Detecting and Isolating Falling Conductors in Midair – First Field Implementation Using Private LTE at Protection Speeds

Charlie Cerezo and Caleb Murphy
San Diego Gas & Electric Company

Tanushri Doshi, Rohit Sharma, and Jay Lopes
Schweitzer Engineering Laboratories, Inc.

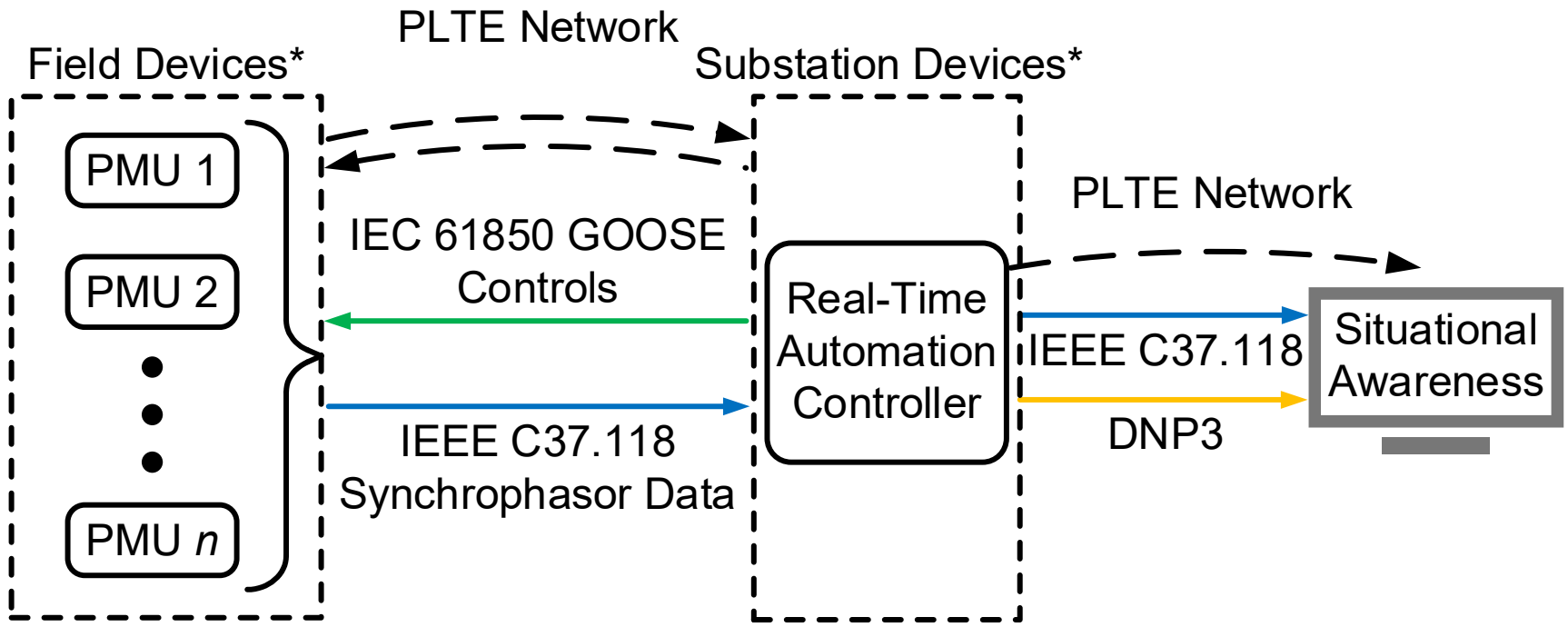
SDG&E distribution network

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

Falling Conductor Protection (FCP)

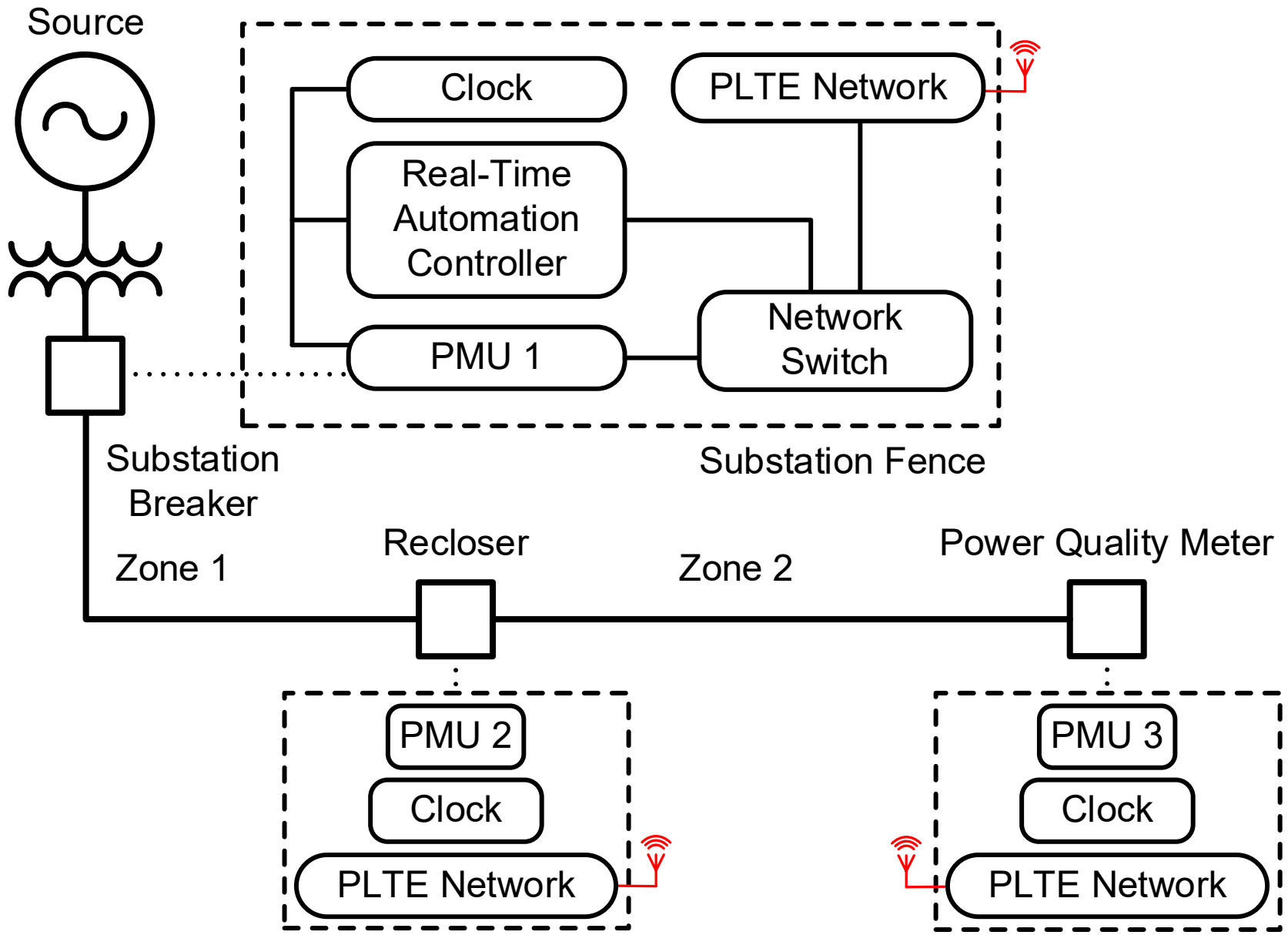
FCP: Design elements

- IEDs:
  - IEEE C37.118
  - IEC 61850 GOOSE protocol
- Real-time automation controller (RTAC)
- Communications network
  - High speed and low latency
  - Ethernet radio, fibers, and private Long-Term Evolution (PLTE)
- Time synchronized with high-accuracy clock



