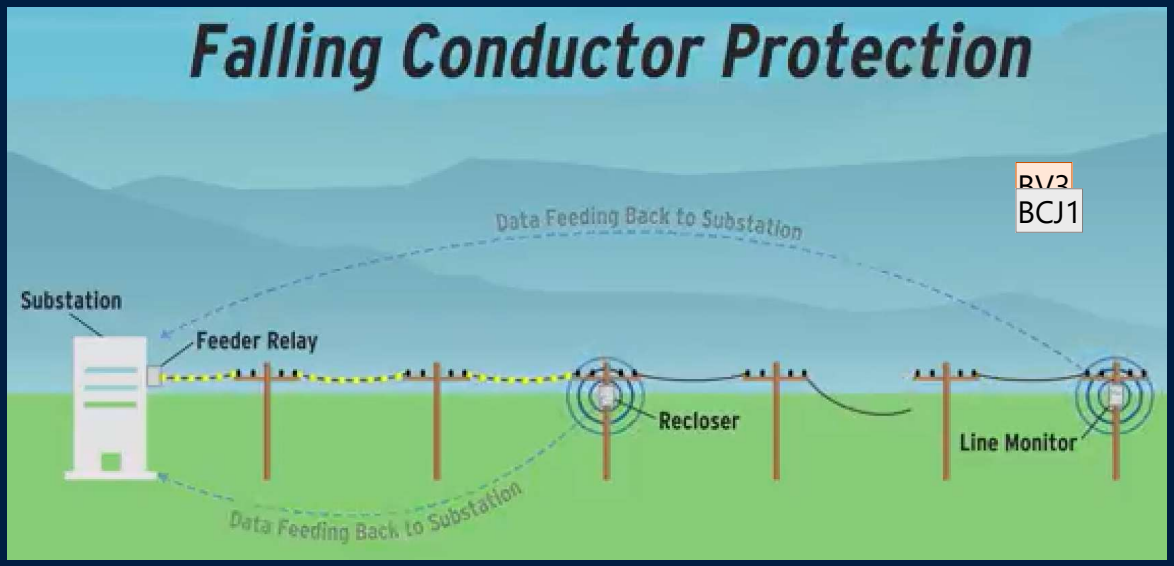
Catching Falling Conductors in Midair – Detecting and Tripping Broken Distribution Circuit Conductors at Protection Speeds



Dan Dietmeyer – Sr. Engineer
San Diego Gas & Electric®

Slide 1

BV1 Add register symbol (R) circle R
Brody, Valerie, 3/7/2019

BCJ4 Done.
Bolton, Christopher J, 3/7/2019

BV2 copyright line TBD
Brody, Valerie, 3/7/2019

BCJ3 This was vetted back in 2016 and likely allowed because we are a part of a joint patent with SEL and Quanta on this technology
Bolton, Christopher J, 3/7/2019

BV3 Does SDG&E own this artwork?
Brody, Valerie, 3/7/2019

BCJ1 Yes, this is ours
Bolton, Christopher J, 3/7/2019

BV7 Add the SDG&E logo. Let me know if you need a logo file.
Brody, Valerie, 3/7/2019

BCJ2 Yes, could you please send it?
Bolton, Christopher J, 3/7/2019

BV8 Replace copyright line with:
Brody, Valerie, 3/12/2019

BV9 (c) 2019 San Diego Gas & Electric Company. Trademarks are property of their respective owners. All rights reserved.
Brody, Valerie, 3/12/2019

BV10 Add SDG&E logo
Brody, Valerie, 3/12/2019

SDG&E® Overhead Distribution System

- Approximately 6,500+ miles of overhead distribution line infrastructure
- Grounded three- and four-wire systems
- Nominally 12kV and 4kV
- High penetration of distribution PV requires new solutions for monitoring, protection, and control

Slide 2

BV4 Register symbol
Brody, Valerie, 3/7/2019

BCJ5 Done.
Bolton, Christopher J, 3/7/2019

Advanced SCADA Project Applications

More Than 60 Use Cases Defined

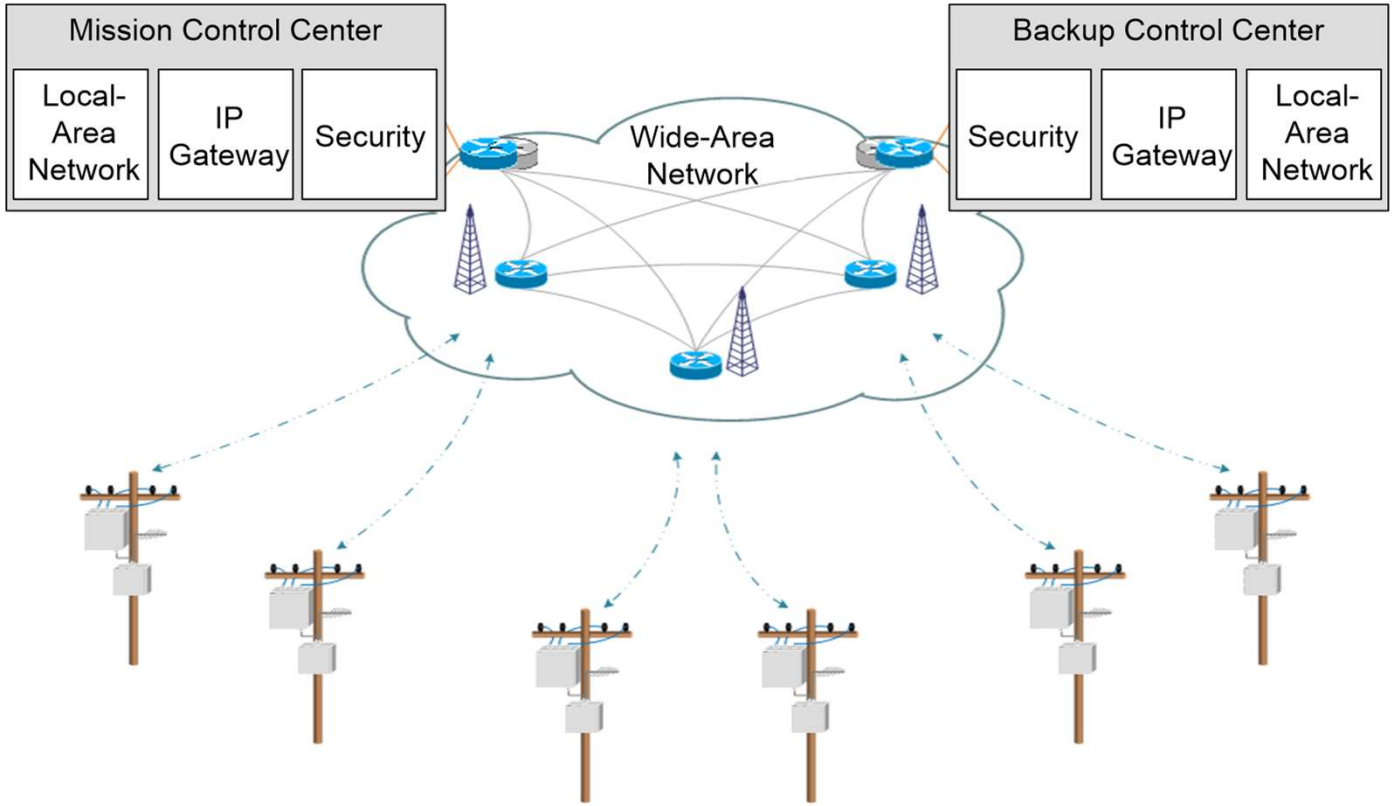
- Falling conductor protection (patented)
- Driven by high penetration of distribution PV
- Voltage profile monitoring and control
- Selective load shedding and restoration
- Power quality monitoring
- Apparatus and system condition monitoring

Advanced SCADA Features

- Increased accuracy of voltage and current
- Phase angle measurements across circuit
- GPS time-stamped data
- 30 synchrophasor samples per second for fast measurement (60 samples/sec in the future)
- IEC 61850 GOOSE messaging for real-time control
- Remote engineering access and event reports
- Advanced security features

