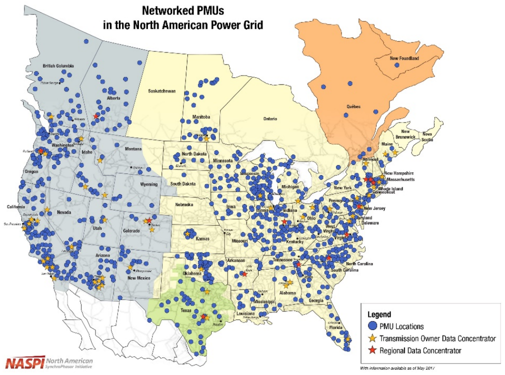


Benefits of Deploying Synchronized Measurements in the T&D Systems - Key Success Factors and Examples

Damir Novosel

President, Quanta Technology

Industry Trends and Drivers for T&D Synchronized Measurement Deployment

Transmission Application Benefits and Roadmap

Distribution Application Benefits and Roadmap

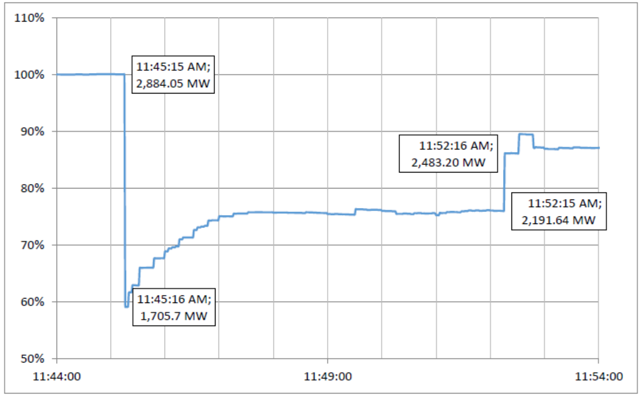
Key Success Factors and Future Plans

The electric utility industry is changing

Operational Challenges of T&D Systems

- Need for fundamental changes in T&D planning, operation, protection, and control, including advanced sensors and measurement devices
- Distribution load, DER, and electrification forecasting required for meaningful T&D planning
- Large portion of generation resources are invisible to operators - it is not possible to directly control distribution
  - Inverter-based resources connected to distribution
  - Behind-the-meter distributed energy resources
- Distribution networks are no longer passive loads
  - Drastically changed daily load curve
  - Weather conditions have major impact on both consumption and distributed generation
  - Circuits exhibit very different dynamic characteristics

- Need for improved visibility and control with distribution circuit monitoring and accurate models or equivalents
- Need for increased information exchange and control action coordination between transmission and distribution networks for the reliable operation of both



Southern California Solar Resource Loss, Aug. 2016

Source: Bob Cummings, NERC

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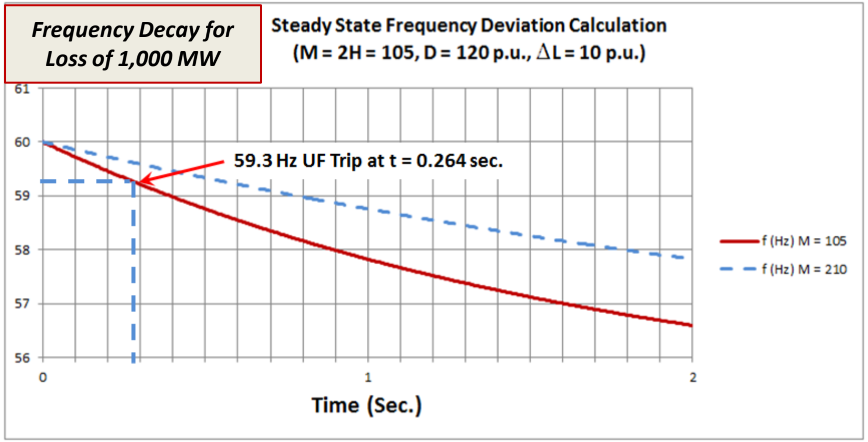
Addressing Operational Challenges

Inverter Based Resources (IBR) → Less Inertia → Things Happen Faster!

- Faster control of system dynamic changes
- Address frequency regulation requirements
- Effective load shedding with DER monitoring saves system from collapse
- Low fault currents and dynamic system changes requiring adaptive protection
- Accurate system modeling for GT&D planning studies and operations
- Etc.

Synchronized measurements - important enabling technology to address visibility and control needs



Source: *IEEE/NERC report on Impact of Inverter Based Generation on Bulk Power System Dynamics and Short-Circuit Performance*

Frequency excursions:
Rate-of-change-of frequency proportional to inertia

$$\Delta P = -k_{in}\frac{df}{dt}$$

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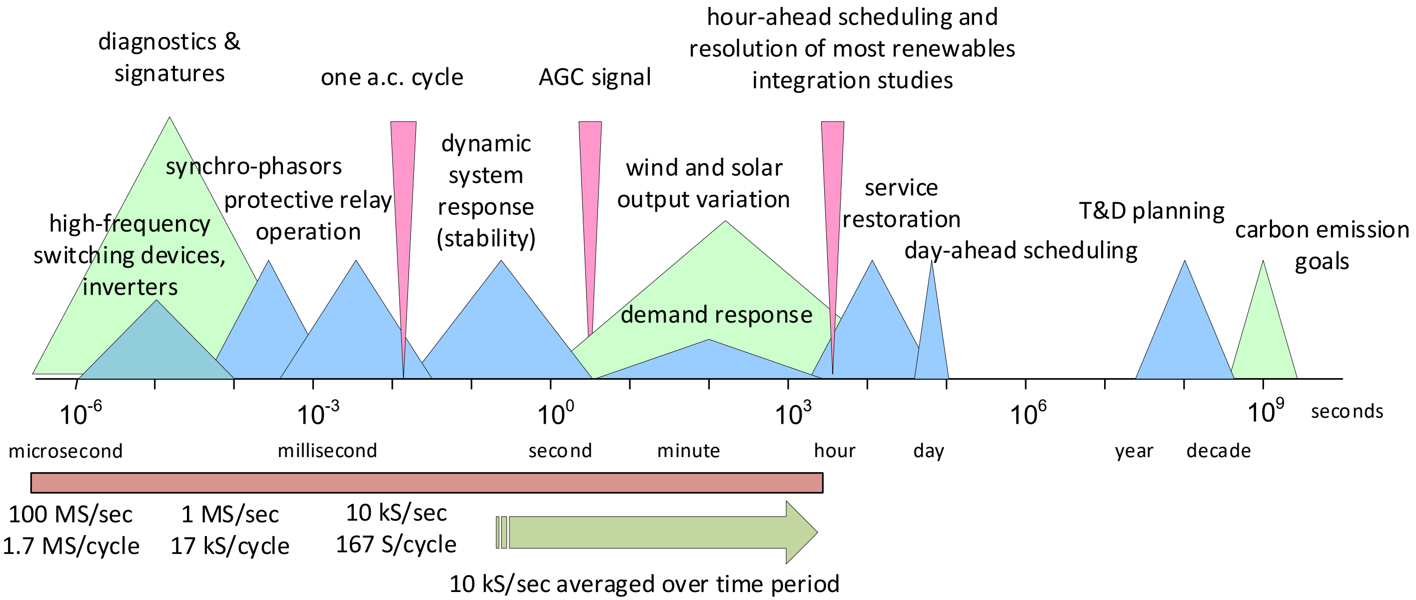
Synchronized Measurements Bridge the Gap in Observability and Control

1 μs time synchronization grid measurements using GPS signals

Dynamic wide-area network view at high speed (30 -240 observations/s) for better indication of grid stress

Time Scales in Operations, Planning & Report Rates



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Status and Trends with Synchronized Measurement Applications

Transmission

- US, India, and others have been deploying large number of PMUs, either integrated in IEDs or stand-alone.
- Many utilities have steadily improved their synchrophasor system reliability, resilience, security, and capabilities.
- A significant percentage of systems are ready or close to ready for real-time operations.
- Efforts started on next-generation systems:
  - System-wide observability.
  - Single information visualization interface serves as data and application integration platform.
  - Measurement-based & model-based applications.
  - Access and integration with EMS/SCADA and GIS, as well as with other data such as point-on-wave, weather, fire, earthquake, etc.