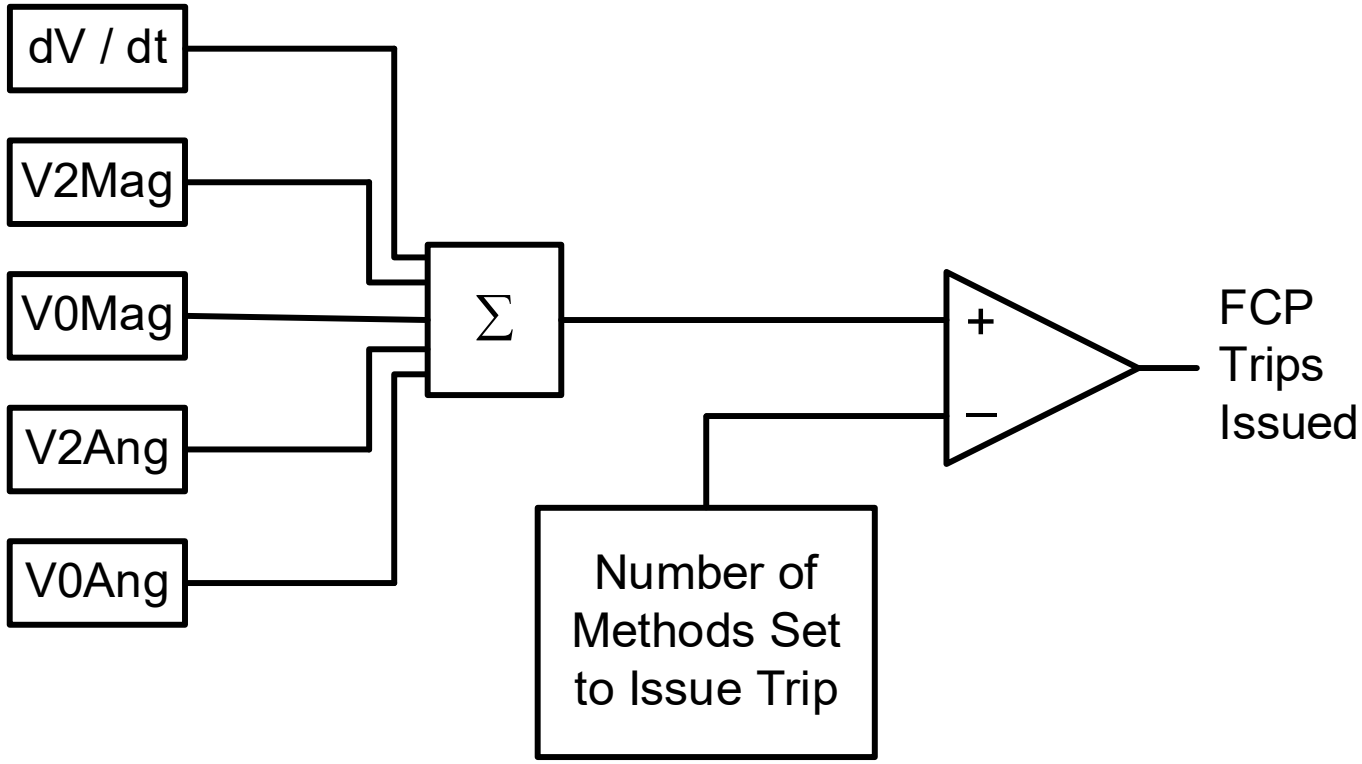
FCP: System architecture

- Substation devices
- Field devices
- Zone assignment
- Communications network

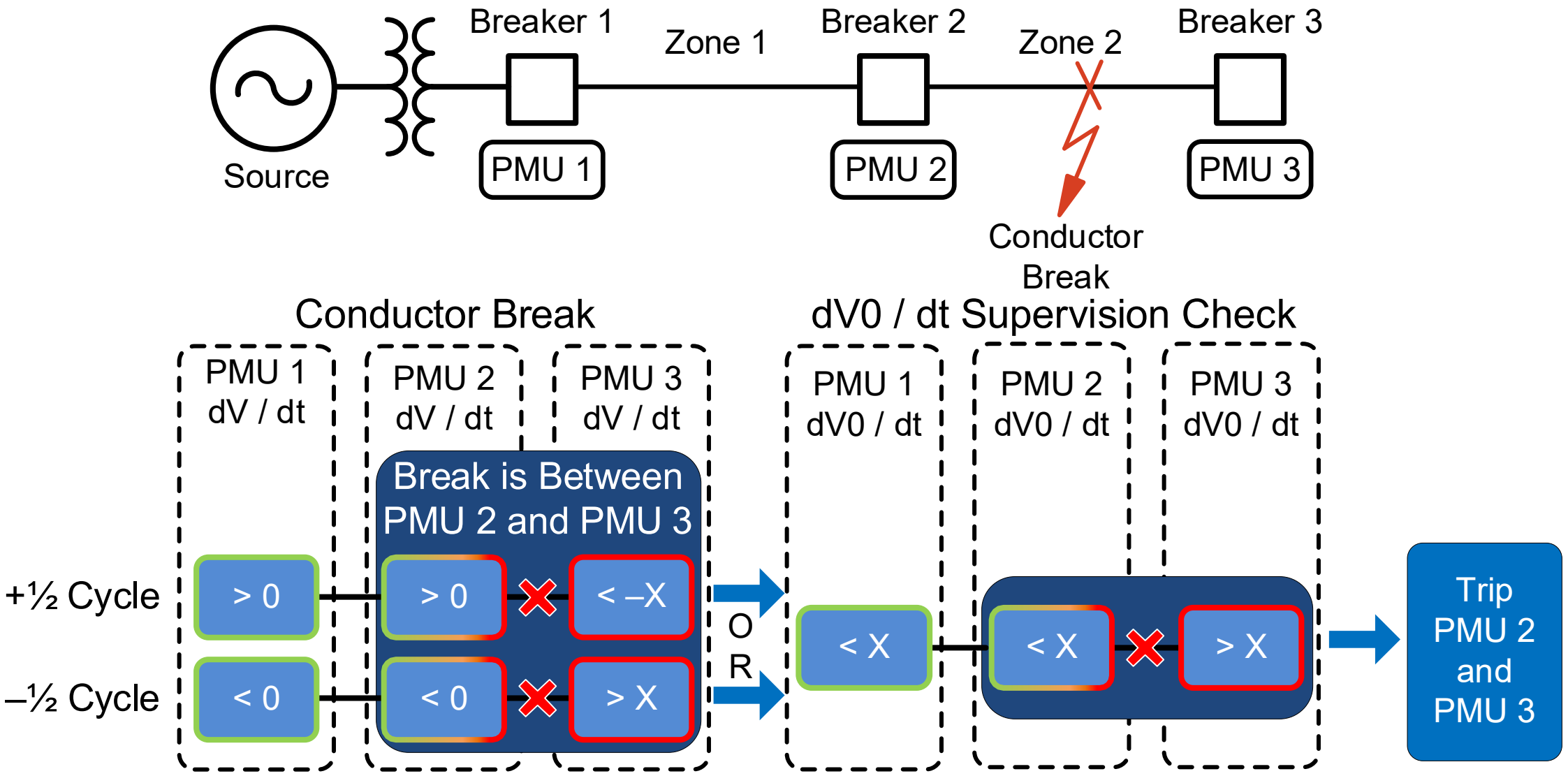


FCP: Detection methods and FCP trip

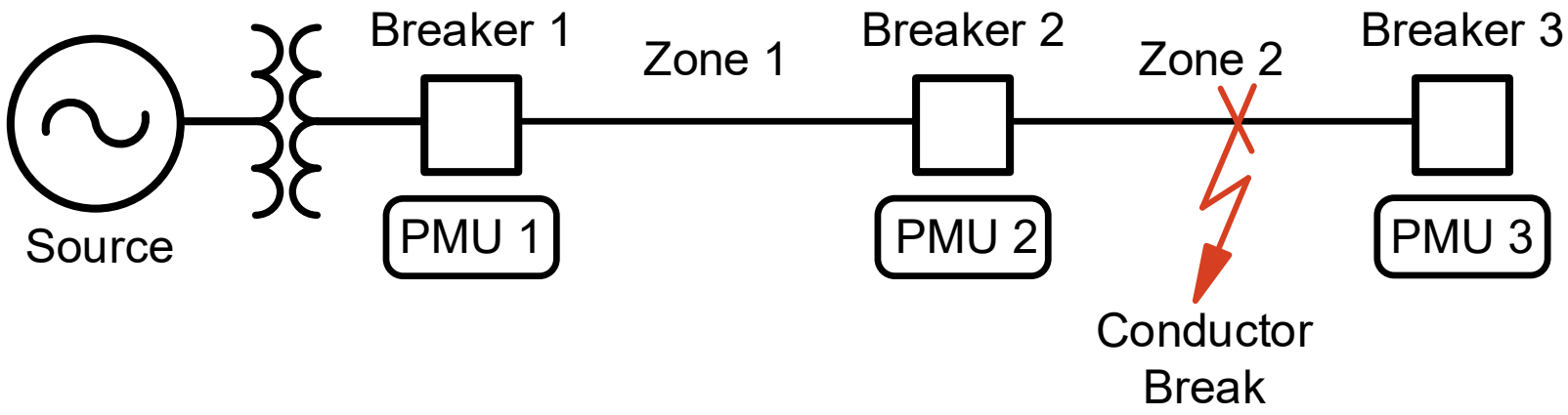
- Detection methods
- User-settable voting scheme to issue FCP trips

