Role of Edge Computing in Synchronized Measurement Systems

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Edge computing definitions from the IT world

1. Any type of computer program that delivers low latency nearer to the requests
2. Computing outside the cloud, happening at the edge of the network, and more specifically in applications where real-time processing of data is required
3. Cloud computing operates on big data while edge computing operates on "instant data" that is real-time data generated by sensors or users
4. Concentrates on servers "in proximity to the last mile network“
5. Can be used in IoT, or not; and is not the same as IoT

Conclusion – our team knows more about edge computing than the IT world

What is edge computing in synchronized measurement systems?

- Our starting point - transmission PMU based WASA and WAMPAC systems with centralized SPDC and application computing platform
- PMUs are only sensors with centrally-bound communications
- Computing functions at PMUs are standard synchronized measurement extractions from sampled data
- Same basic story even if we add new extractions like harmonic synchrophasors or sampled-data snapshot capture
- Central network server platforms and SPDCs perform all analytics, display, historization, extraction, enterprise sharing

Examples of centralized applications – no edge computing

Centralized transmission applications or use cases

- WASA– profiles, flows, trends in angle and frequency, displays, oscillation and stability analytics, event analysis, historization
- WAMPAC– examples
- The sensor can have return control path

Centralized distribution use cases

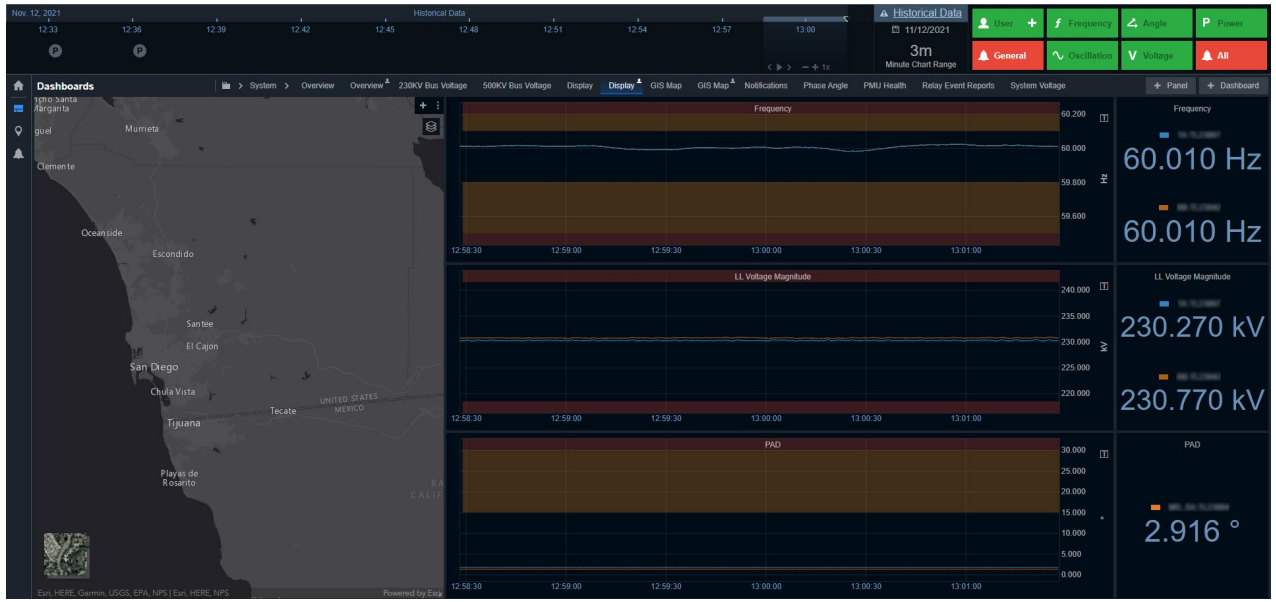
- Voltage and load profile displays, circuit status, fault location
- For some use cases– processing can be distributed

Edge computing – decentralized synchronized measurement systems

- With edge computing - PMU is a function within a circuit application device that also has *embedded local-action applications.*
- Synchronized measurements are used in local processing – calculations and logic :
  - Preprocessing to extract higher-level information to send up to central clients along with or instead of raw synchronized measurements.
  - Direct use of synchronized measurements for local control algorithms.
  - Client for synchrophasor streams from other edge devices in a control area.
  - Publisher of streams for the same purposes.
- For control applications, PMU device may have local control outputs or is part of a local system that has them.

