



QUANTA  
TECHNOLOGY



# Distribution System Synchronized Measurement Technology Deployment Industry Roadmap

## *Project team*

- SDG&E
- ORNL
- Quanta Technology



# Overall Project Objectives and Approach

- Provide high-level guidance for development and investment synchronized measurement technology on distribution circuits, while looking at technical requirements and challenges vs. industry and customer needs.
- The roadmap shows the activities required for successfully deploying synchronized measurement technology and critical applications on the distribution systems of SDG&E and of other utilities in other regions with different needs.
- Helps DOE develop programs that can help the industry accelerate the grid modernization process by incorporating synchronized measurements and systems.

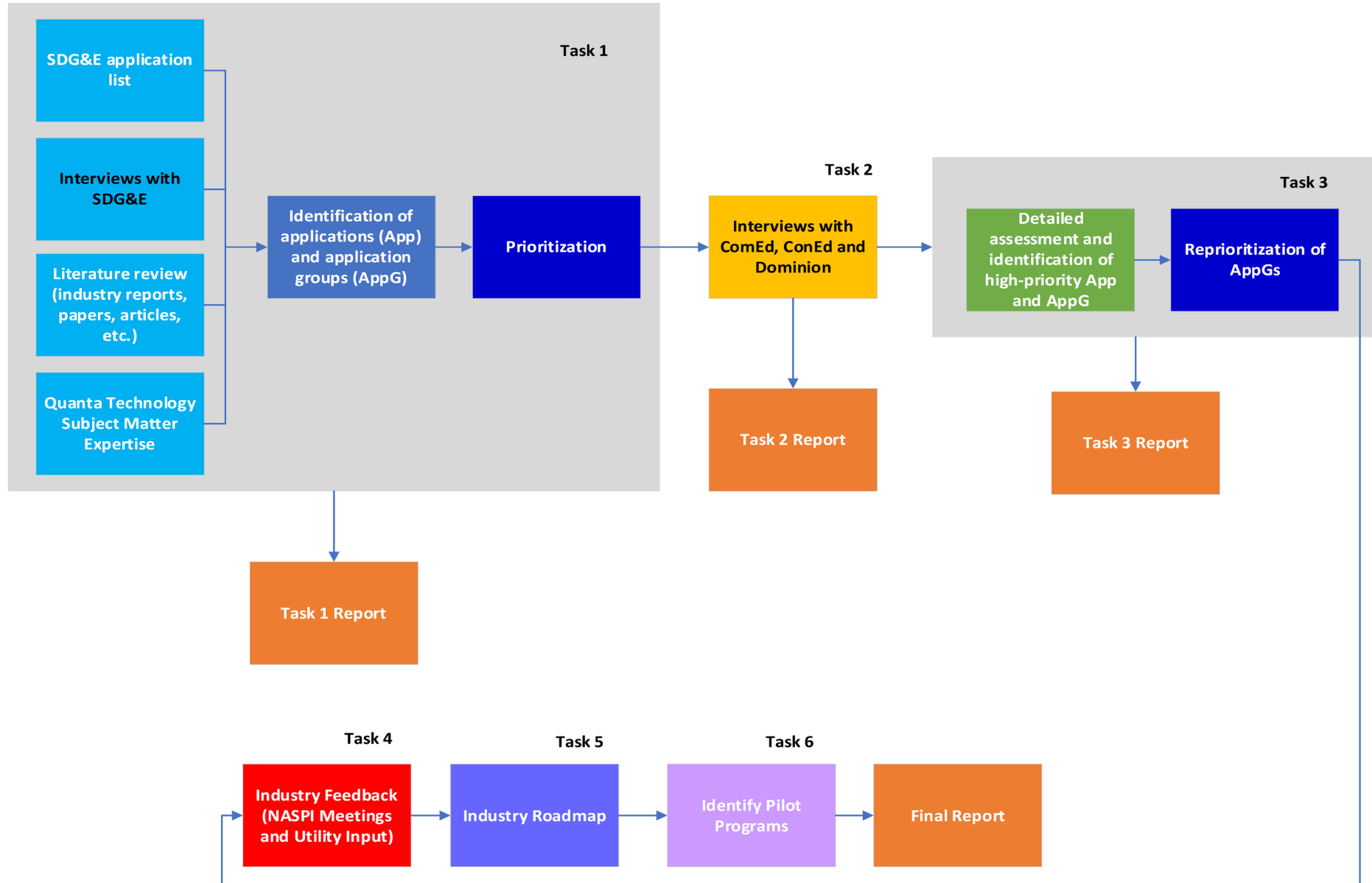
## *Roadmap for and Benefits of Deploying Sensor Technology for Distribution Network Modernization*

- Identify and summarize major business drivers and needs.
- Industry outreach to utilities (SDG&E, ComEd, ConEd, Dominion), including NASPI (particularly Distribution TT).
- 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.

