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Industry Roadmap for Implementation of Distribution Synchronized Measurements

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SUMMARY

Utilities are facing a variety of new distribution system challenges due to a changing environment and added complexity. High-impact obstacles include increasing penetration of Distributed Energy Resources (DER), transportation electrification, increasing frequency of major weather events, and evolving customer expectations of service reliability, resilience, and power quality. Synchronized measurements are a necessary and powerful tool for to address these grid issues, thereby, ensuring successful, efficient, and reliable grid operation during decarbonization efforts. This paper discusses the framework of these challenges and how synchronized measurements can serve the future of power delivery systems.

Synchronized measurements are electric variables calculated at different locations on distribution system using a precise common time synchronization. These measurements may be timestamped measurements of various quantities, or in many applications, these will be synchrophasor measurements of currents and voltages. This paper discusses utility needs and application use cases where synchronized measurements are beneficial. There are many possible applications, so it is important to understand which applications are valuable to a specific utility. The paper describes a methodology to identify valuable applications based on a benefit-cost analysis, and then defines an industry roadmap for adopting synchronized measurements on the distribution system. The important insight is that individual utilities can use the methodology described to perform their own benefit-cost analysis and identify the right uses for synchronized measurements on their distribution system.

KEYWORDS

Distributed Energy Resources [DER], Synchrophasor, PMU, Synchronized Measurements, Microgrids

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UTILITY CHALLENGES

In the case of severe weather impacts, challenges are diverse and vary by geographic region. In some areas, the severity and duration of droughts, frequency of strong winds, and associated risk factors like dry flammable vegetation are increasing. As a consequence, utilities on the West Coast and elsewhere in the U.S. face unprecedented wildfire risk levels, as shown in Figure 1. Monthly burned area due to wildfires in the Western United States between 1984–2000 and 2001–2017. In other areas, the frequency and magnitude of severe summer and winter storms are growing.

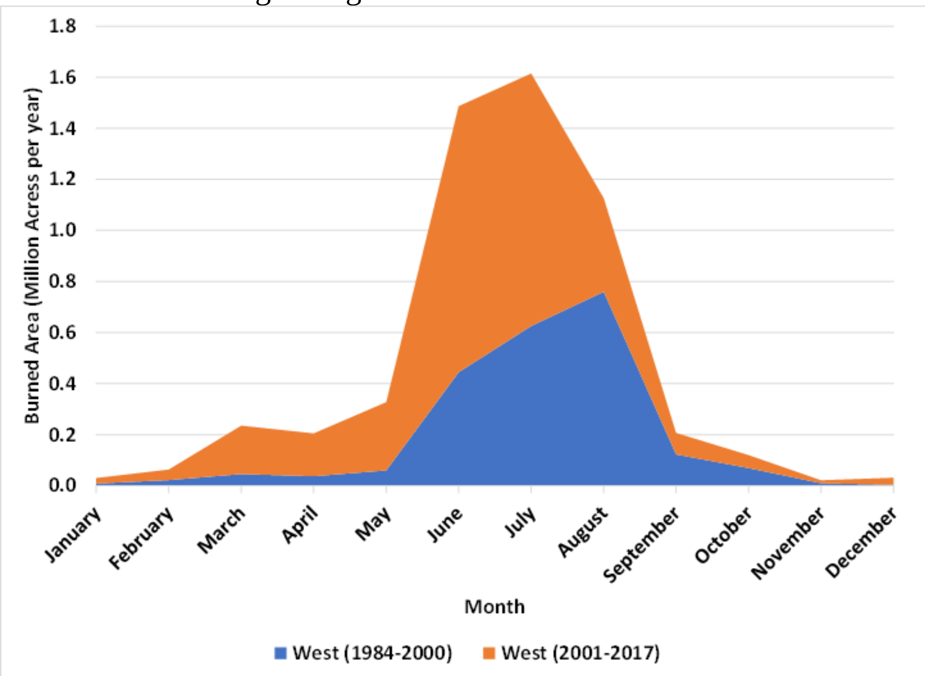

Figure 1. Monthly burned area due to wildfires in the Western United States between 1984–2000 and 2001–2017 [1]

Utilities on the Gulf of Mexico and on the East Coast face impacts from increasing precipitation, strong winds, flooding, and storm surges, as well as quick, dramatic temperature swings. Average temperature increase is also a critical concern since it can subject utility assets to significant stress and increased failure risk. Distribution grids are particularly vulnerable to these events given their expanse, location, largely overhead design, and exposure to external factors such as aggressive vegetation.

DER integration, including the deployment of renewable generation and energy storage, is a key component of meeting clean energy targets. On March 29, 2022, wind generation surpassed coal and nuclear production to become the second largest source of US electricity generation [2]. Trends in the deployment of wind and solar power are projected to continue to increase as more states adopt clean energy standards. DER integration in distribution grids poses substantial challenges for utilities because distribution circuits and substations have not been designed for variable generation interconnection. Impacts can include voltage rise, voltage fluctuations, and reverse power flow. This is illustrated in Figure 2, which shows actual power flow values from a real distribution substation with high penetration of DER that leads to reverse power flow throughout most of the daytime. Depending on PV penetration, native substation loading, and clouding patterns, power flow can change direction (from forward to reverse power and vice versa) in a matter of minutes. This can introduce additional challenges such as frequent operation of volt-var control devices that need to be investigated and addressed. Transmission grid stability is also subject to dynamic performance issues including both chronic and acute oscillatory behaviour of distribution connected energy resources [3, 4].