SCADA System Architecture

Traditional



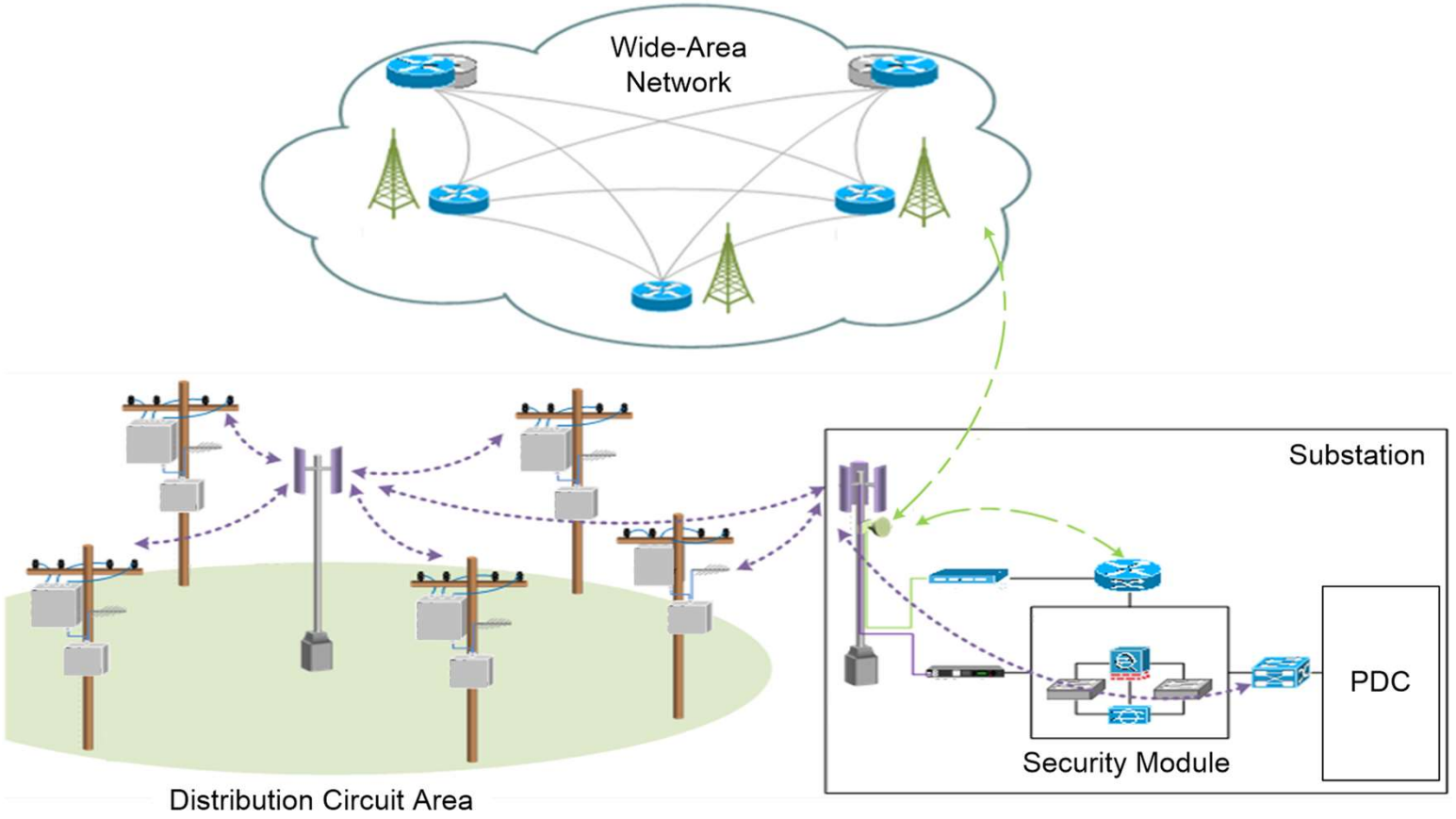
Slide 5

BV5 Does SDG&E own this artwork?
Brody, Valerie, 3/7/2019

BCJ6 Yes.
Bolton, Christopher J, 3/7/2019

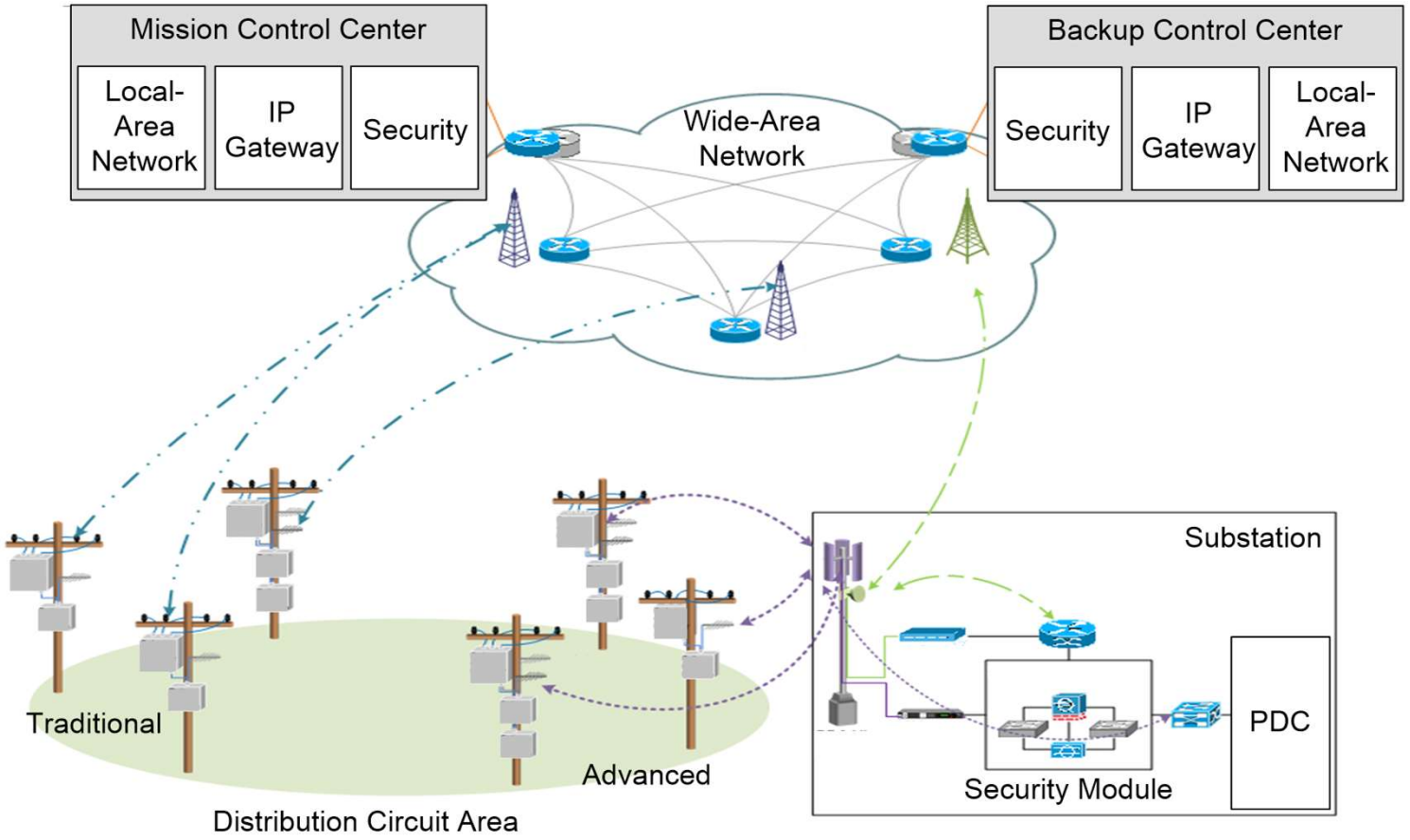
SCADA System Architecture

Advanced

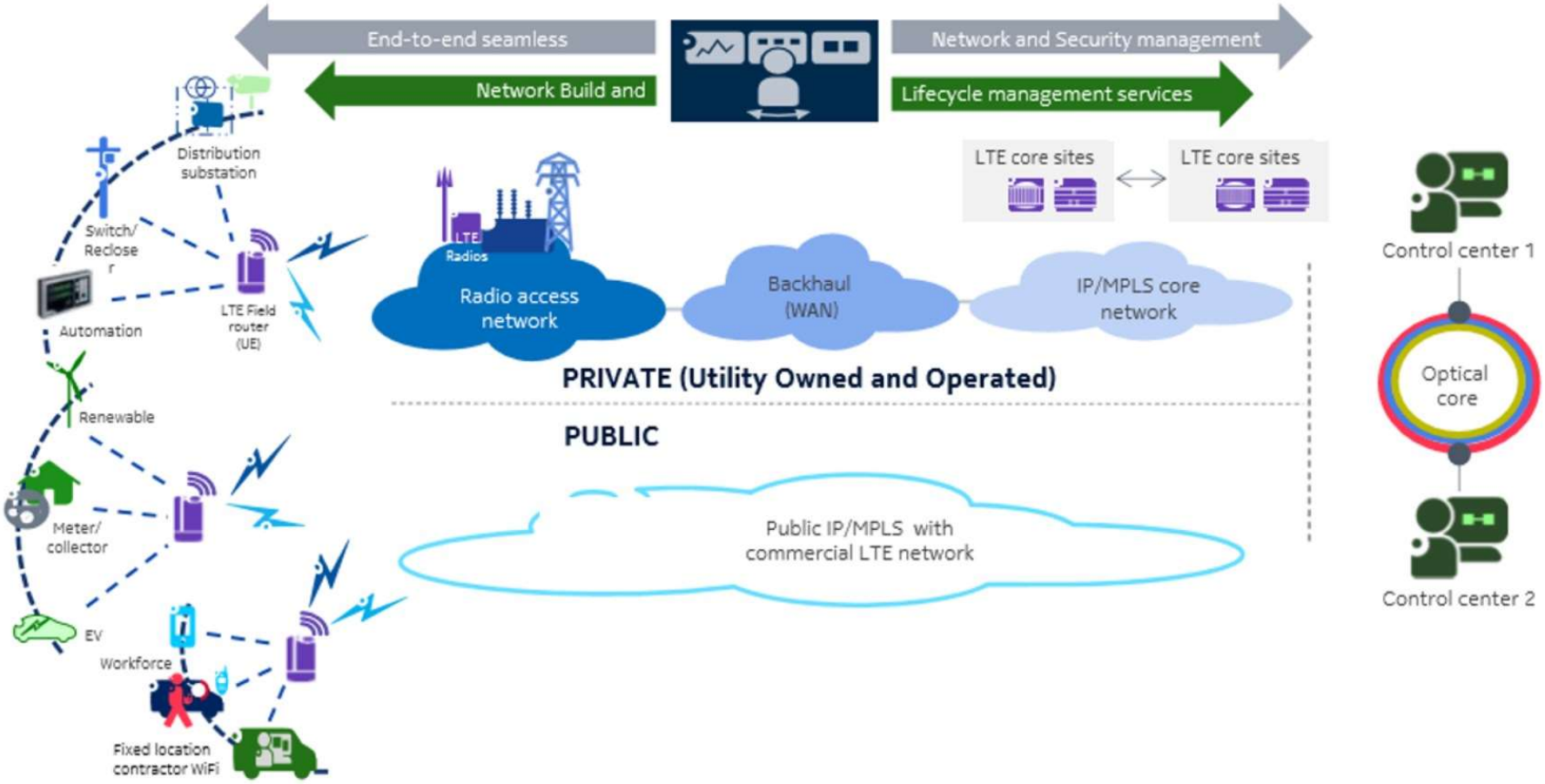


SCADA System Architecture

Traditional and Advanced Overlay

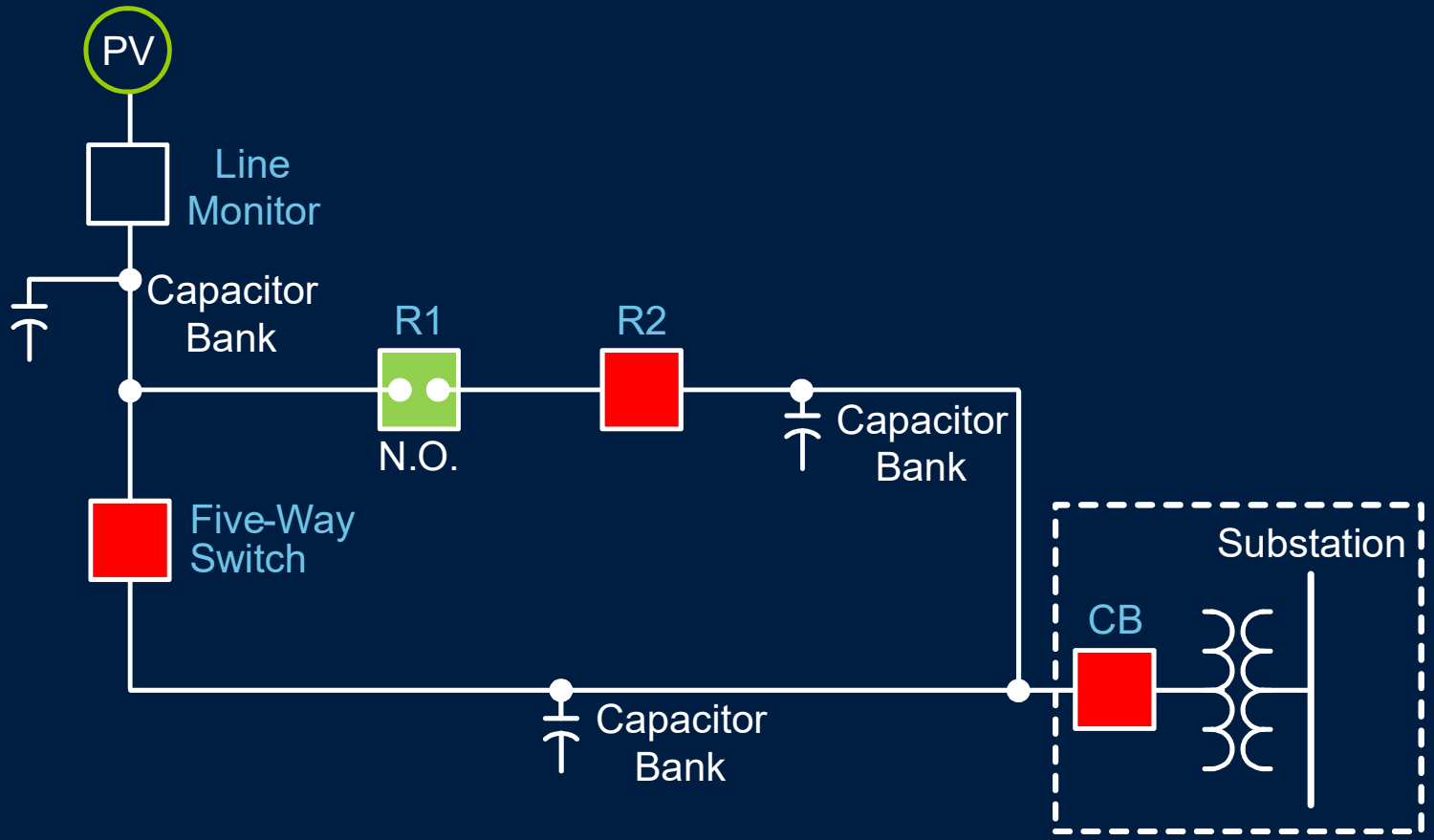


Private Long Term Evolution (LTE)
Advancing Communication
Making FCP More Secure



BV11
BV12

SDG&E Typical Feeder



Slide 9

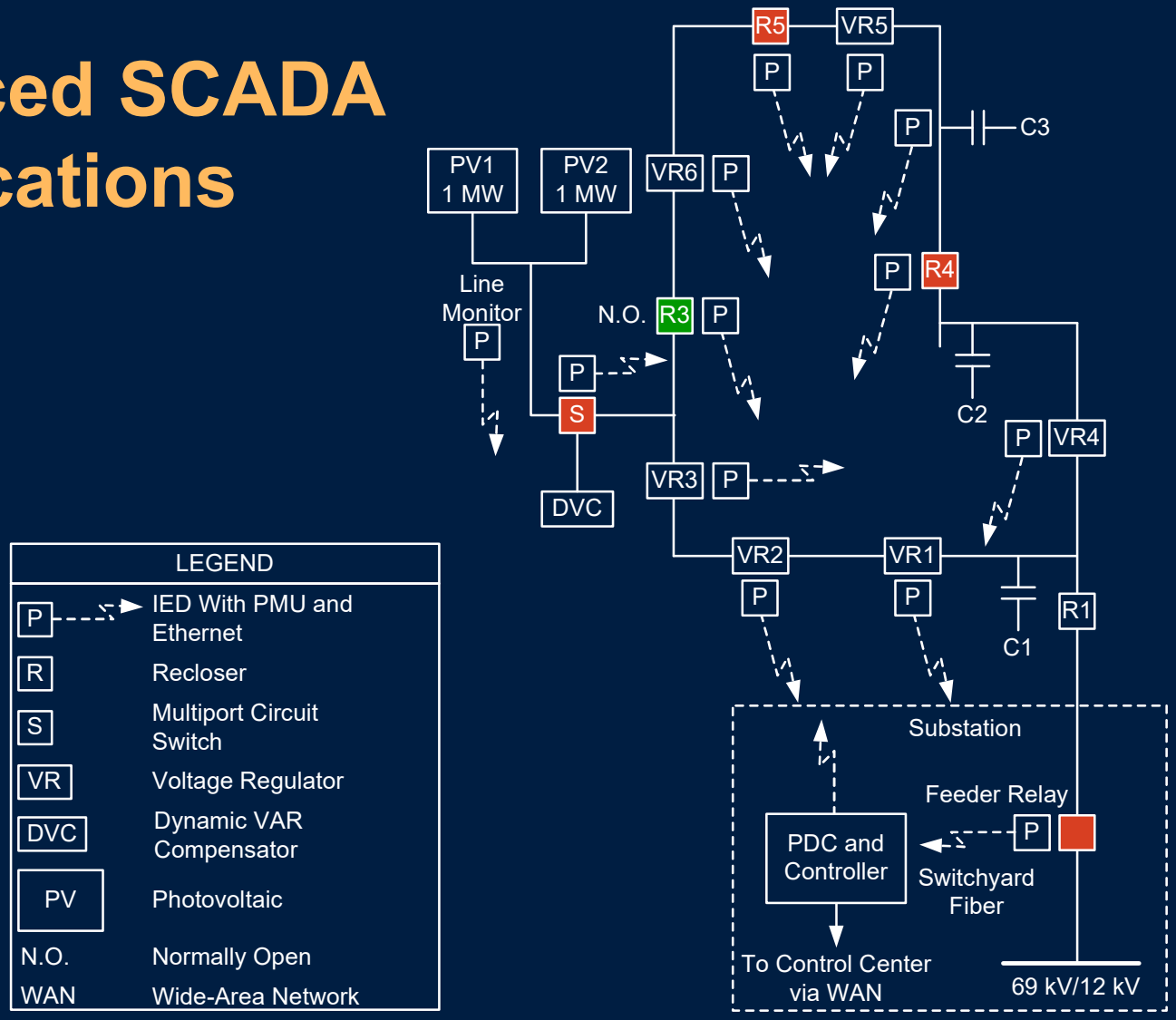
BV11 For slide 9 and on, wherever there are graphs that were developed jointly, please put this line in the lower left corner:

