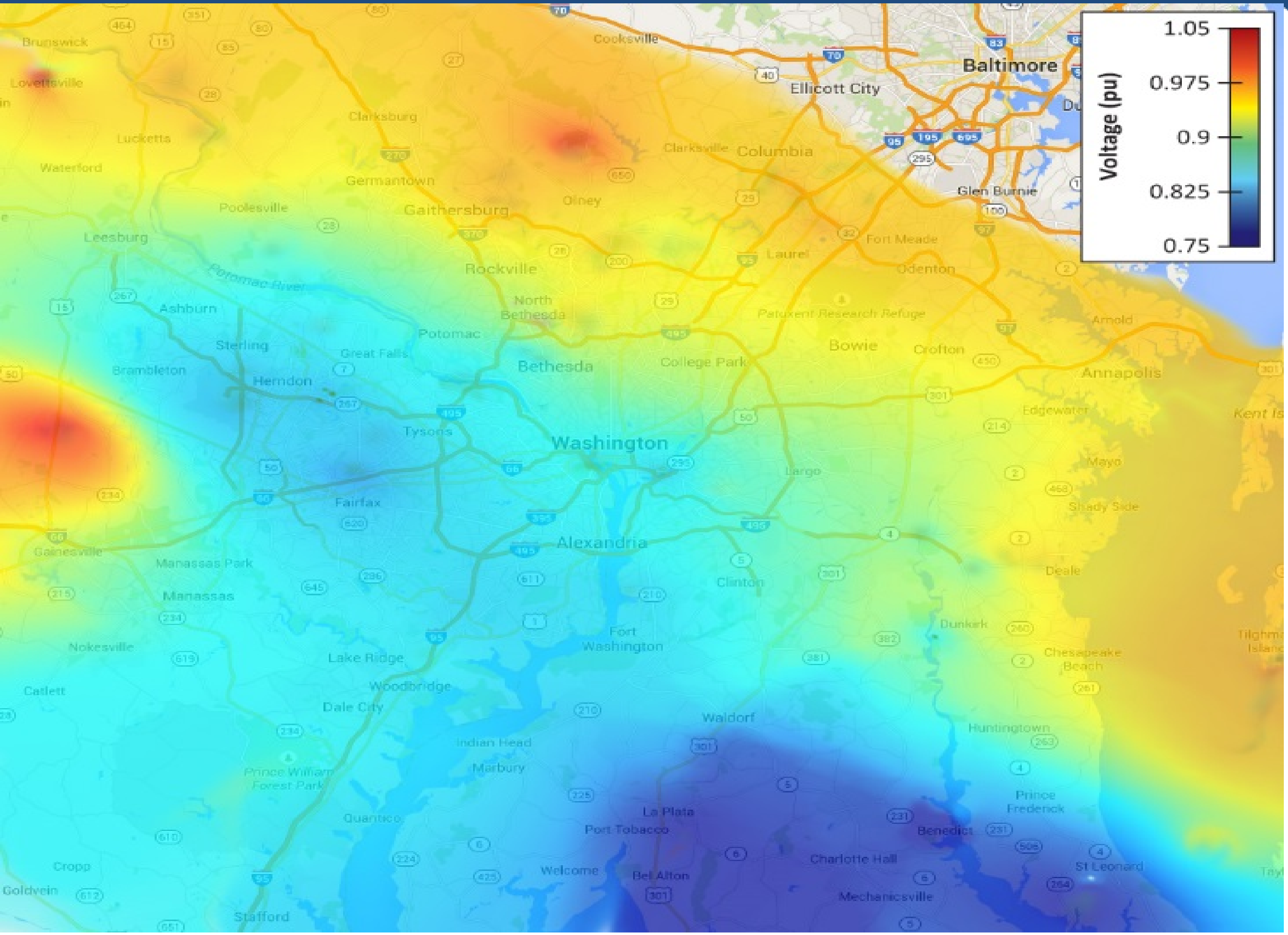
Two-Phase Fault

- 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