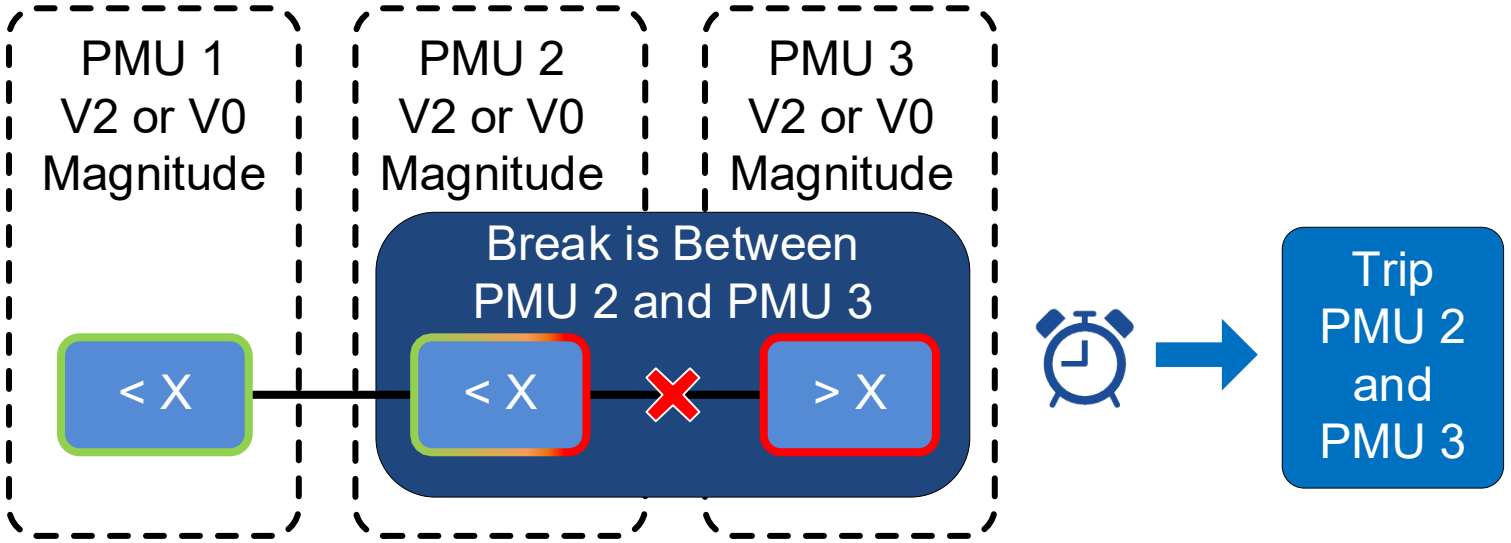


Detection method: dV / dt

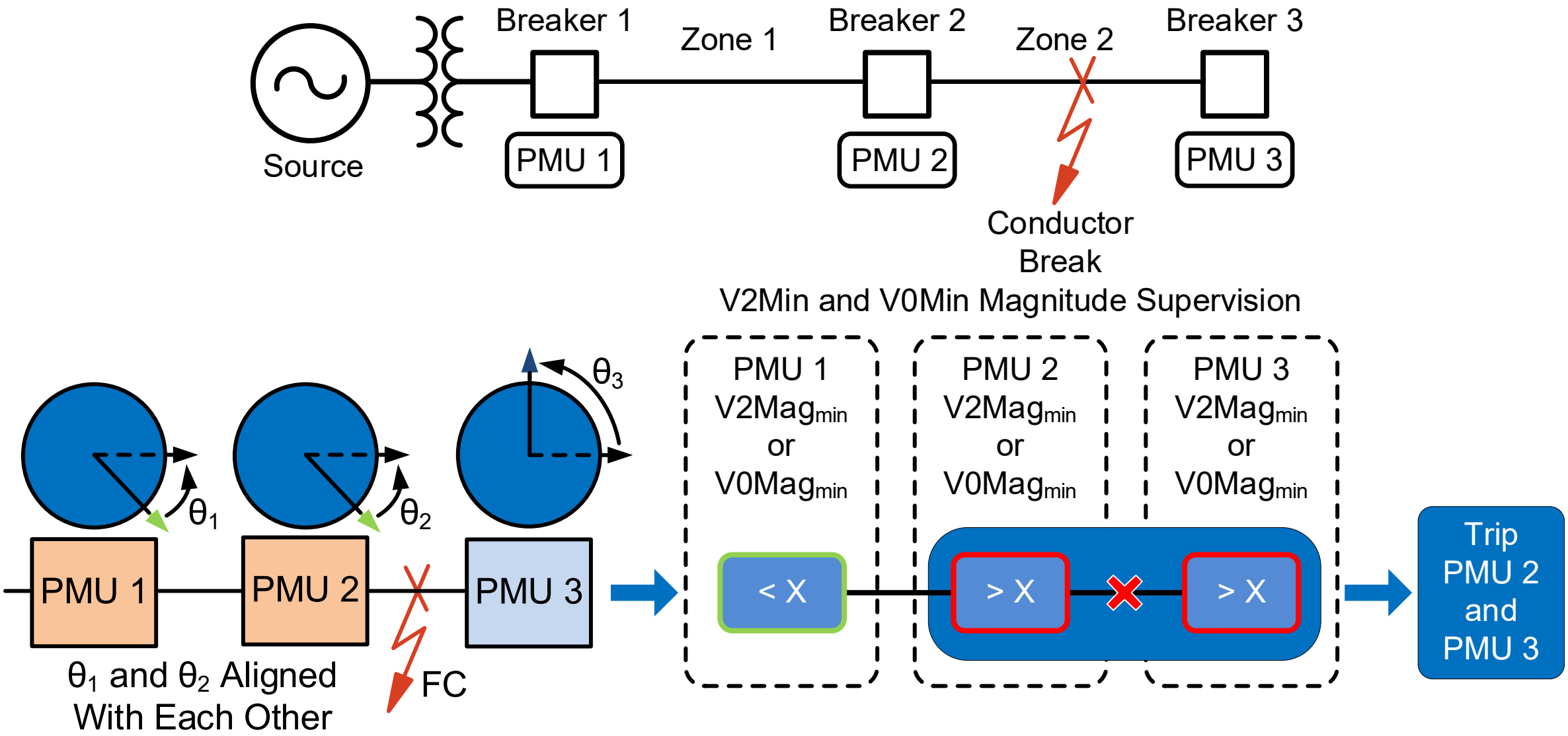


Detection method: V2Mag and V0Mag



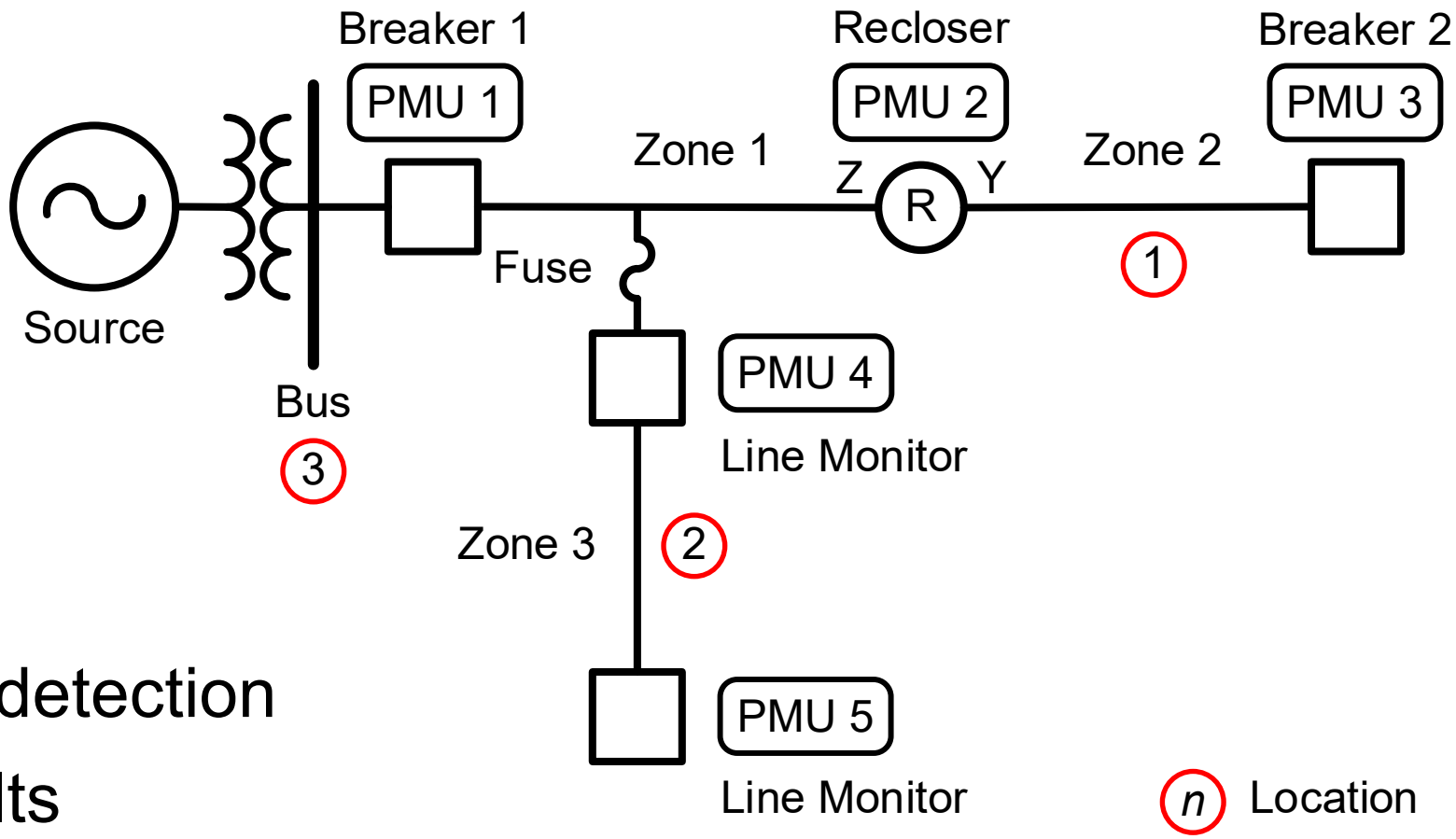


Detection method: V2Ang and V0Ang



Enhancements

- RTAC library package
- Zone topology and zone expansion
- Falling conductor (FC) location identification
- Blown fuse detection
- Faulty voltage sensor detection
- Traditional system faults
- External disturbance



Hardware-in-the-loop testing

- Multiple FC test locations
- Maintenance test
- Contingency test
  - Blown fuse
  - System faults
  - External disturbance
  - Device failure
- Automated batch test to calculate average trip time