Brody, Valerie, 3/12/2019

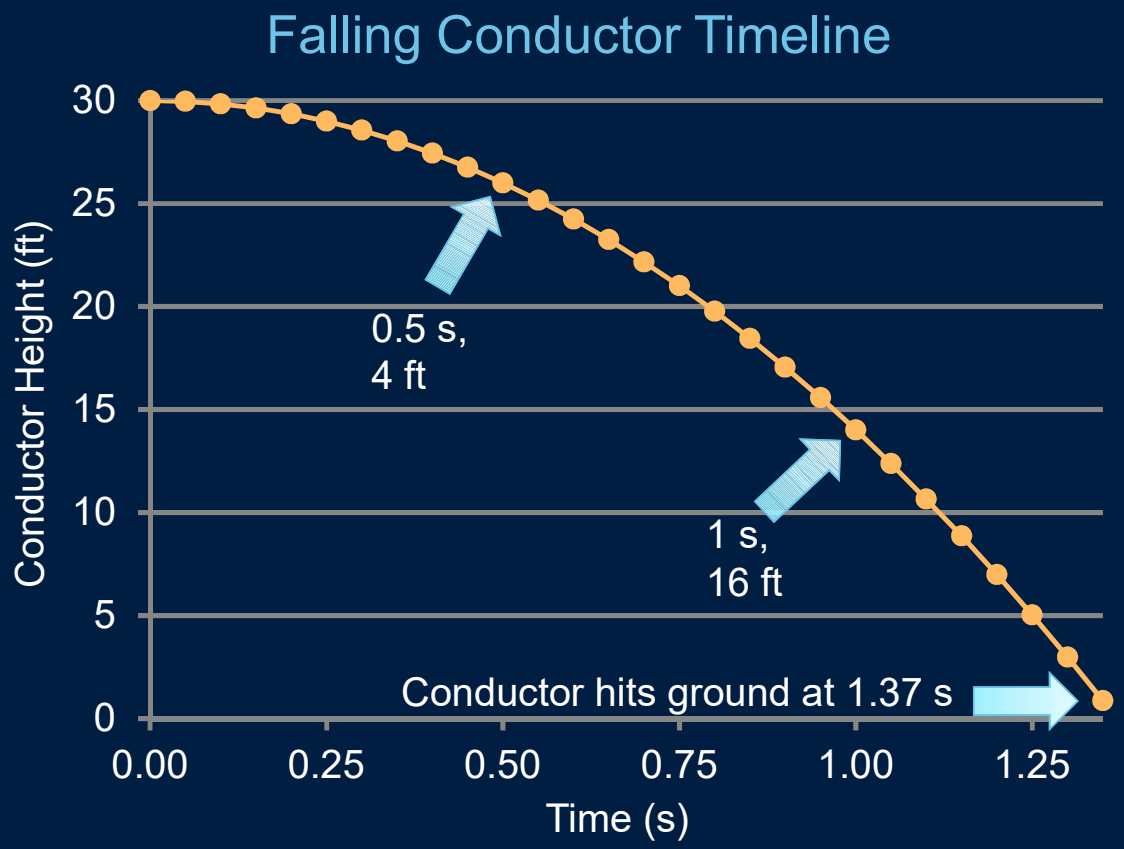
BV12 The illustrations herein were jointly developed by San Diego Gas & Electric, Quanta Technology, and Schweitzer Engineering Laboratories.

Brody, Valerie, 3/12/2019

Advanced SCADA Locations



Detect Broken Conductor and Trip Circuit Before Line Hits the Ground?



$$d = \frac{1}{2}gt^2 \rightarrow t = \sqrt{\frac{2d}{g}}$$

$$t = \sqrt{\frac{2(30)}{32.2}}$$

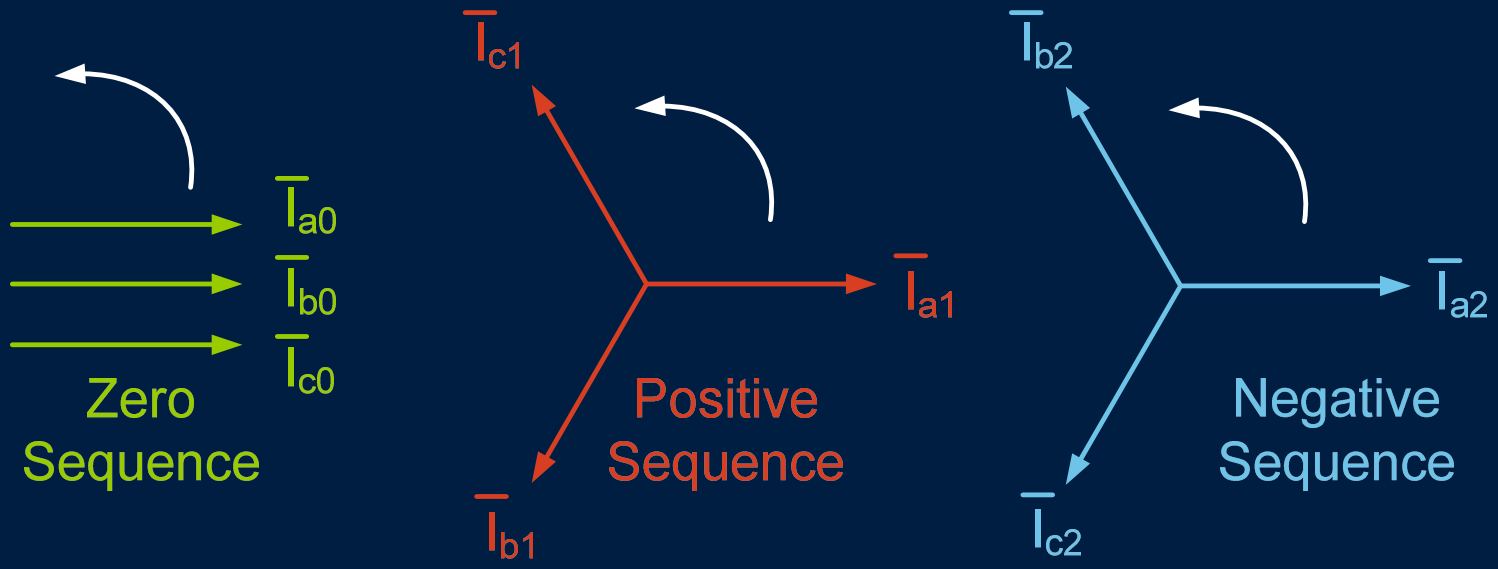
$$\text{time} \approx 1.37\,\text{s}$$

Slide 11

BV6 Do you have proper usage/license rights to use this image? If not, please delete it.
Brody, Valerie, 3/7/2019