Centralized PMU data collection, visualization, analysis at Control Center

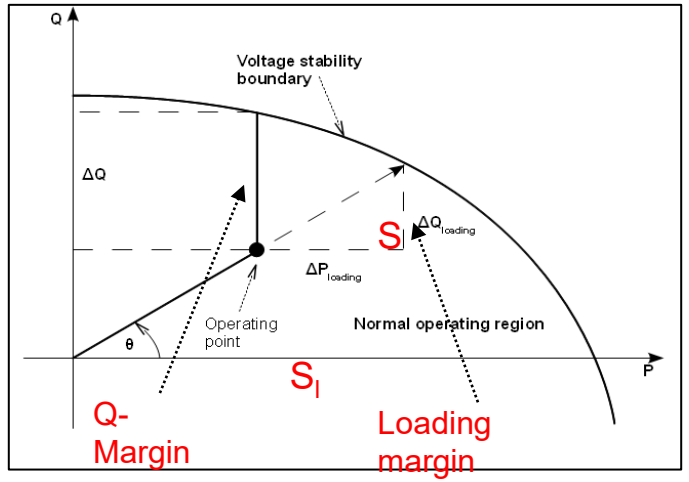
- Visualization client functions
- Measurement analytics
- Edge computing not required

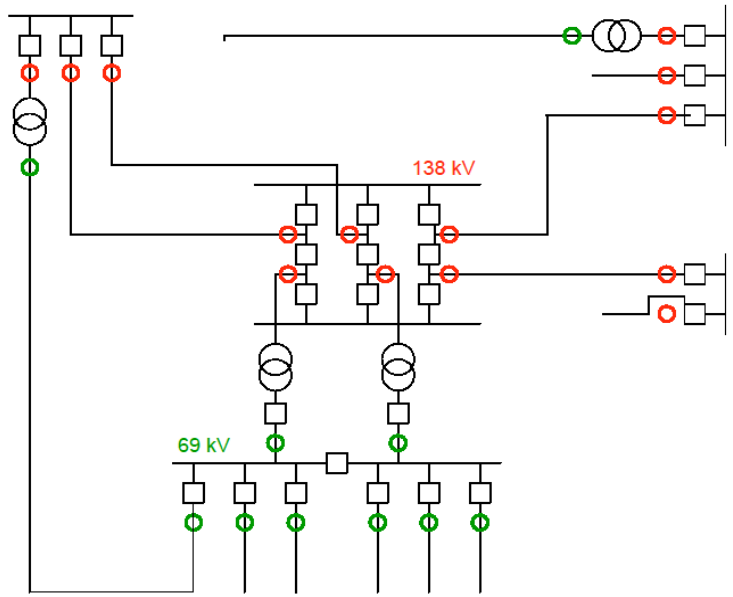


Centralized protection and control – WAMPAC at control center

- PMU-based voltage stability analysis (VSA) detects fast dynamic instabilities that EMS VSA will miss.
- Wide-area backup fault protection surgically removes uncleared faults before Z2 relays regardless of generation mix
  - 87LN fault protection demonstrated in recent development of PMU-based transmission falling conductor protection (TFCP)
- Separate swing protection/islanding with voltage phasors.

Applications are based on centralized holistic evaluation of PMU sensor data





Where is the edge?

