Distribution grid monitoring: Challenges in developing PMU-rich feeders

System Protection, Automation and Control Engineering

Dan Dietmeyer, MSEE, PE – SDG&E

Panayiotis (Panos) Moutis, PhD - CCNY

Distribution Grid Monitoring – Today's Topic

We will review:

Information and Telecommunication challenges & benefits brought about by the wide use of PMUs in distribution systems from both an industrial and an academic perspective.

Distribution Grid Monitoring insights

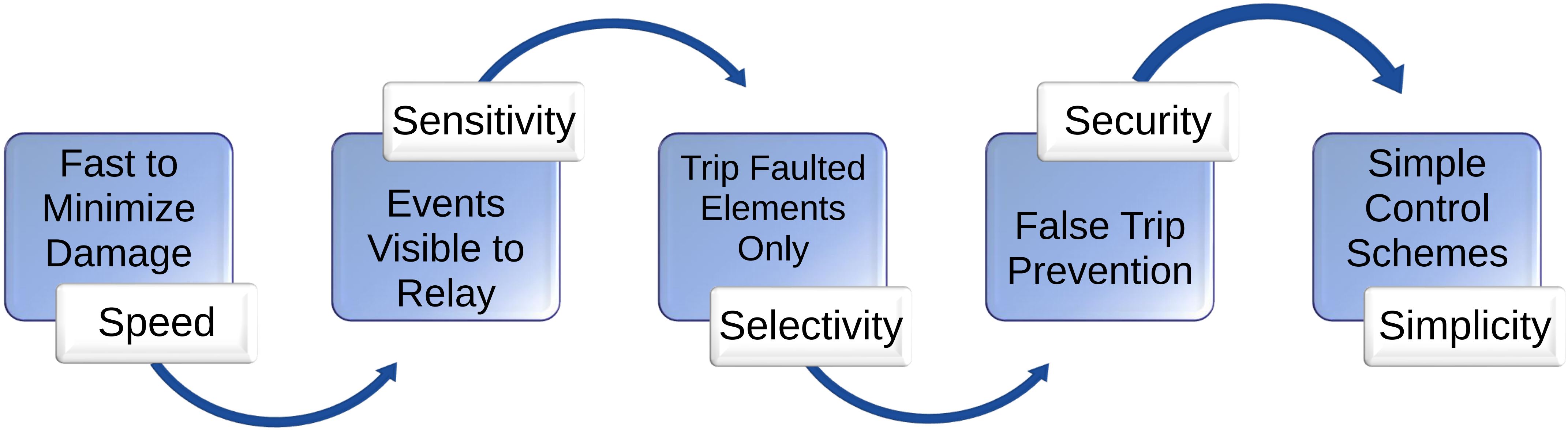
- Increasing visibility into distribution grids requires upgrades to the monitoring infrastructure.
- Distributed Energy Resources disrupt traditional circuit power flow and increases challenges in protection system coordination.
- Synchronized Measurement via Phasor Measurement Units (PMU's) has been successfully developed and deployed on the Bulk Electric System at transmission voltage levels dating back a decade or two and growing.
- Lessons learned from transmission system deployment of PMU's can be brought forward when setting up networks for the distribution system,
  - Traditional means of communication are largely unavailable out of the box at distribution levels due to slow infrastructure development and emergent needs of change.
- The electrification of transportation, IBR based DER assets, and wildfire mitigation concerns have grown the need for synchronized measurement on the distribution system within the service territory of a utility.
- Use cases and value propositions for such present a path forward to develop and deploy distribution PMU's.

SDG&E Overhead Distribution System

- Approximately 24,023 miles of overhead and 15,188 miles of underground 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

System Protection's Role within SDG&E – A Balancing Act

- Within SDG&E, **System Protection's role** includes:
  - Responsibility for studying the electric system, developing an approach to configure protective relays and automation systems that detect, isolate, and restore faulted elements.
  - Producing well designed protective relaying and control schemes, settings, and communication systems while integrating and developing Power Quality data analytics resulting in a clean, safe, and reliable electric transmission and distribution system
  - This involves a great amount of education, training, and experience for an engineer to attain the skills needed to begin protecting the infrastructure.



Distribution Grid Monitoring – Questions

Questions to ask of your organization when considering Distribution PMU integration:

- How does existing IT infrastructure hinder broader PMU adoption and consideration of additional use cases?
- How can we adjust to and overcome the current IT bottlenecks for crucial monitoring and control applications?
- How are both cyber-security and physical security considered for PMU's and IT networks?
- How can hierarchical architectures bridge the gap until we have more answers to our IT framework challenges?

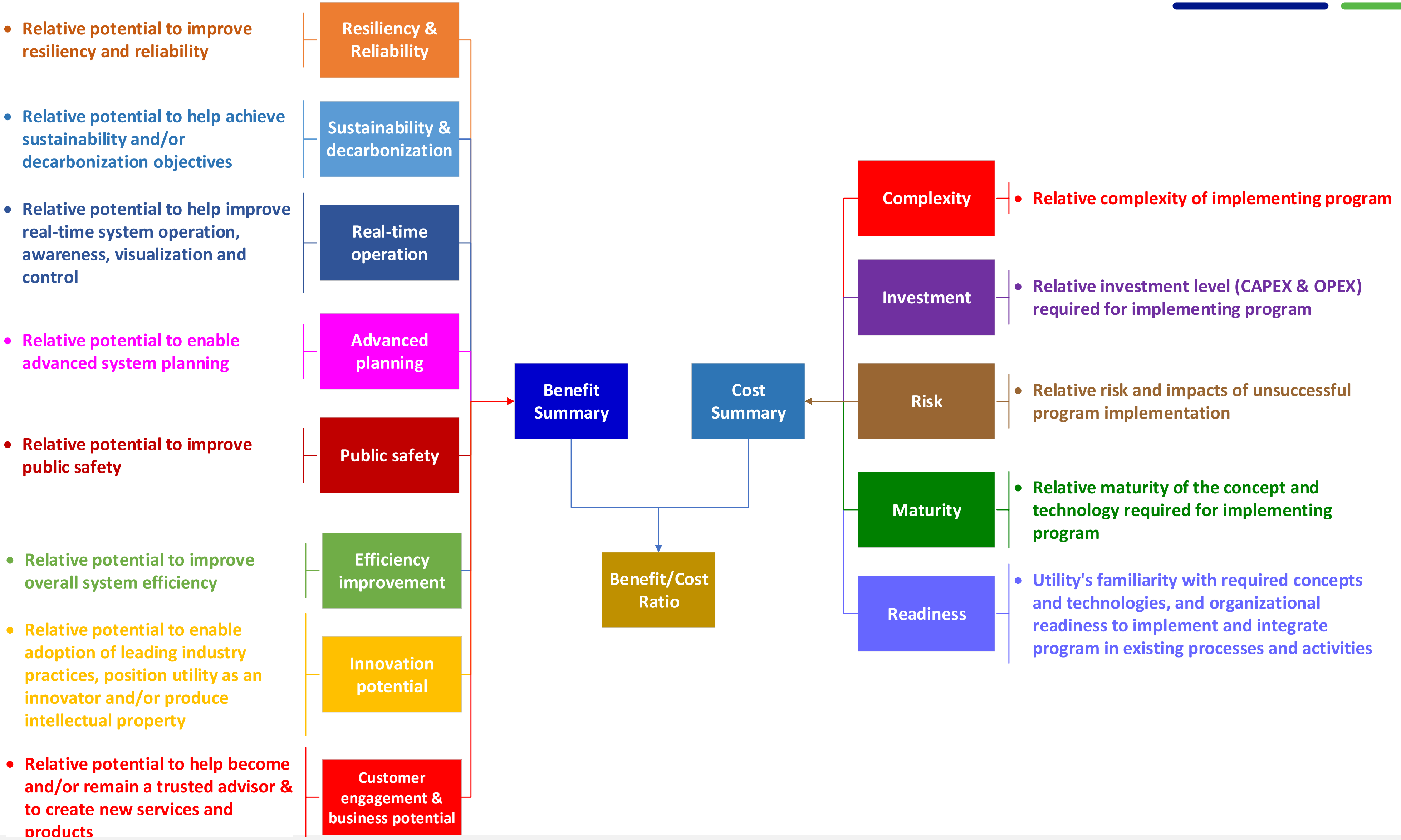
Distribution Grid Monitoring – Challenges