BCJ7 Done.
Bolton, Christopher J, 3/7/2019

Sequence Components Analysis



Single Phase

$\bar{I}_{a0} = \bar{I}_{b0} = \bar{I}_{c0}$

Balanced

$\bar{I}_{b1} = a^2\bar{I}_{a1}$

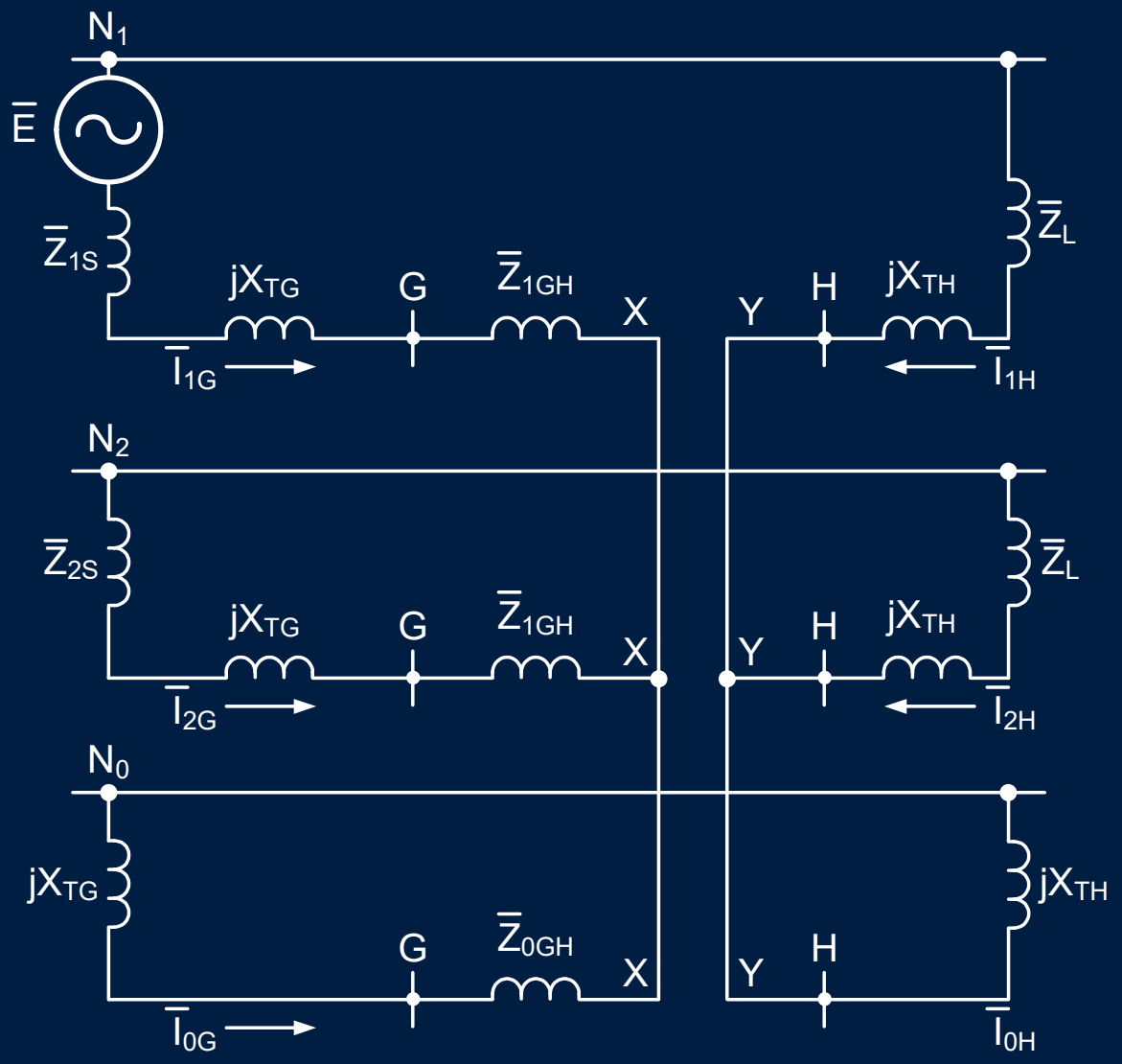
$\bar{I}_{c1} = a\bar{I}_{a1}$

Balanced

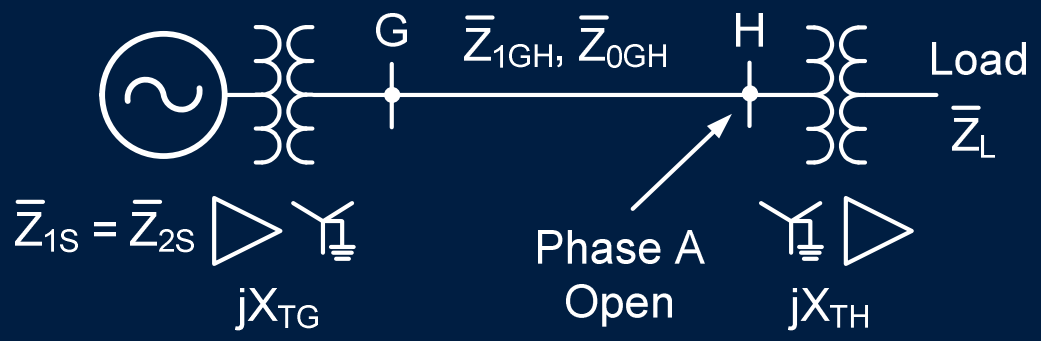
$\bar{I}_{b2} = a\bar{I}_{a2}$

$\bar{I}_{c2} = a^2\bar{I}_{a2}$

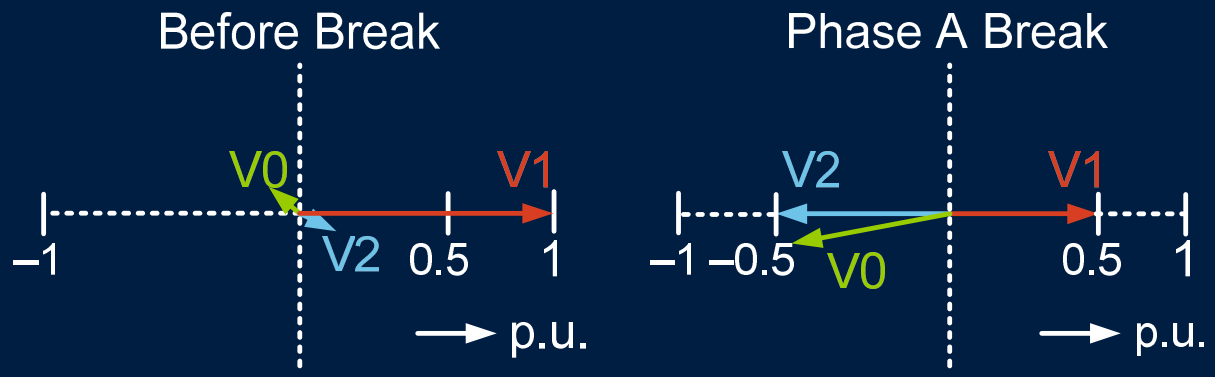
Open-Phase Analysis



Open-Phase Analysis

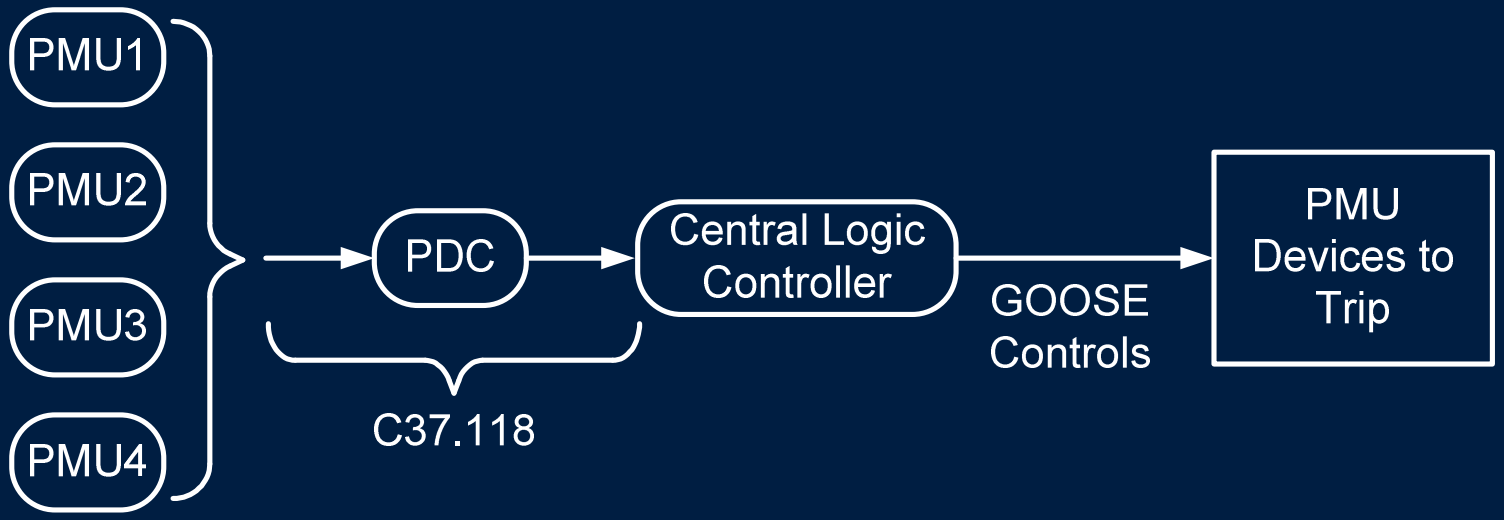


V_{NOM} = 1 p.u.