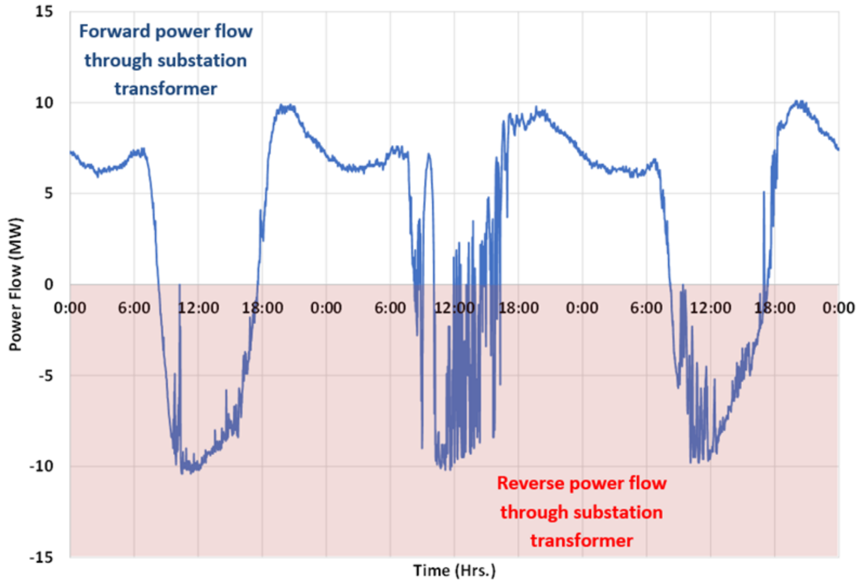

Figure 2. Power flow fluctuations through a real distribution substation in Virginia due to high adoption of photovoltaic (PV) distributed generation [5]

In parallel, utilities are working to support the adoption of electric transportation. Electric vehicle sales in the U.S. grew significantly in 2021 [6]. Electric vehicles, particularly in fleets, can substantially increase distribution system peak demand, create overloads and low-voltage violations, and trigger capital investments to increase capacity (e.g., upgrade substation transformers and distribution line conductors). The daily cyclical impact of electric vehicle charging on loading at the substation is illustrated in Figure 3.

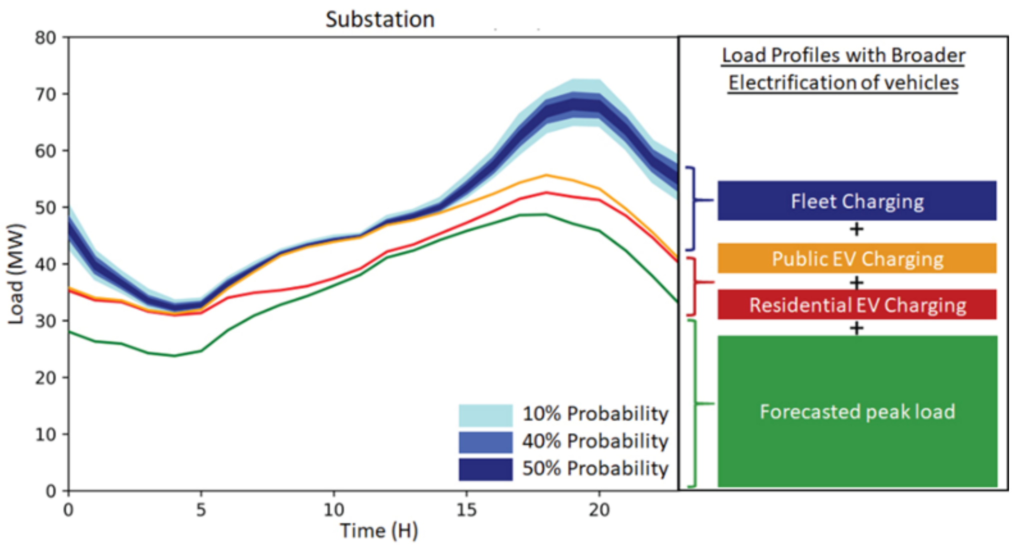

Figure 3. Forecasted impact of EV charging on daily substation load profile if 100% of vehicles are electric [7]

While some of these challenges have traditionally been addressed via the deployment of foundational infrastructure including new construction and grid hardening, a comprehensive solution must also include the implementation of advanced digital technologies for monitoring, protection, automation, and control. Synchronized measurement technologies are an important component of this approach since they can enable the detailed understanding of operating state, asset condition, and system performance via descriptive and predictive analytics, and enable proactive mitigating actions. These capabilities can allow utilities to optimize investments and minimize or prevent the impact of system disruptions.