At the field process measurement locations or close to them

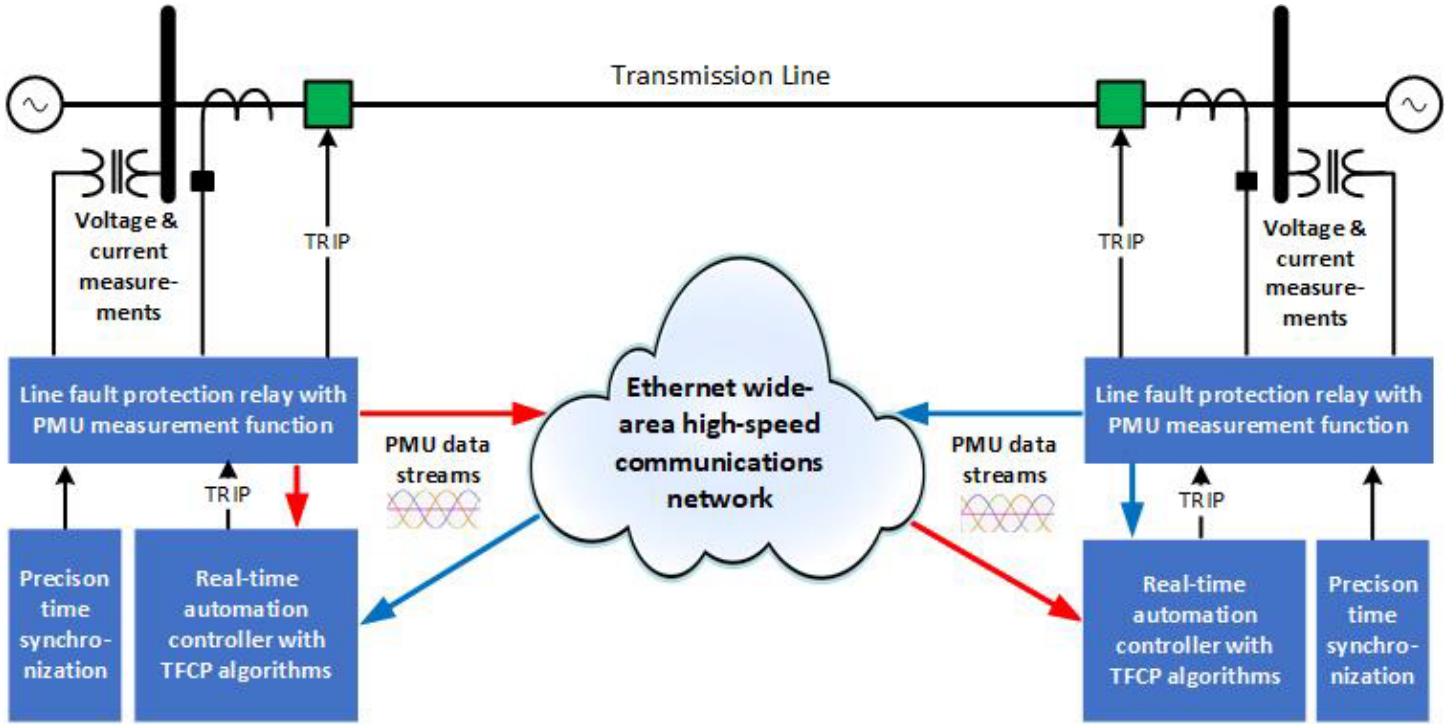
- Transmission– in substations – extending to DER sites, large tapped customers
- Distribution – all of above including smaller customer sites, circuit apparatus controllers like recloser controllers, regulators, cap bank controllers, switch controllers
- The substation can be a concentration and processing point for circuit data – these are still edge computing applications

Transmission decentralized examples use edge computing

- RAS or generator separation based on comparison of angular separation and magnitudes by edge controller
- Transmission falling conductor protection (TFCP) system based on synchronized measurements exchanged between substations
  - Local line detection scheme based on edge computing controller

Transmission PMU-based FCP architecture choices

- Local implementation based on edge computing controller platform is practical for point applications



- Central application can protect every PMU-equipped transmission line using the same data gathering infrastructure as WASA
  - May be a bit slower but not an issue for this application

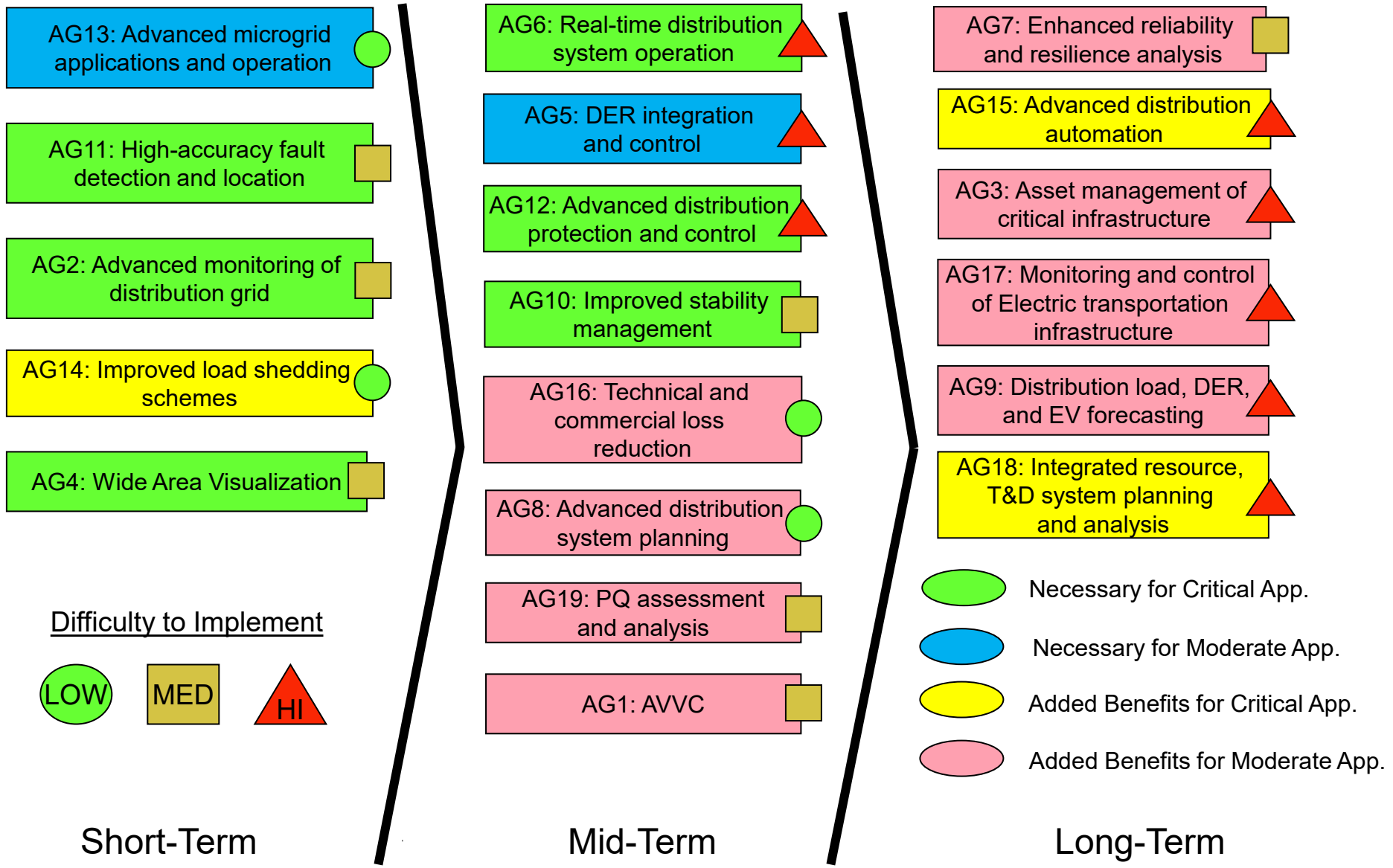
Distribution examples – depends on the application