# Roadmap Development Tasks



# Summary of Industry Interviews

#	Questions	Utility			
		SDG&E	ConEd	Dominion	ComEd
<b>1</b>	<b>Drivers and needs</b>				
	NERC compliance				
	Risk management of major events				
	Enhance transmission operation				
	Grid modernization/transformation				
	DER integration				
	Grid evolution				
	Power quality for major customers				
	Holistic T&D planning and operations				
	Real-time analytics				
	Equipment failure and asset health management				
	Resilience improvement				
	Public Safety				
<b>2</b>	<b>Sensing technology benefits</b>				
	NERC compliance				
	Risk management of major events				
	Enhance transmission operation				
	Distribution reliability improvement				
	Grid evolution				
	Enhance distribution operation				
	Real-time situational awareness				
	Improve DER integration				
<b>3</b>	<b>Utility needs and gaps</b>				
	Safety				
	Risk management				
	DER management				
	Energy storage utilization				
	Electrification				
	T&D system planning				
	T&D system modeling and analysis				
	Asset management				
	Reliability & resilience				
	Power quality				
	Monitoring, protection, automation and control				
	PAC architecture				
	Grid analytics				
	Grid evolution				

#	Questions	Utility			
		SDG&E	ConEd	Dominion	ComEd
<b>4</b>	<b>Existing synchronized measurement applications</b>				
	Linear distribution state estimation				
	Microgrid operation				
	Falling conductor protection				
	System reconfiguration (phase angle monitoring)				
<b>5</b>	<b>Planned initiatives or vision</b>				
	Microgrid monitoring				
	Critical customer monitoring				
	Real-time situational awareness				
	System reconfiguration (phase angle monitoring)				
	Fault detection and protection				
	Power quality				
<b>6</b>	<b>Barriers and gaps for adoption</b>				
	Technology/application maturity				
	Telecommunications requirements				
	Data management/storage needs				
	Cost				
	Business case development				
<b>7</b>	<b>Solutions to facilitate adoption</b>				
	Validation of business cases				
<b>8</b>	<b>Experience with synchronized measurement technology</b>				
	Positive experience				
	Need for data quality verification				
<b>9</b>	<b>What can the industry do to facilitate adoption</b>				
	Demonstration of use cases				
	Large pilot programs				
	Foster innovation before standardization				
<b>10</b>	<b>Other technologies being explored and experience</b>				
	Power quality meters				
	Advanced line sensors				
<b>11</b>	<b>Most valuable information from technology roadmap</b>				
	Implementing existing roadmap				

# Proposed Use Case and Application Grouping (1)

ORIGINAL SDG&E PROGRAM AREA (2012)	ORIGINAL SDG&E USE CASE NUMBER (2012)	PROPOSED GROUP NUMBER	PROPOSED APPLICATION GROUP DESCRIPTION	PROPOSED USE CASE NUMBER	NEW USE CASE DESCRIPTION
Monitoring	M-1	AG1	Advanced Volt-VAR Control (AVVC)	A1	Conservation Voltage Reduction (CVR)
Control & Optimization	C-1		Advanced Volt-VAR Control (AVVC)	A2	Volt-VAR Control (VVC) of distribution systems
Control & Optimization	C-8		Advanced Volt-VAR Control (AVVC)	A3	Volt-Var Optimization (VVO)
Monitoring	M-3	AG2	Advanced monitoring of distribution grid	A4	Active and reactive power flow monitoring
Monitoring	M-5		Advanced monitoring of distribution grid	A5	Voltage profile monitoring
Monitoring	M-11		Advanced monitoring of distribution grid	A6	Monitoring of communications system/equipment performance with management metrics
Monitoring	M-12		Advanced monitoring of distribution grid	A7	Frequency monitoring
Monitoring	M-14		Advanced monitoring of distribution grid	A8	Near real-time event monitoring (physical)
New	New		Advanced monitoring of distribution grid	A9	Near real-time event monitoring (cyber)
Monitoring	M-2		Advanced monitoring of distribution grid	A10	Phase angle monitoring for voltages and currents
Monitoring	M-6	AG3	Asset management of critical infrastructure	A11	Power apparatus asset management
New	New		Asset management of critical infrastructure	A12	Power apparatus functional monitoring
Control & Optimization	C-10		Asset management of critical infrastructure	A13	Monitoring and control of critical infrastructure and large customers
New	New		Asset management of critical infrastructure	A14	Underground secondary/spot network monitoring and analysis
Assessment	A-2		Asset management of critical infrastructure	A15	Dynamic rating of distribution assets
Monitoring	M-8	AG4	Wide area visualization	A16	Circuit status dashboards
Monitoring	M-13		Wide area visualization	A17	Integration of customer site FNET information
Monitoring	M-15		Wide area visualization	A18	Improved wide area situational awareness (T&D)
Model Validation	V-6		Wide area visualization	A19	Visualization of dynamic system response
Monitoring	M-4	AG5	DER integration	A20	Monitoring of intermittent DER
Assessment	A-1		DER integration	A21	Voltage impact assessment and mitigation due to high penetration of intermittent energy resources
Scheme Development	S-7		DER integration	A22	Active and reactive reverse power flow management
Control & Optimization	C-2		DER integration	A23	Customer/smart inverter control
Control & Optimization	C-7		DER integration	A24	DER management and energy balancing with energy storage
New	New		DER integration	A25	Load unmasking (behind-the-meter DER)
Assessment	A-6	AG6	Real-time distribution system operation	A26	Distribution state estimation
Control & Optimization	C-6		Real-time distribution system operation	A27	Closed-loop circuit operation
New	New		Real-time distribution system operation	A28	DERMS implementation
New	New		Real-time distribution system operation	A29	Improved demand response