SDG&E FCP program status

- In planning: 22-substation upgrade
- In 2022
  - 6 circuits successfully commissioned
  - All in monitoring mode
- In 2023
  - 5 circuits planned to commission
  - 2022 circuits placed in service mode – tripping mode

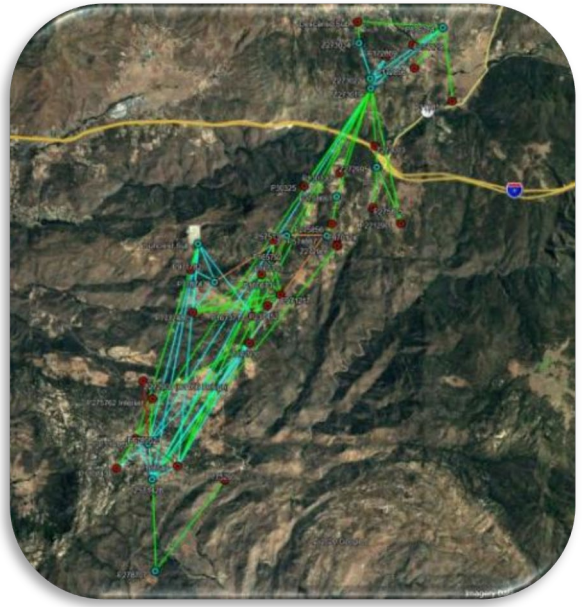
Challenges and opportunities

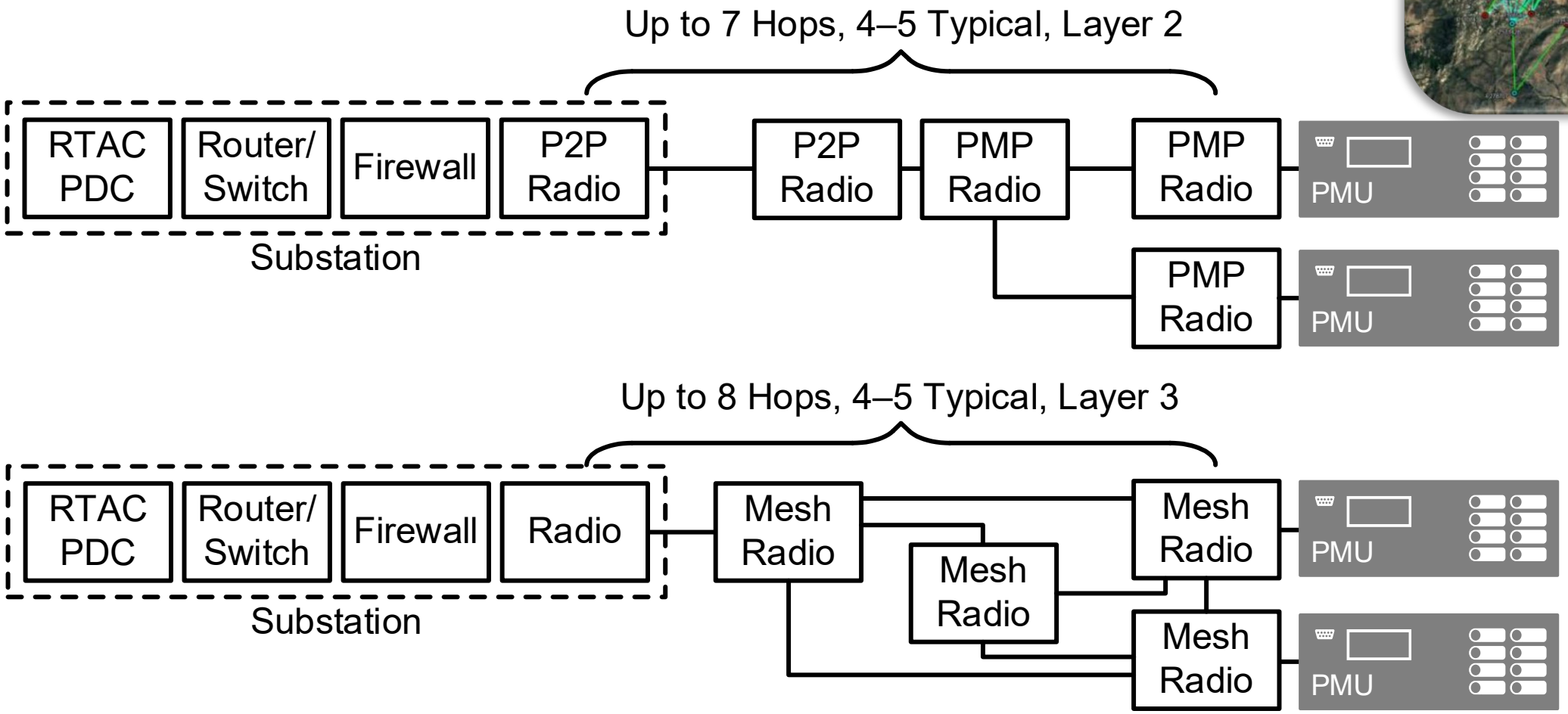
- Project integration with 28 cross-function groups – multiple internal and contract stakeholders
- Long lead time for components
- Evolving requirements and priorities

Challenges and opportunities

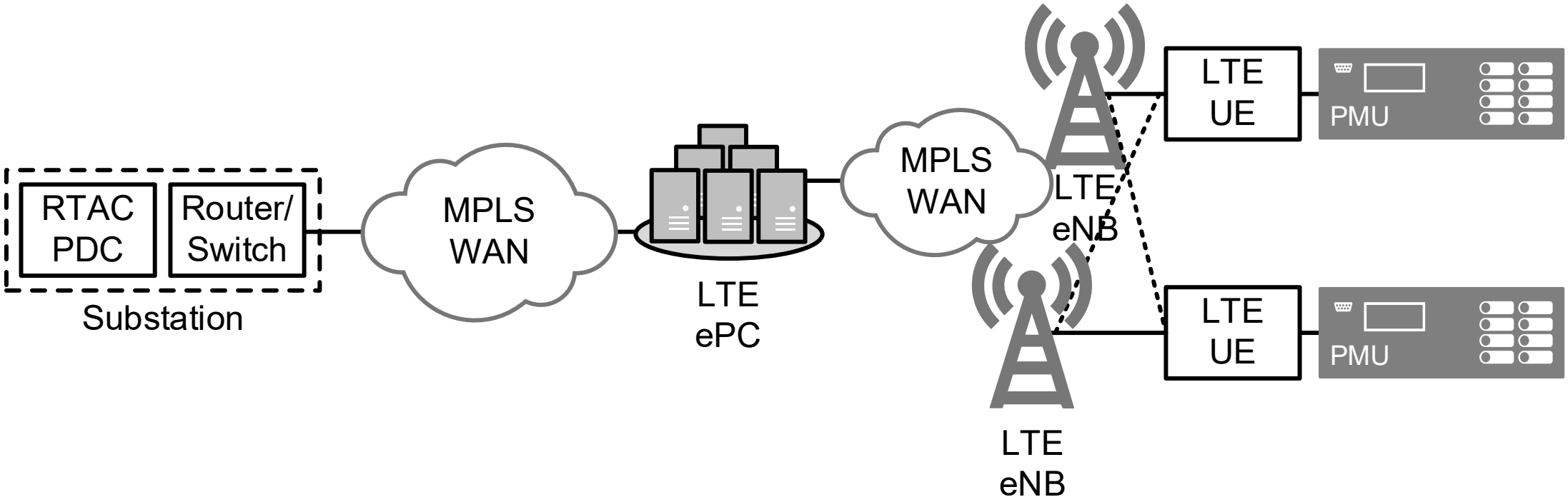
- Local, state, and federal regulatory compliance
  - Cleveland National Forest
  - Bureau of Indian Affairs
  - California Public Utilities Commission (CPUC) / Wildfire Mitigation Plan (WMP) account tracking
- Applicable to radial circuits
- Future development for non-radial circuits
- Extend to single-phase and two-phase laterals