SYNCHRONIZED MEASUREMENTS OVERVIEW

Synchronized measurements refer to electric variables measured at locations across the grid with a precise common timestamp at every location. Variables include but are not limited to voltage and current magnitudes, phase angles, real and reactive power, frequency, rate of change of frequency (ROCOF), and circuit breaker and recloser status.

Voltage and current phasors can be collected from distribution circuits across the grid by relays, recloser controllers, circuit switch controllers, voltage regulator controllers, capacitor bank controllers, and power quality meters. Circuit control devices that gather and publish synchronized phasors are typically referred to as Phasor Measurement Units (PMUs). PMU measurements with consistent timing reference can be reported to central locations like substation application controllers and control centers to be used in advanced real-time applications.

Utilities Using Synchronized Measurements on the Distribution Grid

One of the first advanced applications was for the specific case of reducing risk of fault-triggered wildfires. When distribution line conductors fail and fall to the ground, the resulting high impedance arcing fault may be difficult to detect electrically yet may be capable of igniting dry flammable vegetation or creating an electrical hazard for people in the vicinity of the live downed conductor. As part of a broad program, San Diego Gas & Electric (SDG&E) pioneered the development of a distribution falling conductor protection (DFCP) system that collects streaming synchrophasor measurements from strategic distribution circuit locations and can detect a conductor break in tens of milliseconds. The analysis application opens circuit breakers or switches adjacent to the break long before falling overhead conductors have reached the ground, preventing wildfire ignition [8].

As the penetration levels of DER and EVs increase, it will become more critical to collect data and to centrally observe the impacts on operation and planning of the distribution grid. This has prompted increasing interest in deployment of synchronized measurement technologies across distribution systems. For instance, Commonwealth Edison (ComEd) has deployed more than 100 PMUs in 22 distribution substations for a variety of applications, including microgrid and DER monitoring (solar PV and energy storage) and real-time distribution system operations [9, 10]. Similarly, as part of its Grid Transformation Plan (GTP), Dominion Energy is planning to pilot the deployment of distribution synchronized measurements at key locations in selected distribution substations to monitor and analyze power-frequency events, as well as power quality meters to capture snapshots of high-frequency harmonic behavior and transient events. Synchrophasors enhance event analysis since the data is more complete and accurate and is collected at a rate of up to 300 times that of SCADA data. Synchronized measurement technology is commercially available in distribution system protection and control equipment, such as overcurrent protection relays, power quality meters, apparatus controllers, and in sensors such as micro-PMUs. Many existing microprocessor-based relays and controllers used in distribution applications and some substation power quality devices can provide synchronized measurements if a suitable streaming communications channel is available. High-resolution, time-synchronized data can be used to improve wide-area situational awareness, to observe apparatus and circuit performance or issues, to analyze events and outages, and to understand and enhance overall distribution substation and circuit performance.

Benefits of deploying synchronized measurement technologies in distribution systems include:

- <u>DER impact mitigation</u>: DER adoption and saturation can cause reverse power flow through distribution substation transformers and circuits, impacting protection systems and schemes, and leading to voltage fluctuations and interactions with voltage regulation equipment like load tap changers [11, 12, 13]. Synchronized measurement technologies allow high-resolution, time-synchronized monitoring and control of substation and circuit assets and settings in real time. These capabilities can be used to implement mitigation measures such as adjustment of protection and voltage regulation settings for reverse power flow operation or new protection and control algorithms like reach modification, sensitivity adjustment, or differential comparison. These measures prevent or alleviate impacts of high DER penetration. DERs can in turn provide benefits to the grid such as dynamic volt-var support, reliability and resilience improvement via intentional islanding operation, and microgrid operation [14, 15, 16]. Synchronized measurement technologies are key elements to enable and validate these benefits of DERs.

- <u>Dynamic performance monitoring of DER and power electronics</u>: Both DER and the compensating devices that are installed to counteract grid impacts of DER interconnect through power electronic interfaces. These types of interfaces contribute not only to power quality degradation but also to problems with dynamic and small-signal stability of the grid. The ability to model and predict the behavior of these interfaces through simulation is severely limited. As more and more renewables are brought online, more and more power electronic compensation devices are also installed. As a whole, the likelihood of local and system-wide impacts grows exponentially. However, there is a solution – high-resolution telemetry provided by synchrophasor and waveform data combined with contemporary analytical techniques that can identify, track, diagnose, and enable mitigation of oscillatory behaviors. Suppression of oscillatory behaviors and their DER-penetration-limiting effects maximizes the effectiveness of renewable integration on a per-MW basis [17,18,19, 20, 21, 22]. For example, see Figure 4.

- <u>Electric transportation impact mitigation:</u> Electric vehicle adoption and saturation changes load factors and can increase distribution substation and circuit peak loading and average asset utilization. Real-time monitoring capabilities are key to evaluating substation asset thermal limits and implementing advanced and more effective voltage regulation control strategies that consider fast demand changes in electric vehicle charging stations, DER outputs, and native loads of customers. As technology, regulation, and policy evolve it is expected that Vehicle-to-Grid (V2G) operation of electric vehicles will become more common. This can support grid operations including voltage regulation, reactive power support, and peak shaving; and can provide additional benefits to the grid and its customers [23, 24]. Synchronized measurement technologies can enable and validate these benefits.