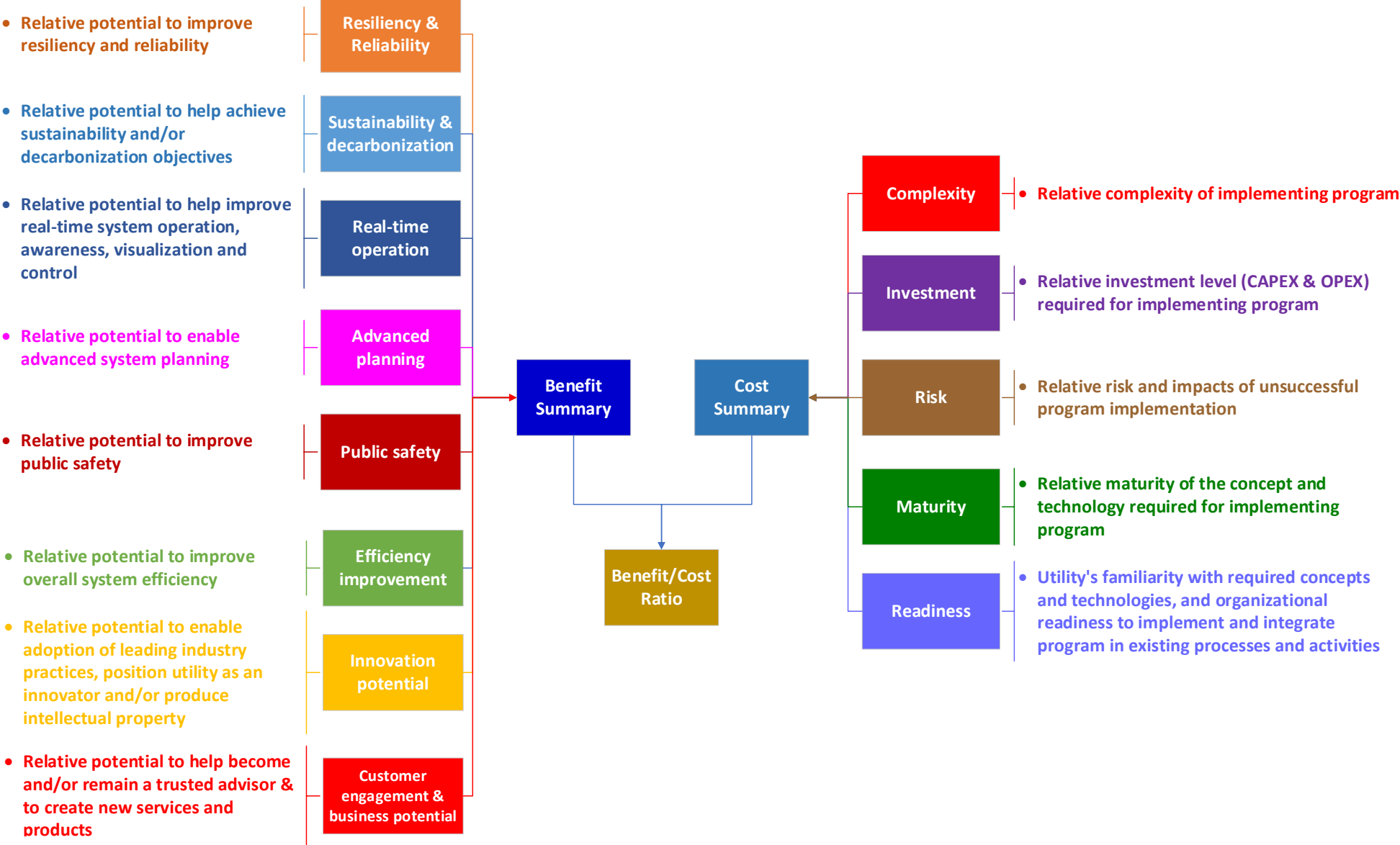
# Proposed Use Case and Application Grouping (2)