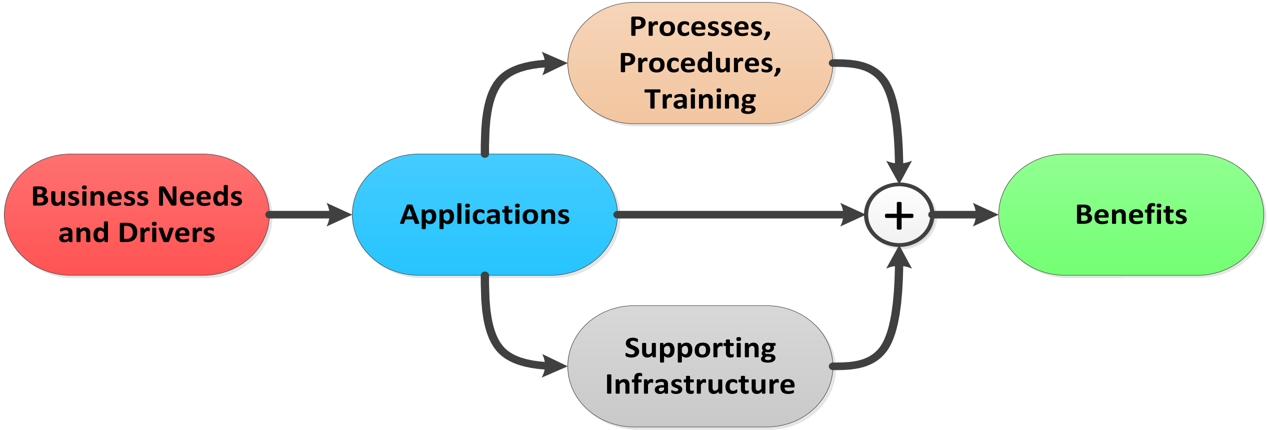
Distribution

- Interest in deploying synchronized measurement technology in distribution has steadily grown
  - DOE co-funded Micro-PMU development.
  - NASPI established a Distribution Task Team.
  - IEEE started a working group on D-PMUs.
- Some deployment examples:
  - SDG&E: Developed a roadmap with use cases and successfully developed advanced SCADA for distribution and Falling Conductor Protection.
  - ComEd: Developed a T&D roadmap and piloted a selected number of applications , including D-LSE.
  - Southern Company: Piloting several applications.
  - Dominion: Plans to pilot several applications, including system improving visibility with DER, power quality, and fault location and analysis

Roadmap Development Approach

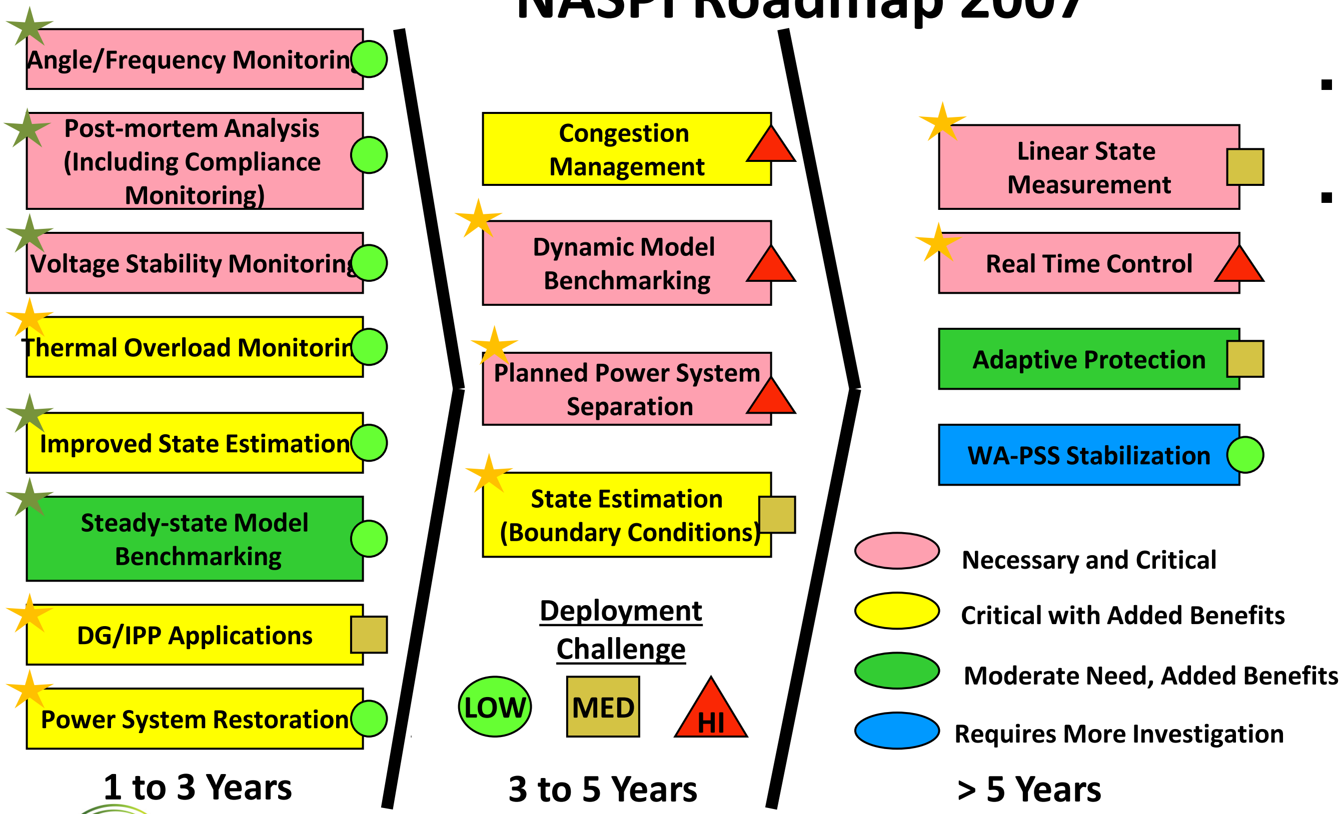
- Applications are determined by business needs & drivers
- Applications dictate the supporting infrastructure requirements and deployment
- Users need processes, procedures, and training to take the full advantage of the deployed system and applications

Cost-benefit analysis to develop
Near-, Mid- and Long-term plans with an impact level: *Low, Medium, High*



- Industry Trends and Drivers for T&D Synchronized Measurement Deployment
- Transmission Application Benefits and Roadmap
- Distribution Application Benefits and Roadmap
- Key Success Factors and Future Plans

NASPI Roadmap 2007



- Developed based on CEC and DOE PMU Benefit-Cost Analysis Project.
- Served as a blueprint for successful transmission PMU deployment.