- Constructing a robust and cost-effective communication network
- Network security for distribution (it does not fall in scope of NERC CIP for BES, 100kV and up, since distribution is below 100kV)
- Placement of PMU's and challenges faced (pole loading, cultural sites, customer sensitivity, access to the pole/equipment)
  - Local, State, and Federal regulatory compliance
- Value vs. cost:
  - Proper site selection
  - Component lead time
  - Rapidly changing communications technology availability
- Realistic use cases

Phasor Measurement Use Cases

Distribution Circuits

Distribution PMU Use Cases – Benefit vs. Cost

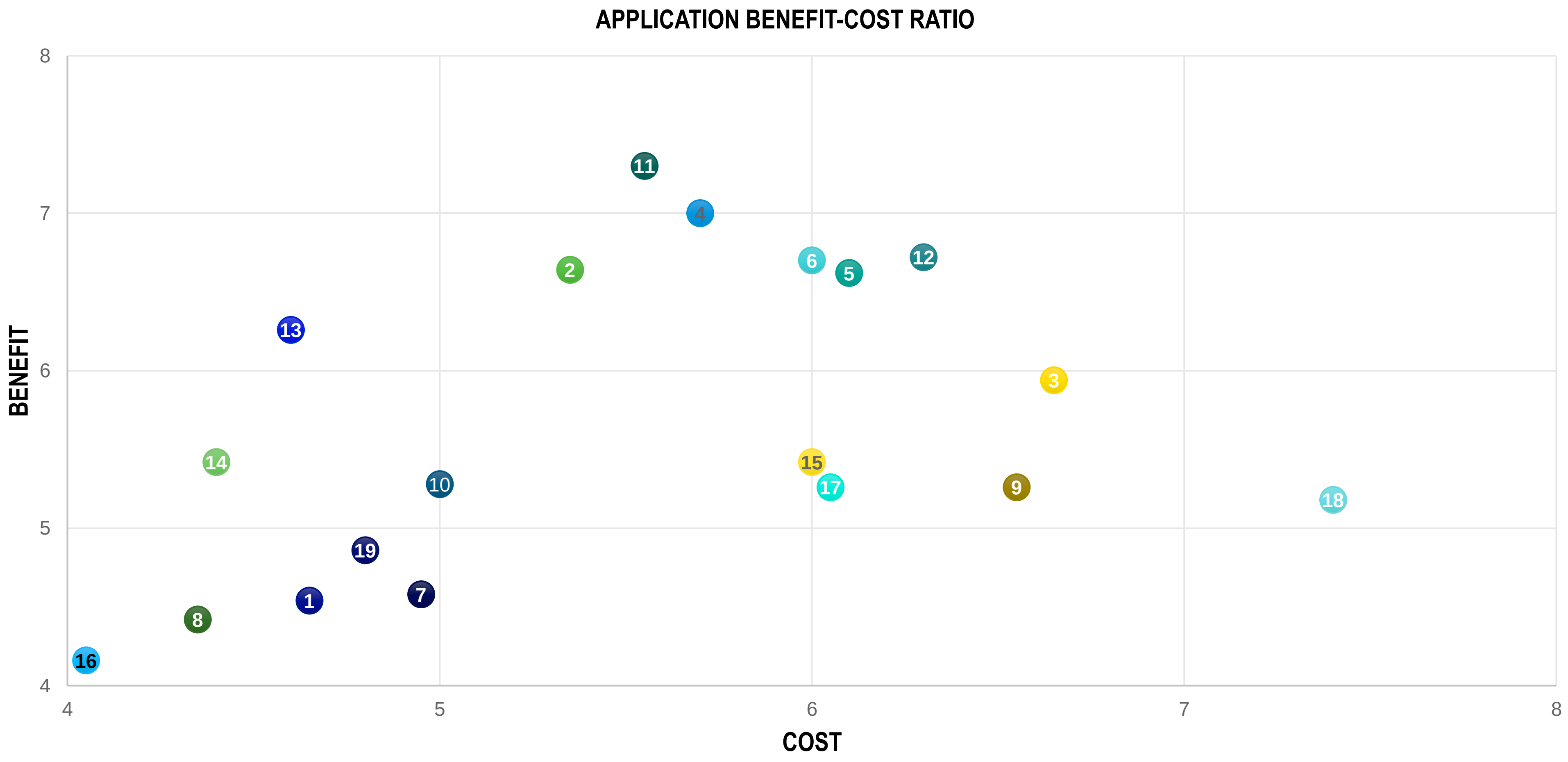


Distribution PMU Use Cases – Prioritization Results

Application Number	Application Description	BCR_i	BCR_i Numerical
AG13	Advanced microgrid applications and operation	HIGH	1.36
AG11	High-accuracy fault detection and location	HIGH	1.32
AG2	Advanced monitoring of distribution grid	HIGH	1.24
AG14	Improved load shedding schemes	HIGH	1.23
AG4	Wide area visualization	HIGH	1.23
AG6	Real-time distribution system operation	MEDIUM	1.12
AG5	DER integration and control	MEDIUM	1.09
AG12	Advanced distribution protection and control	MEDIUM	1.07
AG10	Improved stability management	MEDIUM	1.06
AG16	Technical and commercial loss reduction	MEDIUM	1.03
AG8	Advanced distribution system planning	MEDIUM	1.02
AG19	Power quality measurement	MEDIUM	1.01
AG1	Advanced Volt-VAR Control (VVC)	MEDIUM	0.98
AG7	Enhanced reliability and resilience analysis	MEDIUM	0.93
AG15	Advanced distribution automation	MEDIUM	0.90
AG3	Asset management of critical infrastructure	MEDIUM	0.89
AG17	Monitoring and control of electric transportation infrastructure	MEDIUM	0.87
AG9	Distribution load, DER and EV forecasting	MEDIUM	0.80
AG18	Integrated resource, transmission and distribution system planning and analysis	LOW	0.70

NOTE: Prioritization results from the study conducted are not specific to any individual utility and were used along with potential interdependencies among AGs to develop a proposed timeframe for implementation and overall roadmap.