- Improved reliability: The deployment of synchronized measurement technologies can improve wide-area situational awareness, real-time visibility, asset loading evaluation, and DER and electric transportation impact mitigation. Deployment of PMUs and applications ultimately enhances distribution substation and circuit performance with these capabilities. Combined with advanced analytics, these measurements and functions can improve the overall reliability of the power delivery system.

- Improved power quality: Synchronized measurement technologies enable the detection of voltage and current issues such as frequent voltage sags or swells, short- and long-term flicker, total harmonic distortion, voltage or current imbalance, and inappropriate profiles along the circuit. This information can be used to evaluate overall power quality performance, identify root causes of power quality or circuit stress issues, and implement solutions to alleviate impacts and improve performance.

- Improved resilience: The real-time monitoring and control and advanced analytics capabilities of modern substations with synchronized measurements allow for the implementation of control actions to adapt to changing system conditions and external variables like weather. This increased adaptability improves resilience and reliability by allowing the overall power delivery system to withstand or recover faster from disruptive events [25,26].

- Improved asset health: The high-resolution data collected from substations and circuits via PMUs can be used to evaluate overall asset health [27]. Examples of data that can be used for this type of application include asset loading trends, asset operating history, voltages, temperatures, and signatures that are predictive of end-of-life or failure.

- Effective maintenance: High-resolution data collected from key assets like distribution substation transformers, circuit breakers and reclosers can be used to proactively identify potential performance deterioration due to abnormal operation or incipient faults. This information can be used to implement preventive solutions and identify root causes [28]. Continuous monitoring of circuit assets with streaming PMU and status data can also report partial failures when they happen and reduce the need for time-based maintenance work to discover malfunctions.

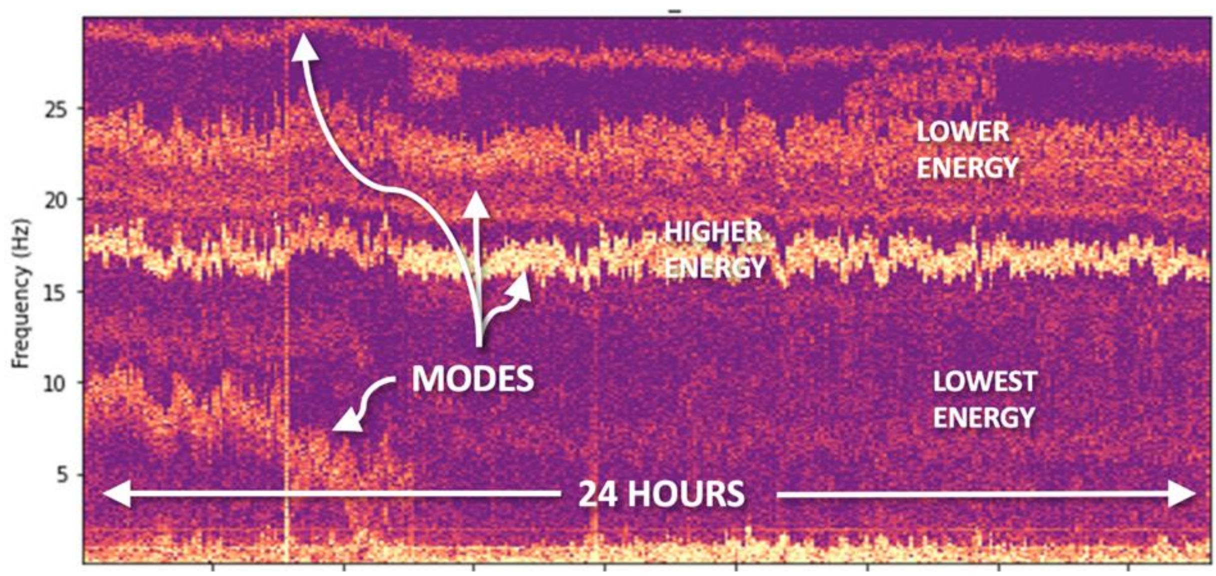

Figure 4. Example spectrogram demonstrating the prevalence of and dynamic nature of persistent modes of oscillation in the Dominion system

CREATING A ROADMAP: PRIORITIZING DISTRIBUTION GRID APPLICATIONS

For a utility to create its own distribution synchronized measurement deployment roadmap, it needs to build a list of applications that will benefit its system and operations. The cost and benefit of each application will need to be assessed considering the available infrastructure and relevance of the application to solving high-impact issues. While each utility has unique needs, the industry needs a comprehensive example list for initial guidance.

Quanta Technology, Oak Ridge National Laboratory (ORNL), and SDG&E partnered to develop an industry framework and a high-level industry roadmap for deploying synchronized measurements in distribution systems for electric power system modernization [29]. The project was supported by the U.S. Department of Energy (DOE) to identify and prioritize applications of synchronized measurement technologies in distribution systems and create a roadmap for future investments. The project included interviews with Consolidated Edison (ConEd), Dominion Energy, and Commonwealth Edison (ComEd) to identify key areas of interest for the industry where deployment of synchronized measurement technologies could add value. The roadmap was based on a framework for quantifying relative benefits and costs for applications and associated infrastructure, these results were used to prioritize and schedule proposed applications.

