Power Sector Transmission & Distribution Data and Information

WEBINAR SERIES

Welcome

Our webinar will start soon

U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY

Los Alamos NATIONAL LABORATORY

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

Power Sector Transmission & Distribution Data and Information

WEBINAR SERIES

Topic 4. Sensor Device and Data Research

Jim Ogle, PNNL - Topic 4 Moderator

Electrical Engineer

U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY

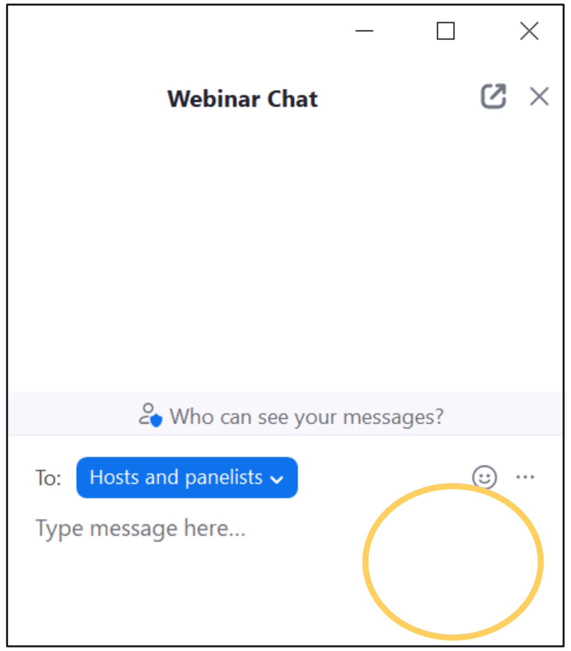
Los Alamos NATIONAL LABORATORY

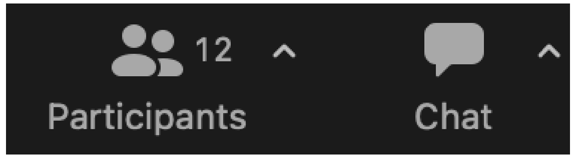
OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

Housekeeping items

- Recording the session (for internal purposes only)
- Slides will be made available on the event page
  https://www.pnnl.gov/events/power-sector-transmission-distribution-data-and-information-webinar-series
- Please type your questions in the chat box (two options)
  - Use “Host and panelists” option for posing questions only to presenters
  - Post questions and comments for all attendees to see
- Q&A
  - We will attempt to answer as many questions as we can, while considering the time.





Agenda

TIME (PDT)	TOPIC	PRESENTERS
10:00 – 10:05 a.m.	Welcome and Introduction	Jim Ogle, PNNL Sandra Jenkins, DOE Chris Irwin, DOE Roshanak Nateghi, DOE
10:05 – 10:15 a.m.	Grid Data Transport Analysis	Jim Ogle, PNNL
10:15 – 10:30 a.m.	Grid Data Privacy	Anna Scaglione, Cornell University
10:30 – 10:45 a.m.	The Distribution PMU in Practice	Sherif Fahmy, Zaphiro
10:45 – 11:00 a.m.	Distributed Intelligent Sensor Platform	Teja Kuruganti, ORNL
11:00 – 11:15 a.m.	Physical Measurements for Grid Insights	Hall Chen, GridWare
11:15 – 11:30 a.m.	Measurement Uncertainty & Trust	Artis Riepnieks, PNNL
11:30 – 11:45 a.m.	Sensor Data Anomaly Detection (SENTIENT)	Kaveri Mahapatra, PNNL
11:45 – 12:00 pm	High Fidelity at the Distribution System	Panos Moutis, CCNY
12:00pm	Concluding Remarks	Jim Ogle, PNNL