Assessment	A-4	AG7	Enhanced reliability and resilience analysis	A30	Improved distribution reliability analysis	
Assessment	A-5		Enhanced reliability and resilience analysis	A31	Post-mortem analysis	
Monitoring	M-7	AG8	Advanced distribution system planning	A32	Phase identification	
Model Validation	V-1		Advanced distribution system planning	A33	Distribution system computational model validation	
Model Validation	V-2		Advanced distribution system planning	A34	Short circuit study validation	
Model Validation	V-5	AG9	Distribution load, DER, and EV forecasting	A35	Load characterization, load modeling and load forecasting	
New	New		Distribution load, DER, and EV forecasting	A36	DER forecasting	
New	New		Distribution load, DER, and EV forecasting	A37	EV Forecasting	
Assessment	A-7	AG10	Improved stability management	A38	Voltage stability monitoring and control	
Scheme Development	S-15		Improved stability management	A39	Control instability, hunting, or oscillation detection - voltage, var, switching	
New	New		Improved stability management	A40	Transient stability monitoring and control	
New	New		Improved stability management	A41	Fault Induced Delayed Voltage Recovery (FIDVR) detection	
Scheme Development	S-1	AG11	High-accuracy fault detection and location	A42	Faulted circuit indication	
Scheme Development	S-4		High-accuracy fault detection and location	A43	Incipient fault & failure detection	
Scheme Development	S-9		High-accuracy fault detection and location	A44	High accuracy fault location	
Scheme Development	S-10		High-accuracy fault detection and location	A45	Communications failure location for maintenance dispatch	
Scheme Development	S-12		High-accuracy fault detection and location	A46	High impedance fault location	
Scheme Development	S-13		High-accuracy fault detection and location	A47	Open conductor fault detection	
Scheme Development	S-2		High-accuracy fault detection and location	A48	Falling conductor protection	
Scheme Development	S-8	AG12	Advanced distribution protection and control	A49	Reclosing assistance for fast circuit recovery after fault	
New	New		Advanced distribution protection and control	A50	Current differential protection of feeder sections	
New	New		Advanced distribution protection and control	A51	Adaptive protection of distribution systems	
Control & Optimization	C-3	AG13	Advanced microgrid applications and operation	A52	Planned islanding and restoration of microgrids	
New	New		Advanced microgrid applications and operation	A53	Advanced protection of microgrids	
New	New		Advanced microgrid applications and operation	A54	Advanced distribution system topology, automation and control (holonic grids)	
Scheme Development	S-3		Advanced microgrid applications and operation	A55	Islanding detection for distributed generation (anti-islanding scheme)	
Scheme Development	S-5	AG14	Improved load shedding schemes	A56	Improved load shedding schemes - frequency	
Scheme Development	S-6		Improved load shedding schemes	A57	Improved load shedding schemes - voltage	
New	New		Improved load shedding schemes	A58	Improved load shedding schemes - load flow based	
Control & Optimization	C-4		Improved load shedding schemes	A59	Load shedding real time compensative arming to balance 1547 compliant PV	
Scheme Development	S-11	AG15	Advanced distribution automation	A60	Load transfer and load balancing	
Control & Optimization	C-5		Advanced distribution automation	A61	Self-healing and enhanced FLISR operation	

# Proposed Use Case and Application Grouping (3)

Assessment	A-3	AG16	Technical and commercial loss reduction	A62	Circuit loss minimization
Scheme Development	S-14		Technical and commercial loss reduction	A63	Energy accounting
New	New		Technical and commercial loss reduction	A64	Technical and commercial loss identification, calculation and reduction
New	New	AG17	Monitoring and control of electric transportation infrastructure	A65	Monitoring and control of electric transportation infrastructure
New	New		Monitoring and control of electric transportation infrastructure	A66	Vehicle-to-Grid (V2G) monitoring and control
Control & Optimization	C-9	AG18	Integrated resource, transmission and distribution system planning and analysis	A67	Running sub-transmission (69 kV) and distribution in parallel
New	New		Integrated resource, transmission and distribution system planning and analysis	A68	Integrated resource, transmission and distribution system planning and analysis
Monitoring	M-9	AG19	Power quality assessment and analysis	A69	Harmonics measurement
New	New		Power quality assessment and analysis	A70	Voltage sag and swell measurement
New	New		Power quality assessment and analysis	A71	Flicker measurement
New	New		Power quality assessment and analysis	A72	Voltage and current imbalance measurement
New	New		Power quality assessment and analysis	A73	Short-duration interruption measurement
New	New		Power quality assessment and analysis	A74	Harmonic state estimation/diagnosis
New	New		Power quality assessment and analysis	A75	Primary meter customer (e.g major customer monitoring -power quality)