DOE Distribution Synchronized Measurement Roadmap presented to NASPI– 76 applications or use cases

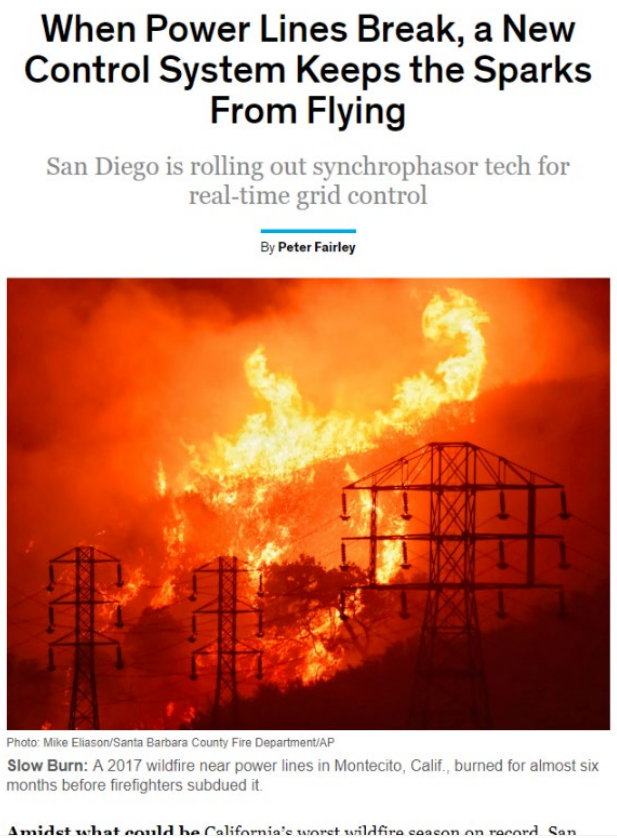
- Centralized
  - Fault location – combine PMU data with relays, FCIs, AMI
  - Voltage and load profiles
  - Distribution apparatus and PMU/SCADA system asset management
  - Smart load shedding
- Decentralized and based on edge computing
  - SDG&E® falling conductor protection
  - Fault location, isolation, and service restoration (FLISR)
  - Fault protection
  - Extraction for upload of harmonic or PQ indices from raw measurements
  - Predictive diagnostics based on wideband signatures

Examples of distribution synchronized measurement use cases

- Some are centralized
- Some need edge computing
- The platform can support both
- The platform drives or is driven by use case prioritization



SDG&E® distribution falling conductor protection (DFCP) – substation edge computing