Power Sector Transmission & Distribution Data and Information

WEBINAR SERIES

DOE-Office of Electricity (OE) Introduction

Sandra Jenkins, DOE-OE

Chris Irwin, DOE-OE

Roshanak Nateghi, DOE-OE

U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY

Los Alamos NATIONAL LABORATORY

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

Power Sector Transmission & Distribution Data and Information

WEBINAR SERIES

Data Transport Analysis & Observability

Jim Ogle, PE; Andrew Reiman
Pacific Northwest National Laboratory

U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY

Los Alamos NATIONAL LABORATORY

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

The Grid is Transforming

Increasing challenges for operations require data driven capabilities

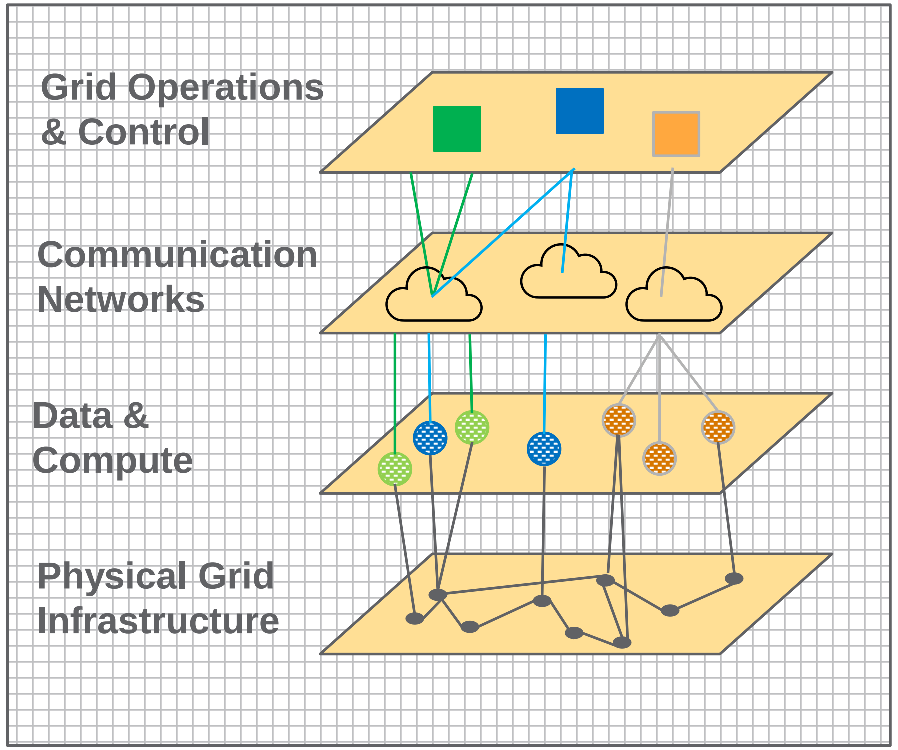
Operational Challenges	Greater Uncertainty	More Stress	Increased Dynamics
Required Grid Characteristics	Flexibility	Resilience	Responsive

Data Driven Grid: How much data is needed?

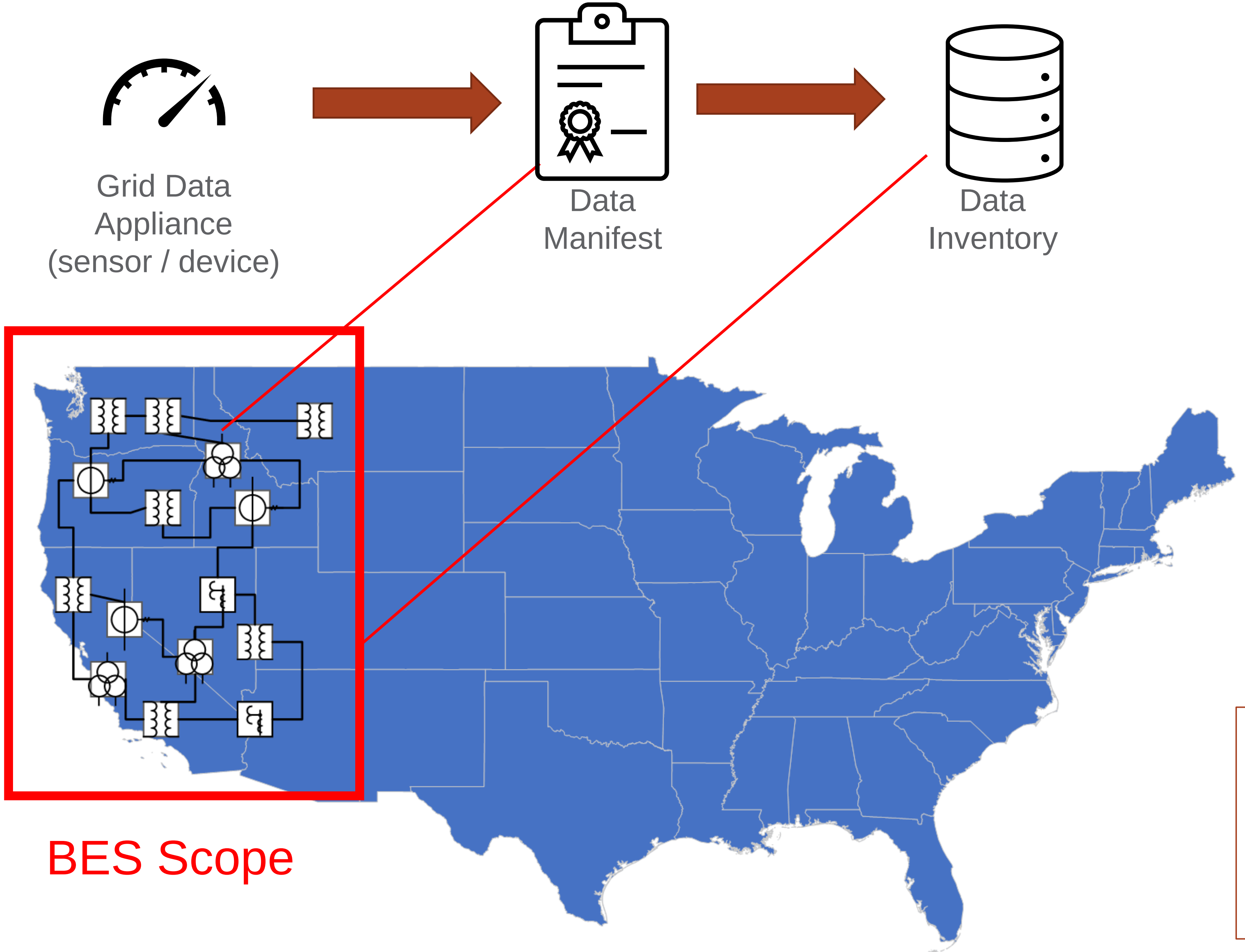
Forecasting, Observability, Automation, Decision Support, Situational Awareness, Distributed Intelligence, Coordination