# Prioritization: Benefit – Cost Ratio Calculation

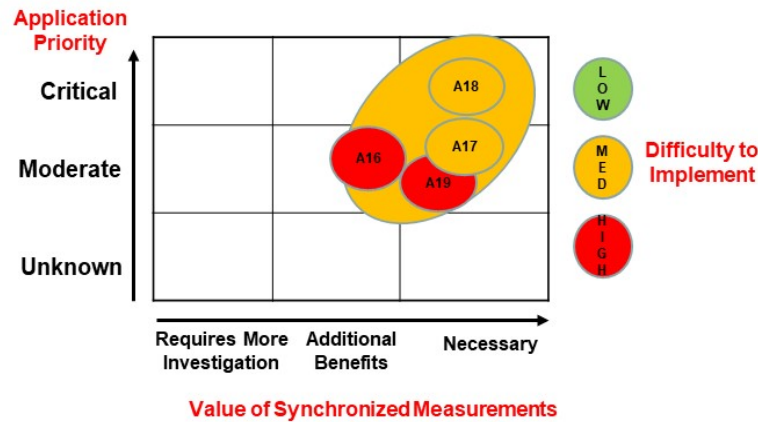


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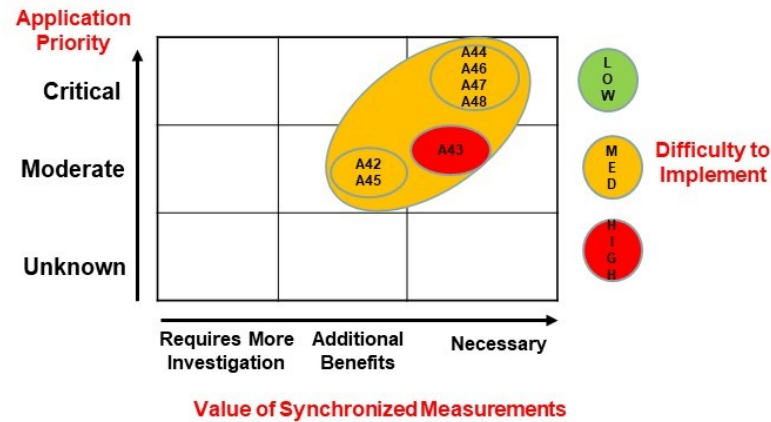
# Example – Value of Synchronized Measurements for AG4, AG11, and AG 13

Value of Synchronized Measurements for Wide Area Visualization (AG4)



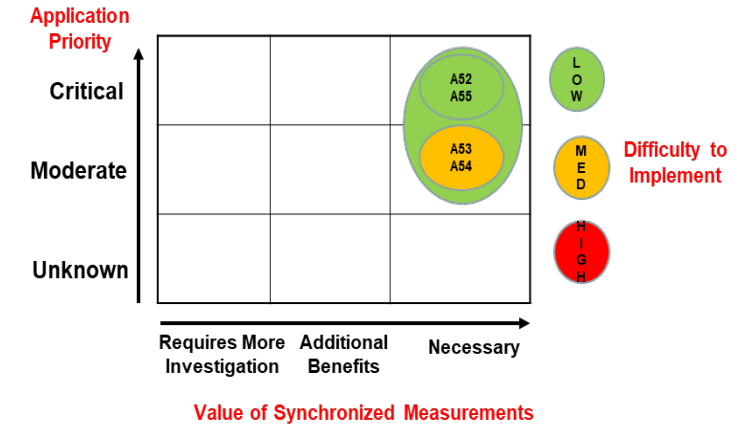
- A16: Circuit status dashboard
- A17: Integration of customer FNET information
- A18: Improved wide area situational awareness
- A19: Visualization of dynamic system response

High-Accuracy Fault Detection and Location (AG11)



- A42: Faulted circuit indication
- A43: Incipient fault and failure detection
- A44: High accuracy fault location
- A45: Communications failure location for maintenance dispatch
- A46: High impedance fault location
- A47: Open-conductor fault detection
- A48: Falling conductor protection

Advanced Microgrid Applications and Operation (AG 13)



- A52: Planned islanding and restoration of microgrids
- A53: Advanced protection of microgrids
- A54: Advanced distribution system topology, automation, and control
- A55: Anti-islanding detection for distributed energy resources (anti-islanding scheme)