When Power Lines Break, a New Control System Keeps the Sparks From Flying

San Diego is rolling out synchrophasor tech for real-time grid control

By Peter Fairley

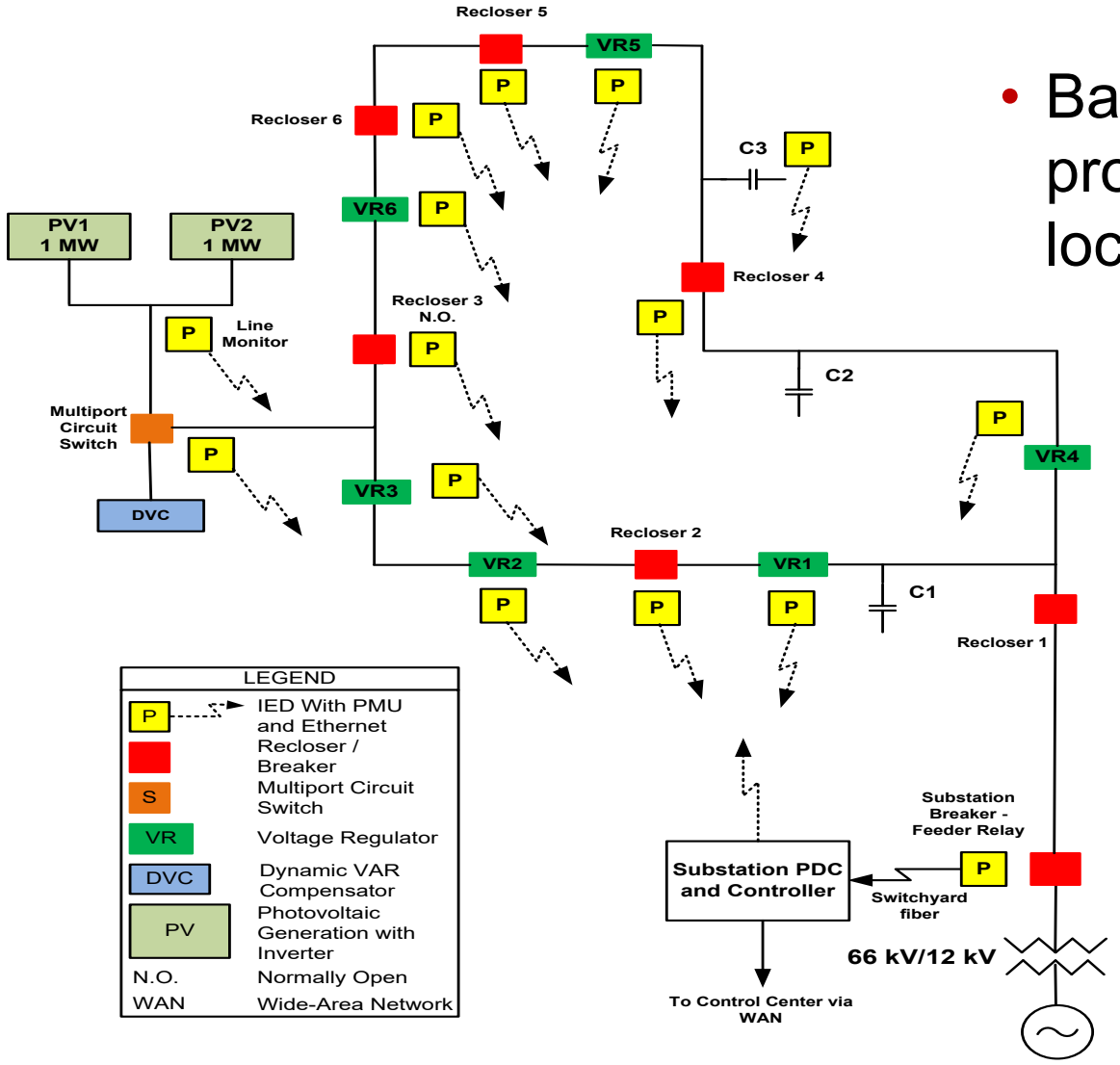
Photo: Mike Eliason/Santa Barbara County Fire Department/AP

Slow Burn: A 2017 wildfire near power lines in Montecito, Calif., burned for almost six months before firefighters subdued it.

Amidst what could be California's worst wildfire season on record, San

- DFCP invented and patented during study of >60 use cases for synchronized measurements in distribution
- Uses synchronized V & I measurements to detect a circuit conductor break and isolate failed section *before* the conductor hits the ground and risks fire ignition.
  - Not ***detection*** of difficult arcing Hi-Z fault, but ***avoidance*** by robust prefault measurement changes
- Since 2015 development, SDG&E is deploying DFCP on circuits in over 150 medium & high fire risk areas.
- Synchronized measurements from circuit device controllers are communicated to substation edge processing array.
- The development team found *sequence voltage magnitude and angle changes* along the circuit, based on PMU measurements, as the practical solution to detect conductor breaks.