★ - *Presently deployed*
★ - *Limited deployment*

Industry needs a roadmap for distribution synchronized measurement deployment, including benefit-cost analysis and equipment requirements

Source: NASPI

NASPI Transmission Application Requirements

Real-Time

Real-time Applications

Application	Latency	Data Resolution	Time Window
Situational Awareness Dashboard	1-5 Seconds	1 sample/sec.	Snapshot
Real Time Monitoring and Alarming (Angle of Separation; Voltage & Angle Profiles; MW, MVAR flows; Load-Resource Imbalance)	1-5 Seconds	1 sample/sec.	1/2 - 1 hour
Frequency Stability/Islanding	1-5 Seconds	30 samples/sec.	Few Minutes
State Estimation	1-2 Minutes	30 sample/sec.	5-10 Minutes
Small-Signal Stability Monitoring	5-10 Seconds	10 samples/sec.	10-15 Minutes
Voltage Stability Monitoring/Assessment	Few Seconds	30 samples/sec.	~ 1 hour
Thermal Monitoring (Overload)	Few Seconds	30 samples/sec.	~ 1 hour

Disturbance and Data Analysis

Disturbance Analysis and Model/Data Validation

Application	Latency	Data Resolution	Time Window
Baseline Normal Phase Angle Trends	N/A	1 sample/sec.	24 hrs +
Pattern Recognition/Correlation Analysis	N/A	1 sample/sec.	1 hour +
Disturbance Analysis Compliance	N/A	30 samples/sec.	1 m pre & 2 m post event
Frequency Response Analysis	N/A	10 samples/sec.	1 m pre & 2 m post event
Model Validation	N/A	30 samples/sec.	5-10 minutes
New Applications Evaluation & Limits Definition	N/A	30 samples/sec.	Application Depedant
Phasor Network performance monitoring & data quality	N/A	30 samples/sec.	24 hrs +

Vendors need users' requirements to guide development of cost-effective sensor products and systems

Protection and Control

Advanced Protection and Control

Application	Latency	Data Resolution	Time Window
Automatic Alarming of Remedial Action Schemes	~ 100 ms	30 samples/sec.	~ Minutes
Out of step protection	~ 100 ms	30 samples/sec.	~ Seconds
Short-term stability control (e.g. transient stability)	~ 100 ms	30 samples/sec.	~ Seconds
Long-term stability control (e.g. wide area frequecy, voltage stability)	1-5 Seconds	30 samples/sec.	~ Minutes
FACTS feedback control, Smart switch-able networks	1-5 Seconds	30 samples/sec.	~ Minutes

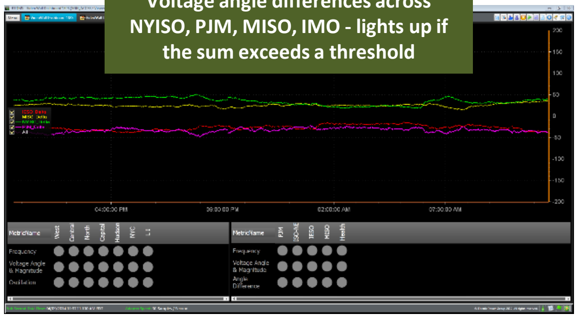
Source: NASPI

Transmission Applications

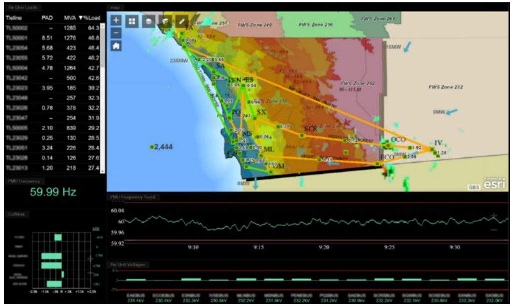
- Large number of PMUs have been and continue to be deployed to meet
  - NERC PRC-002-2 requirements
  - ISOs/RCs specified requirements for new or existing lines and generators
  - Utility's own drive to reach full observability of its transmission grid
- Offline non-real-time operations
  - Post-event analysis
  - Model validation and calibration
- Real-time operations
  - Wide-area situational awareness and control within and beyond a utility's own control area
  - Weather conditions, fire, lightning, etc.

- Protection and control
  - System Integrity Protection Systems (SIPS)
  - Black Start
  - Controlled islanding and islanding operation
  - Falling conductor detection and tripping
  - Wide-area backup protection
  - Real-time fault detection and fault location

Voltage angle differences across NYISO, PJM, MISO, IMO - lights up if the sum exceeds a threshold



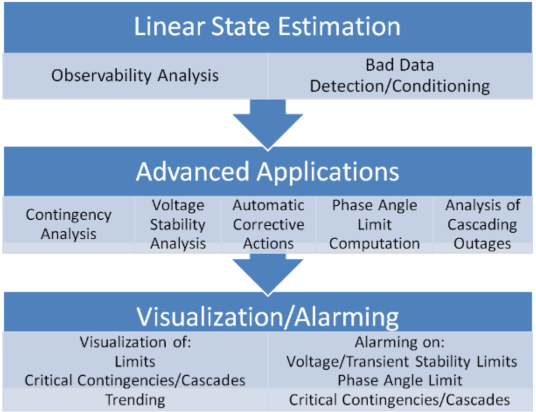
Source: NYISO



Source: SDG&E

Control Room Operations

- Benefits realized in first few years of deployment
  - Comprehensive information visualization and situational awareness, with high resolution trending
  - Oscillation and frequency monitoring, event location, and source determination
  - Assist in system restoration and inter-tie breaker closing
  - Three phase information
  - Heat-map (contour) display for voltage
- Start/shutdown generators and connect/disconnect load
- Dynamic real-rime contingency analysis (RTCA), Transient Stability Analysis, Voltage Stability Analysis and margins, and Linear State Estimation
- Dispatch reactive power resources



Source: V&R Energy

Mitigation of Oscillation

Oscillation Threat Levels

High

Control Room operators:

- Shut down the identified Source, or
- Curtail MW output of the Source generator(s)

Medium

Control Room and Source's personnel coordinate on mitigation measures:

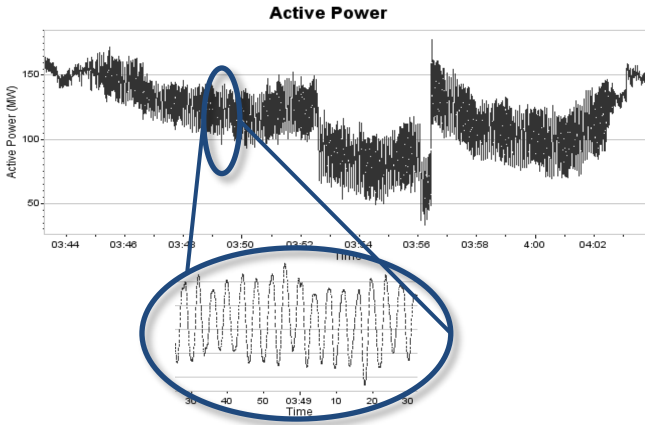
- Verify observations
- Adjust operating conditions
- Change control mode at the Source

Low

Off-line analysis personnel at grid operation and Source coordinate efforts

- To identify the actual reason of oscillations within the Source
- Eliminate the reason to prevent future oscillatory events

Event originated in Florida on January 11, 2019 –
Interarea oscillations of 0.25Hz and up to RMS=12MW lasted for 15 minutes and caused multiple Alarms in ISO-NE



This example illustrates the ability to identify on whether the Source is located inside or outside of control area

Source: *Slava Maslennikov, ISO NE*

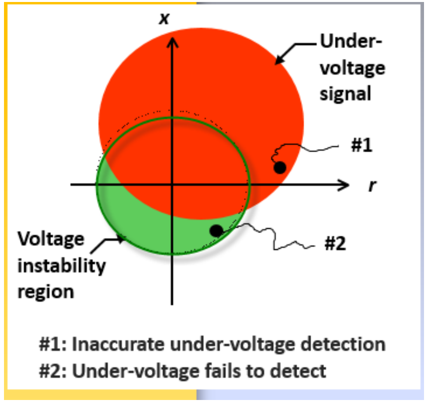
Measurement-based vs. Model-based Applications