A total of 75 applications or use cases were identified and mapped into 19 different application groups. The applications and their associated groupings are shown in Table 1.

Table 1. Distribution synchronized measurement applications and associated application groups

Application	New Use Case Description	Application Group Number	Proposed Application Group Description
A1	Conservation Voltage Reduction (CVR)	AG1	Advanced Volt-VAR Control (AVVC)
A2	Volt-VAR Control (VVC) of distribution systems		

A3	Volt-VAR Optimization (VVO)		
A4	Active and reactive power flow monitoring	AG2	Advanced monitoring of distribution grid
A5	Voltage profile monitoring		
A6	Communications system/equipment performance with management metrics monitoring		
A7	Frequency monitoring		
A8	Near real-time event monitoring (physical)		
A9	Near real-time event monitoring (cyber)		
A10	Phase angle monitoring for voltages and currents		
A11	Power apparatus asset management	AG3	Asset management of critical infrastructure
A12	Power apparatus functional monitoring		
A13	Monitoring and control of critical infrastructure and large customers		
A14	Underground secondary/spot network monitoring and analysis		
A15	Dynamic rating of distribution assets		
A16	Circuit status dashboards	AG4	Wide area visualization
A17	Integration of customer site FNET information		
A18	Improved wide-area situational awareness (T&D)		
A19	Visualization of dynamic system response		
A20	Monitoring of intermittent DER	AG5	DER integration
A21	Voltage impact assessment and mitigation due to high penetration of intermittent energy resources		
A22	Active and reactive reverse power flow management		
A23	Customer/smart inverter control		
A24	DER management and energy balancing with energy storage		
A25	Load unmasking (behind-the-meter DER)		
A26	Distribution state estimation	AG6	Real-time distribution system operation
A27	Closed-loop circuit operation		
A28	DERMS implementation		
A29	Improved demand response		
A30	Improved distribution reliability analysis	AG7	Enhanced reliability and resiliency analysis
A31	Post-mortem analysis		
A32	Phase identification	AG8	Advanced distribution system planning
A33	Distribution system computational model validation		
A34	Short-circuit study validation		
A35	Load characterization, load modeling, and load forecasting	AG9	Distribution load, DER, and EV forecasting
A36	DER forecasting		
A37	EV forecasting		
A38	Voltage stability monitoring and control	AG10	Improved stability management
A39	Control instability, hunting, or oscillation detection (voltage, VAR, switching)		
A40	Transient stability monitoring and control		
A41	Fault-Induced Delayed Voltage Recovery (FIDVR) detection		
A42	Faulted circuit indication	AG11	High-accuracy fault detection and location
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 location		
A48	Falling conductor protection		
A49	Reclosing assistance for fast circuit recovery after fault	AG12	Advanced distribution protection and control
A50	Current differential protection of circuit sections		
A51	Adaptive protection of distribution systems		
A52	Planned islanding and restoration of microgrids	AG13	Advanced microgrid application and operation
A53	Advanced protection of microgrids		
A54	Advanced distribution system topology, automation, and control (holonic grids)		
A55	Islanding detection for distributed generation (anti-islanding scheme)		
A56	Improved load shedding schemes (frequency)	AG14	Improved load shedding schemes
A57	Improved load shedding schemes (voltage)		

A58	Improved load shedding schemes (load flow-based)		
A59	Load shedding real-time compensative arming to balance 1547-compliant PV		
A60	Load transfer and load balancing	AG15	Advanced distribution automation
A61	Self-healing and enhanced FLISR operation		
A62	Circuit loss minimization	AG16	Technical and commercial loss reduction
A63	Energy accounting		
A64	Technical and commercial loss identification, calculation, and reduction		
A65	Monitoring and control of electric transportation infrastructure	AG17	Monitoring and control of electric transportation infrastructure
A66	Vehicle-to-Grid (V2G) monitoring and control		
A67	Running sub-transmission (69 kV) and distribution in parallel	AG18	Integrated resource, transmission, and distribution system planning and analysis
A68	Integrated resource, transmission, and distribution system planning and analysis		
A69	Harmonics measurement	AG19	Power quality assessment and analysis
A70	Voltage sag and swell measurement		
A71	Flicker measurement		
A72	Voltage and current imbalance measurement		
A73	Short-duration interruption measurement		
A74	Harmonic state estimation/diagnosis		
A75	Primary meter customer (e.g., major customer monitoring power quality)		

Each application group was evaluated in terms of the relative benefit-cost ratio. Benefit-cost analysis and prioritization of application groups were conducted based on relative value to address key industry needs and relative implementation costs. Relative benefits were evaluated based on:

1. Resilience and reliability
2. Sustainability and decarbonization
3. Real-time operation
4. Advanced planning
5. Public safety
6. Efficiency improvement
7. Innovation potential, and
8. Customer engagement and business potential

Relative costs were evaluated based on:

1. Direct capital and operating costs
2. Complexity
3. Investment in development
4. Risk
5. Maturity of the associated concept and supporting technology
6. Readiness of the industry to implement the application

Each benefit and cost category were assigned a weight to model its relative importance based on the project team's technical opinion and on industry experience. Application groups were graded for the benefit and cost categories using a scale from 0 to 10. The results were then used to calculate a BCR to prioritize the application groups. The high-level process is illustrated in Figure 5 Benefit-cost analysis for synchronized measurement technologies roadmap.