Distribution circuit area network with substation location of edge processing

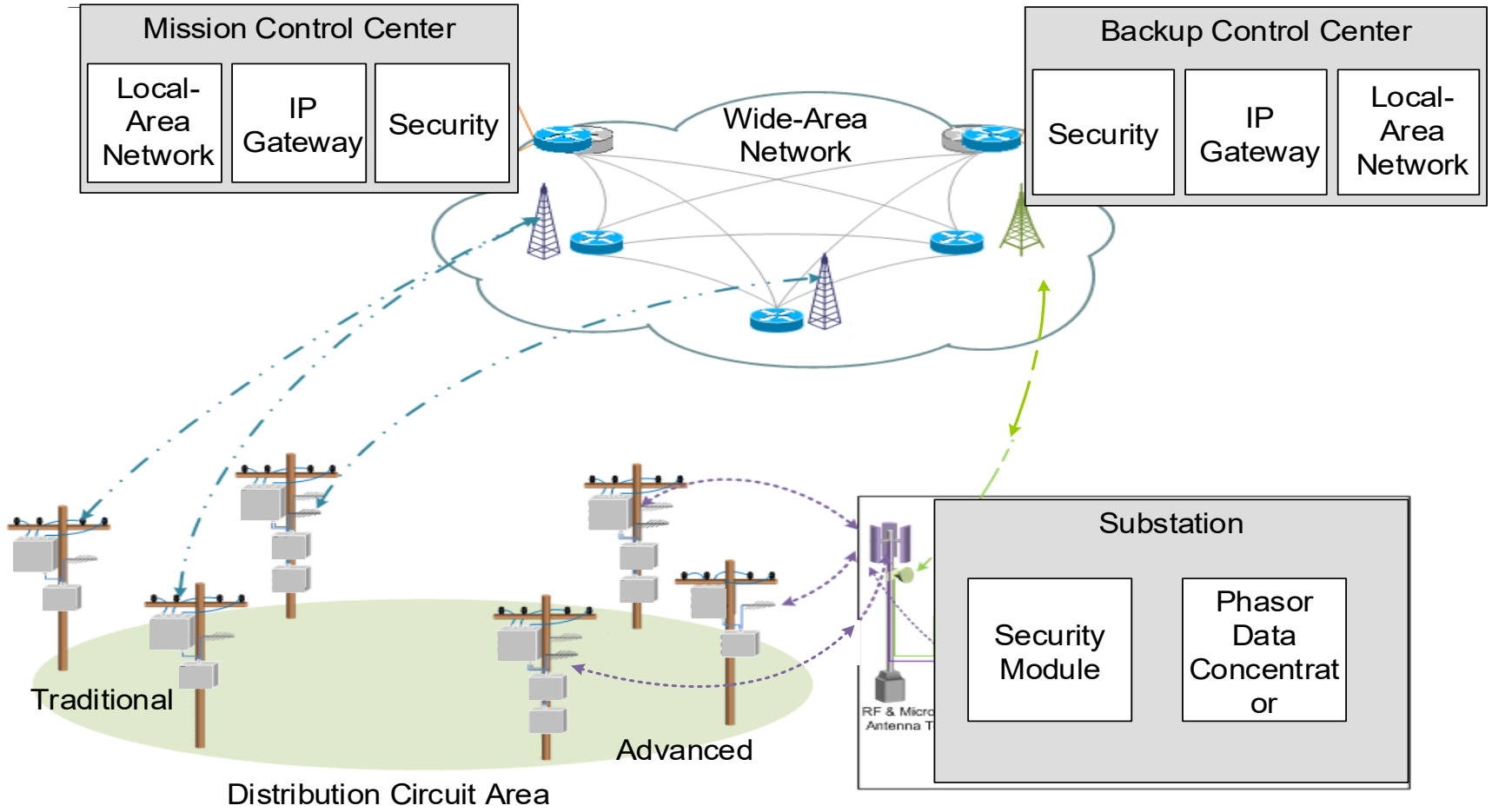


- Backhaul communications of raw and processed information to data center location of centralized functions

Communications impact

- Communications latency is critical for some use cases like DFCP
- Latency depends on communications layers (Ethernet LAN, WAN, services like IEC 61850 GOOSE or R-GOOSE)
- Number of communications hops – latency delays add
- Path and hop arrangements:
  - Radial or point-to-multipoint communications between field sites and processing center
  - Point-to-point communications between/among field locations
  - Point-to-multipoint communications between field edge devices and substation edge processors
  - Mesh networks can serve all arrangements.

Traditional SCADA with advanced high -speed Ethernet mesh radio communications overlay



Benefits of edge versus central computing architectures

Edge-based applications

- **Reduced or eliminated communications paths, data volume, and latency serves highest-speed control and protection applications** (basis of edge computing IT-world definition).
- Reduced data handling at central locations.