Traditional FCP communications network solutions





PLTE solution



FCP communications network solution comparison

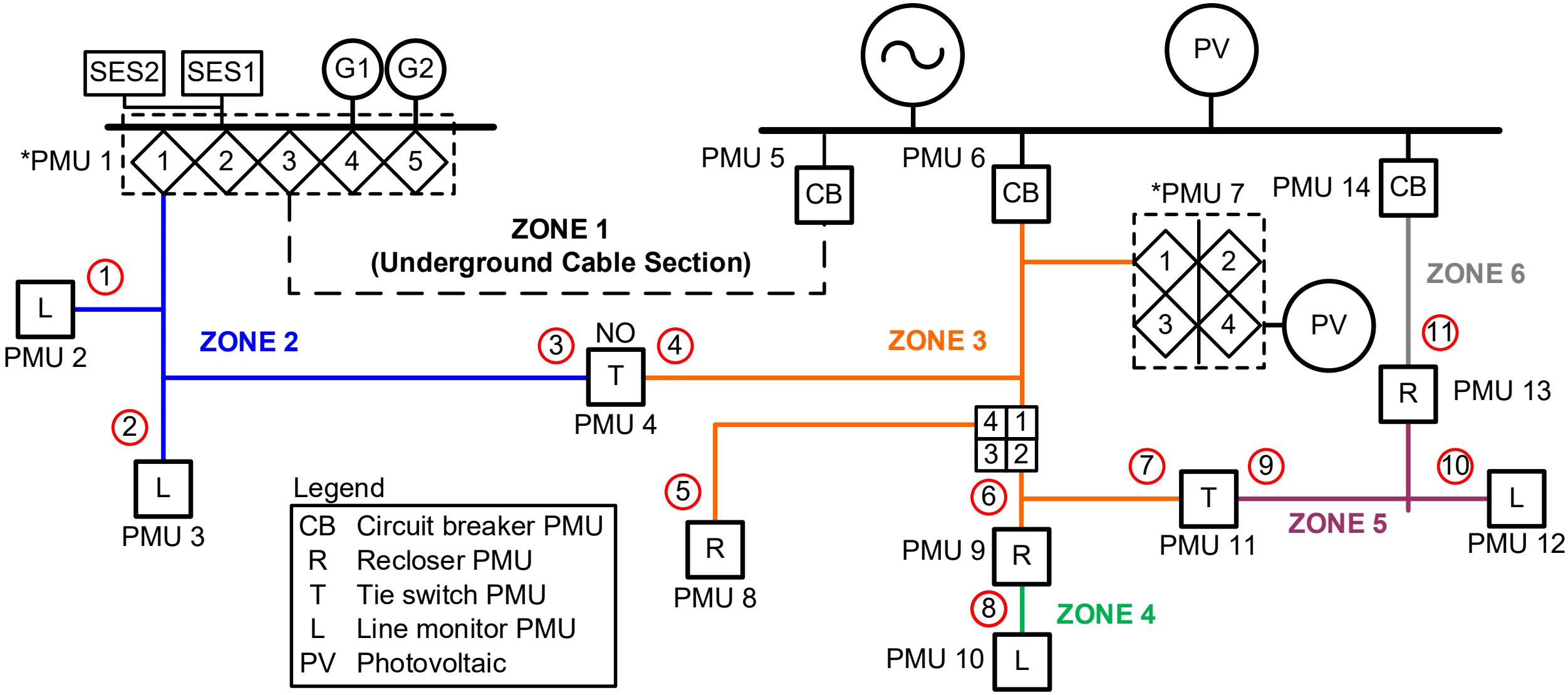
	Point-to-Point (2P) / Point-to-Multipoint (PMP)	Mesh	Worldwide Interoperability for Microwave Access (WiMAX)	PLTE
Standards-based, non-proprietary	○	○	●	●
Wireless protection, redundancy, and failover	○	○	◐	●
Integrated quality of service (QoS)	○	●	●	●
Centralized traffic inspection	○	○	○	●
Endpoint construction and operations efficiency	○	○	○	●

● Fully complies ◐ Partially complies ○ Does not comply

Field implementation: Site readiness

- FCP settings check
- PLTE network check
- Communications network check
- Web Application Security Assessment (WASA) and SCADA P2P check
- Switch plan check

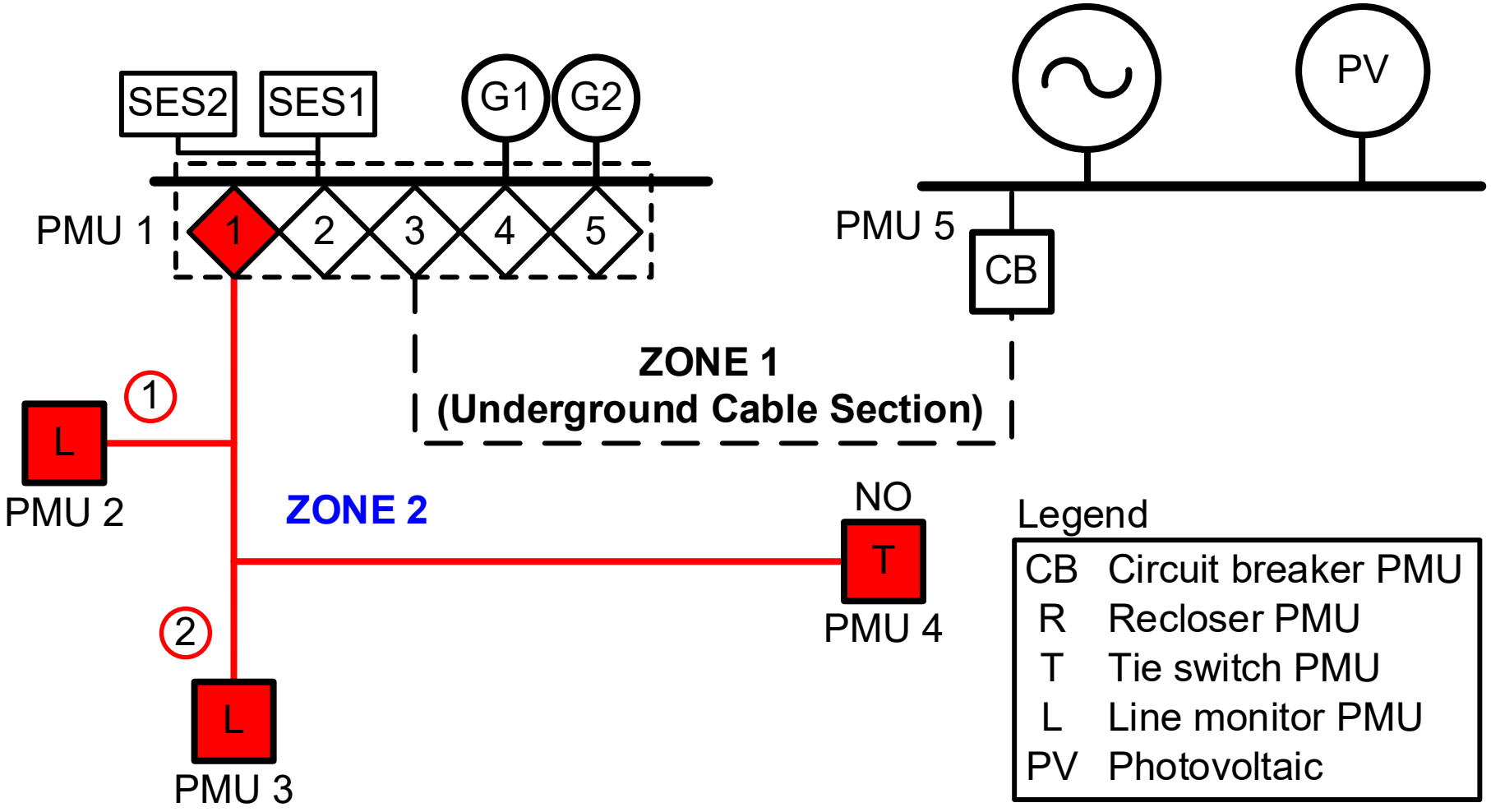
Field implementation: Circuit

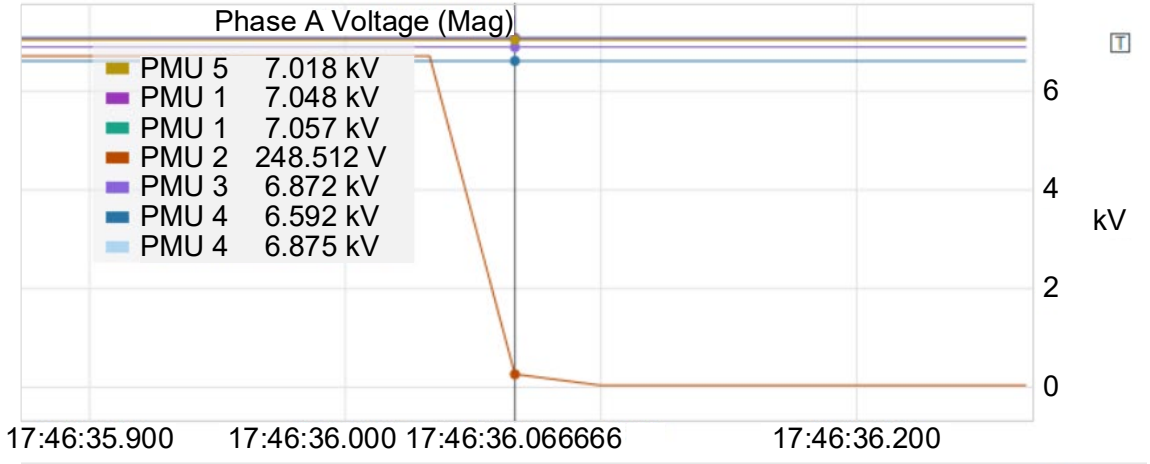


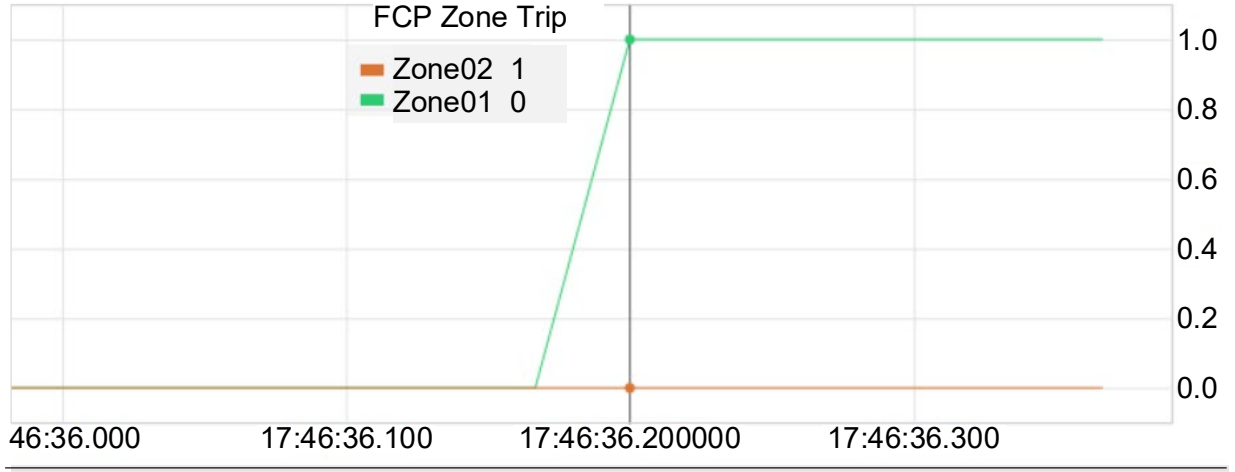
*PMU 1 and PMU 7 are single-unit PMUs monitoring and controlling multiple breakers / switches