Distribution PMU Use Cases – Benefit vs. Cost Ratio



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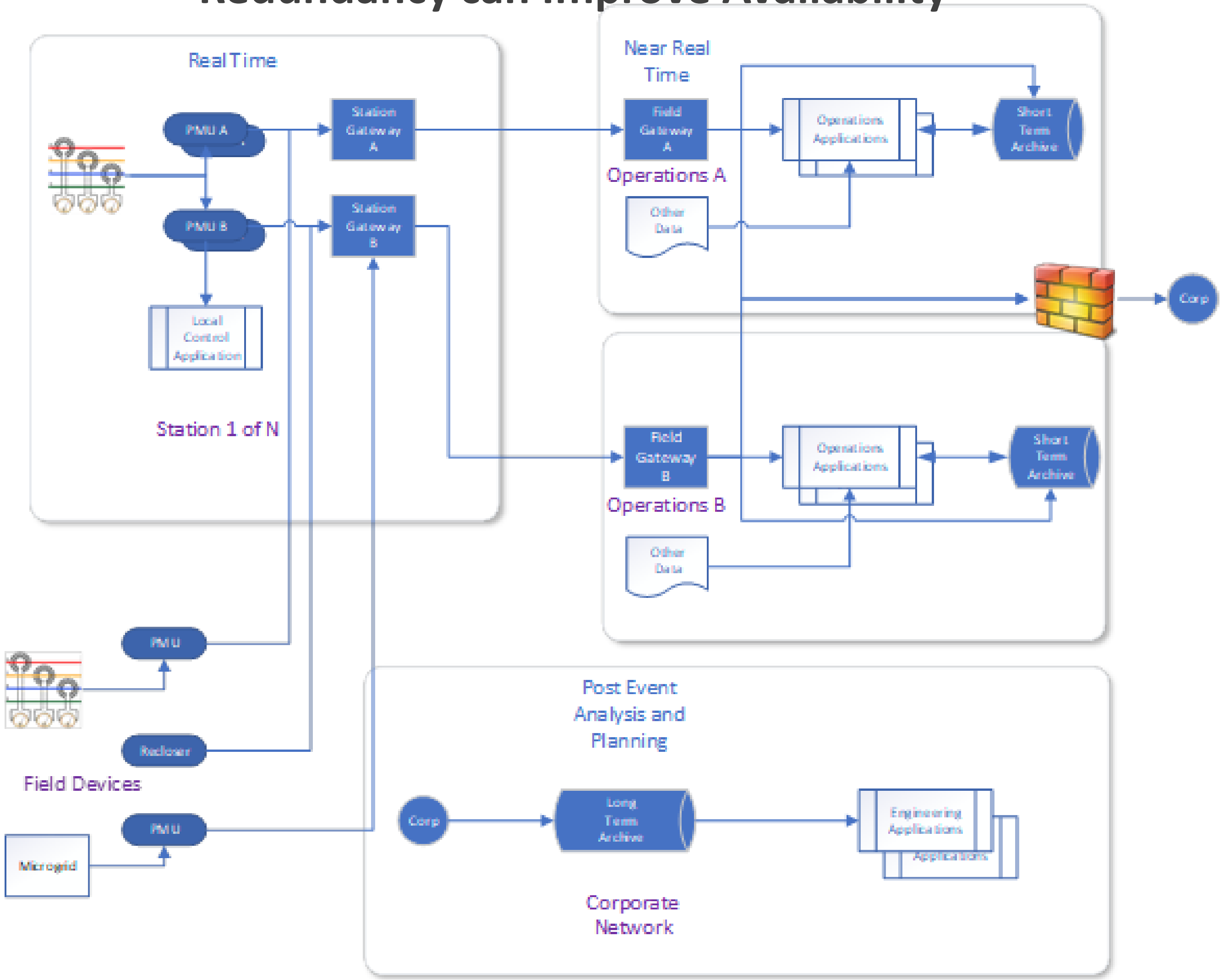
Distribution PMU Use Cases – Application Requirements

Proposed Group Number	Application Group	Minimum Availability %	Maximum Latency (ms)	Minimum Report Rate (Hz)
AG1	AVVC	80	2000	1
AG2	Advanced monitoring of distribution grid	95	1000	30
AG3	Asset management of critical infrastructure	80	5000	1
AG4	Wide area monitoring and visualization	95	1000	30
AG5	DER integration	80	2000	1
AG6	Real-time distribution system operation	95	2000	1
AG7	Enhanced reliability and resilience analysis	80	5000	1
AG8	Advanced distribution system planning	95	5000	30
AG9	Distribution load, DER, and EV forecasting	80	5000	1
AG10	Improved stability management	99	500	30
AG11	High-accuracy fault detection and location	99.9	300	30
AG12	Advanced distribution protection and control	99.9	150	30
AG13	Advanced microgrid applications and operation	99	500	30
AG14	Improved load shedding schemes	80	5000	1
AG15	Advanced distribution automation	99	300	30
AG16	Technical and commercial loss reduction	70	5000	1
AG17	Monitoring and control of electric transportation infrastructure	80	5000	1
AG18	Integrated resource, transmission and distribution system planning and analysis	80	5000	1
AG19	PQ assessment and analysis	99.9	5000	120

Distribution PMU Use Cases – Availability

- Availability is the ratio of measurements expected by an application at a given report rate vs. the measurements that arrive at the application.
- Latency is a subcategory of availability - Certain near real-time applications are sensitive to latency issues.
- Report rate of 30 and 60Hz typical