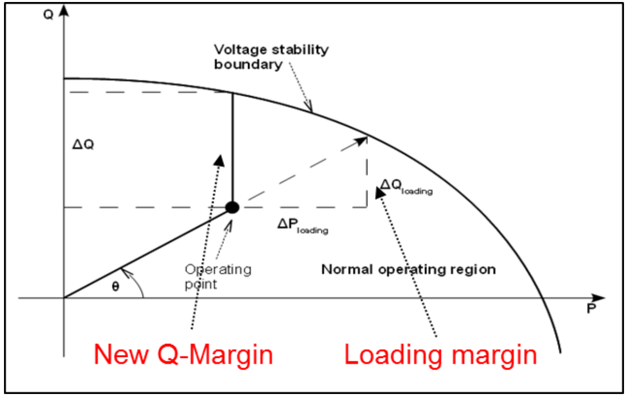
Measurement-based	Model-based
Not rely on system and component models	System and component models are required
Could establish correlations across measurements	Could also establish links among measurements through models
Measurement-based predictions	Model-based predictions
Must have observability at all points of interest	Need enough measurements to make the system observable
Data quality of the measurements is critical	Model accuracy also critical in addition to data quality

Comprehensive Voltage Stability Management

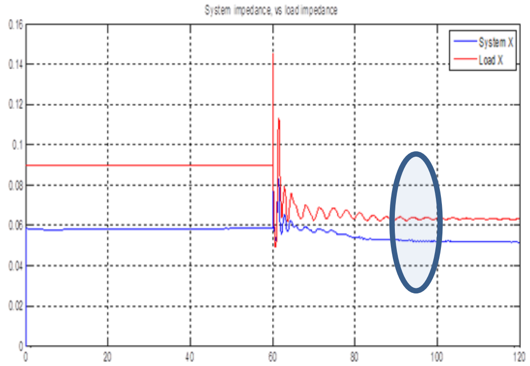
Hybrid solution is preferred

- **Voltage Security Assessment**
  - For pre-contingency mitigation actions
  - Accurate margins if accurate models and well-predicted scenarios
- **Model-free** methods using PMUs
  - Good for dynamic and fast voltage instability detection and trend monitoring
  - Able to distinguish FIDVR from voltage instability even if voltage is very low
- **Hybrid:** Nothing "falls between the cracks"
  - If VSA model not accurate, model-free will detect instability; converse also true
  - Could automatically trigger "out of sequence" SE/VSA on instability



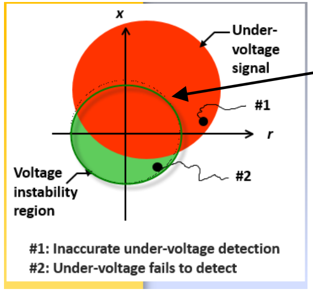


RVII Example: Security



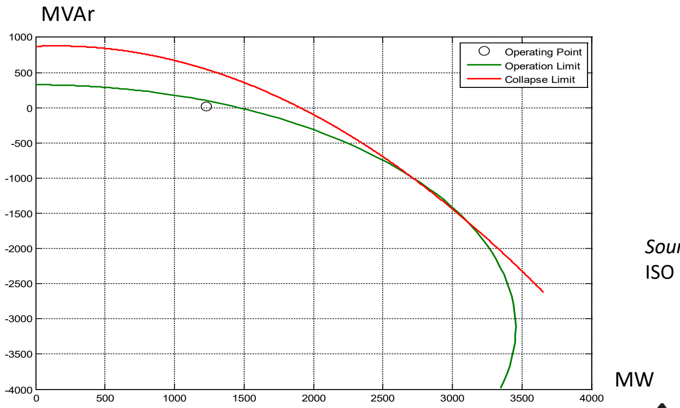
- Impact of outage on a critical interface
- This references post - outage condition
- Low voltages in the vicinity of the study zone, but clear separation between Thevenin & Load Impedance

Conclusion: System Voltage Stable



Note: in this case voltage was relatively low

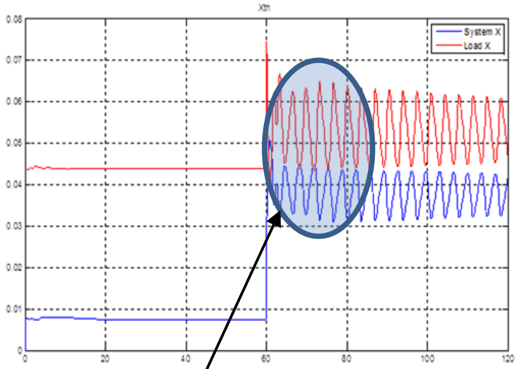
System operating further away (wider margin) from operational or collapse limits



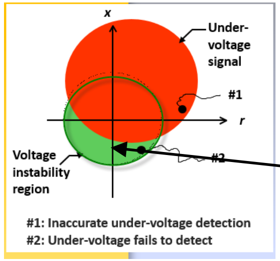
Source:
ISO NE

RVII Example: Dependability

- Impact of outage at **interface transfer limit**
- Path limited by transient stability problem
- RVII successfully detects instability
- System is operating with close to zero margins, at the boundary of instability limits



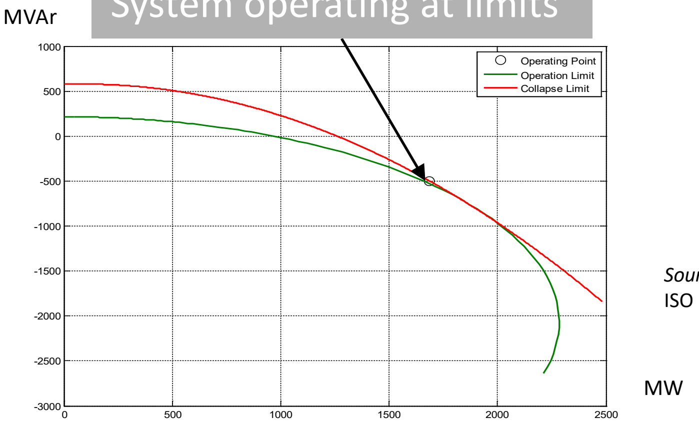
RVII detects instability



Conclusion:
System Voltage Unstable

Note: in this case voltage was relatively high

System operating at limits

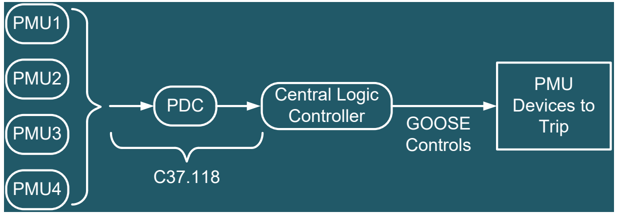


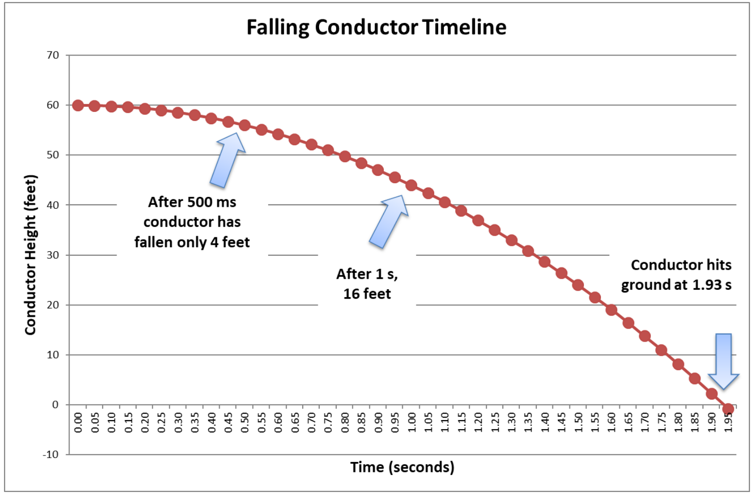
Source:
ISO NE

Transmission Falling Conductor Protection (TFCP)

Fire and hazard risk reduction

- Transmission falling conductor protection being developed on transmission PMU infrastructure.
- Based on current and voltage synchrophasor measurement streams.
- Current comparisons detect open conductors and faults.
- TFCP uses existing PMUs and communications (Distribution FCP needs radio system and distributed circuit PMUs).
- Initial focus on 69 kV lines.