Grid Data Transport Analysis
A data centric approach to understanding transport needs

- Examine the data flow characteristics of the grid across different modes of operation
- Quantify the data needs to support grid operations
- Develop predictive models for future data demand
- Develop analytical methods to analyze different transport architectures
- Support methods to co-optimize data, control, transport, and compute architectures



Total Available Data Concept



The data inventory represents the **Total Available Data** that can be used to support the operation & maintenance of the system.

For a transport system this data at rest is:

- Peak potential data demand

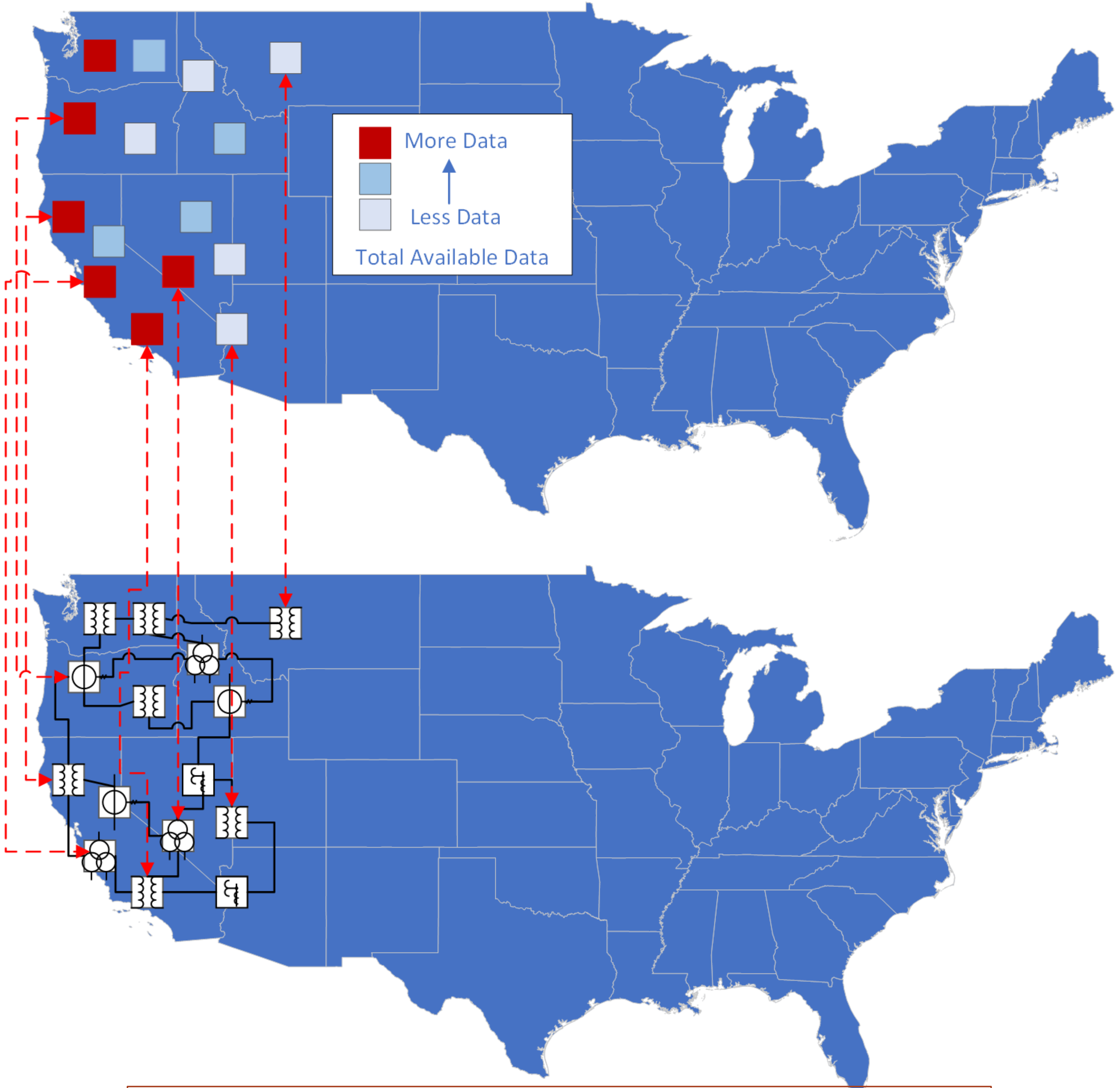
Foundation for Data Transport Planning

Where are the data generators?