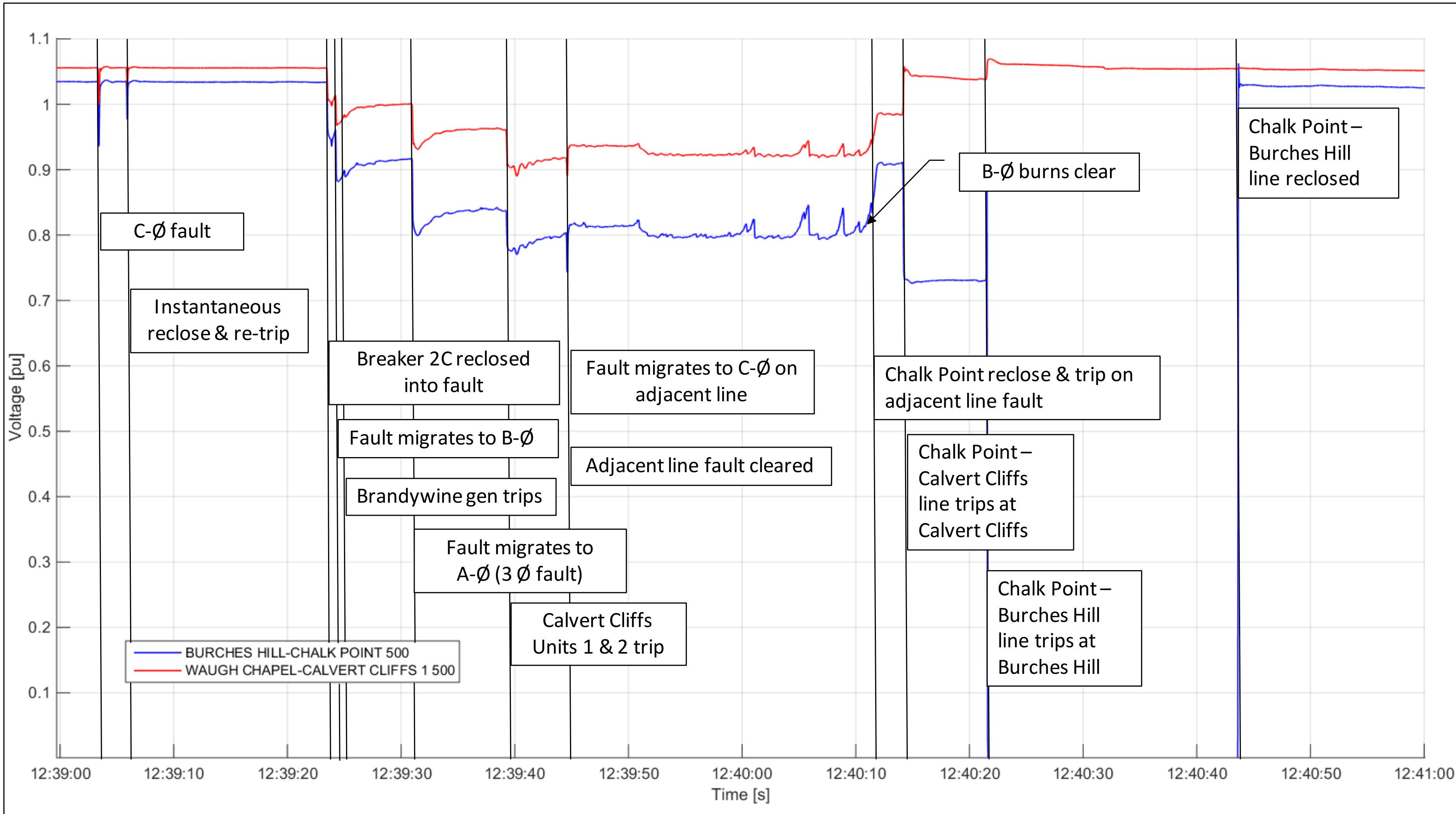
Fault Continues to Migrate

- 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