Redundancy can Improve Availability

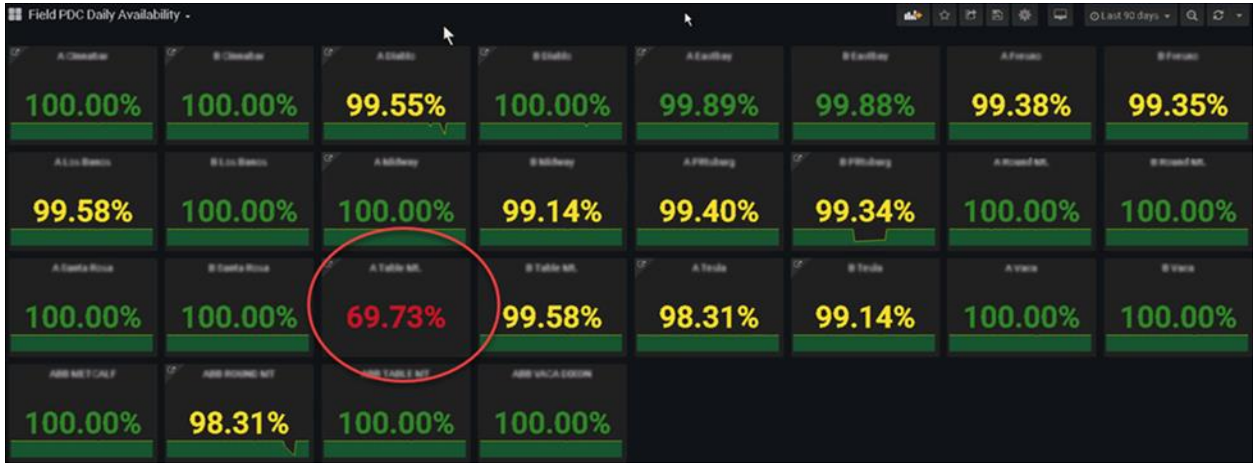


Maintaining Availability - Coordination among Business Units

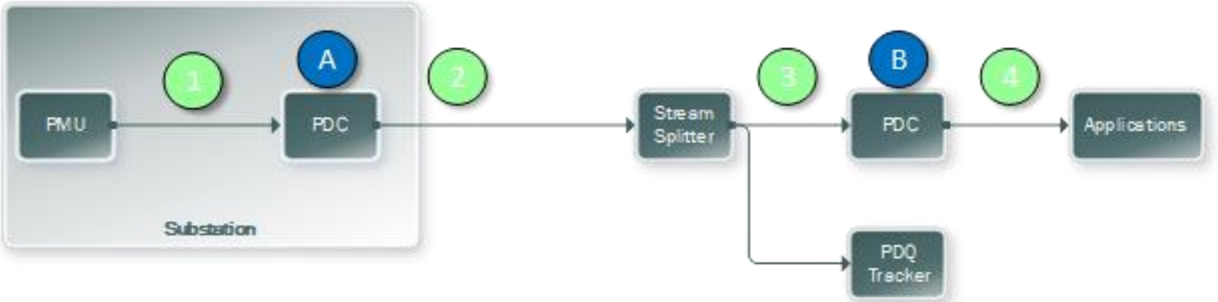
- **SCADA Technicians** – Maintain and install settings.
- **Network Support** - Network Operations Center (NOC) is responsible for maintaining communications between field devices and control centers.
- **Distribution Applications Support** – New applications require ongoing support
- **Accurate real time clock distribution** – Is there a business unit at the utility responsible for accurate Time of Day clock data distribution?
- **Dispatchers** - control centers operators must be trained on their use.

Job Aids and KPI Dashboards

99+% availability may seem to be sufficient but can mean a minutes long dropout that would compromise post event or near real time applications



Techs must know how to interpret status flags along the data path



Advanced SCADA Project Applications

54 use cases were defined with FCP being most useful to SDG&E

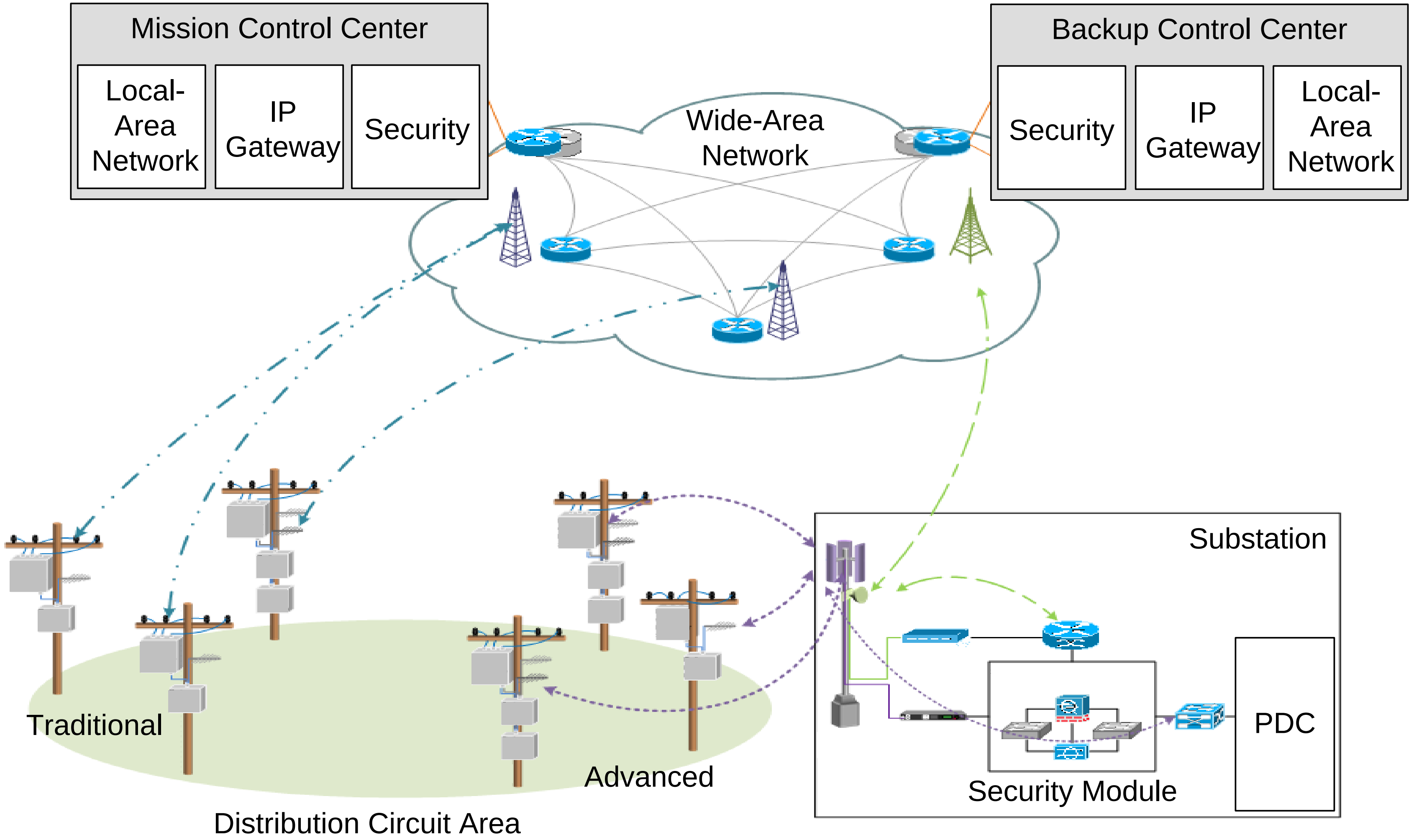
- **Falling conductor protection (FCP)**
  - **(patented & highest priority case for wildfire mitigation)**
  - Increased accuracy of voltage and current
  - Phase angle measurements across circuit
  - GPS time-stamped data
  - 30 synchrophasor samples per second for fast measurement
  - Industry standard control messages for real-time control
  - Remote engineering access and event reports (faster real-time response) to events)
  - Advanced cyber security features

Distribution Grid Monitoring:

Bridging the gap in IT and Comms networks

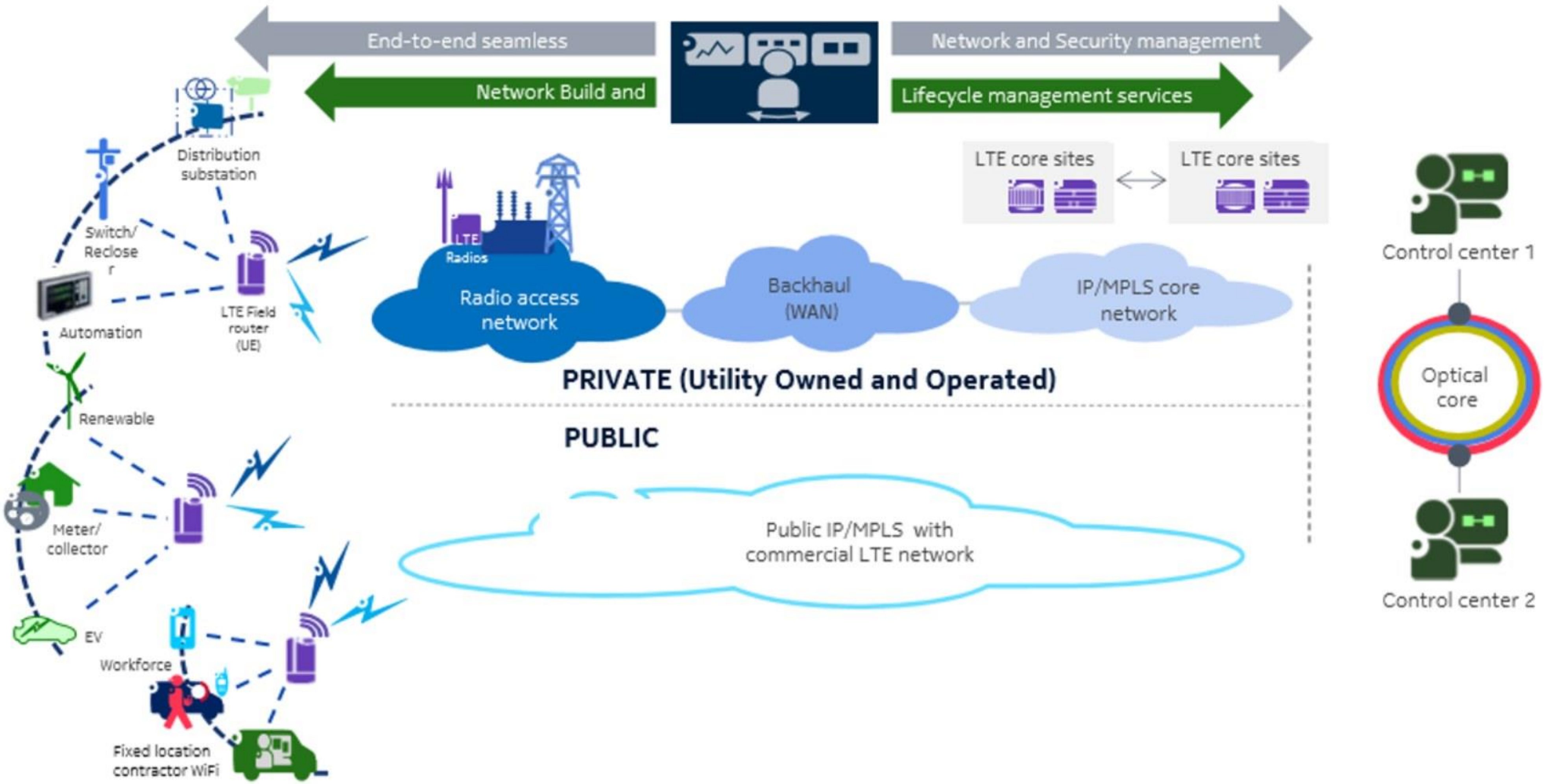
SCADA Traditional and Advanced Overlay

Existing Communications Infrastructure



Private Long-Term Evolution (pLTE)

Decreases FCP Cost / Increases Security



Distribution FCP – Intelligent Electronic Devices

Substation Breaker based PMU via protective relay

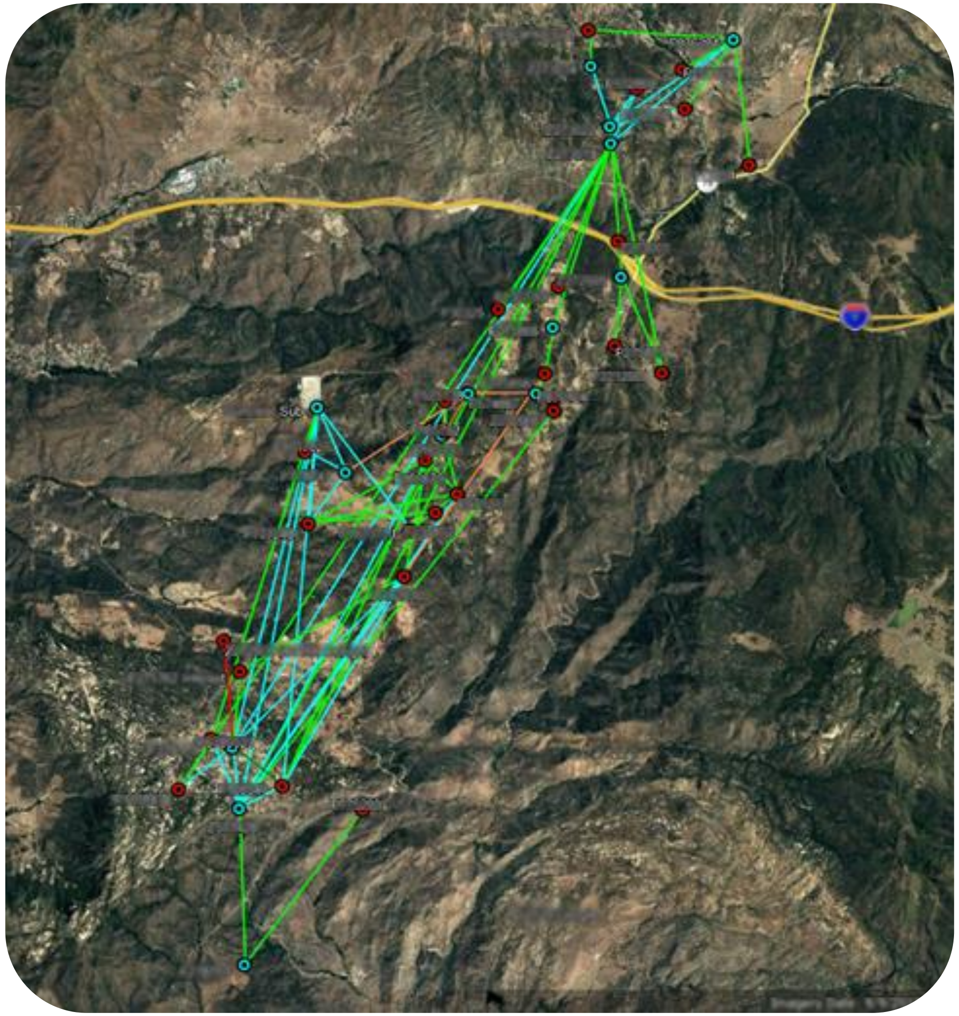
Distribution Recloser based PMU via protective relay