Centrally-based applications

- Standardized and simplified field PMU-IED configuration
- Simplified configuration, logic, and settings management
- *Can* be easier to maintain

Key design recommendations for edge -based applications

*Distributed systems with edge computing should monitor themselves and help with power system maintenance– they must **not** become a new maintenance burden of their own*

- Design for condition-based maintenance (CBM) – self-monitoring methods as used in NERC PRC-005-6
  - Avoid unmonitored gaps in sensing or processing at edge
  - Include monitoring and maintenance applications linking edge sites with central manager.
  - Monitor holistic behavior of distributed system – catch anomalies
- Collect monitoring and alarms from the edge– manage the edge from the center
- Work to achieve secure remote firmware and setting updates
- Create airtight configuration and setting management system, for the edge sites and central processing *together*

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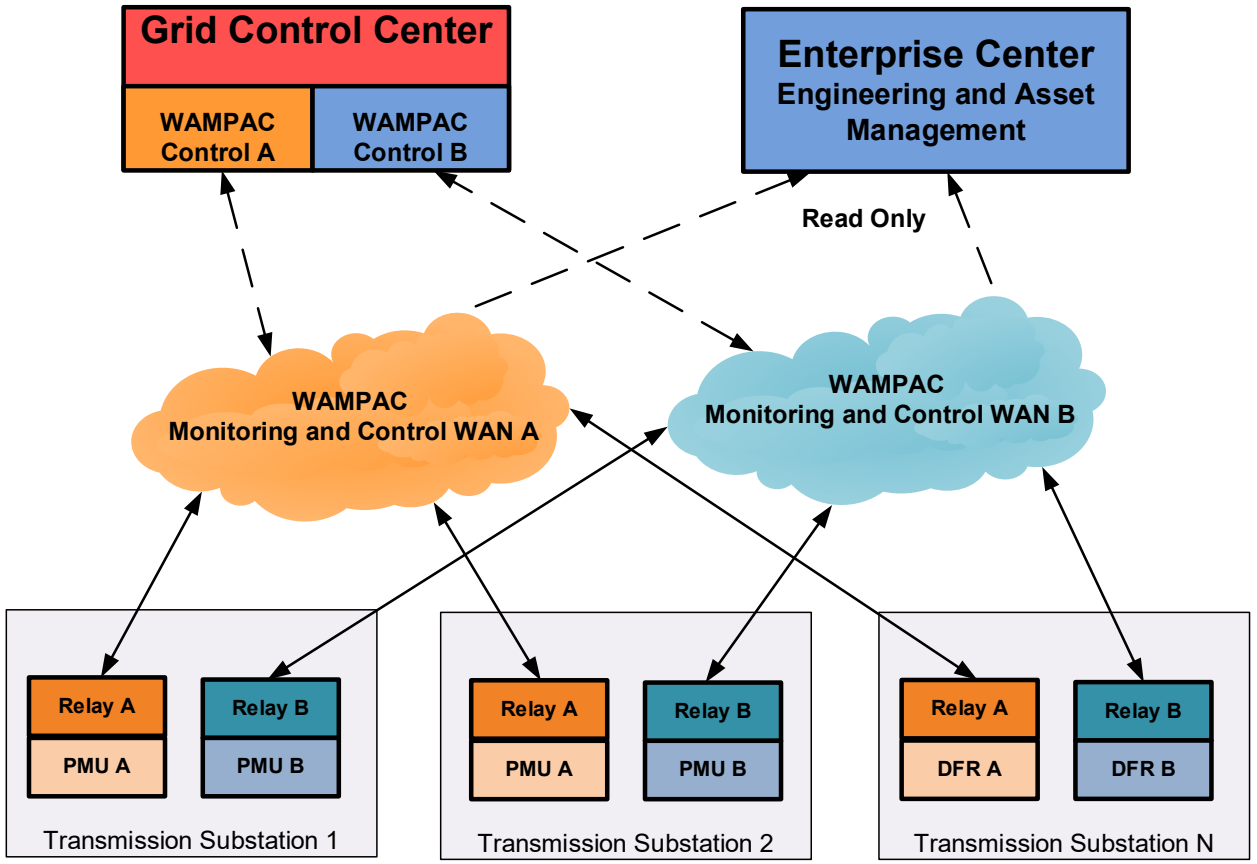
Mission-critical functions require redundant field or centralized computing platforms and communications