- When associated with an electric network Total Available Data represent the **overall data density** across the system.

A basis for grid data transport planning:

- Understanding how current and future grid operations impact this data density data transport systems

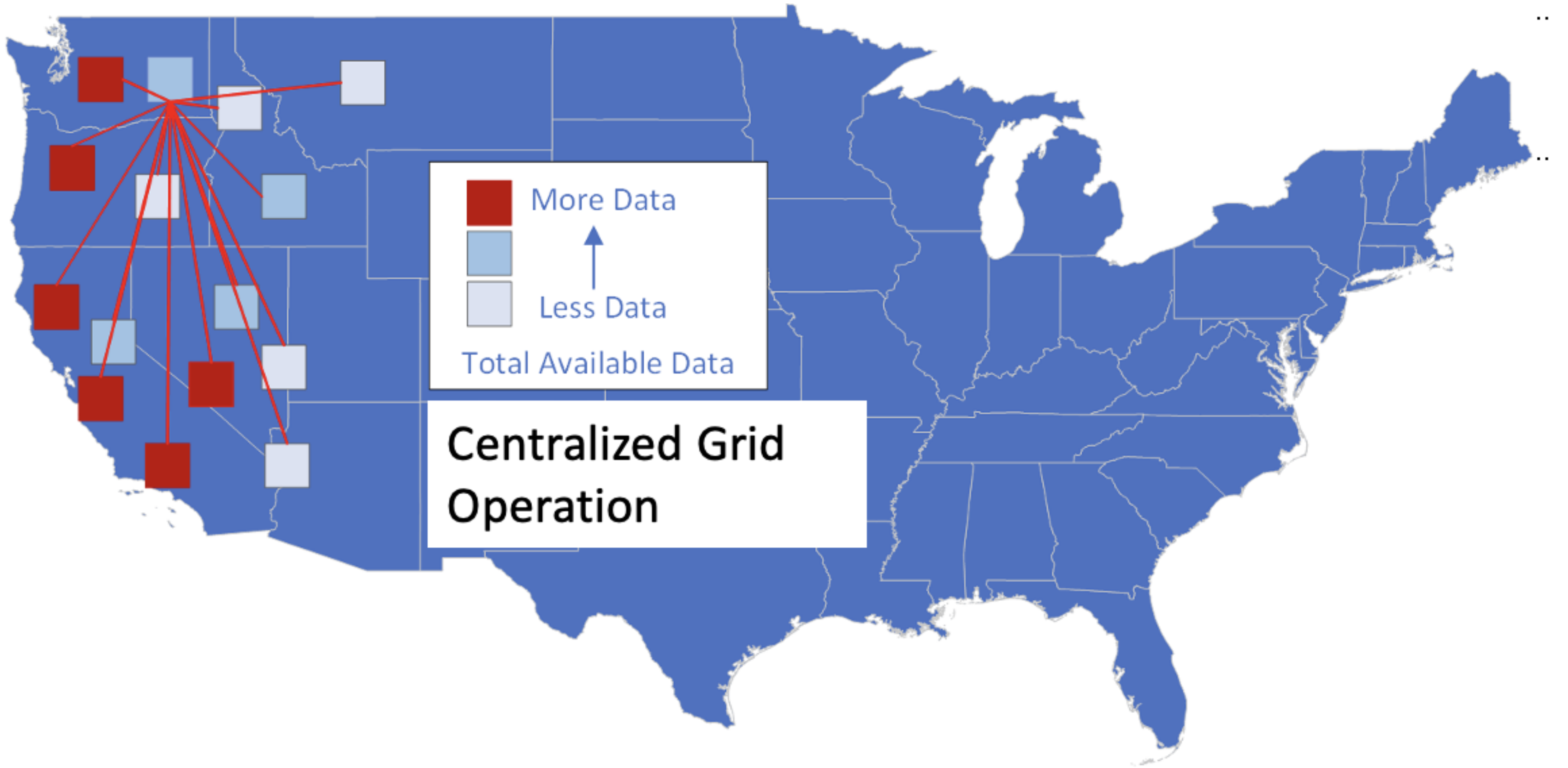


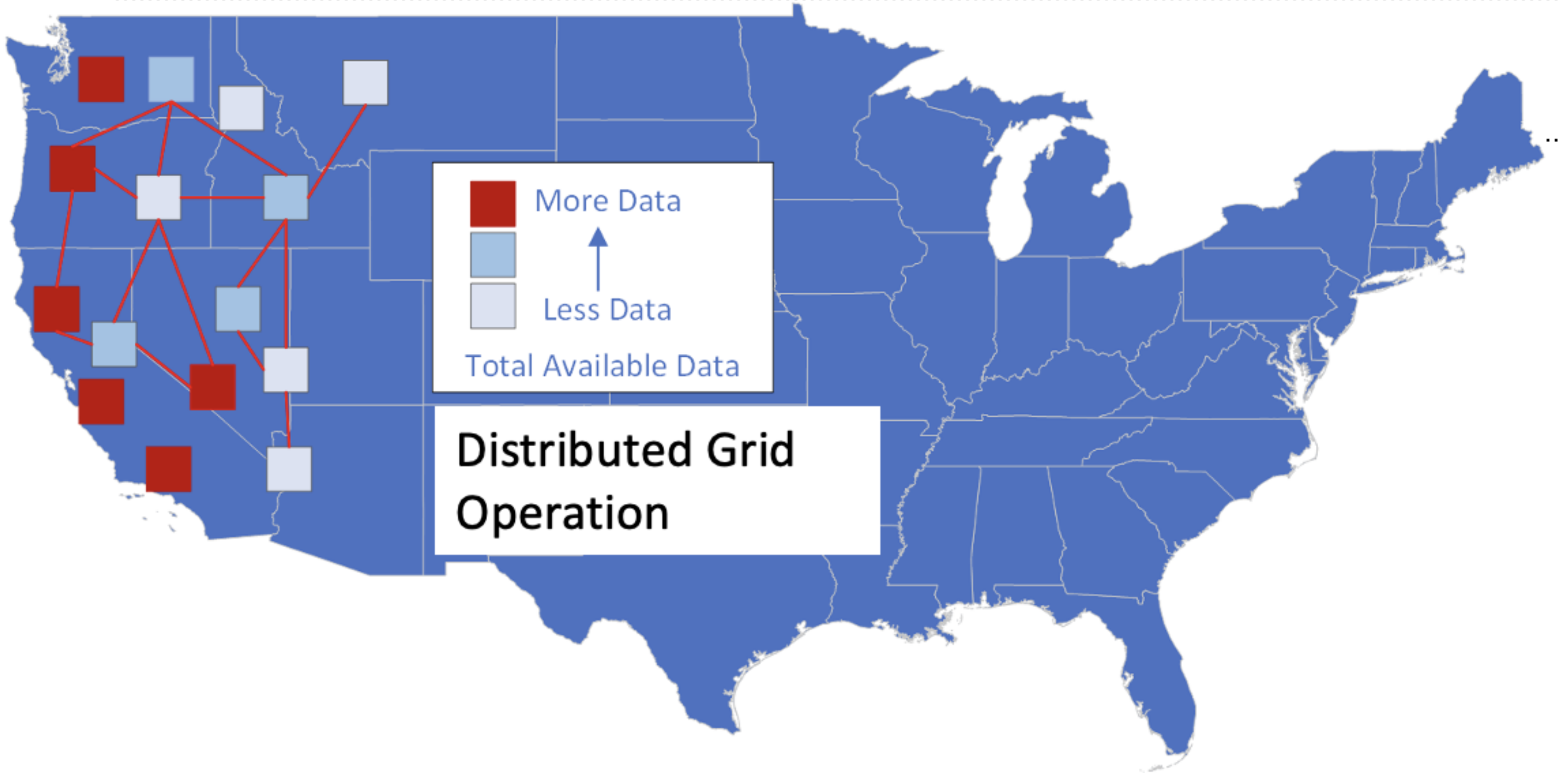
Data At Rest: Peak Potential Demand