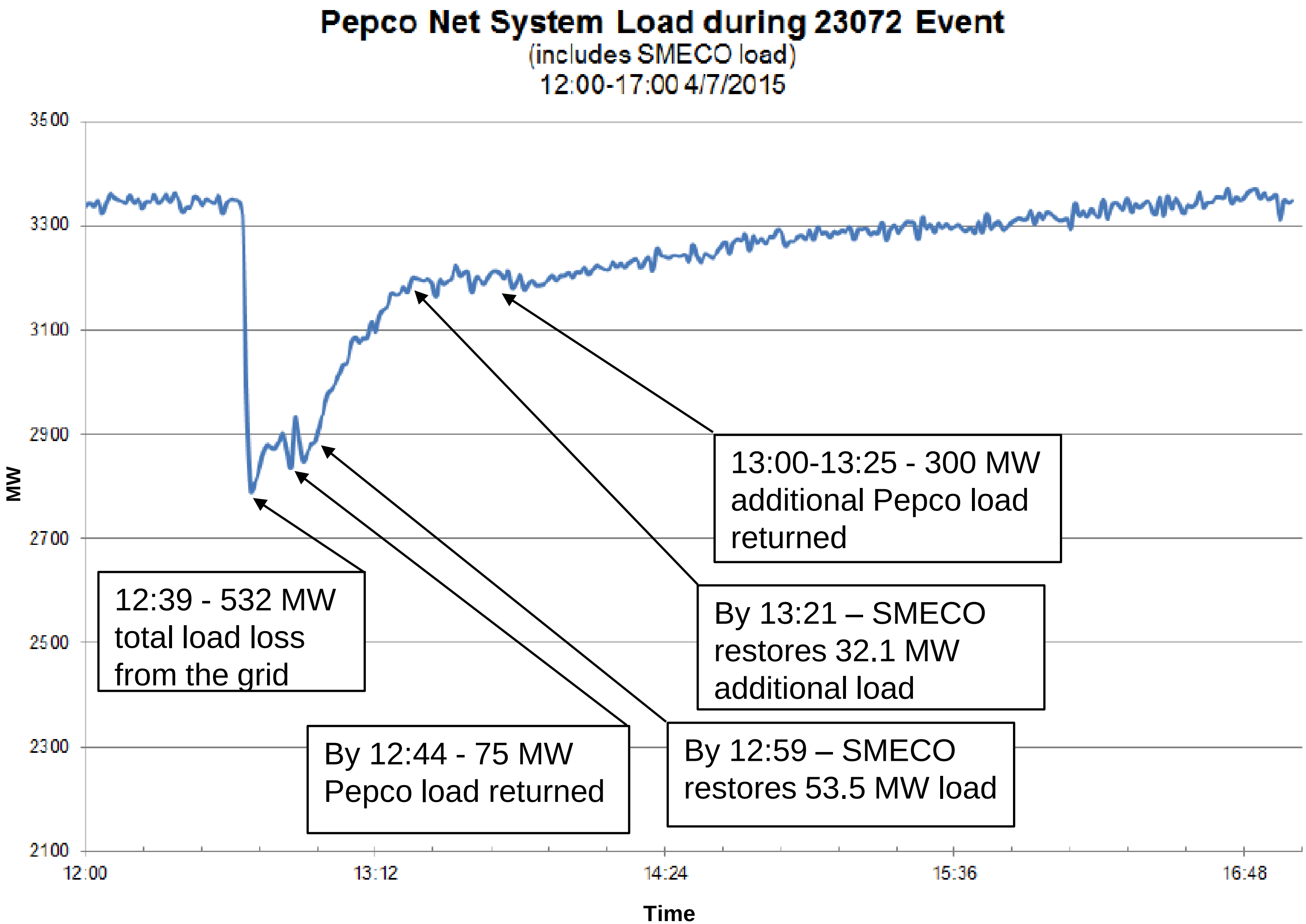
Equipment Restoration

- 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

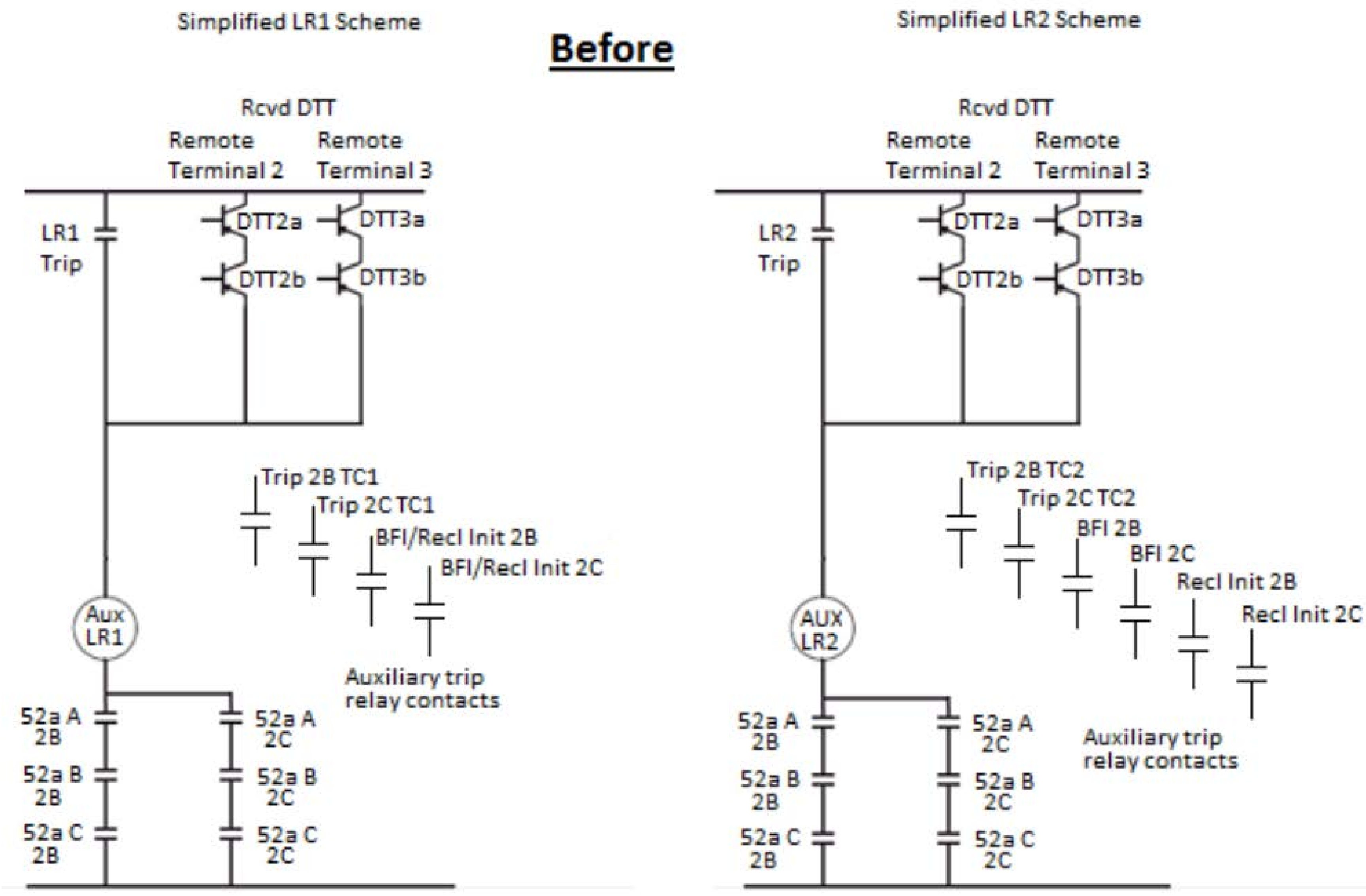


We Learn from Every Event

- 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.

How did this happen?