Source: SDG&E

- Industry Trends and Drivers for T&D Synchronized Measurement Deployment
- Transmission Application Benefits and Roadmap
- Distribution Application Benefits and Roadmap
- Key Success Factors and Future Plans

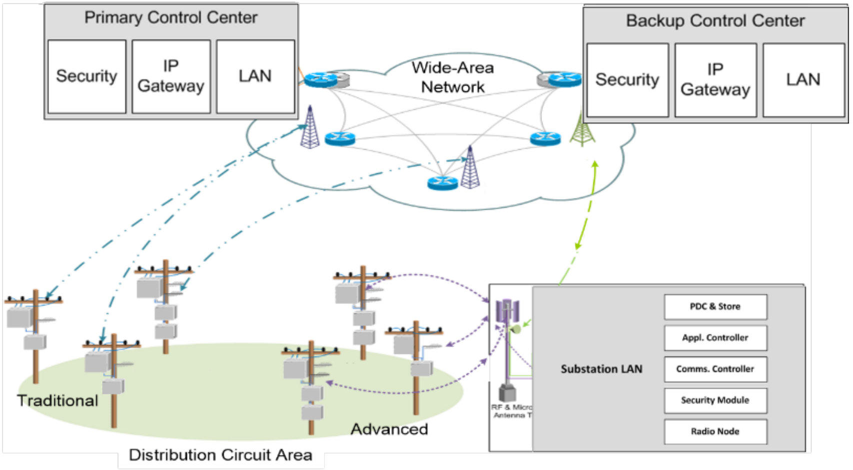
SDG&E Advanced SCADA for Distribution (ASD)

Addressing legacy system challenges

- Legacy sensors & measurement systems are failing Distribution Operations situational awareness and control needs.
- Mass of existing systems & components are difficult and expensive to manage.

What has been created

- System platform design to support 50 use cases.
- Distribution Falling Conductor Protection with Control Center operator interface is in service.
- Circuit voltage and current profile monitoring.
- Apparatus, IED, communications monitoring.
- System based on PMU-enabled circuit IEDs, fast ethernet, circuit-centric architecture, IEC 61850 GOOSE.



Source: SDG&E

Use Case Example - Distribution Falling Conductor Protection

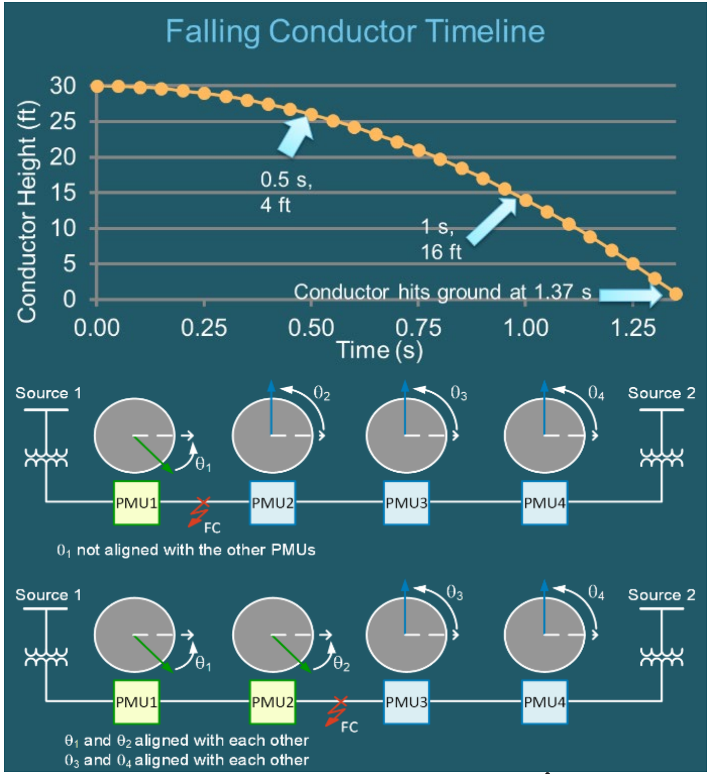
Falling conductor protection using distribution PMUs and wireless WAN to detect a line break - deenergizes the conductor before it hits the ground

- Break is isolated in 200-500 ms – uses 30 frames/s from PMU-enabled IEDs on two sides of the break.
- ***Avoids*** high-impedance fault arcing and fire risk.
- First live circuit trial in January 2015; in service 2016.

Status:

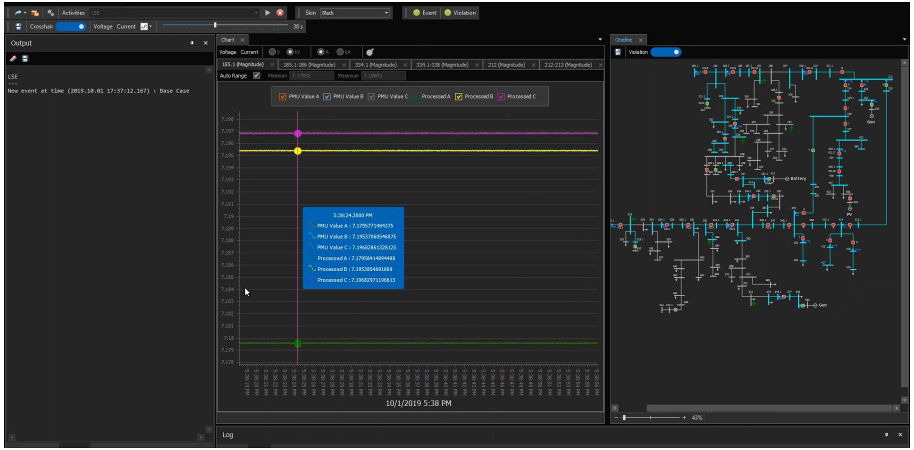
- Eight circuits in high fire risk areas now with DFCP trials.
- Six more high-risk circuits with DFCP in deployment.
- SDG&E planning 70 circuits by 2023 and 135 by 2028 and deploying next-generation wideband Ethernet radio system using private cells.

Source: SDG&E



ComEd: Distribution Linear State Estimation

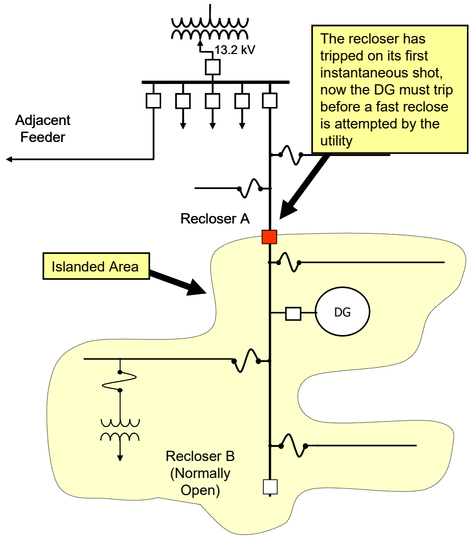
- Three-phase D-LSE using PMU data to perform fast state estimation (or state measurement)
  - Voltage and current vectors are considered as the state variable
  - Solve up to 60 samples/sec, compared to traditional SE solving once every few minutes
- Advantages and applications of D-LSE
  - Improves real-time resilience: A backup to the conventional SE solution if it fails to solve or SCADA data is not available
  - Helps identify and correct cases when bad or false data, including that injected by hostile actors, would have impact
  - Monitoring the microgrid and microgrid controller
  - Visualization, alarming/archiving, and metrics gathering/reporting
  - Identifying limited switching events (topology changes)