- Monitoring reports failures as second systems maintains control and protection



Process for scoping a distribution synchronized measurement system platform

1. Rank and roadmap use cases or applications to deploy
2. Imagine a comprehensive system platform with:
   - Central, substation, and circuit edge computing abilities
   - Functionally radial communications from central platform to subs
   - Same from substations to circuit devices
   - Same from circuit devices to central location
   - All synchronized and other measurements, values, states flow upward to central
3. For each selected use case:
   - Set performance requirements
   - Conceive high-level process flow design with bias to centralize
   - Map requirements and functions to platform boxes

Process for scoping a distribution synchronized measurement system platform

4. Evaluate difficult or expensive edge computing platforms
   - What functions are important to keep?
   - What needs to be developed and what will it cost?
5. Evaluate communications paths
   - Which functions cause loading
   - Which paths can be routed differently to combine and eliminate?
   - What communications options are practical?
6. Trim or trade off use cases and revise design concepts– circular evaluation
   - Tune the roadmap
   - Trim low-utilization comms paths and edge devices
   - Forecast schedules and budgets
7. This process minimizes chance that platform design will*miss opportunities to support future roadmapped use cases* after a huge investment.

Use case review 1– prospective platform needs

APPLICATION DESCRIPTION	Central or Edge or Combo
Conservation Voltage Reduction (CVR)	Central or sub edge
Volt-VAR Control (VVC) of distribution systems	Central
Volt-Var Optimization (VVO)	Central
Phase angle monitoring for voltages and currents	Central
Active and reactive power flow measurement for circuit design evaluation	Central - planning
Voltage profile monitoring	Central
Power quality measurement	Edge
Monitoring of communications system/equipment performance with management metrics	Edge
Frequency monitoring	Central*
Primary meter customer (e.g major customer monitoring -power quality)	Edge
Condition monitoring and asset management of power apparatus (two use cases) asset management support	Central
Near real-time event monitoring	Central
Monitoring and control of critical infrastructure and large customers	Central
Underground secondary/spot network monitoring and analysis	Central
Circuit status dashboards	Central or sub edge
Recording, retrieval, trigger marking, archiving, and disposal of gathered synchrophasor and other circuit data	Both central and edge parts
Integration of customer site FNET information	Combo
Improved wide area situational awareness (T&D)	Central
Visualization of dynamic system response	Central
Monitoring of intermittent DER	Central
Voltage impact assessment and mitigation due to high penetration of intermittent energy resources	Central or sub edge

Use case review 2 – prospective platform needs

Voltage impact mitigation for high penetration of intermittent DG	Central or sub edge
Active and reactive reverse power flow management	Central or sub edge
Customer/smart inverter control	Central or sub edge
DER management and energy balancing (energy storage)	Central or sub edge
Load unmasking (behind-the-meter DER)	Central or sub edge
Dynamic rating of distribution assets	Central
Distribution state estimation	Central
Closed-loop circuit operation	Edge
DERMS implementation	Central
Improved demand response	Central
Improved distribution reliability analysis	Central
Post-mortem analysis	Central
Phase identification	Combo
Distribution system computational model validation	Central
Short circuit study validation	Central
Load characterization, load modeling and load forecasting	Central
DER forecasting	Central
Voltage stability monitoring and prediction	Combo
Control instablility, hunting, or oscillation detection - voltage, var, switching	Combo
Transient stability assessment	Central
Faulted circuit indication	Edge
Incipient fault & failure detection	Edge
High accuracy fault location	Combo
Communications failure location for maintenance dispatch	Combo
High impedance fault location	Edge
Open conductor fault detection	Edge

Use case review 3 – prospective platform needs

Fault Induced Delayed Voltage Recovery (FIDVR) detection	Central or sub edge
Permanent circuit laboratory for trying new functions and equipment before impacting real customers	Central
Test circuit for validating behavior of falling conductors	Central
Falling conductor protection	Edge
Islanding detection for distributed generation (anti-islanding scheme)	Combo
Reclosing assistance for fast circuit recovery after fault	Edge
Current differential protection of feeder sections	Edge
Adaptive protection of distribution systems	Combo
Planned islanding and restoration of microgrids	Edge
Advanced protection of microgrids	Edge
Advanced distribution system topology, automation and control (holonic grids)	Central
Improved load shedding schemes - frequency	Edge
Improved load shedding schemes - voltage	Central
Load shedding real time compensative arming to balance 1547 compliant PV	Edge
Load transfer and load balancing	Edge
Self-healing and enhanced FLISR operation	Edge
Circuit loss minimization	Central
Energy accounting	Central
Techical and commercial loss identification, calculation and reduction	Combo
Monitoring and control of electric transportation infrastructure	Combo
Vehicle-to-Grid (V2G) monitoring and control	Combo
Running sub-transmission (69 kV) and distribution in parallel	Combo
Integrated resource, transmission and distribution system planning and analysis	Central

Questions and discussion

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