Line Sensors for V, I, f measurands

Distribution Feeder Comms - Radio Design

- Many radios require line-of-sight
- Radio network tuned to ensure high speeds with low latency
- Back country terrain challenging
  - Multiple repeaters required
  - Requires cross-functional coordination with multiple project teams
  - Additional pole replacements required

- Private LTE (PLTE) simplifies deployment
  - Less radio repeaters & cost
  - Faster installation
  - Higher risk due to project complexity & changing communications technologies to assess



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Distribution Grid Monitoring:

Results of Synchrophasor Deployment

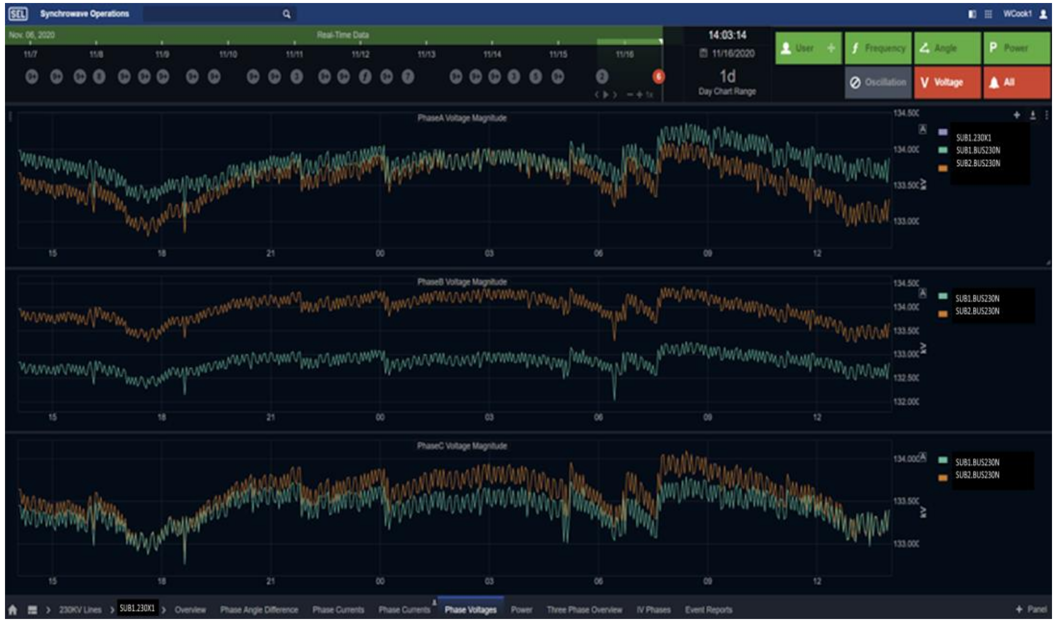
Examples from the BES & Distribution Systems

Use Case: Real and Reactive Power Monitoring

Solar Plant Power Flow monitoring post major path loss

Use Case Factors

Description	• *Identify thermal/voltage issues that persist after the loss of a major path and take action to return the system to acceptable performance*
Objectives	• *Identify thermal limit exceedance* • *Recognize the line relay operation within SDG&E area as the cause* • *Recognize thermal / voltage issues after suspected RAS operation* • *Determine if a RAS trip was issued* • *Analyze mitigating actions to address thermal/voltage issues*
Events	• *Loss of major path could result in N-1 RAS operation. Loading increases on other tie lines and system voltages are affected*
Data and Displays	• *Geospatial visualization of voltage measurements* • *Voltage profile of SDG&E operating area*



Outcomes & Actions

Notifications	• *Notify the CAISO of thermal limit exceedance*
Actions	• *Take actions to return the system to acceptable performance* • *Track total amount of time that voltage limits are exceeded.*

Use Case: Real and Reactive Power Monitoring

Event

- Review operation of a solar plant

Step 1

- View 230kV Lines > TL230X3 > Power dashboard
- Initial reading before fault, 109 MW

Step 2

1. View 230kV Lines > TL230X3 > Power dashboard
2. One second after fault, power flow reduced below 1 MW

Step 3

1. View 230kV Lines > TL230X3 > Power dashboard
2. After 2 seconds, power flow returns to 84 MW
3. Determined that there was not a RAS operation

Use Case: Frequency Monitoring

Local Area Frequency Oscillations

Use Case Factors

Description	• *Identify frequency, voltage and real/reactive power oscillations and low damping levels that may adversely impact system reliability and take action to return the system within acceptable operating bounds*
Objectives	• *Recognize relay operations within SDG&E area* • *Identify negative damping levels and excessive oscillations* • *Monitor system return to normal operation*
Events	• *Loss of multiple renewable generation resources in SDG&E area leading to negative damping levels accompanied by oscillations across the transmission system*
Data and Displays	• *Geospatial visualization of T-line power flow (MW, MVAR, voltage)* • *Generation data (MW, MVAR, voltage, UCON status) to identify the unit that relayed, MW amount lost and time of relay operation* • *Generation values (MW, MVAR, voltage) to recognize oscillatory behavior*

Outcomes & Actions

Notifications	• *If required, notify the CAISO of real/reactive power oscillations and low damping levels that may adversely impact system reliability* • *Coordinate with adjacent TOPs of actions taken to return the system within acceptable operating bounds*
Actions	• *Take the actions necessary to return the system within acceptable operating bounds*