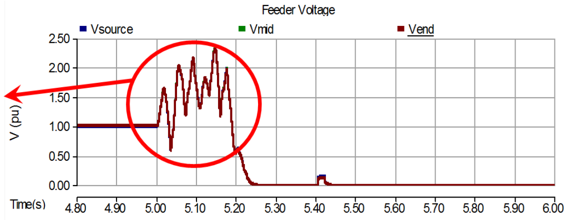
Source: ComEd and V&R

DG and Microgrid Islanding Detection and Restoration

- Promptly detect islanding conditions
- Avoid issues like Temporary Overvoltage (TOV), reclosing out of synchronism, and damage to DG equipment
- Sustain islanding operation using PMUs and controls
  - Power balancing among DERs
  - Automatic load switching and sectionalizing
  - Voltage and reactive power management
  - Large PV facility control & power curtailment
  - Restoration and synchronization with the grid - Checks voltages, pre-fault loads to support, closing angles
  - Needs high-speed, cross-validated status and measurement reports to controller



TOV caused by opening feeder circuit breaker at t = 5 seconds



DOE Industry Roadmap Objectives and Approach

- High-level guidance for development and investment of synchronized measurement technology on distribution circuits, while looking at technical requirements based on industry needs.
- The roadmap shows the activities required for successfully deploying synchronized measurement technology and critical applications for SDG&E and of other utilities (ComEd, ConEd, Dominion) with different needs.
- Helps DOE develop programs that can help the industry accelerate the grid modernization process by incorporating synchronized measurements and systems.

Roadmap for and Benefits of Deploying Sensor Technology for Distribution Network Modernization

- Identify and summarize major business drivers and needs.
- Industry outreach, including NASPI.
- Revise and update use cases and link them to key business drivers and needs.
- Identify system and product requirements and costs.
- Develop example budgetary cost estimates for typical deployment scenarios.
- Develop example roadmaps to help utilities accelerate the process - Applications, Infrastructure, and Processes.

Pilot programs

- Identify pilot programs for selected applications.
- Develop benefit-cost analysis for those pilots.

SDGE A Sempra Energy utility

OAK RIDGE National Laboratory

QUANTA TECHNOLOGY

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Distribution Use Case and Application Grouping (1)

PROPOSED GROUP NUMBER	PROPOSED APPLICATION GROUP DESCRIPTION	PROPOSED USE CASE NUMBER	NEW USE CASE DESCRIPTION
AG1	Advanced Volt-VAR Control (AVVC)	A1	Conservation Voltage Reduction (CVR)
	Advanced Volt-VAR Control (AVVC)	A2	Volt-VAR Control (VVC) of distribution systems
	Advanced Volt-VAR Control (AVVC)	A3	Volt-Var Optimization (VVO)
AG2	Advanced monitoring of distribution grid	A4	Active and reactive power flow monitoring
	Advanced monitoring of distribution grid	A5	Voltage profile monitoring
	Advanced monitoring of distribution grid	A6	Monitoring of communications system/equipment performance with management metrics
	Advanced monitoring of distribution grid	A7	Frequency monitoring
	Advanced monitoring of distribution grid	A8	Near real-time event monitoring (physical)
	Advanced monitoring of distribution grid	A9	Near real-time event monitoring (cyber)
	Advanced monitoring of distribution grid	A10	Phase angle monitoring for voltages and currents
AG3	Asset management of critical infrastructure	A11	Power apparatus asset management
	Asset management of critical infrastructure	A12	Power apparatus functional monitoring
	Asset management of critical infrastructure	A13	Monitoring and control of critical infrastructure and large customers
	Asset management of critical infrastructure	A14	Underground secondary/spot network monitoring and analysis
	Asset management of critical infrastructure	A15	Dynamic rating of distribution assets
AG4	Wide area visualization	A16	Circuit status dashboards
	Wide area visualization	A17	Integration of customer site FNET information
	Wide area visualization	A18	Improved wide area situational awareness (T&D)
	Wide area visualization	A19	Visualization of dynamic system response
AG5	DER integration	A20	Monitoring of intermittent DER
	DER integration	A21	Voltage impact assessment and mitigation due to high penetration of intermittent energy
	DER integration	A22	Voltage impact mitigation for high penetration of intermittent DG
	DER integration	A23	Active and reactive reverse power flow management
	DER integration	A24	Customer/smart inverter control
	DER integration	A25	DER management and energy balancing with energy storage
	DER integration	A26	Load unmasking (behind-the-meter DER)
AG6	Real-time distribution system operation	A27	Distribution state estimation
	Real-time distribution system operation	A28	Closed-loop circuit operation
	Real-time distribution system operation	A29	DERMS implementation
	Real-time distribution system operation	A30	Improved demand response

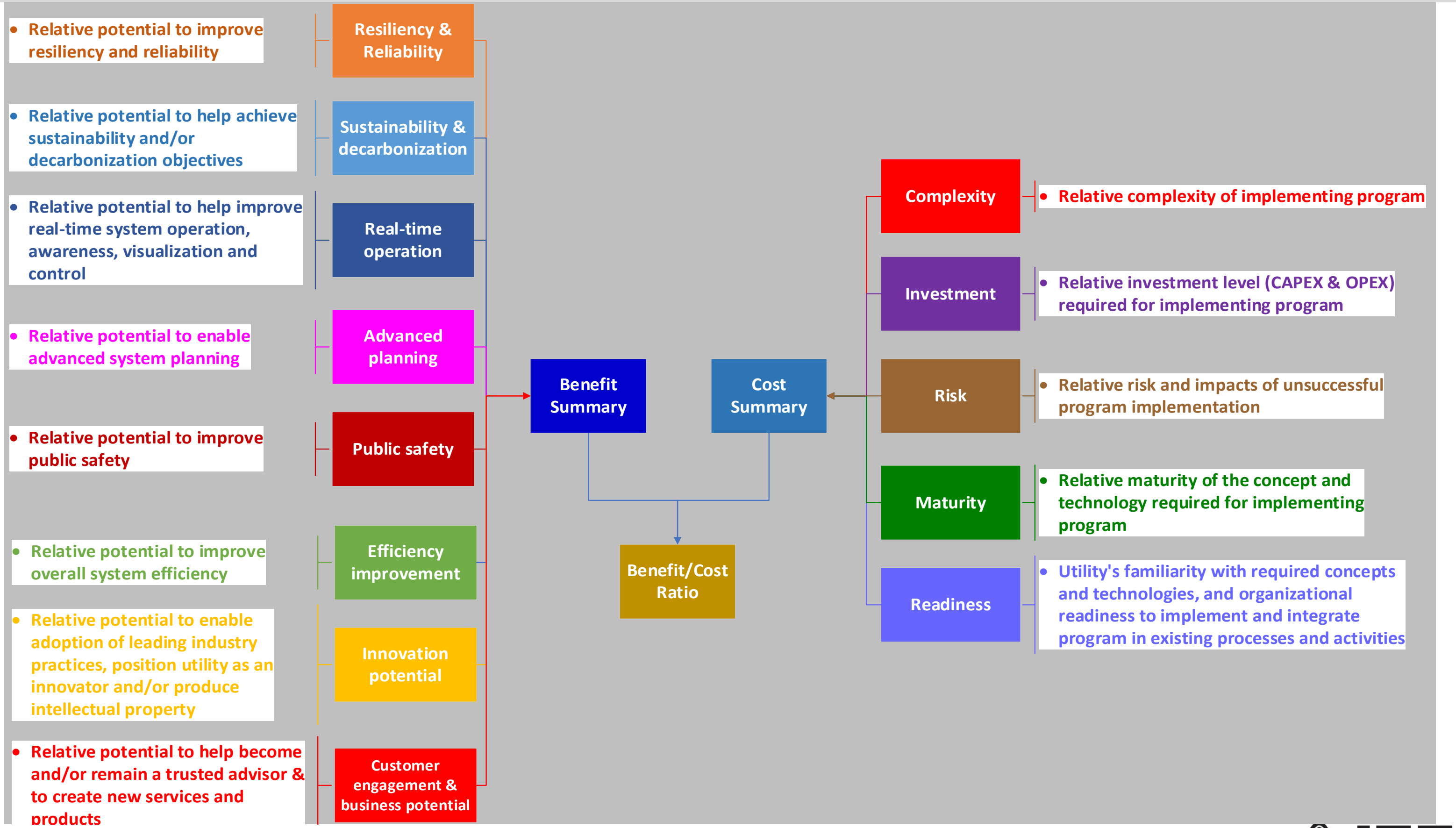
Distribution Use Case and Application Grouping (2)