Evaluating Data Transport Architectures

Where are the data generators and consumers?

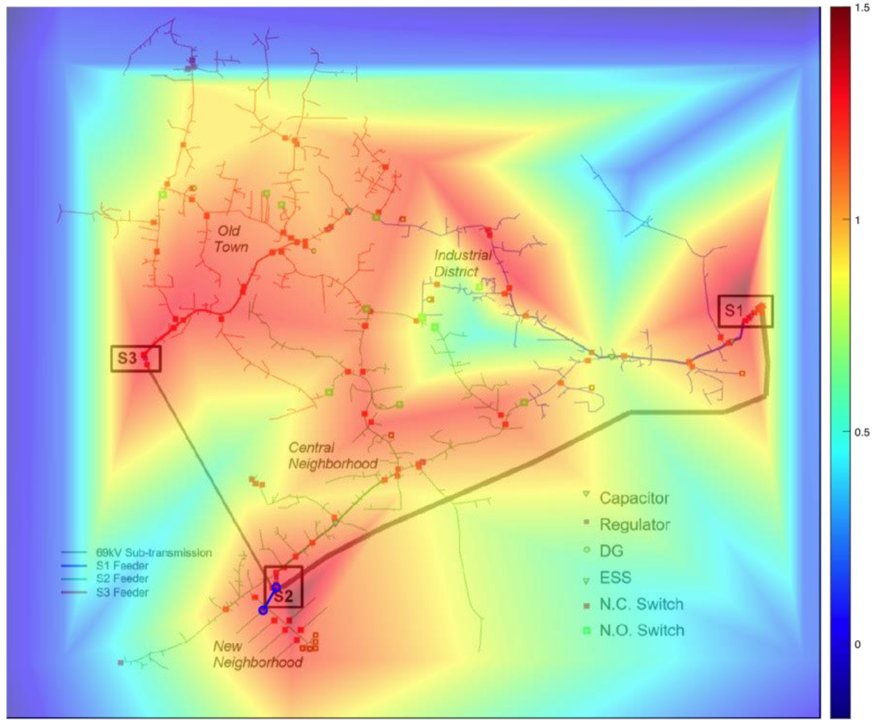
- **Data in Motion:** data flows across transport networks relative to grid operation needs.
- **Dynamic Data Valuation:** Correlate data statistics with grid state & operations
- **Data Transport Optimization**: Identify span of data relative to control structures