Detection Methods

- dV/dt (change detection)
- V0 and V2 magnitude
- V0 and V2 angle

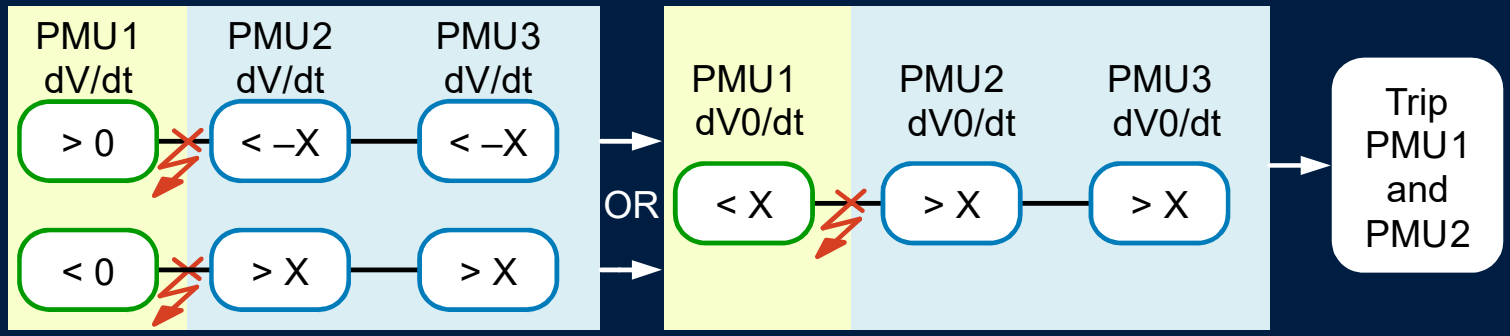


dV/dt Method

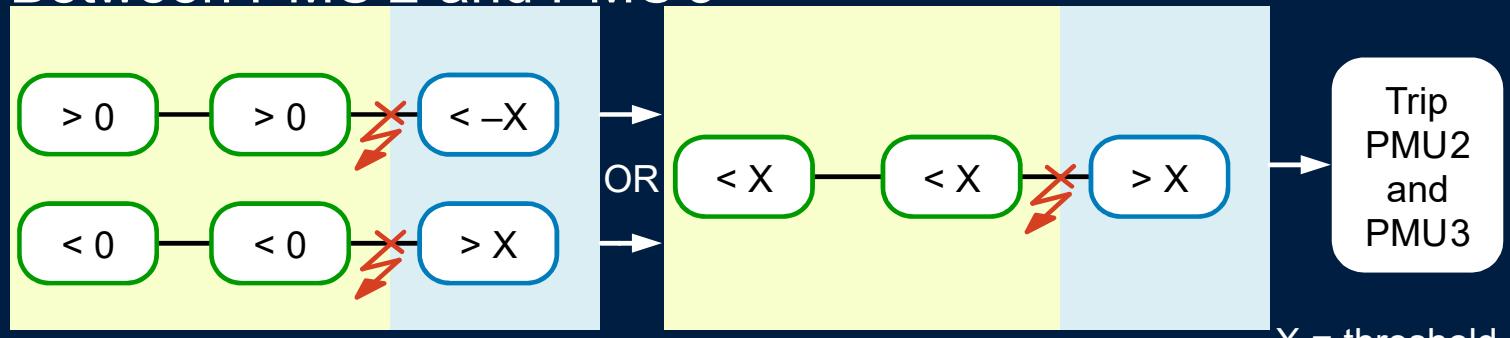
Conductor Break

dV0/dt Supervision Check

Between PMU 1 and PMU 2



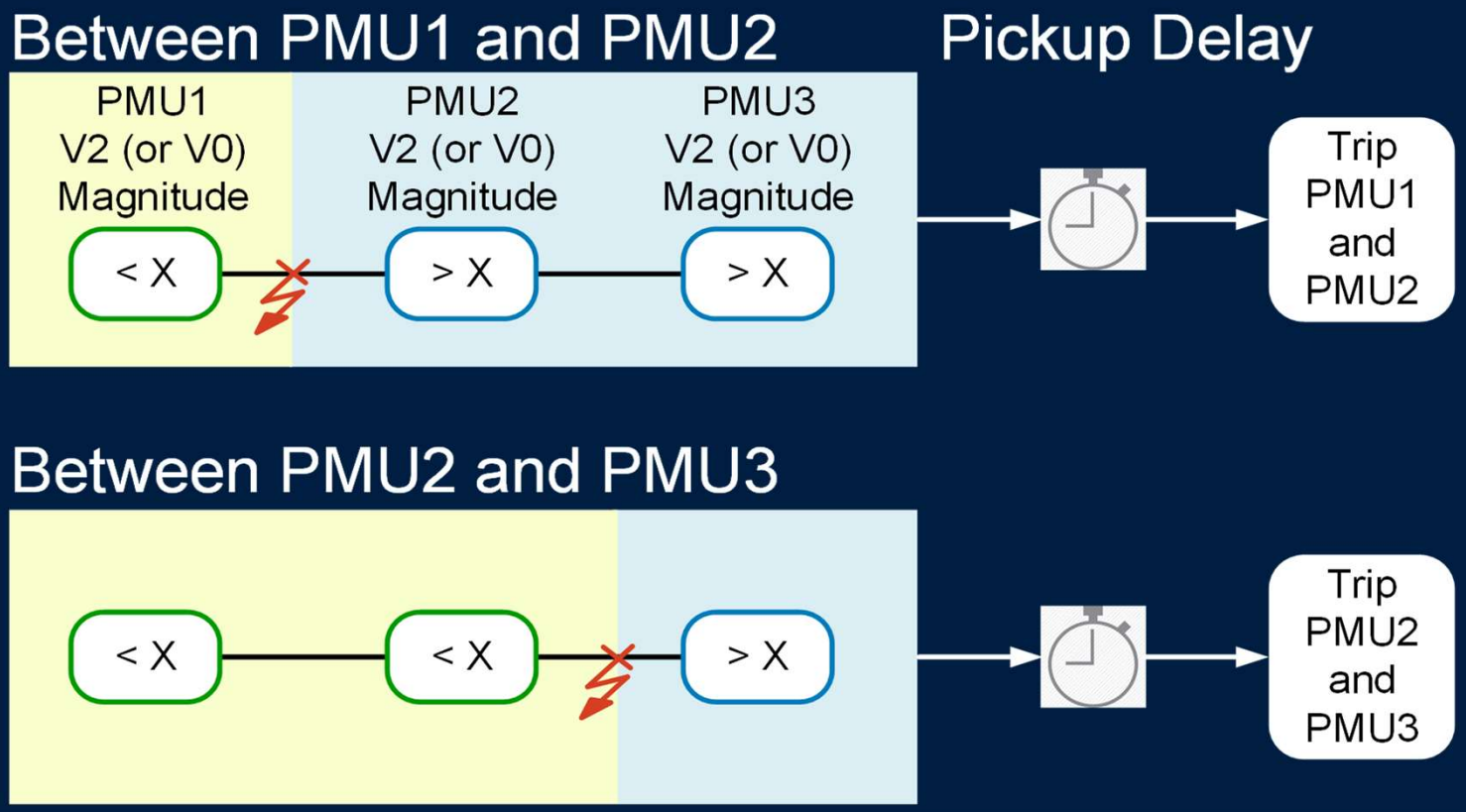
Between PMU 2 and PMU 3



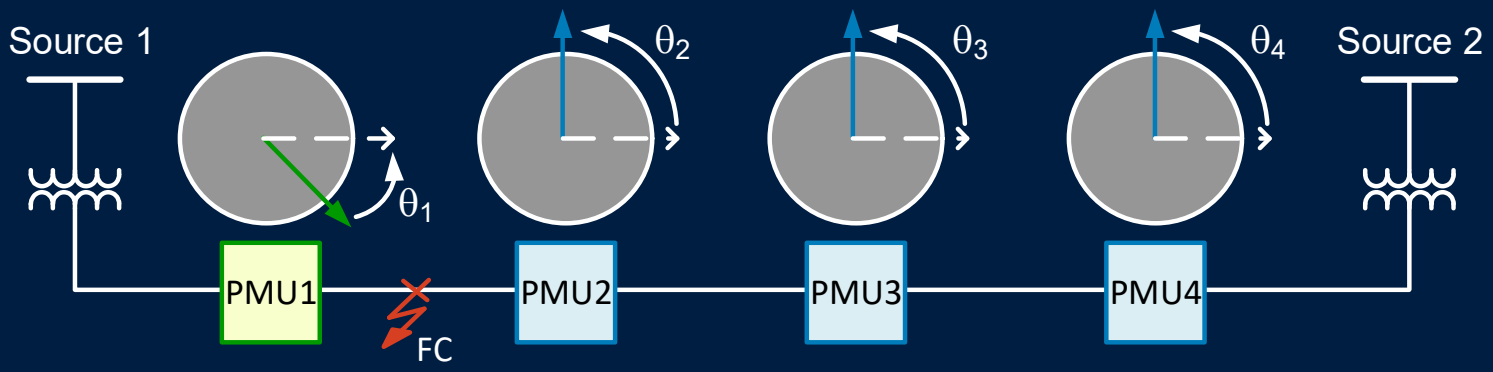
X = threshold

V2 and V0 Magnitude Method

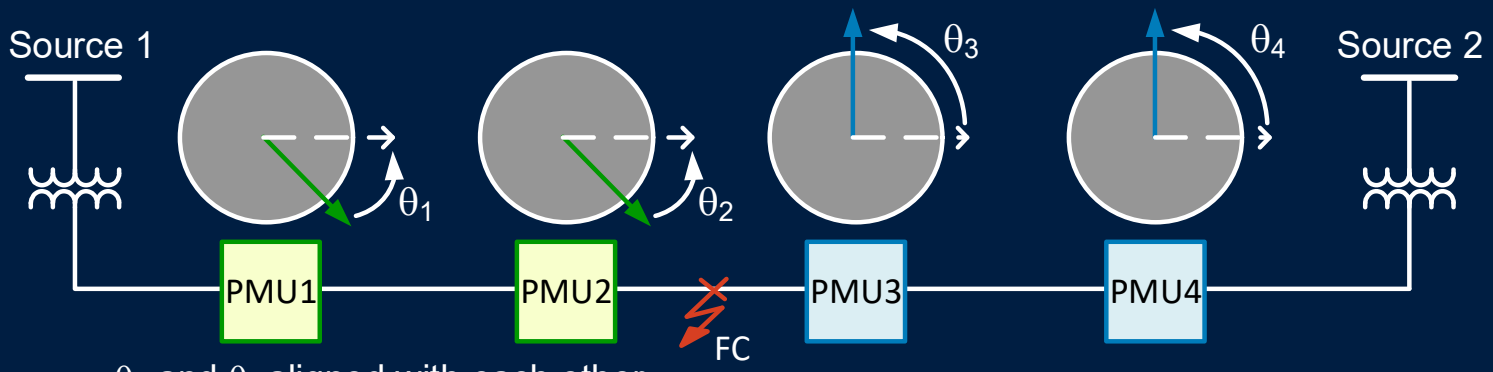
Conductor Break



V2 and V0 Angle Method



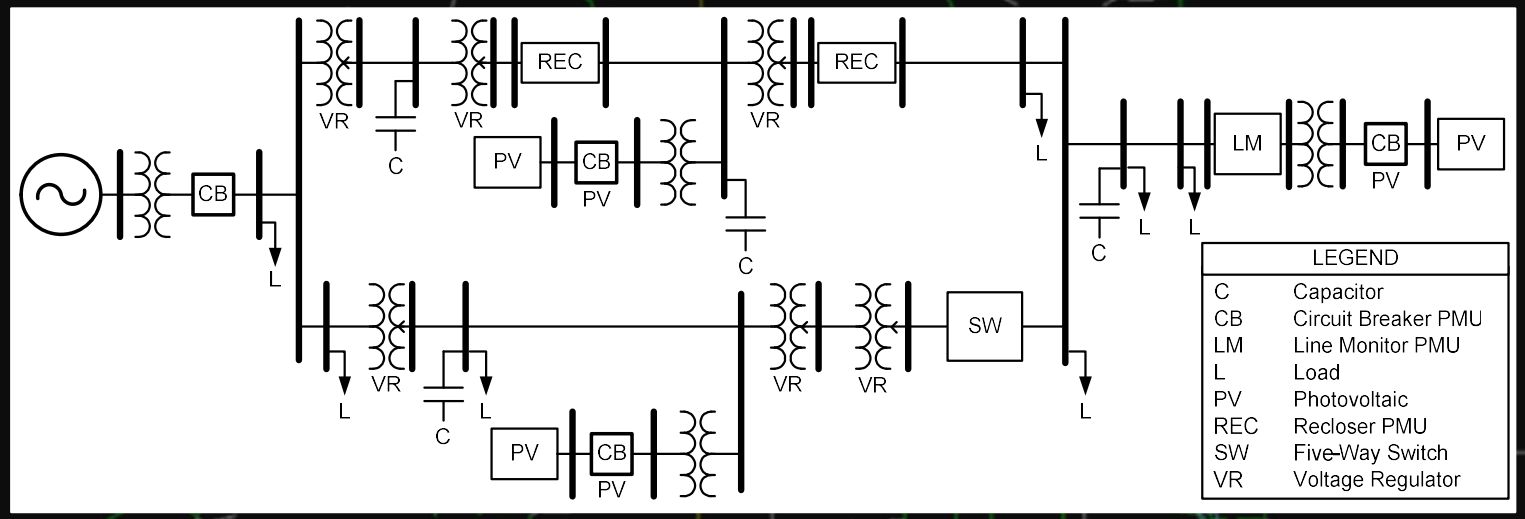
θ_1 not aligned with the other PMUs



θ_1 and θ_2 aligned with each other
θ_3 and θ_4 aligned with each other

θ is V2 or V0 angle

RTDS Feeder Model



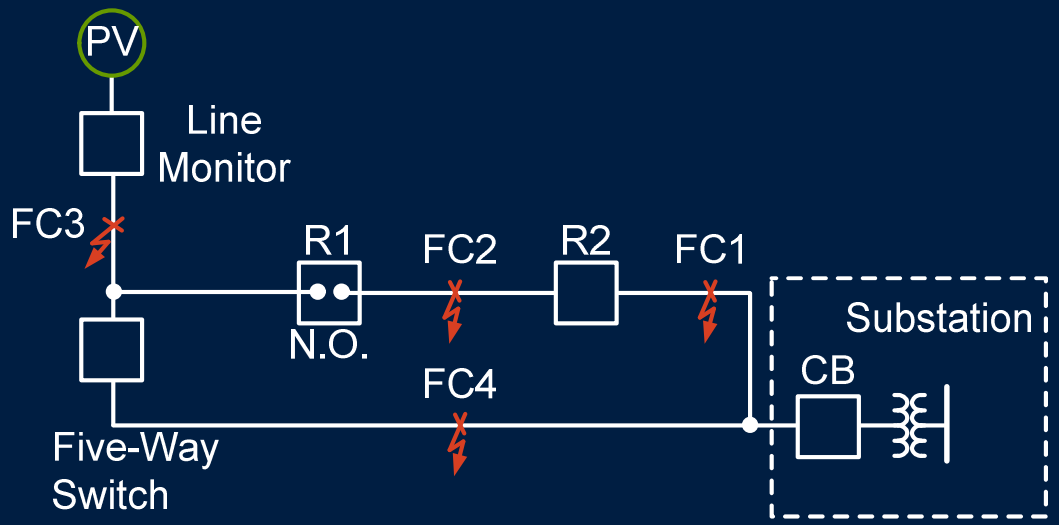
R1

CB1

Example Lab Test Results

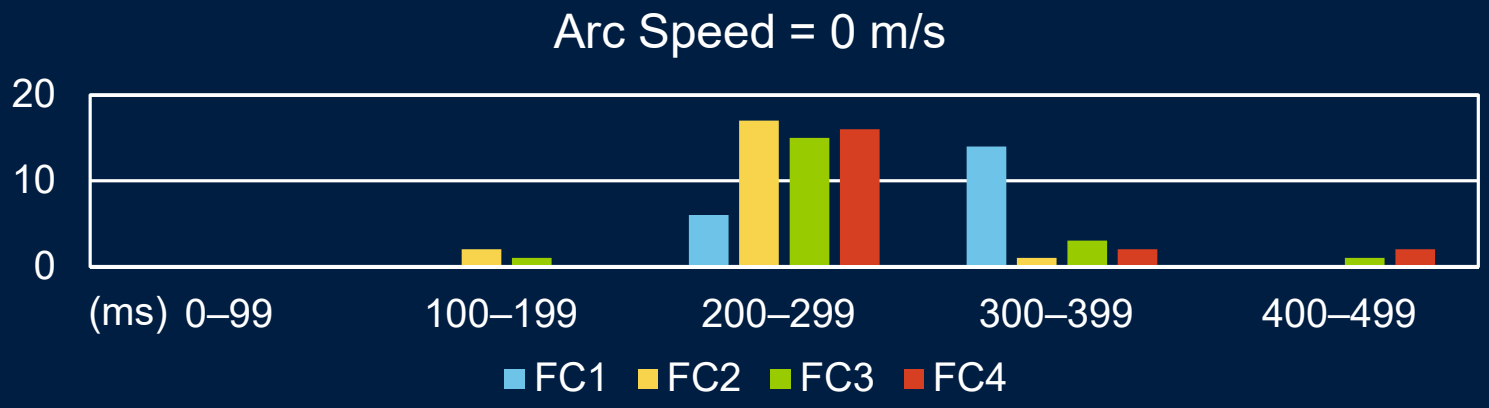
PV Off, Loop Open				
Load %	FC1	FC2	FC3	FC4
100	3	3	3	3
75	3	3	3	3
25	3	3	3	3

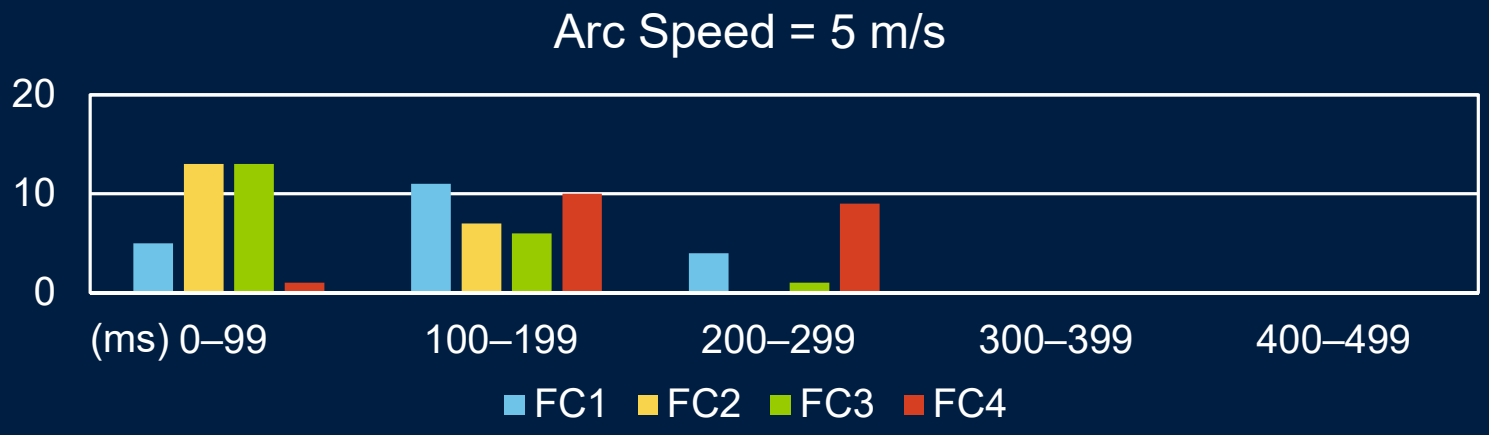
PV On, Loop Open					
Load %	PV%	FC1	FC2	FC3	FC4
100	100	3	3	3	3
	75	3	3	4	4
	50	3	3	3	3
	25	3	3	3	3
25	100	3	3	3	3
	75	3	3	3	3
	50	3	3	3	3
	25	3	3	3	3