AG7	Enhanced reliability and resilience analysis	A31	Improved distribution reliability analysis
	Enhanced reliability and resilience analysis	A32	Post-mortem analysis
AG8	Advanced distribution system planning	A33	Phase identification
	Advanced distribution system planning	A34	Distribution system computational model validation
	Advanced distribution system planning	A35	Short circuit study validation
AG9	Distribution load, DER, and EV forecasting	A36	Load characterization, load modeling and load forecasting
	Distribution load, DER, and EV forecasting	A37	DER forecasting
	Distribution load, DER, and EV forecasting	A38	EV Forecasting
AG10	Improved stability management	A39	Voltage stability monitoring and control
	Improved stability management	A40	Control instablility, hunting, or oscillation detection - voltage, var, switching
	Improved stability management	A41	Transient stability monitoring and control
	Improved stability management	A42	Fault Induced Delayed Voltage Recovery (FIDVR) detection
AG11	High-accuracy fault detection and location	A43	Faulted circuit indication
	High-accuracy fault detection and location	A44	Incipient fault & failure detection
	High-accuracy fault detection and location	A45	High accuracy fault location
	High-accuracy fault detection and location	A46	Communications failure location for maintenance dispatch
	High-accuracy fault detection and location	A47	High impedance fault location
	High-accuracy fault detection and location	A48	Open conductor fault detection
	High-accuracy fault detection and location	A49	Falling conductor protection
AG12	Advanced distribution protection and control	A50	Reclosing assistance for fast circuit recovery after fault
	Advanced distribution protection and control	A51	Current differential protection of feeder sections
	Advanced distribution protection and control	A52	Adaptive protection of distribution systems
AG13	Advanced microgrid applications and operatic	A53	Planned islanding and restoration of microgrids
	Advanced microgrid applications and operatic	A54	Advanced protection of microgrids
	Advanced microgrid applications and operatic	A55	Advanced distribution system topology, automation and control (holonic grids)
	Advanced microgrid applications and operatic	A56	Islanding detection for distributed generation (anti-islanding scheme)
AG14	Improved load shedding schemes	A57	Improved load shedding schemes - frequency
	Improved load shedding schemes	A58	Improved load shedding schemes - voltage
	Improved load shedding schemes	A59	Improved load shedding schemes - load flow based
	Improved load shedding schemes	A60	Load shedding real time compensative arming to balance 1547 compliant PV
AG15	Advanced distribution automation	A61	Load transfer and load balancing
	Advanced distribution automation	A62	Self-healing and enhanced FLISR operation

Distribution Use Case and Application Grouping (3)

AG16	Technical and commercial loss reduction	A63	Circuit loss minimization
	Technical and commercial loss reduction	A64	Energy accounting
	Technical and commercial loss reduction	A65	Techical and commercial loss identification, calculation and reduction
AG17	Monitoring and control of electric transportation infrastructure	A66	Monitoring and control of electric transportation infrastructure
	Monitoring and control of electric transportation infrastructure	A67	Vehicle-to-Grid (V2G) monitoring and control
AG18	Integrated resource, transmission and distribution system planning and analysis	A68	Running sub-transmission (69 kV) and distribution in parallel
	Integrated resource, transmission and distribution system planning and analysis	A69	Integrated resource, transmission and distribution system planning and analysis
AG19	Power quality assessment and analysis	A70	Harmonics measurement
	Power quality assessment and analysis	A71	Voltage sag and swell measurement
	Power quality assessment and analysis	A72	Flicker measurement
	Power quality assessment and analysis	A73	Voltage and current imbalance measurement
	Power quality assessment and analysis	A74	Short-duration interruption measurement
	Power quality assessment and analysis	A75	Harmonic state estimation/diagnosis
	Power quality assessment and analysis	A76	Primary meter customer (e.g major customer monitoring -power quality)

Prioritization: Benefit – Cost Ratio Calculation



Preliminary Prioritization Results

Prioritization results were used along with potential interdependencies among AGs to develop a proposed timeframe for implementation and overall roadmap

APPLICATION NUMBER	APPLICATION DESCRIPTION	BENEFIT-COST RATIO	BENEFIT-COST RATIO NUMERICAL	PRIORITY NUMBER
A11	High-accuracy fault detection and location	◐	1.47	1
A2	Advanced monitoring of distribution grid	◐	1.41	2
A6	Real-time distribution system operation	◐	1.34	3
A8	Advanced distribution system planning	◐	1.32	4
A5	DER integration	◐	1.29	5
A9	Distribution load, DER and EV forecasting	◐	1.21	6
A4	Wide area visualization	◐	1.21	7
A17	Monitoring and control of electric transportation infrastructure	◐	1.20	8
A3	Asset management of critical infrastructure	◐	1.17	9
A7	Enhanced reliability and resilience analysis	◐	1.15	10
A12	Advanced distribution protection and control	◐	1.14	11
A14	Improved load shedding schemes	◐	1.13	12
A15	Advanced distribution automation	◐	1.12	13
A18	Integrated resource, transmission and distribution system planning and analysis	◐	1.11	14
A13	Advanced microgrid applications and operation	◐	1.08	15
A10	Improved stability management	◐	1.00	16
A19	Power quality measurement	◔	0.94	17
A1	Advanced Volt-VAR Control (VVC)	◔	0.91	18
A16	Technical and commercial loss reduction	◔	0.87	19