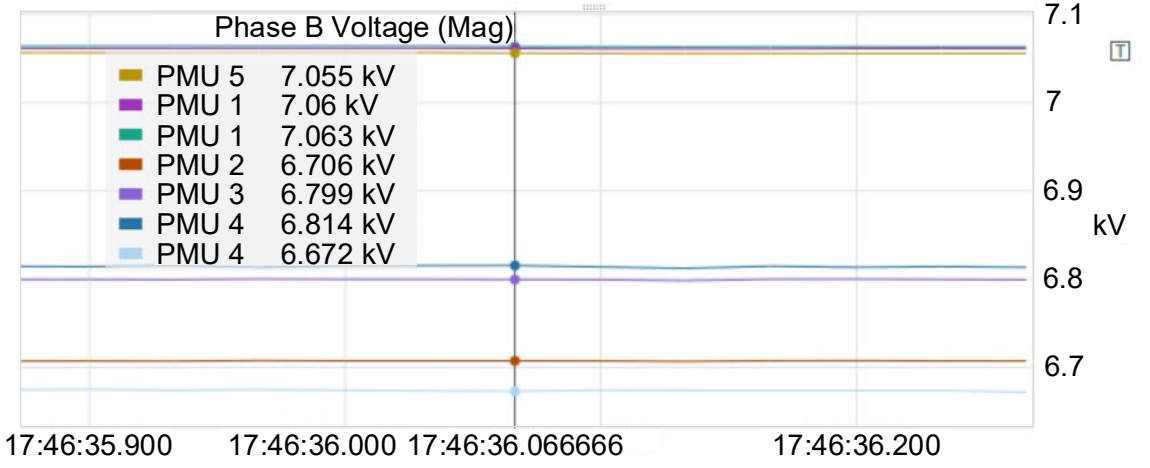
Field implementation: FC at Location 1

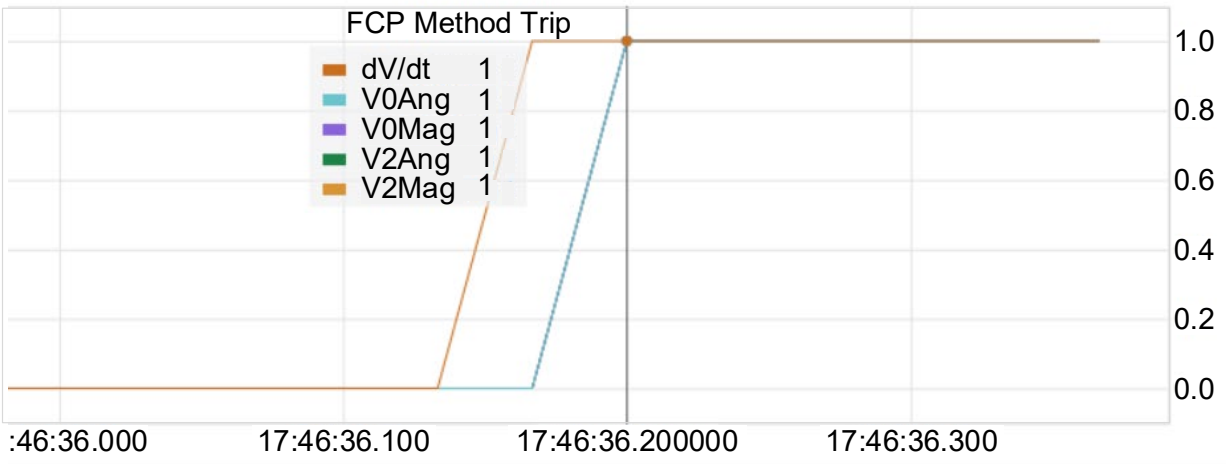
- FC event simulated at Location 1
- A-phase voltage decreased

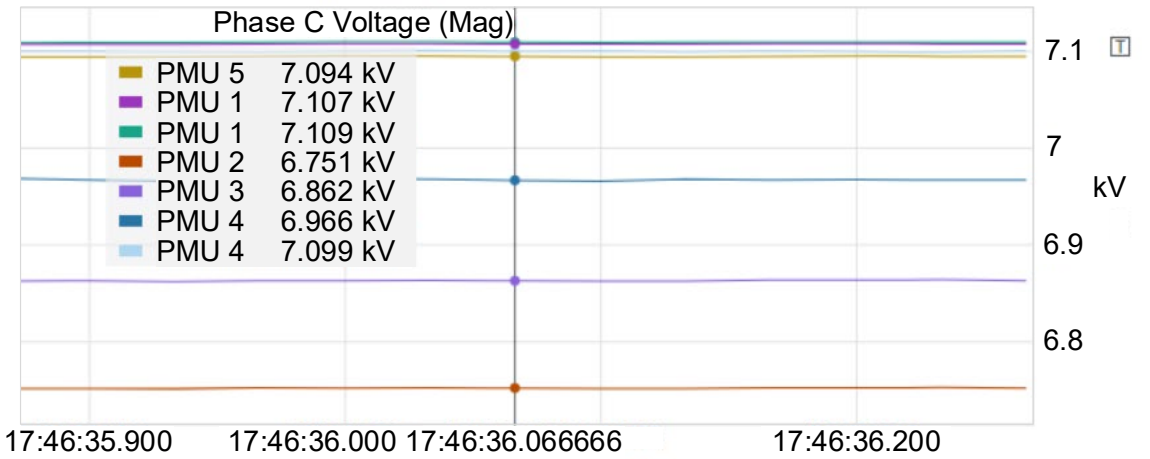


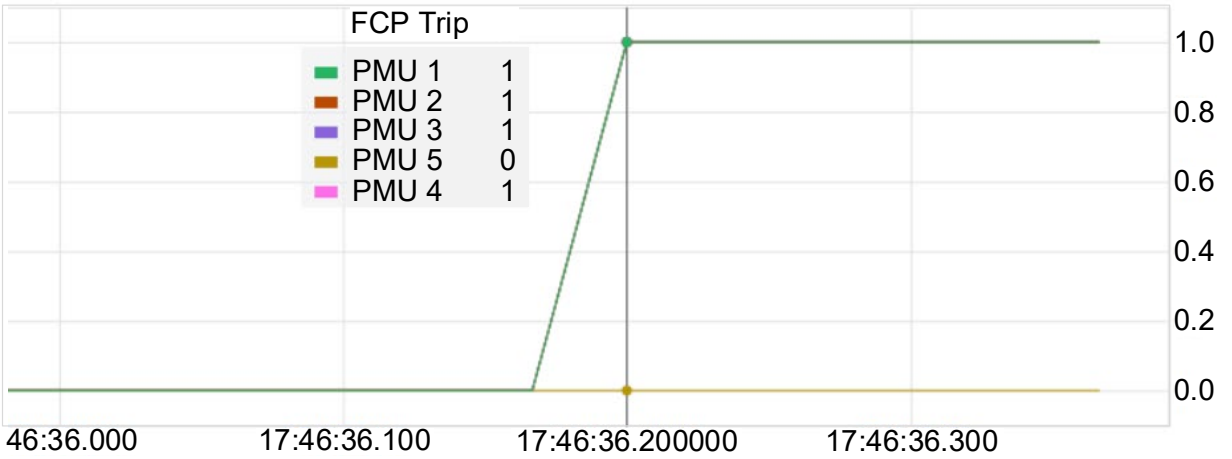

Phase A Voltage (Mag)
PMU 5 7.018 kV
PMU 1 7.048 kV
PMU 1 7.057 kV
PMU 2 248.512 V
PMU 3 6.872 kV
PMU 4 6.592 kV
PMU 4 6.875 kV
6
4
2
0
kV
17:46:35.900
17:46:36.000
17:46:36.066666
17:46:36.200


FCP Zone Trip
Zone02 1
Zone01 0
1.0
0.8
0.6
0.4
0.2
0.0
46:36.000
17:46:36.100
17:46:36.200000
17:46:36.300


Phase B Voltage (Mag)
PMU 5 7.055 kV
PMU 1 7.06 kV
PMU 1 7.063 kV
PMU 2 6.706 kV
PMU 3 6.799 kV
PMU 4 6.814 kV
PMU 4 6.672 kV
7.1
7
6.9
6.8
6.7
kV
17:46:35.900
17:46:36.000
17:46:36.066666
17:46:36.200