Use Case: Frequency Monitoring

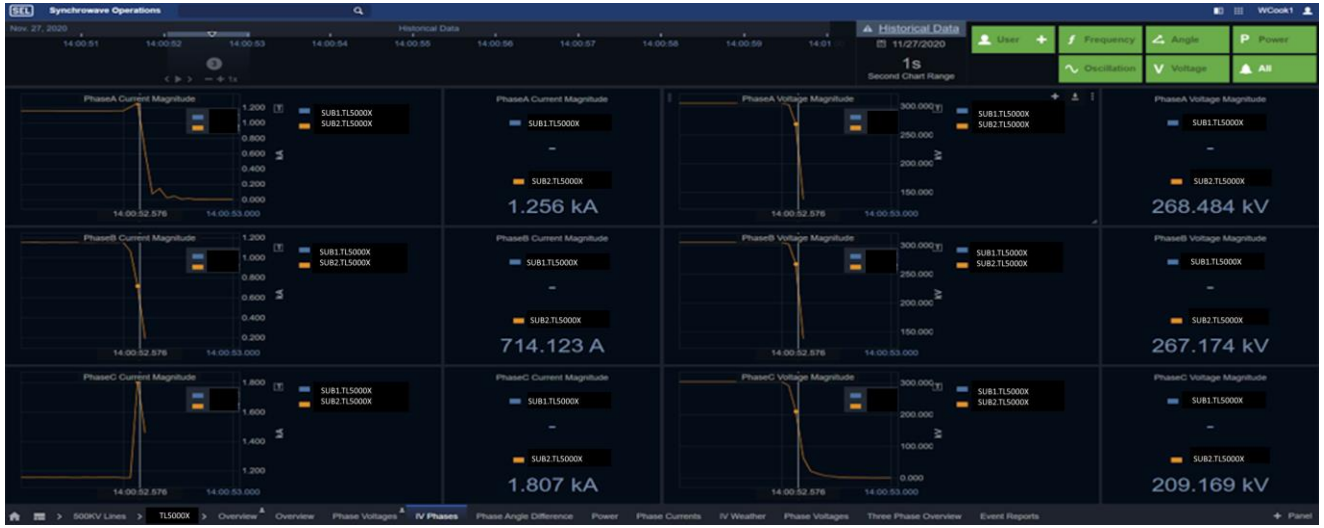
Local Area Frequency Oscillations

Event

- Loss of multiple renewable generation resources in SDG&E area leading to frequency changes accompanied by oscillations across the transmission system

Step 1

1. View 500kV > TL5000X > IV Phases dashboard
2. TL5000X fault at 1400
3. C-ground fault, note reduced C-phase voltage



Step 2

1. View 230kV Lines > TL230X3 > Overview dashboard
2. Check IV 230kV bus frequency
3. Frequency drops from 60.015 to 59.98 Hz

Use Case: Fault Detection and Location

Double Line Loss from Common Structure Flashover

Use Case Factors

Description	• *Identify frequency, voltage and real/reactive power oscillations that may adversely impact system reliability and take action to return the system within acceptable operating bounds*
Objectives	• *Recognize multiple relay operations in SDG&E Area.* • *Identify the proximity of the facilities involved.* • *Determine the nature of the faults.* • *Conclude that the events may have been related.* • *Establish an expected sequence of events.*
Events	• *TL230X1 (SUB3–SUB1-SUB2) and TL230X2 (SUB1-SUB2) relay near the same time and PMU data is reviewed to determine the nature of the faults*
Data and Displays	• *Geospatial visualization of T-line power flow (MW, MVAR, voltage)*

Outcomes & Actions

Notifications	• *Notify the CAISO of common structure faults that appear to be related* • *Coordinate with adjacent TOPs of actions taken to return the system within acceptable operating bounds*
Actions	• *Take the actions necessary to return the system within acceptable operating bounds*

Use Case: Fault Detection and Location

Double Line Loss from Common Structure Flashover

Event

- TL230X1 and TL230X2 relay near the same time. PMU data is reviewed to determine the nature of the two faults. These two lines are on common structures between SUB1 and SUB2.

Step 1

1. View 230kV Lines, TL230X1 > IV Phases dashboard
2. Check TL230X1 currents and voltages
3. C-ground fault

Step 2

1. View 230kV Lines, TL230X2 > IV Phases dashboard
2. Check TL230X2 currents and voltages
3. C-ground fault, at same instant in time

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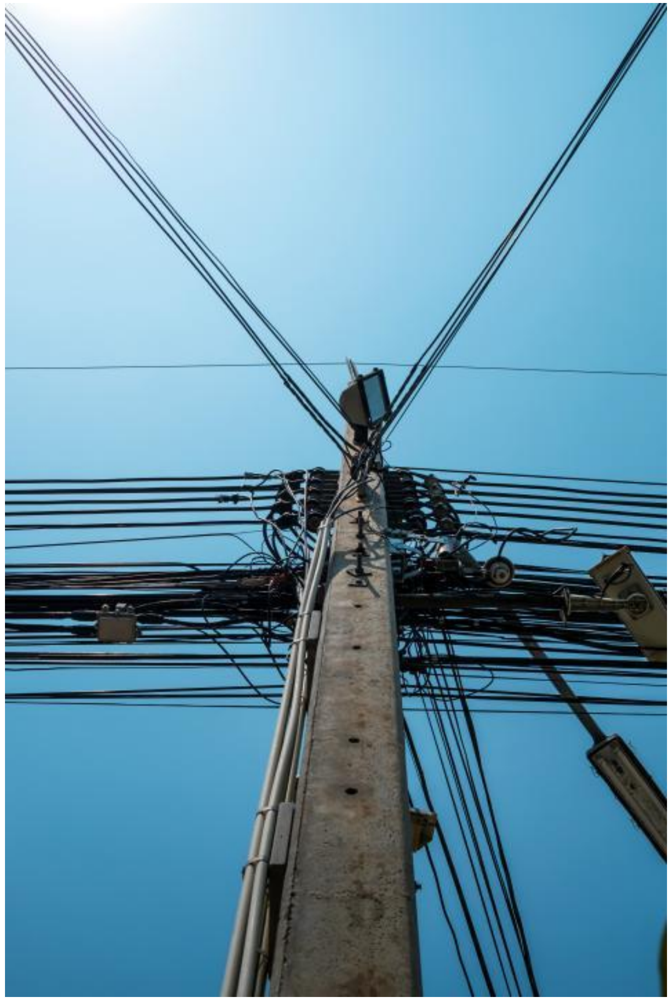
Use Case: Falling Conductor Protection (FCP)