Arc Speed and Results Comparison

Number of Test Cases Versus dV/dt Pickup Times





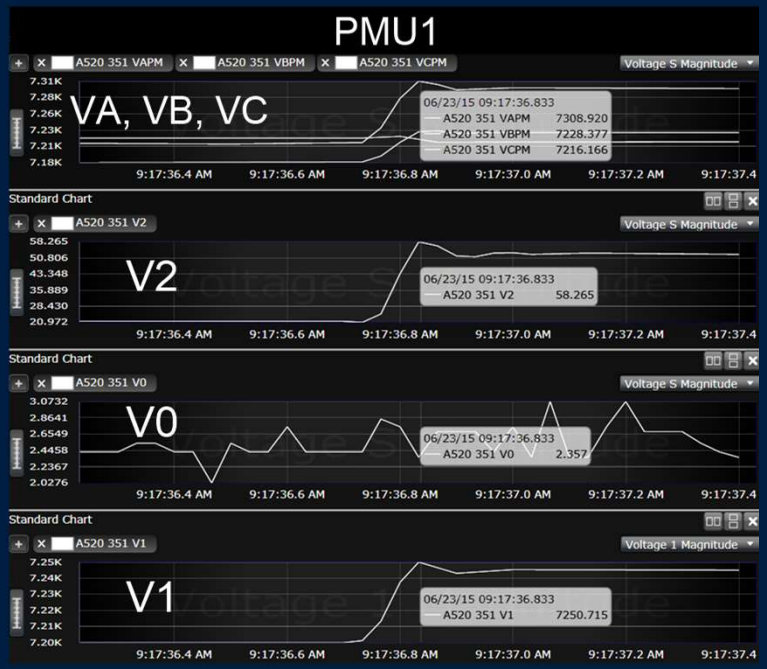
Security Testing

- Capacitor bank switching
- Voltage regulator tap unbalance
  - Angle method for ≈ 4.5% voltage (6 taps)
  - V0 magnitude method for ≈ 10% voltage (15 taps)
- Largest single-phase load switching
- PV operation
- Internal / external faults

Results

Detection Screen

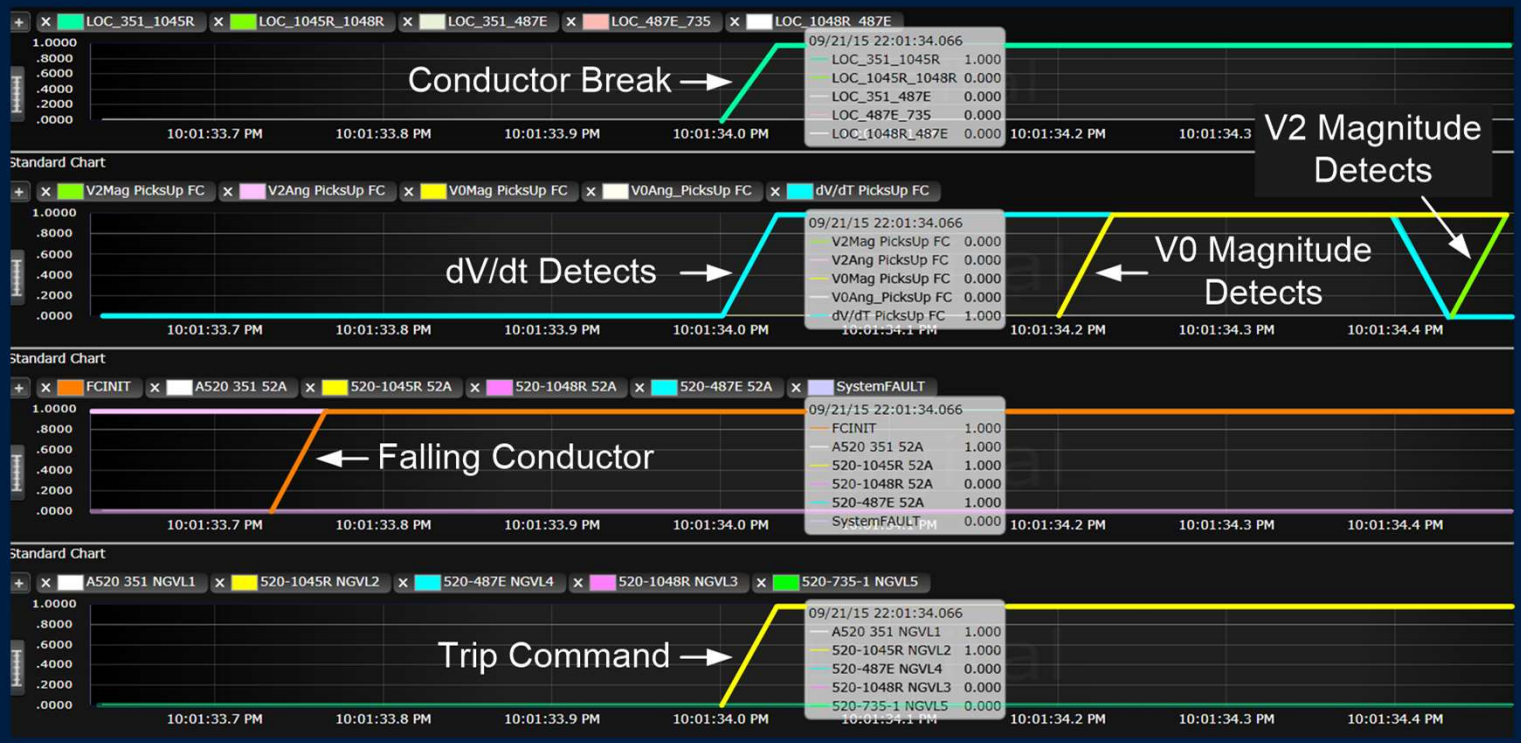
Inverter Response



- Conductor break between PMU1 and PMU2
- PV inverter source ON

Results

dV/dt and Magnitude Methods

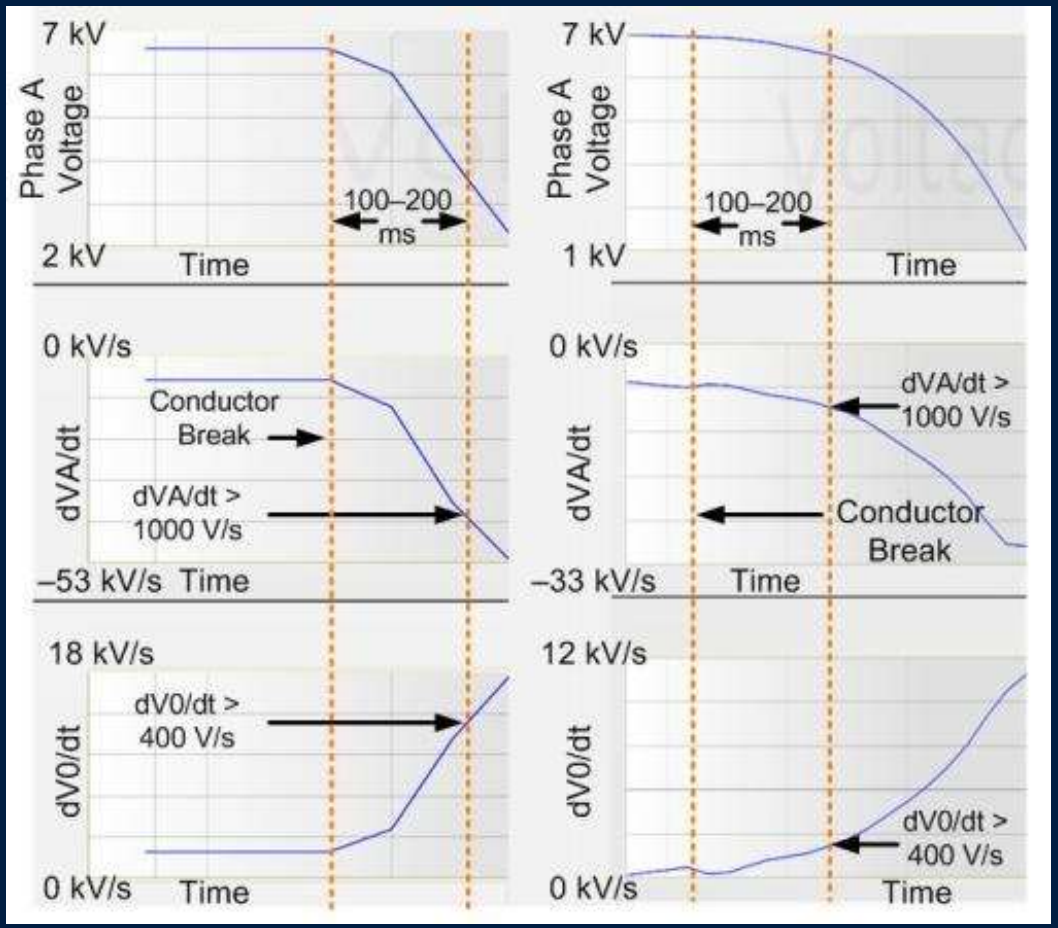


Field Installation and Testing

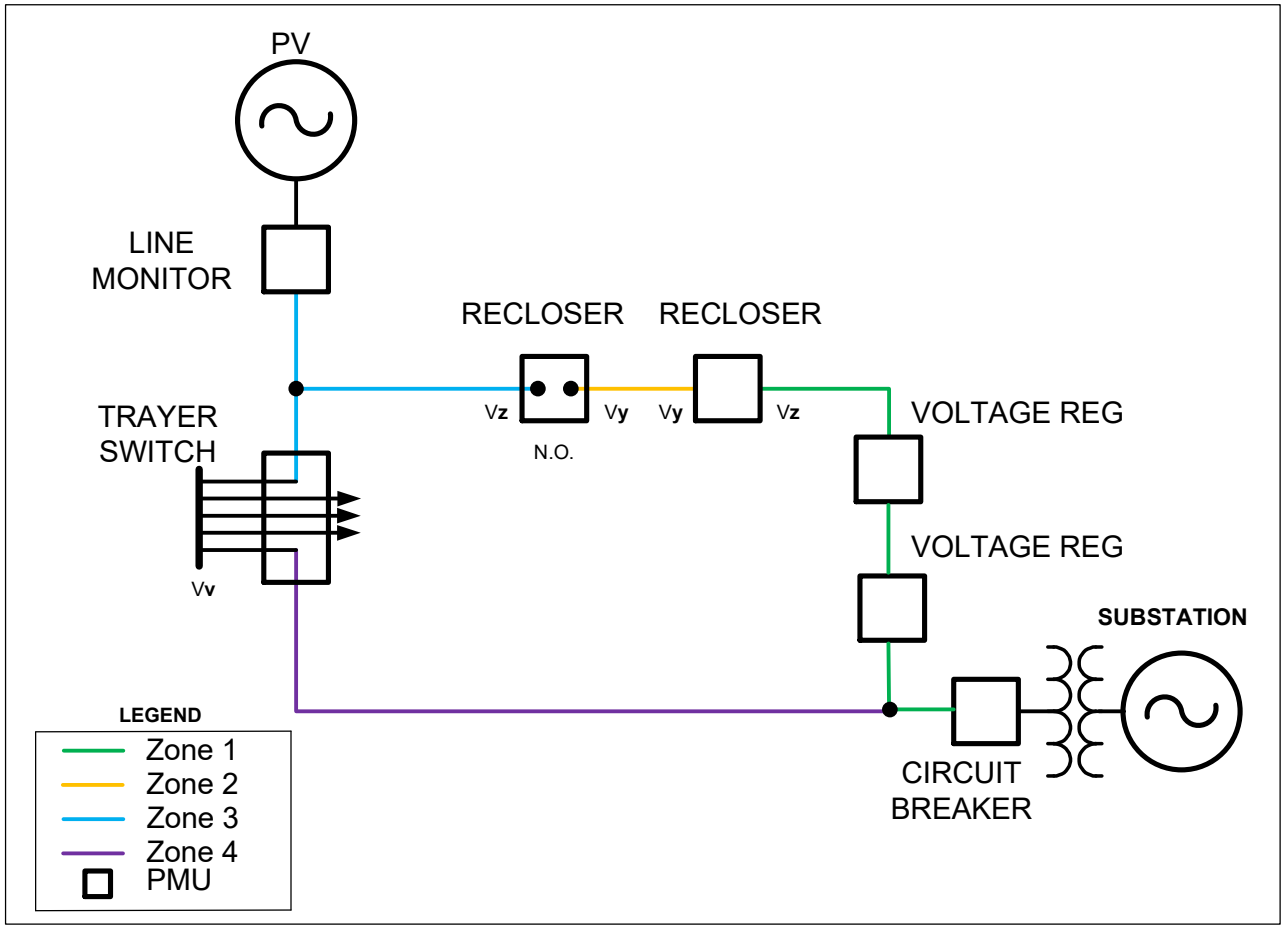
- First system installation in January 2015
- Falling Conductor Protection (FCP) in monitoring mode
- Simulation of conductor breaks with disconnect switch opening on recloser
- 100% correct operation
- Ethernet radio tuning required