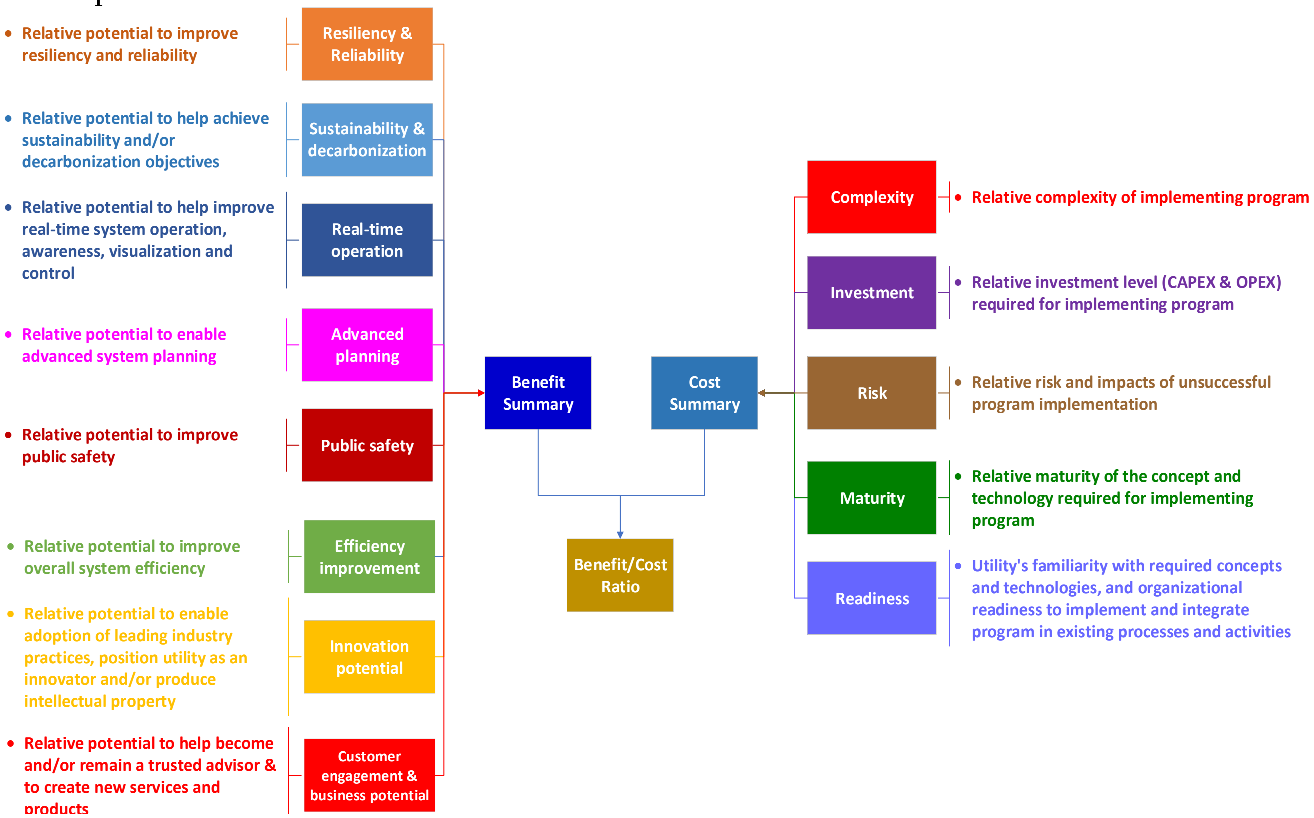

Figure 5. Benefit-cost analysis for synchronized measurement technologies roadmap

A scatter plot of the benefits and costs for each application group is shown in Figure 6, with the BCR of each application group summarized in Table 2. The full methodology and derivation for these values can be seen in the industry roadmap report [29].