# Results from Benefits Analysis (Relative Benefits by Initiative)

Application Number	Application Description	Relative Benefit								Benefit Summary	Benefit Summary Numerical
		Resilience & Reliability	Sustainability & Decarbonization	Real-Time Operation	Advanced Planning & Asset Mgmt.	Public Safety	Efficiency Improvement	Innovation Potential	Customer Engagement & Bus. Potential		
AG1	AVVC	4	5	5	5	3	6	4	6	MEDIUM	4.54
AG2	Advanced monitoring of distribution grid	7	6	8	6	6	8	6	5	HIGH	6.64
AG3	Asset management of critical infrastructure	7	4	5	7	6	7	7	5	MEDIUM	5.94
AG4	Wide-area visualization	8	6	9	6	7	5	6	7	HIGH	7.00
AG5	DER integration and control	7	9	7	7	4	6	8	7	HIGH	6.62
AG6	Real-time distribution system operation	8	5	9	4	7	7	6	5	HIGH	6.70
AG7	Enhanced reliability and resilience analysis	6	4	3	6	4	4	6	5	MEDIUM	4.58
AG8	Advanced distribution system planning	6	5	2	7	2	6	6	4	MEDIUM	4.42
AG9	Distribution load, DER and EV forecasting	6	7	5	7	2	6	5	6	MEDIUM	5.26
AG10	Improved stability management	7	4	9	3	4	4	7	3	MEDIUM	5.28
AG11	High-accuracy fault detection and location	8	4	8	6	9	8	7	7	HIGH	7.30
AG12	Advanced distribution protection and control	8	7	8	2	9	4	7	5	HIGH	6.72
AG13	Advanced microgrid applications and operation	8	8	7	4	5	4	7	7	HIGH	6.26
AG14	Improved load shedding schemes	7	4	7	4	4	6	6	6	MEDIUM	5.42
AG15	Advanced distribution automation	7	4	6	3	6	6	6	4	MEDIUM	5.42
AG16	Technical and commercial loss reduction	2	5	4	5	3	7	5	6	MEDIUM	4.16
AG17	Monitoring and control of electric transportation infrastructure	5	7	5	7	3	5	7	6	MEDIUM	5.26
AG18	Integrated resource, T&D system planning and analysis	6	6	4	7	3	7	6	4	MEDIUM	5.18
AG19	PQ measurement	6	5	5	6	2	5	6	7	MEDIUM	4.86

# Results from Cost Analysis (Relative Costs by Initiative)

Application Number	Application Description	Relative Cost					Cost Summary	Cost Summary Numerical
		Complexity	Investment (CapEx & OpEx)	Maturity	Risk	Readiness		
AG1	AVVC	4	6	7	3	7	MEDIUM	4.65
AG2	Advanced monitoring of distribution grid	4	7	6	3	7	MEDIUM	5.35
AG3	Asset management of critical infrastructure	8	8	6	4	5	HIGH	6.65
AG4	Wide-area visualization	6	7	6	3	6	MEDIUM	5.70
AG5	DER integration and control	7	7	6	5	5	HIGH	6.10
AG6	Real-time distribution system operation	7	7	6	5	7	HIGH	6.00
AG7	Enhanced reliability and resilience analysis	5	5	5	5	6	MEDIUM	4.95
AG8	Advanced distribution system planning	4	4	5	5	5	LOW	4.35
AG9	Distribution load, DER and EV forecasting	7	7	4	5	4	HIGH	6.55
AG10	Improved stability management	5	5	5	5	5	MEDIUM	5.00
AG11	High-accuracy fault detection and location	4	7	6	4	5	MEDIUM	5.55
AG12	Advanced distribution protection and control	7	7	5	5	5	HIGH	6.30
AG13	Advanced microgrid applications and operation	5	5	7	5	5	LOW	4.60
AG14	Improved load shedding schemes	5	5	7	3	5	LOW	4.40
AG15	Advanced distribution automation	6	7	6	6	6	HIGH	6.00
AG16	Technical and commercial loss reduction	5	4	6	3	6	LOW	4.05
AG17	Monitoring and control of electric transportation infrastructure	6	6	3	4	3	HIGH	6.05
AG18	Integrated resource, T&D system planning and analysis	8	8	3	4	2	HIGH	7.40
AG19	PQ measurement	5	6	7	2	5	MEDIUM	4.80

# 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	BCR <sub>i</sub>	BCR <sub>i</sub> 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

# Prioritization Results – Application Benefit-Cost Ratio



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# Industry Application Roadmap



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AG13: Advanced microgrid applications and operation