Breaking Arc – Field Versus Lab Tests

Field Result RTDS Model

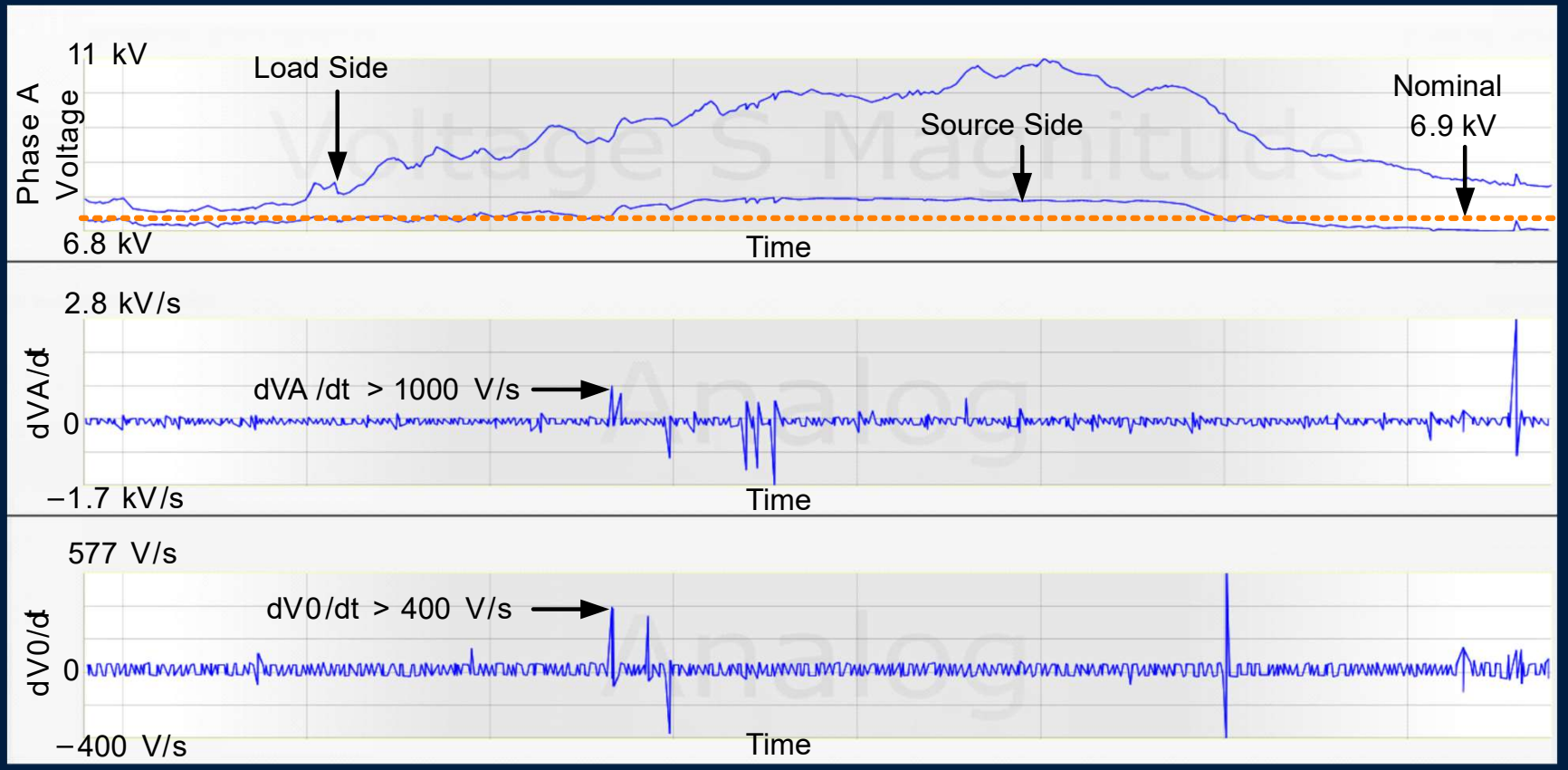


Falling Conductor Zones

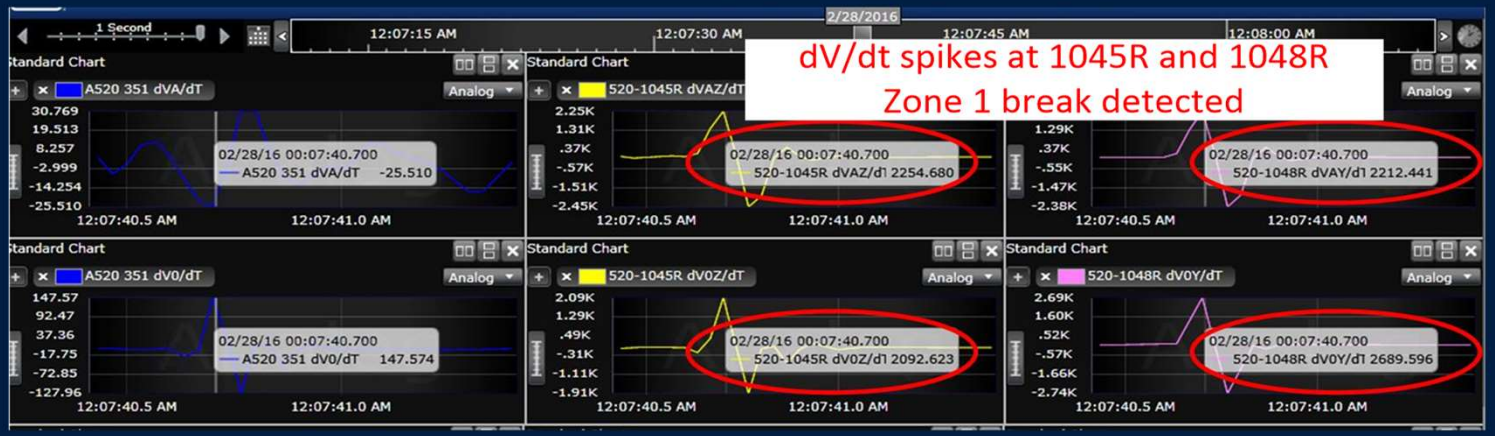


Synchrophasors show detailed circuit behavior

Capacitive voltage sensor discoveries

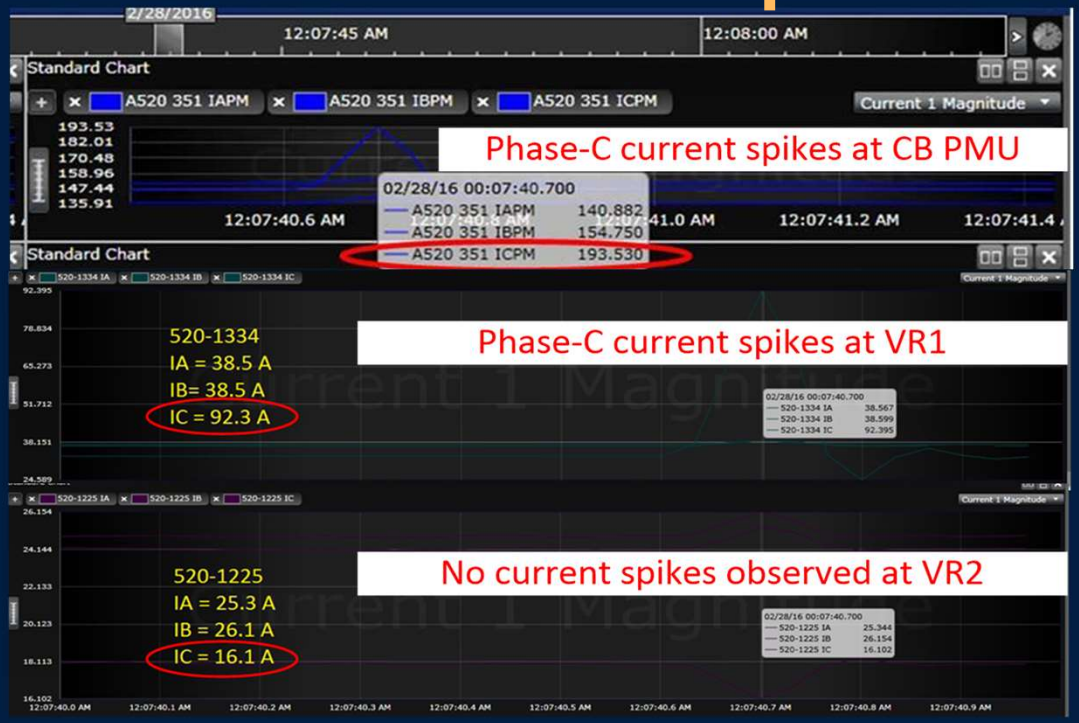


Zone 1 dV/dt Operation



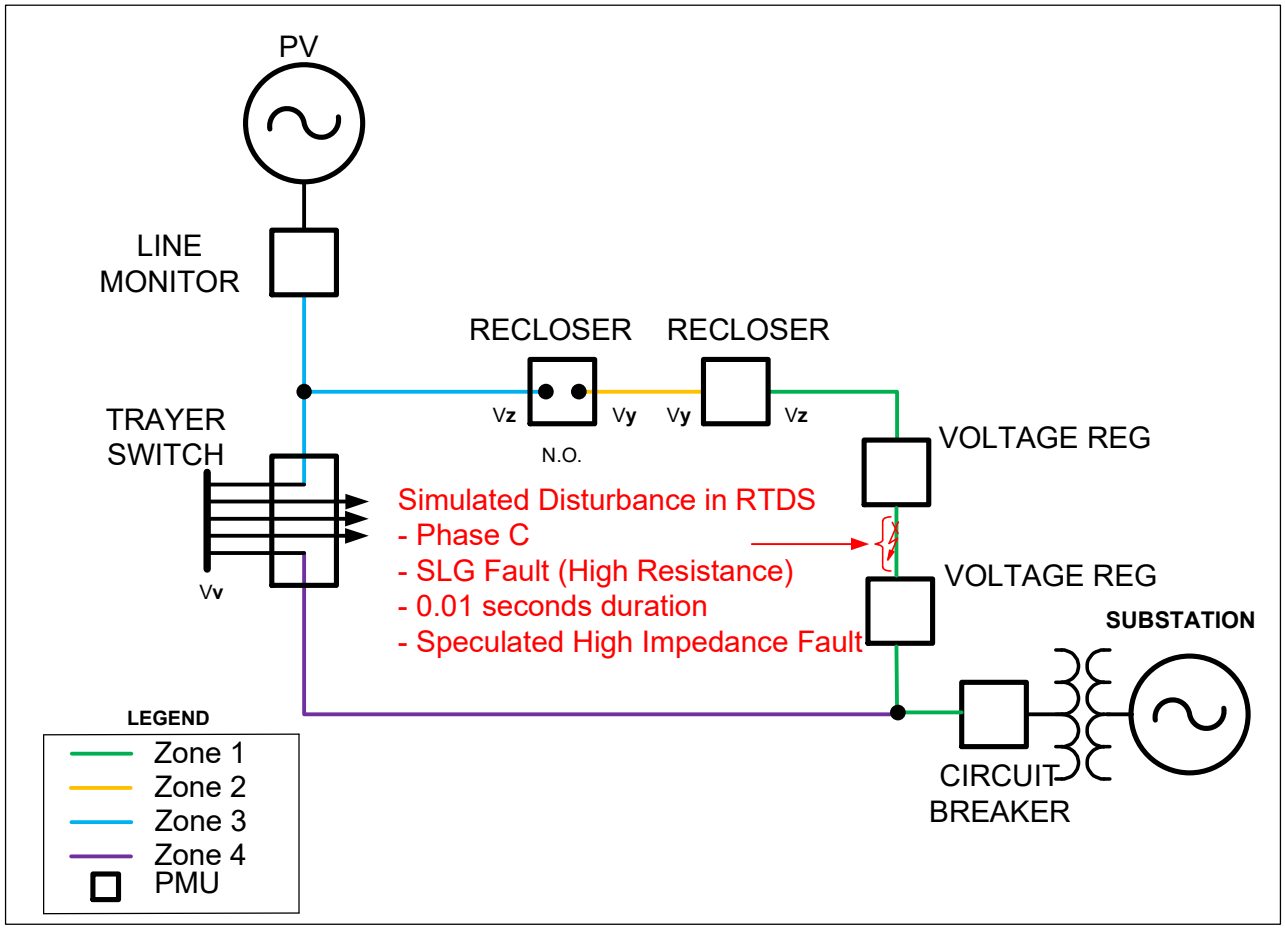
- Field Event – 28th Feb 2016
- FC detected by dV/dt between CB and R1