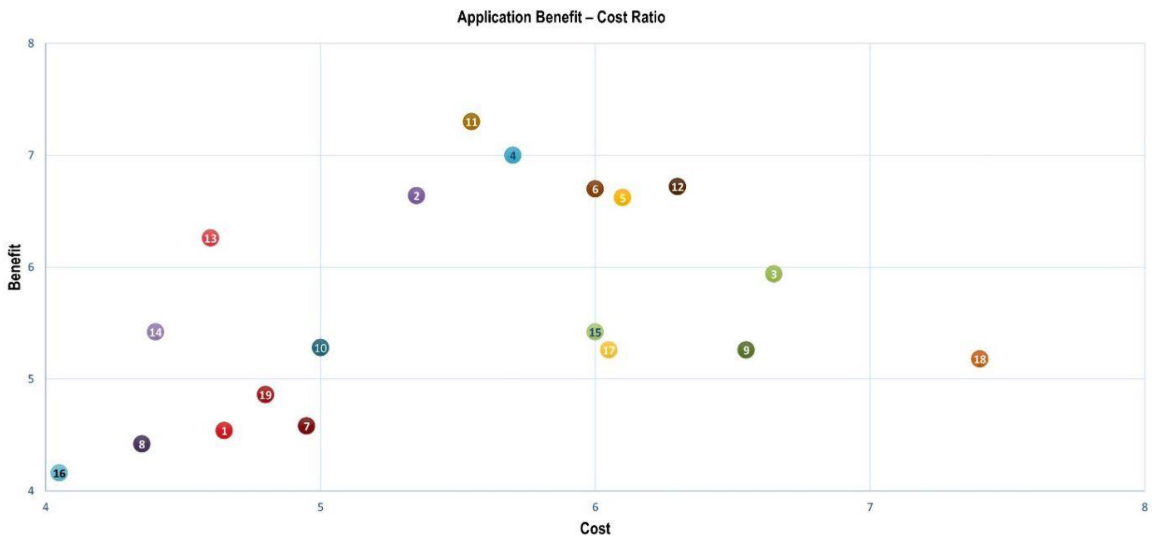

Figure 6. Application groups benefit-cost plot

Table 2. BCR calculation of application groups

Group	Description	Benefit Numerical Assignment	Cost Numerical Assignment	BCR
AG1	Advanced volt-var control	4.54	4.65	0.98
AG2	Advanced monitoring of distribution grid	6.64	5.35	1.24
AG3	Asset management of critical infrastructure	5.94	6.65	0.89
AG4	Wide area visualization	7.00	5.70	1.23
AG5	DER integration and control	6.62	6.10	1.09
AG6	Real-time distribution system operation	6.70	6.00	1.12
AG7	Enhanced reliability and resilience analysis	4.58	4.95	0.93
AG8	Advanced distribution system planning	4.42	4.35	1.02
AG9	Distribution load, DER, and EV forecasting	5.26	6.55	0.80
AG10	Improved stability management	5.28	5.00	1.06
AG11	High-accuracy fault detection and location	7.30	5.55	1.32
AG12	Advanced distribution protection and control	6.72	6.30	1.07
AG13	Advanced microgrid applications and operation	6.26	4.60	1.36
AG14	Improved load shedding schemes	5.42	4.40	1.23
AG15	Advanced distribution automation	5.42	6.00	0.90
AG16	Technical and commercial loss reduction	4.16	4.05	1.03
AG17	Monitoring and control of electric transportation infrastructure	5.26	6.05	0.87
AG18	Integrated resource, transmission, and distribution system planning and analysis	5.18	7.40	0.70
AG19	Power quality measurements	4.86	4.80	1.01

Figure 6 shows how the top application groups identified using this methodology were mapped into an industry application roadmap. While the Figure 7 DOE roadmap is based on experience of participating utilities and Subject-matter Experts (SMEs), an individual utility will face drivers and challenges that may result in a different prioritization. However, the same methodology utilized to develop the industry application roadmap can be used by individual utilities to determine their own application roadmaps.

Figure 7. Industry application roadmap from DOE investigation

WHAT'S NEXT?

As utilities continue working on decarbonization initiatives, integration of renewables and DER, adoption of electric transportation, and climate change readiness, they face increasing need to observe and proactively manage the distribution system and the active components attached to it to optimize operations, improve performance, and minimize system disruptions. Synchronized measurements deployed in distribution substations and on circuits can provide high-resolution time-synchronized data to support these activities. It is therefore a critical component in the portfolio of solutions and overall grid modernization strategy. Reviewing the requirements for the applications shows that most of them can be achieved with existing hardware and software products available on today's market.

Each utility can create its own roadmap for implementation of applications using the methods described in this paper. However, adopting new technologies will impact utility organizations comprehensively. An organizational plan should identify the operating groups and roles for the system architecture, communications infrastructure, application design, data archiving and storage, ongoing support and maintenance, training, and diagnostics tools.

BIBLIOGRAPHY

[1] Climate Change Indicators: Wildfires https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires

[2] Wind was second-largest source of U.S. electricity generation on March 29 https://www.eia.gov/todayinenergy/detail.php?id=52038

[3] C. Mishra, L. Vanfretti, D. Yang, X. Xu, K.D. Jones, R.M. Gardner, Analysis of STATCOM Oscillations using Ambient Synchrophasor Data in Dominion Energy, ISGT 2022

[4] C. Wang, C. Mishra, L. Vanfretti, K.D. Jones, Identifying Oscillations Injected by Inverter-Based Solar Energy Sources, Accepted to 2022 IEEE PES General Meeting.

[5] Direct Testimony of Dr. Julio Romero Agüero on behalf of Virginia Electric and Power Company before the State Corporation Commission of Virginia Case No. PUR-2021-00127

[6] Electric vehicles and hybrids surpass 10% of U.S. light-duty vehicle sales https://www.eia.gov/todayinenergy/detail.php?id=51218

[7] The Road to Transportation Decarbonization: Understanding Grid Impacts of Electric Fleets, Sep. 2021 https://www.nationalgridus.com/media/pdfs/microsites/ev-fleet-program/understandinggridimpactsofelectricfleets.pdf

[8] Udren, E., Bolton, C., Dietmeyer, D., Rahman, T., Flores-Castro, S., “Managing Wildfire Risks: Protection System Technical Developments Combined with Operational Advances to Improve Public Safety”, IEEE PES Power and Energy Magazine, January–February 2022.