Before


Simplified LR1 Scheme
Rcvd DTT
Remote Terminal 2
Remote Terminal 3
LR1 Trip
DTT2a
DTT3a
DTT2b
DTT3b
Trip 2B TC1
Trip 2C TC1
BFI/Recl Init 2B
BFI/Recl Init 2C
Aux LR1
Auxiliary trip relay contacts
52a A 2B
52a B 2B
52a C 2B
52a A 2C
52a B 2C
52a C 2C
Simplified LR2 Scheme
Rcvd DTT
Remote Terminal 2
Remote Terminal 3
LR2 Trip
DTT2a
DTT3a
DTT2b
DTT3b
Trip 2B TC2
Trip 2C TC2
BFI 2B
BFI 2C
Recl Init 2B
Recl Init 2C
AUX LR2
Auxiliary trip relay contacts
52a A 2B
52a B 2B
52a C 2B
52a A 2C
52a B 2C
52a C 2C

Lessons Learned

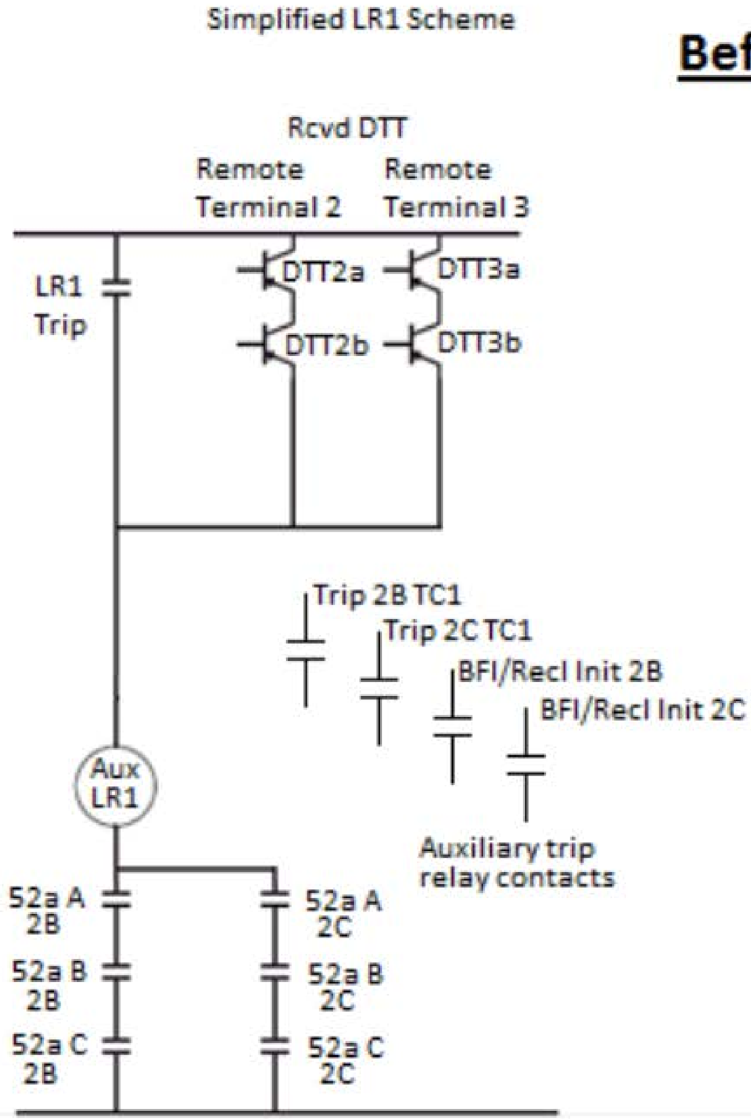
Lessons Learned

A Lessons Learned was issued by NERC on 9-5-15 for a more reliable protection scheme

1. Three options for a more reliable BFI design are:
   - Use a separate contact from protective relay to provide BFI signal
   - Use dedicated aux. relay for BFI if separate contact not available on relay
   - Connect the protective relay trip contact directly to a breaker failure relay input if the breaker failure relay will accommodate a voltage input
2. Aux. trip circuit design enhancements
   - Evaluate whether 52a contacts in series with the trip auxiliaries is necessary. If not, avoid use of 52a contacts.
   - Where 52a contacts in series with the trip auxiliary relays are necessary and where independent pole breakers are used, connect the 52a contacts in parallel rather than in series

1. Consider including the following for the periodic functional testing of protection circuits:
   - If functional tests fail to detect open circuits or other defects in any portion of the protection circuit, these defects could prevent either the tripping of the required local remote breakers (as applicable) or the initiation of breaker failure.
   - Verification that primary elements of the protection scheme generate trip output(s), as applicable, to the associated trip auxiliary relay, directly to the breakers, or both.
   - Verification that the required breakers do, in fact, trip as a result of a trip output(s). This verification should be performed during the functional testing if possible.