AG11: High-accuracy fault detection and location

AG2: Advanced monitoring of distribution grid

AG14: Improved load shedding schemes

AG4: Wide Area Visualization

AG6: Real-time distr. system operation

AG5: DER integration and control

AG12: Advanced distr. protection and control

AG10: Improved stability management

AG16: Technical and commercial loss reduction

AG8: Advanced distr system planning

AG19: PQ assessment and analysis

AG1: AVVC

AG7: Enhanced reliability and resilience analysis

AG15: Advanced distr. automation

AG3: Asset management of critical infrastructure

AG17: Monitoring & control of electric transportation infrastructure

AG9: Distribution load, DER, and EV forecasting

AG18: Integrated resource, T&D system planning and analysis

Difficulty to Implement



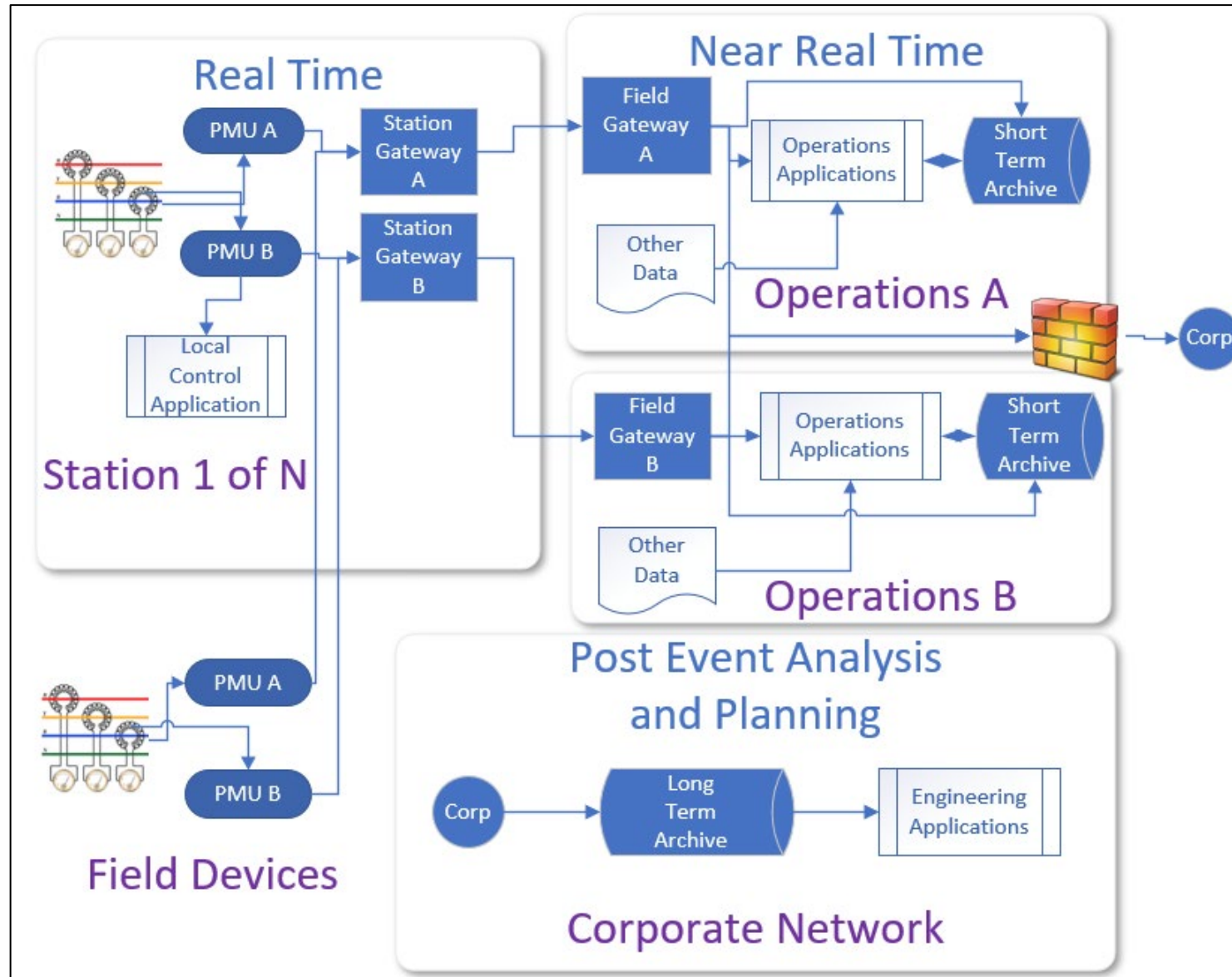
Short-Term

Mid-Term

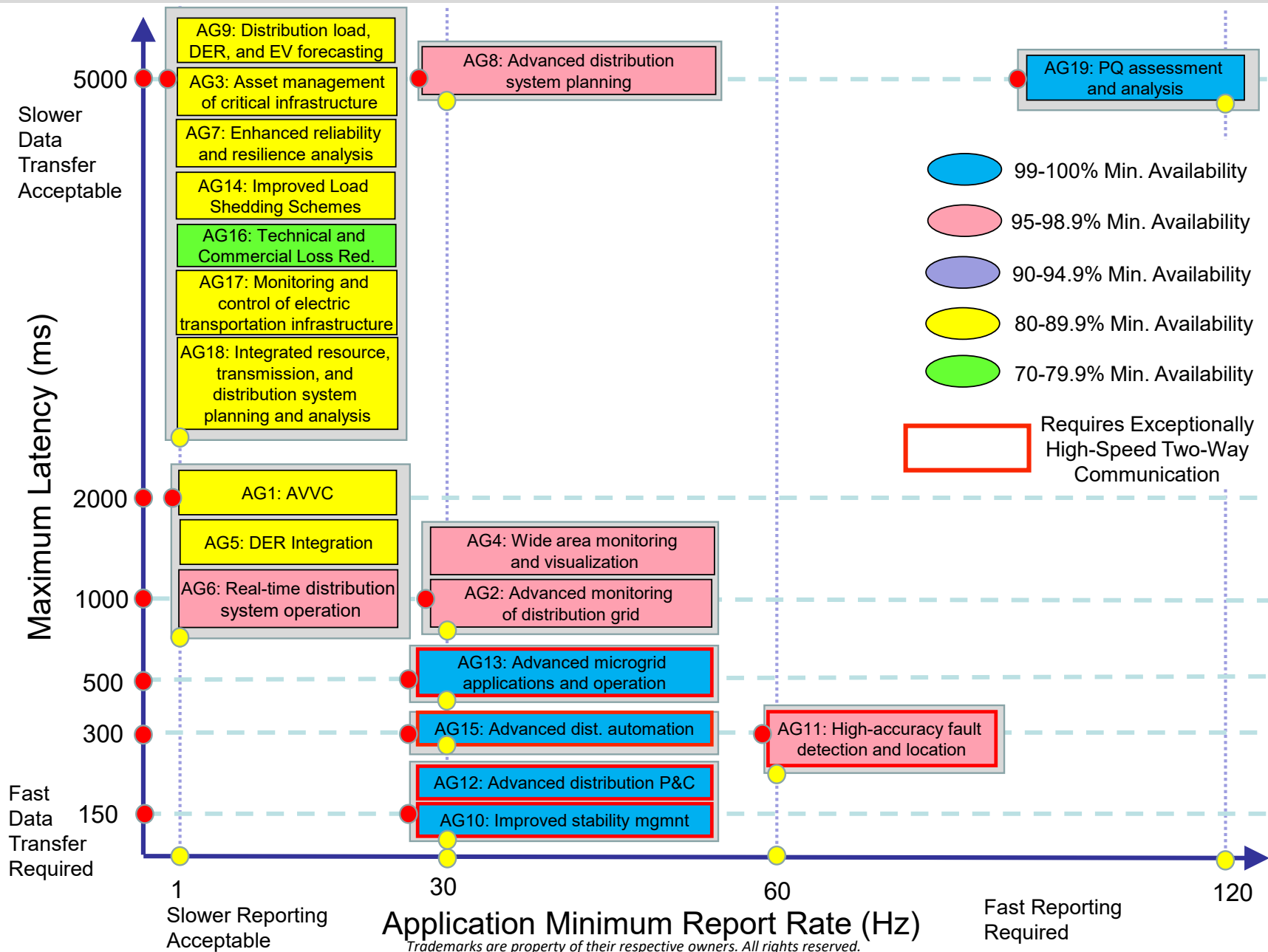
Long-Term

- Synchronized Measurements are Necessary for Critical App.
- Synchronized Meas. Provide Added Benefits for Critical App.
- Synchronized Meas. Provide Added Benefits for Moderate App.

# High Level System Architecture



# Infrastructure and Process Requirements



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# Conclusions (1)

## **Five top-priority application groups use synchronized measurements at medium cost with high benefit:**

- Advanced microgrid applications and operation
- High-accuracy fault detection and location
- Advanced monitoring of distribution grid
- Improved load shedding schemes
- Wide area visualization

## **Mid-tier application groups with high benefits needing more development effort:**

- Advanced distribution protection and control
- Real time distribution system operation
- DER integration and control

## **Many practical synchronized measurement applications can benefit distribution system operations**

- We need to acquire and process large volumes of real-time synchronized measurements from across the grid
- Plan for strategic investment in infrastructure, system architecture, and change management

## Conclusions (2)

- Future research may uncover additional applications, with more stringent HW and communications requirements, but it should not slow-down technology deployment for most of the applications identified in this roadmap
- While development of SW tools is required, analysis of applications' requirements show that most of the applications could be achieved with existing HW products (e.g., angle accuracy is not a major requirement for most applications and does not require more expensive, customized HW)
- Architecture planning must consider availability, accuracy, latency, and archiving of data - Some applications require resilient, high-capacity, fast-streaming communications infrastructure beyond what the industry uses in distribution systems today
- Adoption requires a plan for organizational change, new tools, and training to deploy and sustain synchronized measurement systems and applications
- The organizational plan should identify the operating groups and roles for:
  - System architecture
  - Communications infrastructure
  - Application design
  - Data archiving and storage
  - Maintenance, repair, and support
  - Diagnostics tools, sustainment and development systems, and training



*Thank You!*