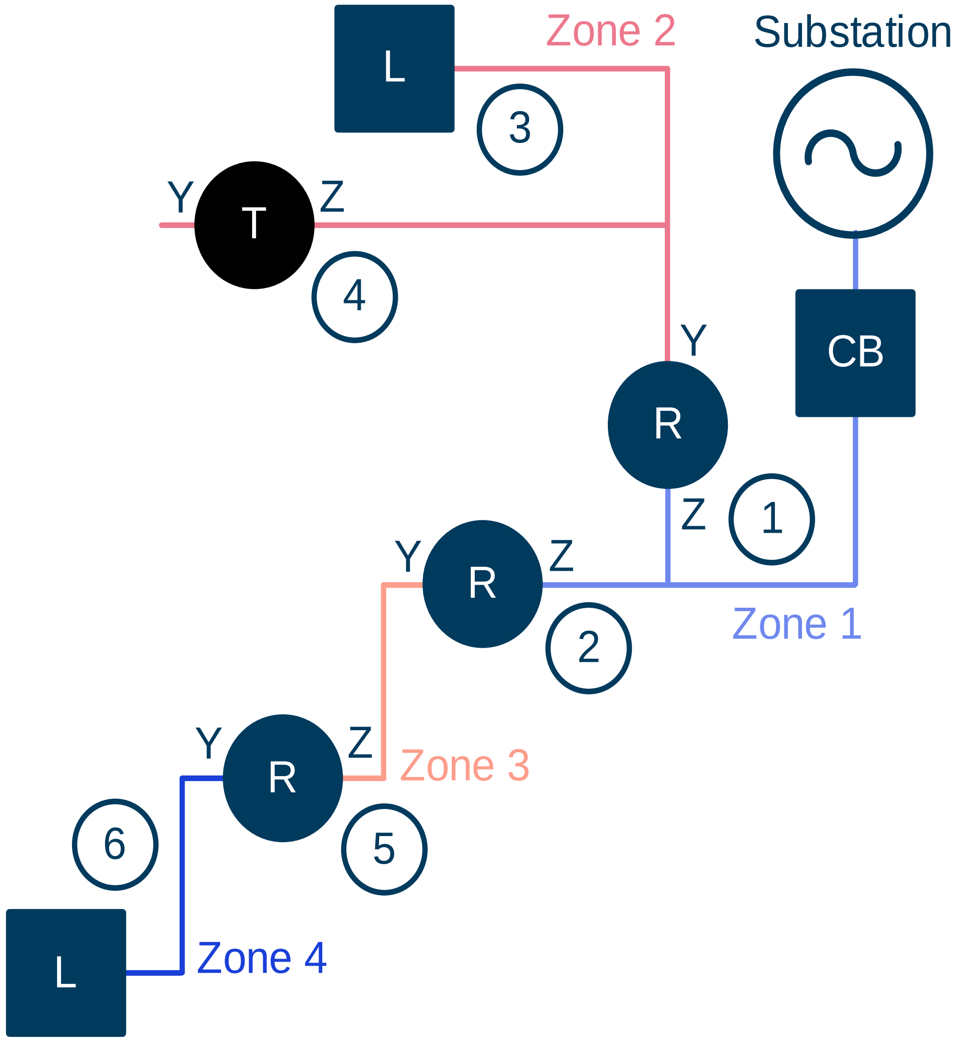
12 kV Substation:

- PMUs (1 substation-level, 6 field)
- 1 RTAC/PDC central controller
- 4 FCP zones of protection
- Private LTE network



Example: FCP Circuit B-Phase Broken Conductor

- Substation CB detects fault
- Data are sent to FCP RTAC over C37.118 protocol
- Trip commands sent via 61850 GOOSE
- RTAC restrains FCP operation during traditional faults (LL, LG, 2LG, 3PH)



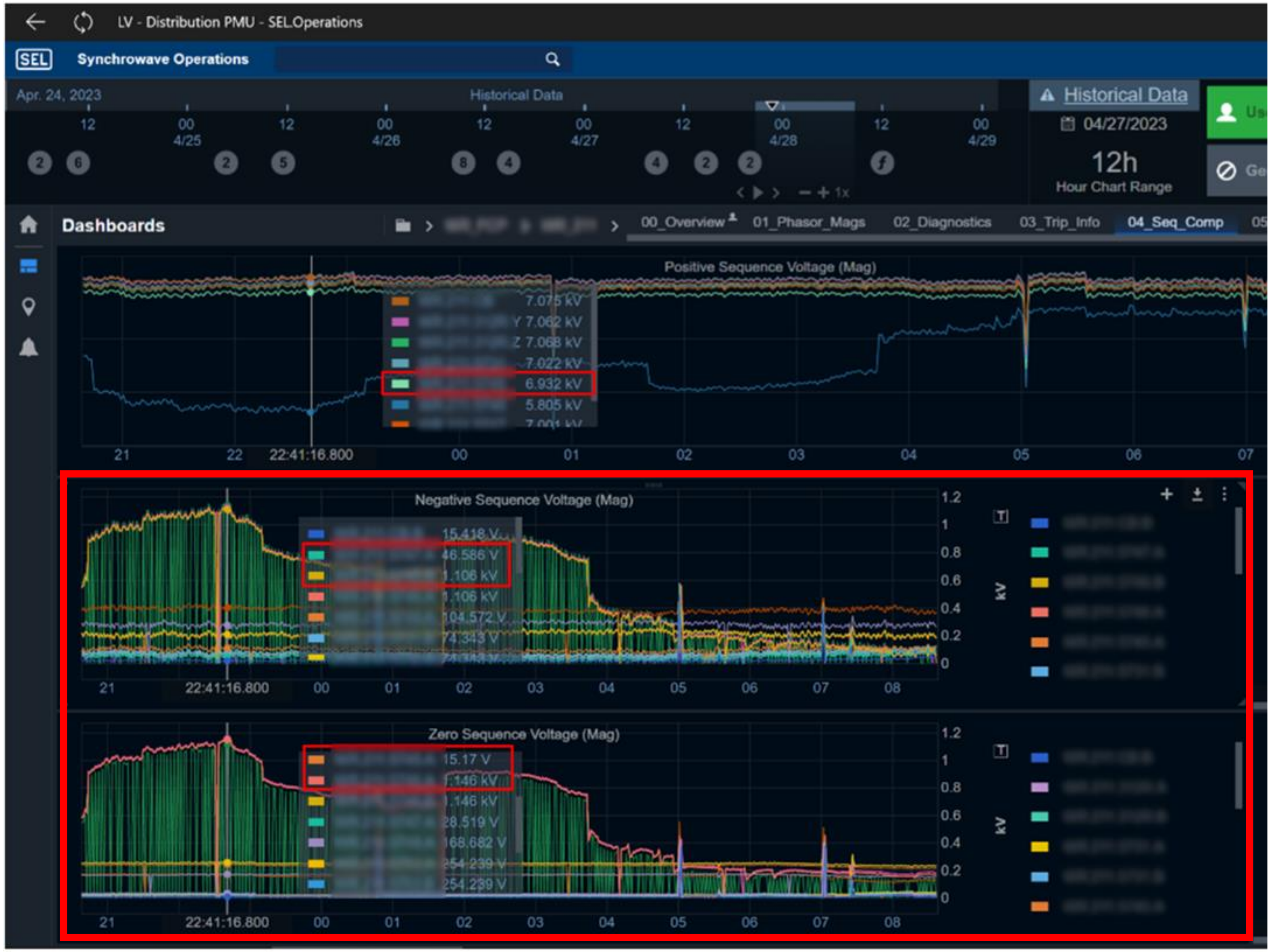
Example: FCP Circuit B-Phase Broken Conductor

Line Recloser detects B-phase voltage decrease

Example: FCP Circuit B-Phase Broken Conductor

FCP detection method
& operating quantity assert:

- Mag (negative- sequence)
- Mag (zero-sequence)



Q&A Topics:

What is the biggest challenge faced in Distribution PMU's?

- Deployment of communications infrastructure to allow the transport of PMU data to centralized locations for distribution and processing
- Use case implementation
- Benefit vs. Cost

What use cases can we look at applying when we install distribution PMU's?

- Wildfire Mitigation – Falling Conductor Protection
- IBR power flow monitoring
- Frequency monitoring
- Development of distribution PMU based fault location

How is Cyber-Security addressed at the local site on a distribution line?

- Encrypted locally at the point of collection and transferred over a secure VPN to the distribution or centralized processing location
- Cyber-secure Firmware validation prior to deployment
- Monitoring of traffic for unusual types of data or data not within scope of the expected traffic/bad data

Thank you for your time.