Before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Auxiliary trip relay contacts
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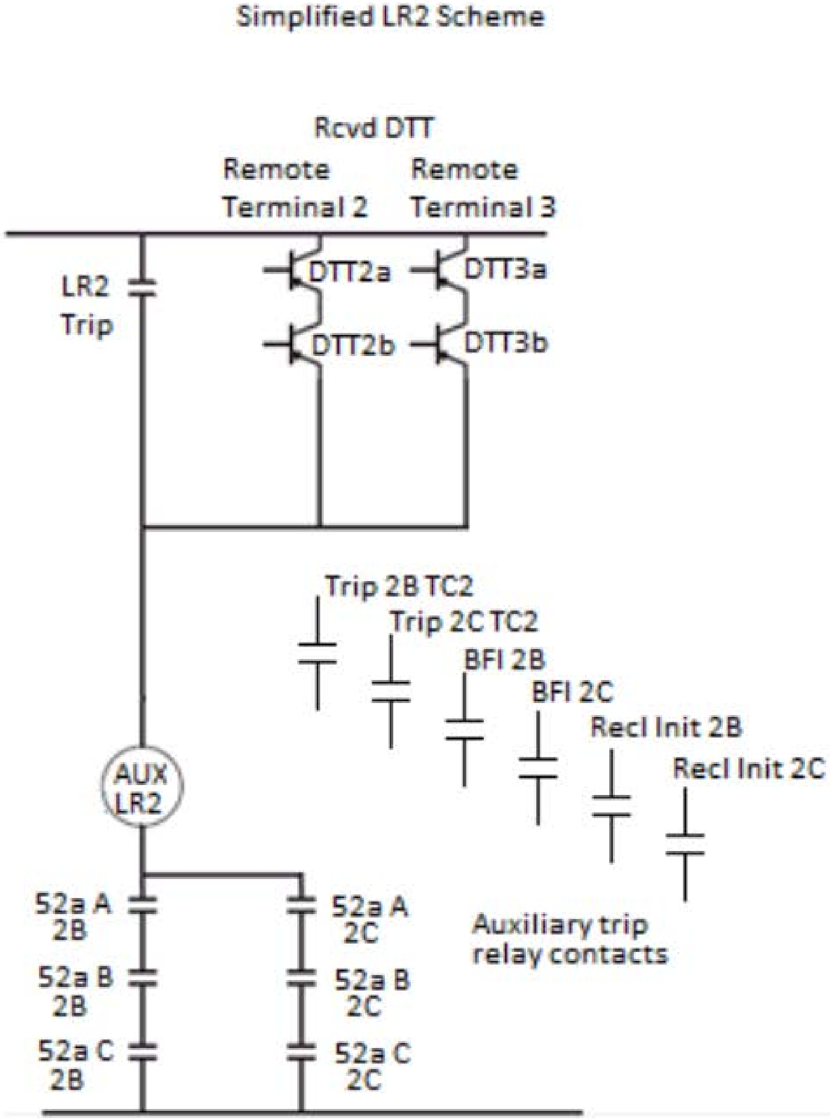
52a C 2B
52a A 2C
52a B 2C
52a C 2C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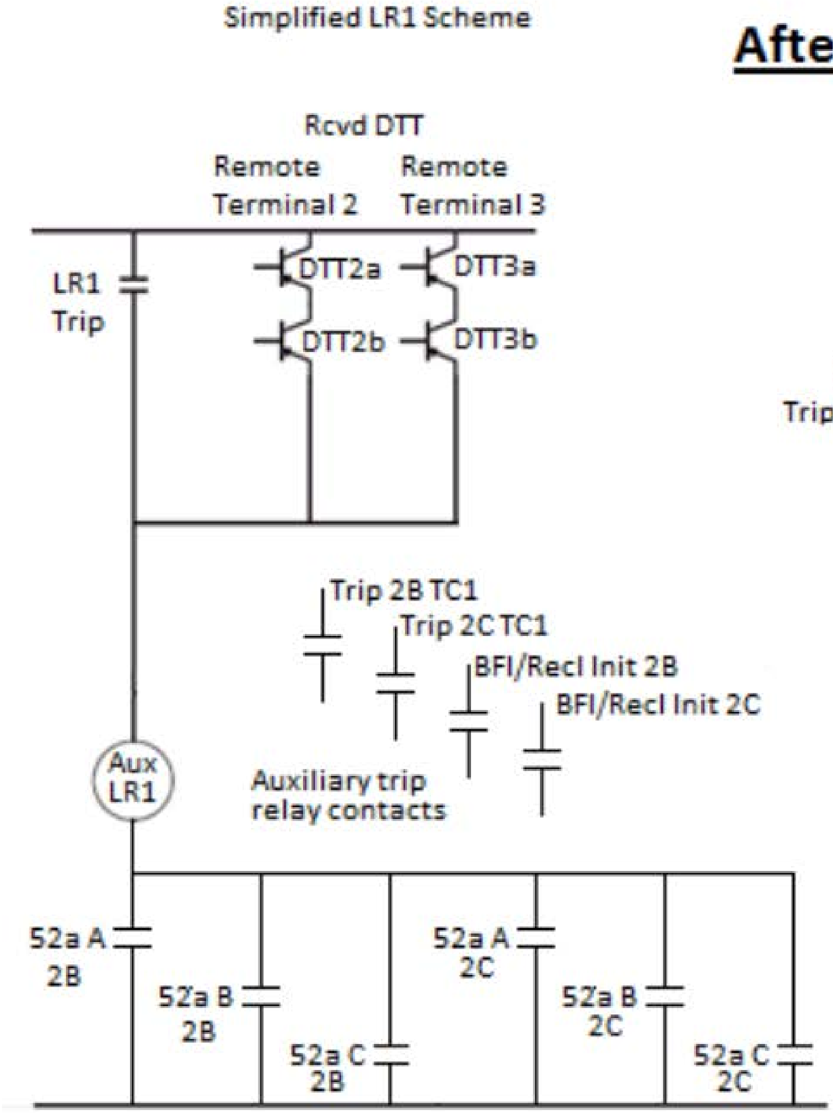
Rcvd DTT
Remote Terminal 2
Remote Terminal 3
LR2 Trip
DTT2a
DTT3a
DTT2b
DTT3b
Trip 2B TC2
Trip 2C TC2
BFI 2B
BFI 2C
Recl Init 2B
Recl Init 2C
AUX LR2
Auxiliary trip relay contacts
52a A 2B
52a B 2B
52a C 2B
52a A 2C
52a B 2C
52a C 2C