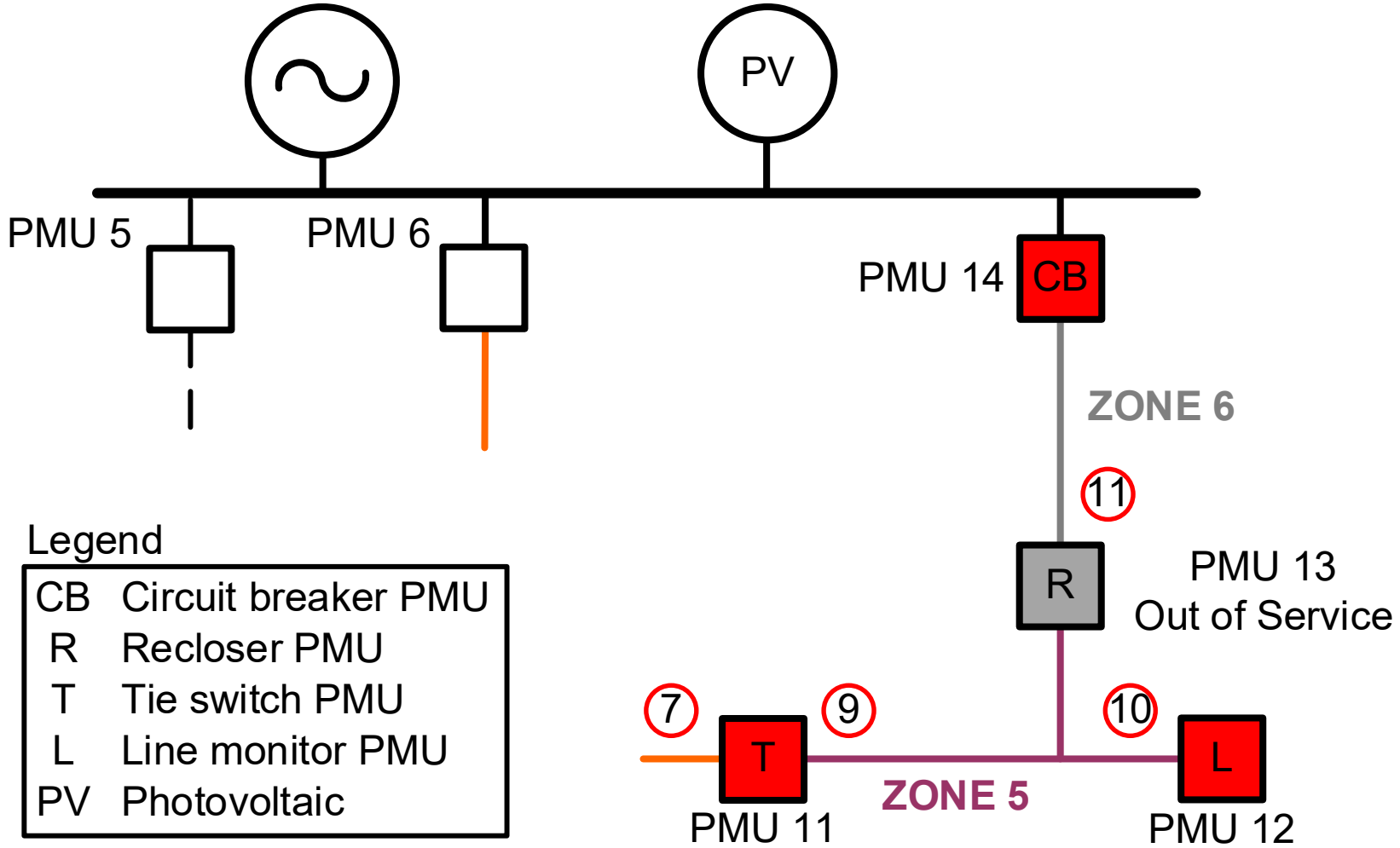

FCP Method Trip
dV/dt 1
V0Ang 1
V0Mag 1
V2Ang 1
V2Mag 1
1.0
0.8
0.6
0.4
0.2
0.0
:46:36.000
17:46:36.100
17:46:36.200000
17:46:36.300

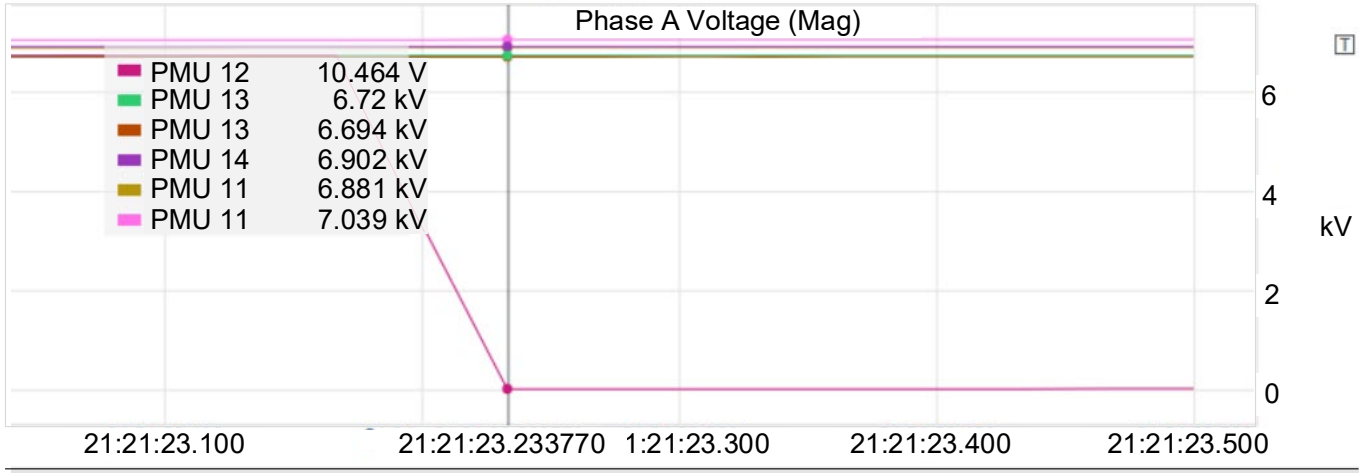

Phase C Voltage (Mag)
PMU 5 7.094 kV
PMU 1 7.107 kV
PMU 1 7.109 kV
PMU 2 6.751 kV
PMU 3 6.862 kV
PMU 4 6.966 kV
PMU 4 7.099 kV
7.1
7
6.9
6.8
kV
17:46:35.900
17:46:36.000
17:46:36.066666
17:46:36.200

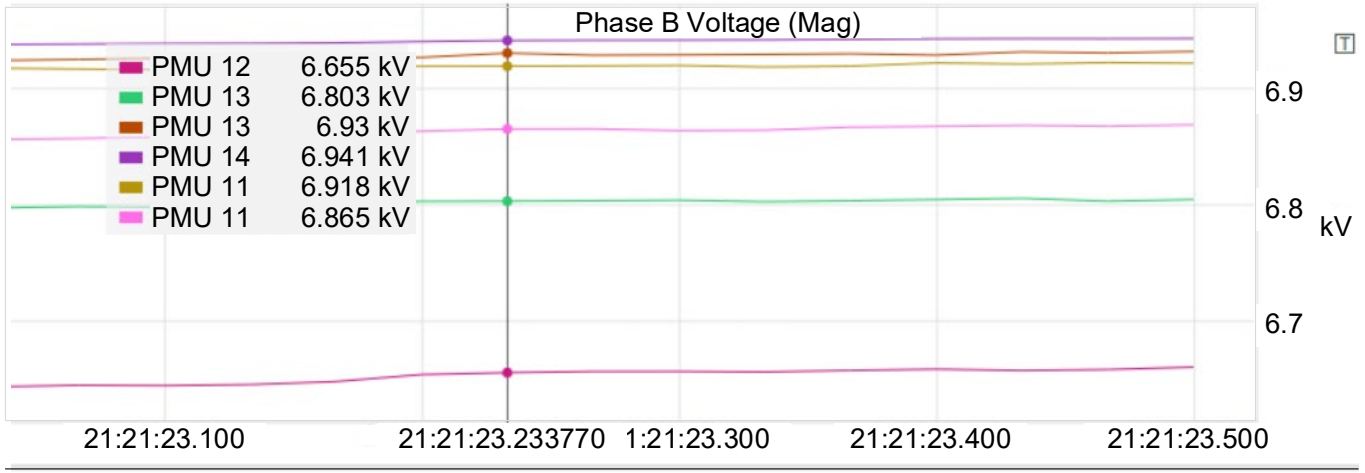

FCP Trip
PMU 1 1
PMU 2 1
PMU 3 1
PMU 5 0
PMU 4 1
1.0
0.8
0.6
0.4
0.2
0.0
46:36.000
17:46:36.100
17:46:36.200000
17:46:36.300