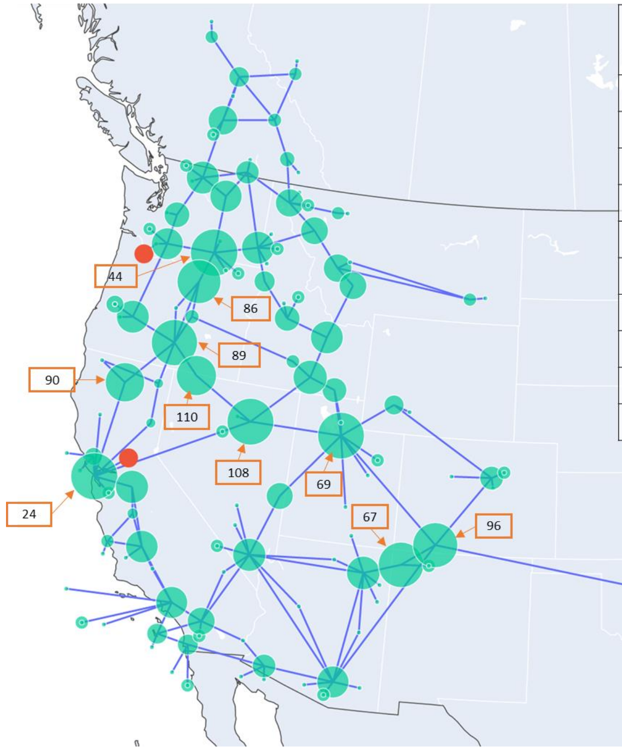


Establish Common Data Transport Analysis Framework

- Standards-based (CIM) grid data transport information model for grid data, flows, and planning models
- Building open repository for equipment data, operation data flows, reference network models
- Case studies (e.g. methods to characterize centralized vs distributed distribution operations