After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Remote
Terminal 2
Remote
Terminal 3
LR1
Trip
DTT2a
DTT3a
DTT2b
DTT3b
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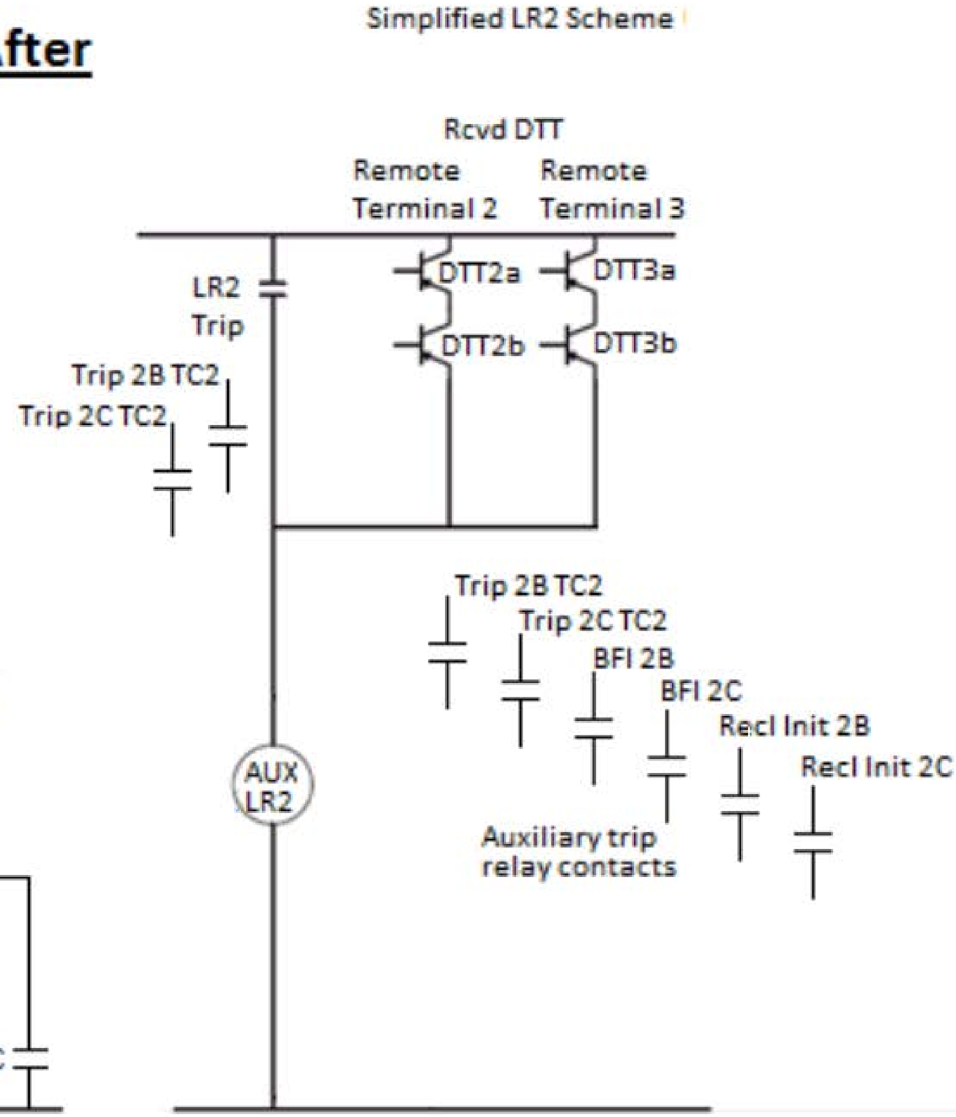
Trip 2C TC1
BFI/Recl Init 2B
BFI/Recl Init 2C
Aux
LR1
Auxiliary trip
relay contacts
52a A
2B
52a B
2B
52a C
2B
52a A
2C
52a B
2C
52a C
2C


Simplified LR2 Scheme
Rcvd DTT
Remote
Terminal 2
Remote
Terminal 3
LR2
Trip
DTT2a
DTT3a
DTT2b
DTT3b
Trip 2B TC2
Trip 2C TC2
Trip 2B TC2
Trip 2C TC2
BFI 2B
BFI 2C
Recl Init 2B
Recl Init 2C
AUX
LR2
Auxiliary trip
relay contacts

Other Protection System Lessons Learned

Lessons Learned Located at:

http://www.nerc.com/pa/rrm/ea/Pages/Lessons-Learned.aspx

- LL20150902 – Relay Design and Testing Practices to Prevent Scheme Failures
- LL20150401 – Detailed Installation and Commissioning Testing to Identify Wiring or Design Errors
- LL20150202 – Consideration of the Effects of Mutual Coupling when Setting Ground Instantaneous Overcurrent Elements
- LL20150201 – Digital Inputs to Protection Systems May Need to be Desensitized to Prevent False Tripping Due to Transient Signals

Questions and Answers

More reliable designs