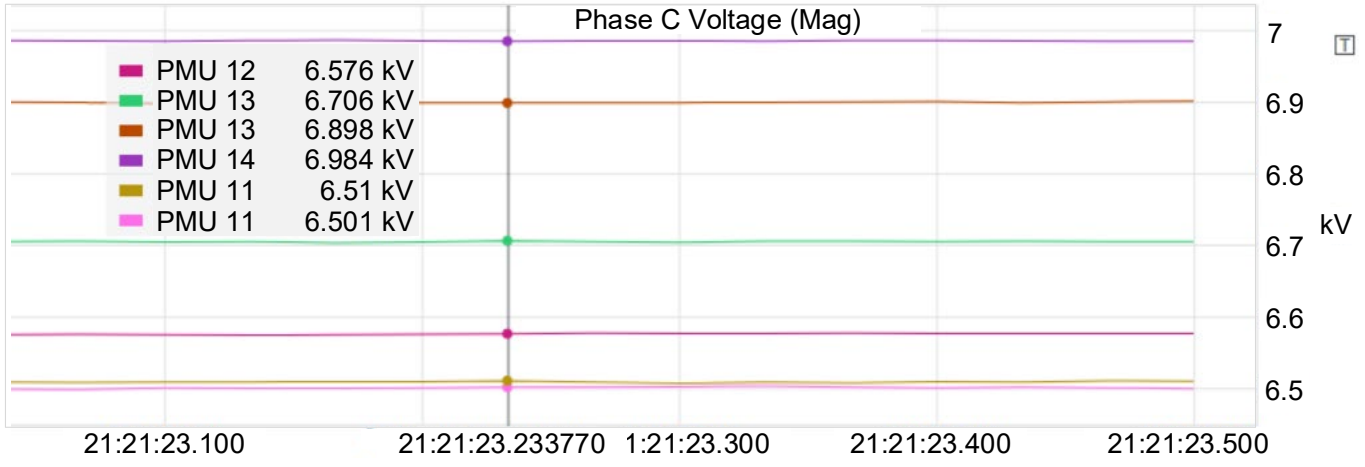
Field implementation: Zone expansion at Location 10

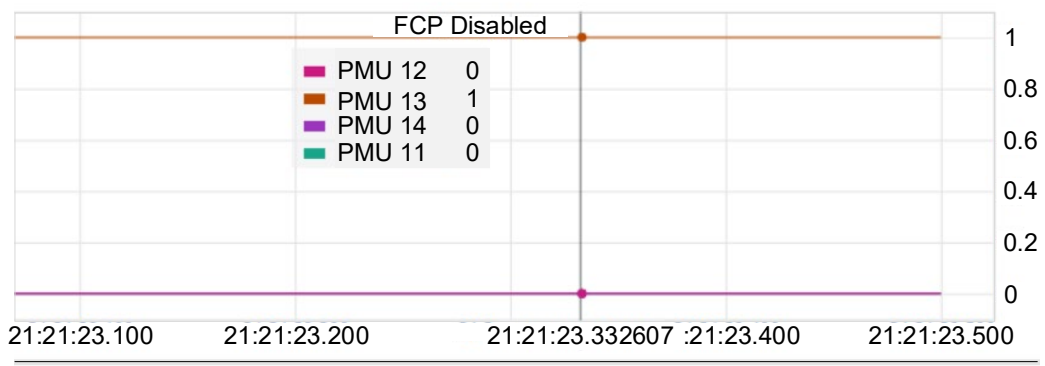
- Secure during maintenance on circuit
- FCP disabled on PMU 13 to simulate out-of-service of PMU

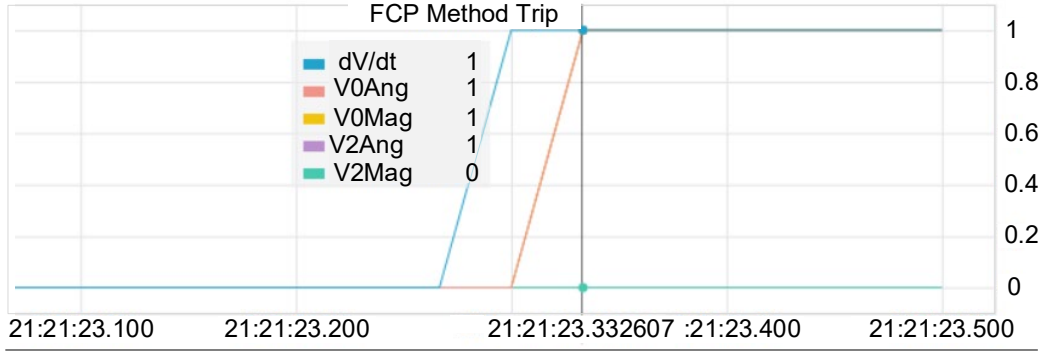


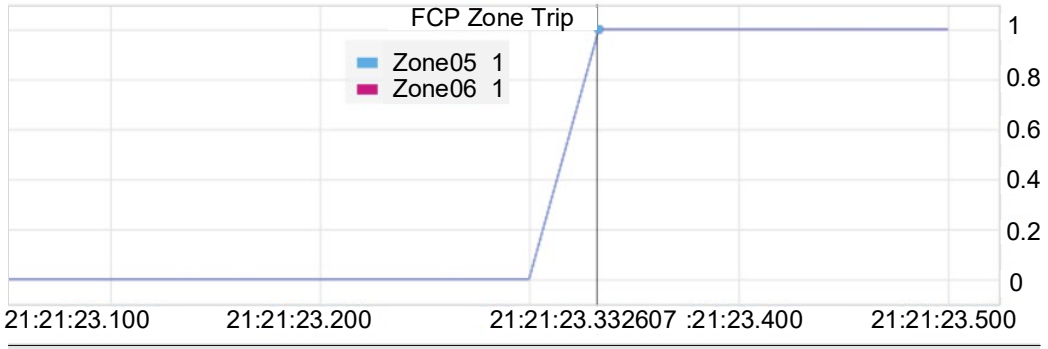

Phase A Voltage (Mag)
PMU 12 10.464 V
PMU 13 6.72 kV
PMU 13 6.694 kV
PMU 14 6.902 kV
PMU 11 6.881 kV
PMU 11 7.039 kV
6
4
2
0
kV
21:21:23.100
21:21:23.233770
1:21:23.300
21:21:23.400
21:21:23.500

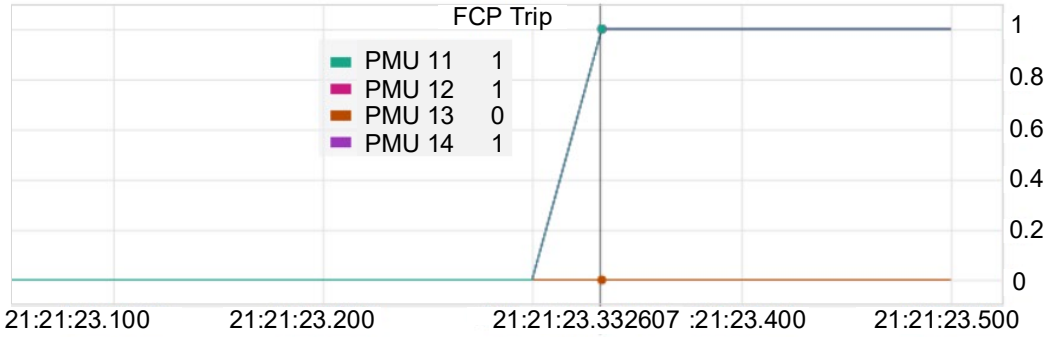

Phase B Voltage (Mag)
PMU 12 6.655 kV
PMU 13 6.803 kV
PMU 13 6.93 kV
PMU 14 6.941 kV
PMU 11 6.918 kV
PMU 11 6.865 kV
6.9
6.8
6.7
kV
21:21:23.100
21:21:23.233770
1:21:23.300
21:21:23.400
21:21:23.500


Phase C Voltage (Mag)
PMU 12 6.576 kV
PMU 13 6.706 kV
PMU 13 6.898 kV
PMU 14 6.984 kV
PMU 11 6.51 kV
PMU 11 6.501 kV
7
6.9
6.8
6.7
6.6
6.5
kV
21:21:23.100
21:21:23.233770
1:21:23.300
21:21:23.400
21:21:23.500


FCP Disabled
PMU 12 0
PMU 13 1
PMU 14 0
PMU 11 0
1
0.8
0.6
0.4
0.2
0
21:21:23.100
21:21:23.200
21:21:23.332607
:21:23.400
21:21:23.500


FCP Method Trip
dV/dt 1
V0Ang 1
V0Mag 1
V2Ang 1
V2Mag 0
1
0.8
0.6
0.4
0.2
0
21:21:23.100
21:21:23.200
21:21:23.332607
:21:23.400
21:21:23.500


FCP Zone Trip
Zone05 1
Zone06 1
1
0.8
0.6
0.4
0.2
0
21:21:23.100
21:21:23.200
21:21:23.332607
:21:23.400
21:21:23.500


FCP Trip
PMU 11 1
PMU 12 1
PMU 13 0
PMU 14 1
1
0.8
0.6
0.4
0.2
0
21:21:23.100
21:21:23.200
21:21:23.332607
:21:23.400
21:21:23.500

Conclusion

- FCP detects and de-energizes falling conductor before it hits the ground
- FCP is a wide-area protection scheme (WAPS), which compliments existing protection scheme
- Successfully validates field results
- FCP is flexible to maintenance on circuit
- FCP is secure against conventional short-circuit fault event

Conclusion

- Communications network must be reliable and strong for FCP
- PLTE network provides greater overall value than traditional network solution
- PLTE is more reliable and efficient
- PLTE is standards-based and non-proprietary
- PLTE also hardens network cybersecurity

Questions?