[9] P. Pabts, H. Chen, Synchronized Measurements in Distribution Systems, Mar. 2021 https://www.naspi.org/sites/default/files/2021-04/20210331_naspi_webinar_comed.pdf

[10] ComEd Engineers Real-Time Situational Awareness, T&D World Magazine, Sep. 2020 https://www.tdworld.com/test-andmeasurement/article/21138063/comed-engineers-realtime-situational-awareness

[11] F. Katiraei, J. Romero Agüero, Solar PV integration challenges, IEEE Power and Energy Magazine, May/June 2011 https://ieeexplore.ieee.org/abstract/document/5753332

[12] J. Romero Agüero, S.J. Steffel, Integration challenges of photovoltaic distributed generation on power distribution systems, 2011 IEEE PES General Meeting, Detroit, MI, July 2011 https://ieeexplore.ieee.org/abstract/document/6039097

[13] M.M. Rezvani et. al, Interaction of the Substation Load Tap Changer with the High Penetration of Distributed Energy Resources, 2020 IEEE Texas Power and Energy Conference (TPEC), Feb. 2020 https://ieeexplore.ieee.org/document/9042577

[14] Leading the Way U.S. Electric Company Investment and Innovation in Energy Storage, Edison Electric Institute, Oct. 2018 https://www.eei.org/issuesandpolicy/Energy%20Storage/Energy_Storage_Case_Studies.pdf

[15] Microgrids Help Integrate Renewable Energy and Improve Community Resiliency https://www.sdge.com/more-information/environment/smart-grid/microgrids

[16] ComEd Bronzeville Community Microgrid Demonstrates Ability to Keep Power Flowing in Event of an Emergency https://www.comed.com/News/pages/newsreleases/2019_04_17.aspx

[17] M. de Castro Fernandes, C. Mishra, L. Vanfretti, K.D. Jones, A Novel Method for Despiking Spectra from Synchrophasor Measurements, 2021 IEEE PES General Meeting

[18] C. Mishra, L. Vanfretti, K.D. Jones, Power System Frequency Domain Characteristics for Inertia Estimation from Ambient PMU Data, 2021 IEEE PES General Meeting

[19] X. Xu, C. Mishra, C. Wang, L. Vanfretti, K.D. Jones, R.M. Gardner, Fast Oscillation Detection and Labeling vis Course Grained Time Series Data for ML Applications, ISGT 2022

[20] C. Mishra, L. Vanfretti, K.D. Jones, Designing Time Derivatives in the Frequency Domain for Ambient PMU Data Applications, Accepted to 2022 IEEE PES General Meeting.

[21] E. Segerstrom, L. Vanfretti, C. Mishra, K.D. Jones, R.M. Gardner, Using Spectral Flatness to Detect and Label Power System Oscillations in the Presence of Intermittent Broadband Noise, Accepted to 2022 IEEE PES General Meeting

[22] M. de Castro Fernandes, C. Mishra, L. Vanfretti, K.D. Jones, Experiences with Dynamical Mode Decomposition for Wide-Area Mode Estimation, Accepted to MSCPES 2022 10th Workshop on Modeling and Simulation of Cyber Physical Energy Systems
[23] Open Standards-Based Vehicle-to-Grid: Value Assessment, Technology Development, Technical Report 3002014770, EPRI, June 2019 https://www.epri.com/research/products/000000003002014770
[24] Open Standards-Based Vehicle-to-Grid: Value Assessment, Value Assessment, Technical Report 3002014771, EPRI, June 2019 https://www.epri.com/research/products/000000003002014771
[25] Resilience Framework, Methods, and Metrics for the Electricity Sector, IEEE PES Technical Report PES-TR83, Oct. 2020 https://resourcecenter.ieee-pes.org/publications/technical-reports/PES_TP_TR83_ITSLC_102920.html
[26] J. Romero Agüero, D. Hall, Resiliency of Electric Power Systems, Apr. 2020 https://quanta-technology.com/wp-content/uploads/2020/05/Resiliency-of-Electric-Power-Systems-FINAL.pdf
[27] N. Nayak, J. Chynoweth, Substation Asset Health Monitoring Using Synchrophasors, North American Synchrophasor Initiative (NASPI), Nov. 2020 https://www.naspi.org/sites/default/files/2020-11/06_epg_nayak_substation_health_20201103.pdf
[28] G. Wolf, Asset Health Awareness Changing the Grid, Transmission and Distribution World, Jun. 2017 https://www.tdworld.com/grid-innovations/asset-management-service/article/20969836/asset-health-awareness-changing-the-grid
[29] Distribution Synchronized Measurements Roadmap Final Report, North American Synchrophasor Initiative (NASPI), Sep. 2021, https://www.naspi.org/node/934
[30] A. von Meier et al, Synchronized Measurements and their Applications in Distribution Systems: An Update, North American Synchrophasor Initiative (NASPI), Jun. 2020, https://www.naspi.org/node/851