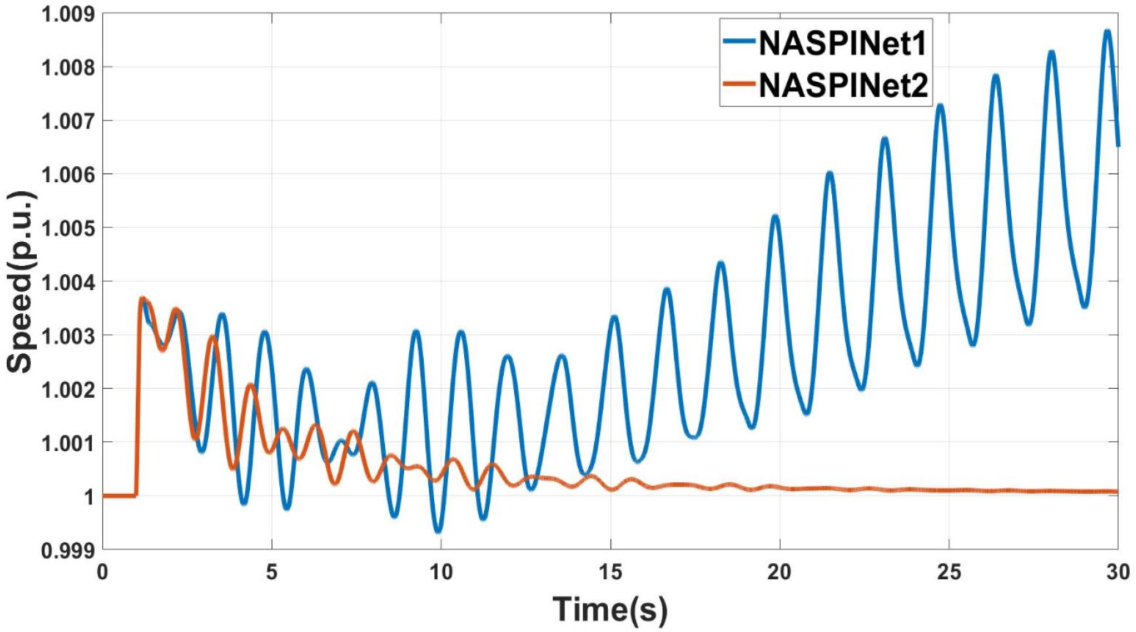


Distribution Grid Data Density



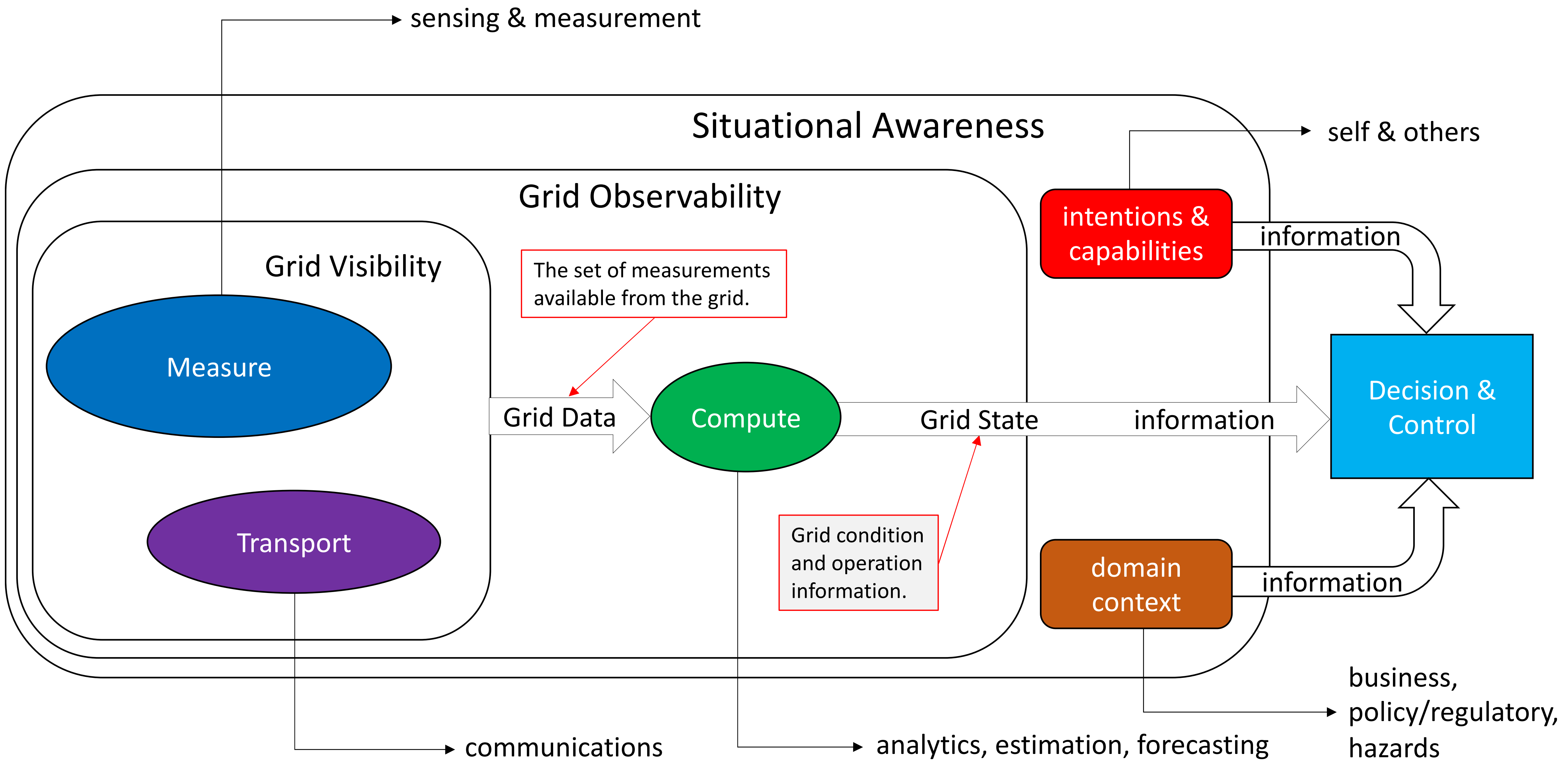
Rank	Node Importance
1	C_24
2	C_44
3	C_108
4	C_69
5	C_89
6	C_67
7	C_96
8	C_86
9	C_110
10	C_90