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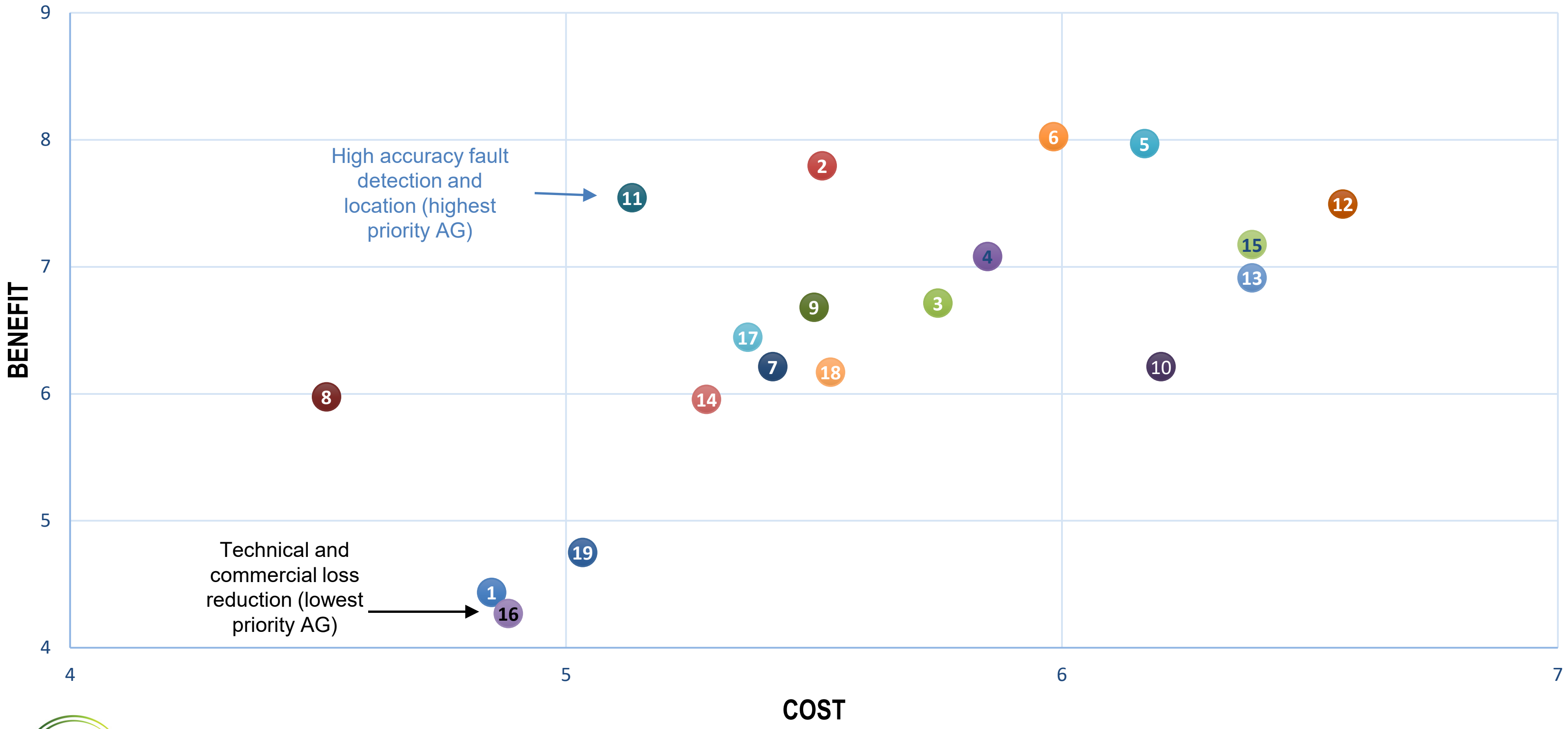
Prioritization Results – Application Benefit-Cost Ratio



Application Requirements – Critical for Product and System Development

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	150	30
AG11	High-accuracy fault detection and location	99.9	300	60
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

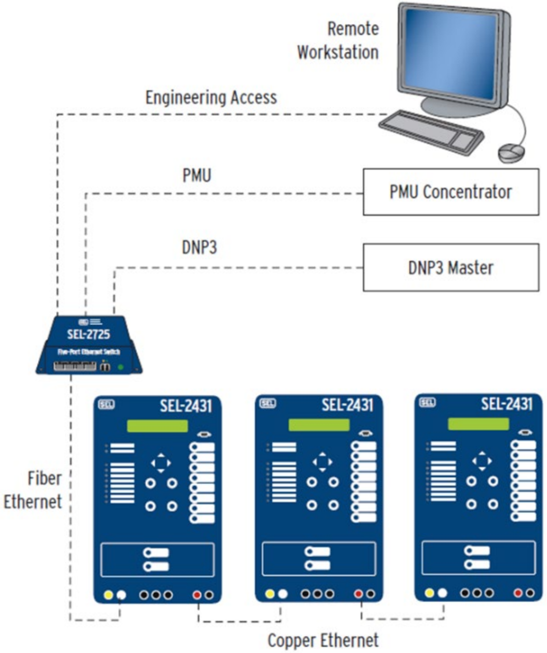
Examples of Products

Source: Power Sensors Ltd.

Power Sensors Ltd. MicroPMU (μPMU)

- High accuracy, but may be expensive to deploy
- Connects to single- or 3-phase, secondary distribution or substation PT.
- Local data storage on SD card as low-cost backup of or replacement for real-time streaming.
- Synchronized disturbance recordings.
- Precision calibrated inputs.
- PQ embedded functions and displays.

Schweitzer Engineering Laboratories (SEL) distribution circuit IEDs with built-in PMU function



- SEL-751 Feeder Protection Relay
- SEL-651R Recloser Control
- SEL-487E multiport switch controller & relay
- SEL-751 PQ Line Monitor
- SEL-2431 Voltage Regulator Control
- Others – see SEL catalog.

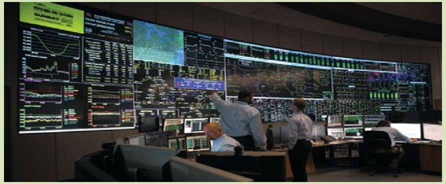
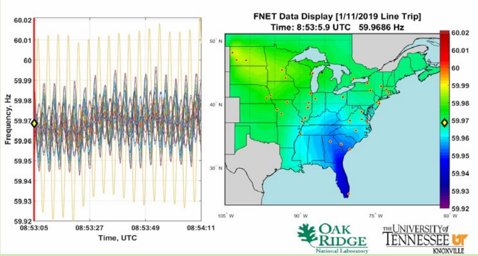
Source: SEL

- Industry Trends and Drivers for T&D Synchronized Measurement Deployment
- Transmission Application Benefits and Roadmap
- Distribution Application Benefits and Roadmap
- Key Success Factors and Future Plans

Key Deployment Success Factors

- **Business case / roadmap / plan**: Critical for securing funding for full deployment, ensuring the deployment is directed towards the end-state.
- **Well-defined architecture & technical requirements for production-grade system with quality measurements**
- **Baselining to set norms**: Historical Data/Simulations.
- **Engineering and Operations - guidelines and training**
  Shortcuts impair deployment and reliable operation
- **Data and information exchange**:
  - Sharing information between T&D is needed for grid with renewables and storage.
  - Sharing data across each interconnection and among TOs is needed for transmission.

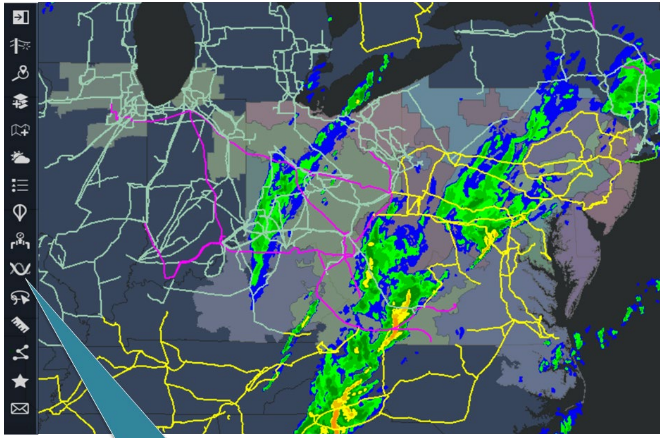
Synchronized Measurement Progression

Before	Products Now	2020	2025
 First PMU  Analog Displays	  	Standard feature (relays, DFR, controllers, monitors) On major interconnections and generators Standard SW tools included in EMS/SCADA Primary use for monitoring and event analysis but deployed for control Interoperability standards deployed Distribution PMUs expansion due to DER Improvements in communication infrastructure	Tens of Thousands of PMUs world-wide Integrated in standard business and operational practices Integrated with EMS/DMS/SCADA or Independent system Higher data rates Numerous applications in Distribution with different sets of requirements (POW) Distributed comm. and processing architecture Integration with various data sources (e.g. weather, GIS) Fast and Adaptive Protection and Control

Summary of Next Generation Synchronized Measurement

- Expand the deployed systems, with enhanced ability to meet new business needs & requirements
  - Mitigate the risks of major system events by integrated existing and new sources of data, including severe weather conditions, fires, earthquakes, GIS data, etc.
  - Augment and backup EMS/DMS/SCADA systems
- Provide necessary tools for operating ever-changing grid – Increased focus on distribution applications, products, and systems
- High security and reliability of deployed systems
- Support regulatory standards compliance

Linking weather conditions to power system operating conditions is becoming increasingly important



Synchrophasors
Location, Data, Contours, etc.

Source: Emanuel Bernabeu, PJM