Zone 1 Current Spikes

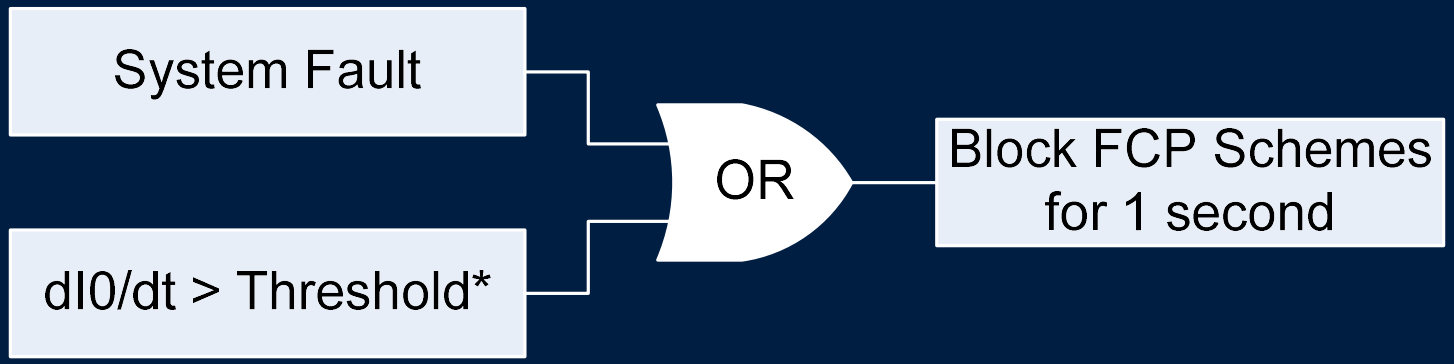


- Current spikes observed at CB and VR1, but not at VR2
- Indicates temporary fault between VR1 and VR2

RTDS Simulation

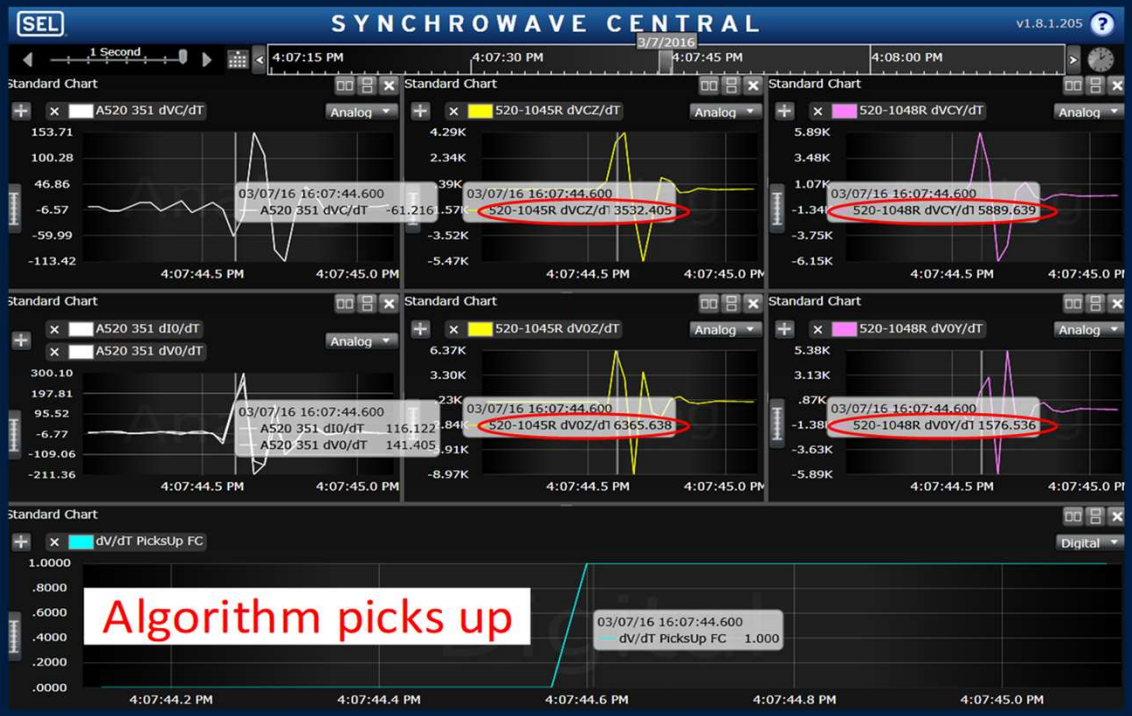


dI0/dt Supervision



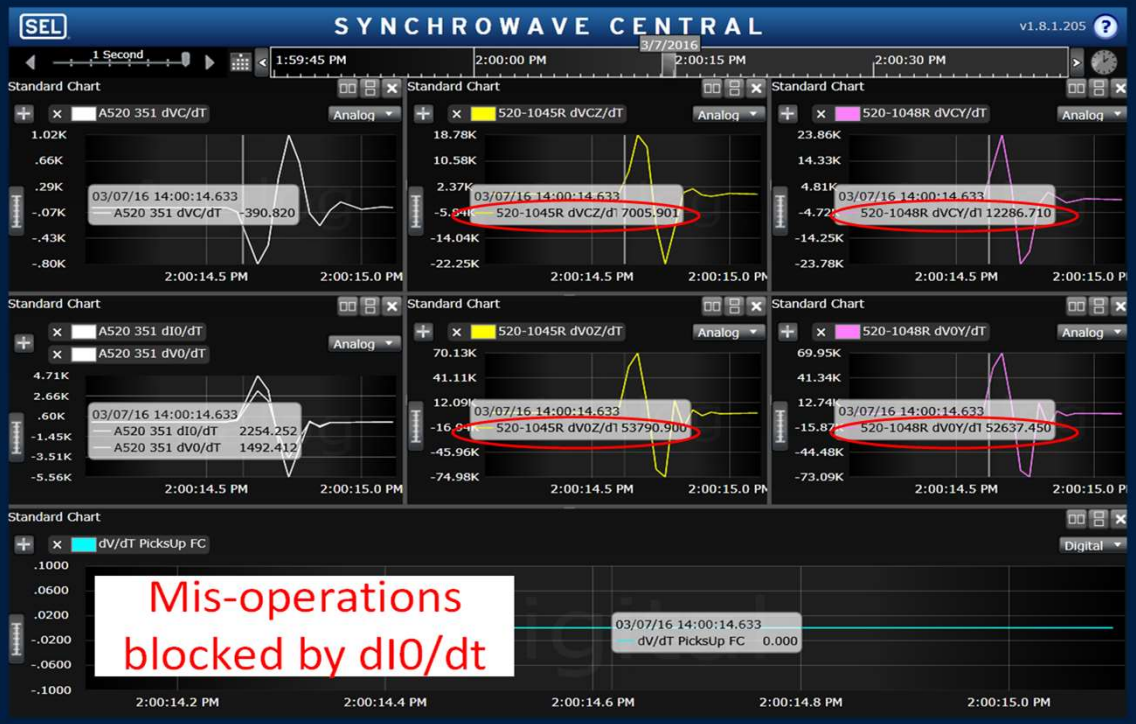
- Threshold based on RTDS testing results
- dI0/dt spikes at CB PMU used to block falling conductor detection algorithms
- Temporary faults can be blocked using this supervision

Lab Simulation – Before dI0/dt



- Zone-1 mis-operation confirmed in lab
- dI0/dt block not implemented
- Mis-operation similar to field event

Lab Simulation – After dI0/dt



- Zone-1 mis-operation simulated in lab
- dI0/dt blocks Falling Conductor scheme
- System abnormal alarm condition

System Protection is a Balancing Act

- **SPEED** FAST TO MINIMIZE DAMAGE
- **SENSITIVITY** RELAY SEES FAULT
- **SELECTIVITY** REMOVE FAULTED ELEMENT ONLY
- **SECURITY** DO NOT TRIP FALSELY
- **SIMPLICITY** SIMPLE CONTROL SCHEMES

FCP Compliments Existing Layers of Protection

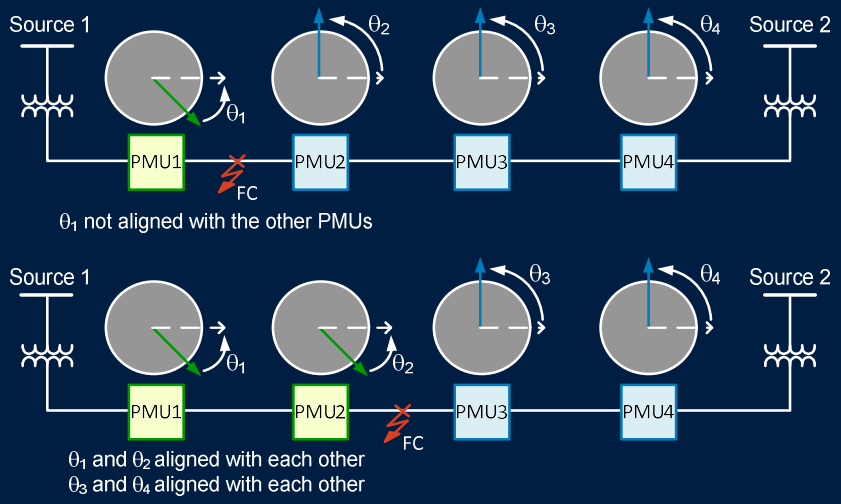
- FCP – Falling Conductor Protection detects break in conductor
  - Fastest – trips before the fault
  - Coordination – FCP should be first
- Overcurrent – Time and Instantaneous
  - Simple coordination
- SGF – Sensitive Ground Fault detects high-impedance ground fault
  - Slow – 3.5 to 5.5 seconds
- Advanced SGF - More sensitive than SGF using adaptive set point, spike counting, and/or harmonics
  - Slower – > 5 seconds

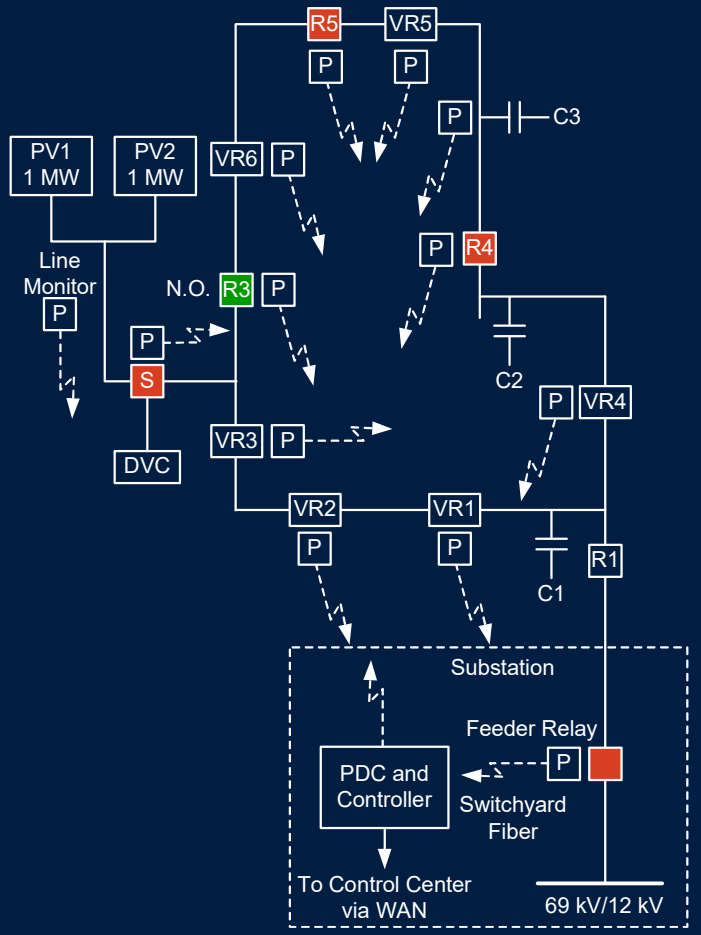
FCP Limitations

- Does not detect wire down without break
- Needs fast, secure, and available communication path to circuit PMUs
- Uses voltage from each protected circuit path end – a journey of years for coverage
- Learning features of new technology

Ease of Application

- Key requirement achieved – no circuit-dependent application settings
- FCP logic only needs topology of circuit and PMU IEDs





Summary

- Advanced SCADA has 60 use cases including FCP
- FCP isolates broken conductors in 0.2 – 0.5 s (half the distance to the ground) preventing the fault
- FCP is dependable in lab test including high PV penetration
- FCP mitigates HILP events – **fire and hazard reduction**
- Confidence built from secure and reliable field performance
- Compliments existing protection
- Scalable design needs only circuit layout information

Next Steps

- FCP of first equipped circuit commissioned on 11/18/2016
- Additional circuits equipped and commissioned in 2017-2019
- Pursuing ongoing work to reduce fire risk and enhance public safety
- Installing new IEDs with PMU capable devices with moderate additional cost
- SDG&E will be well positioned for future PV penetration
- Overall goal of enabling FCP on 100% of HFTD Tier 2 and Tier 3 circuits

Questions?