Grid Data Valuation



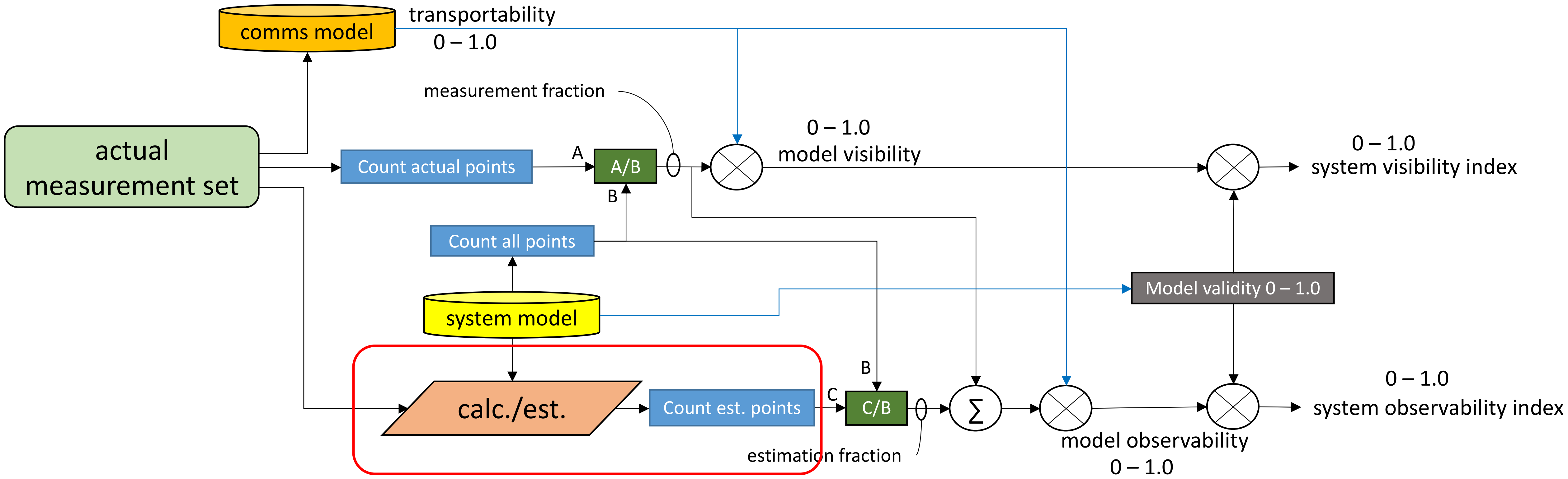
Quantifying Data Transport Requirements

Grid Observability Tool
Visibility, Observability, and Situational Awareness

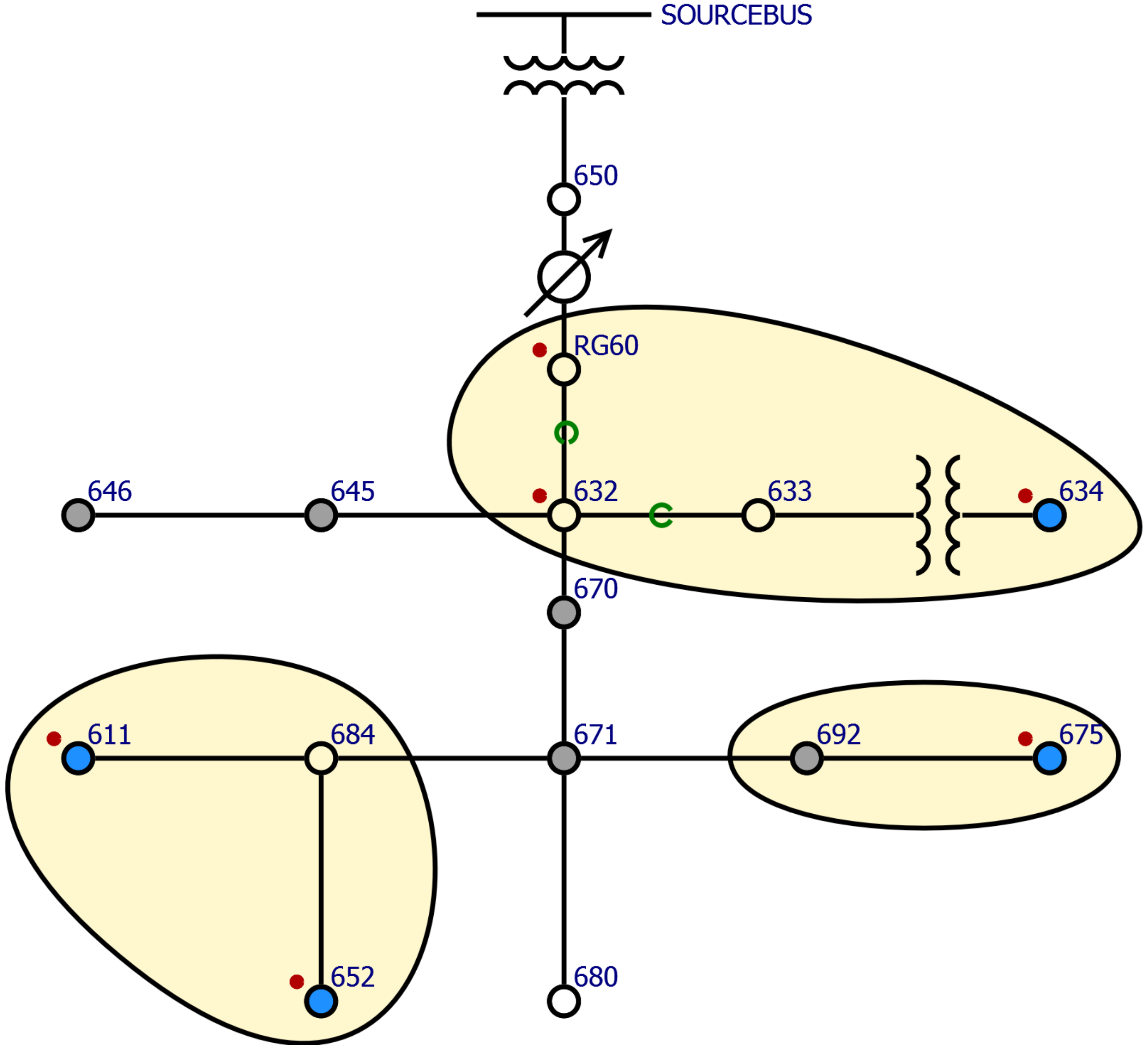


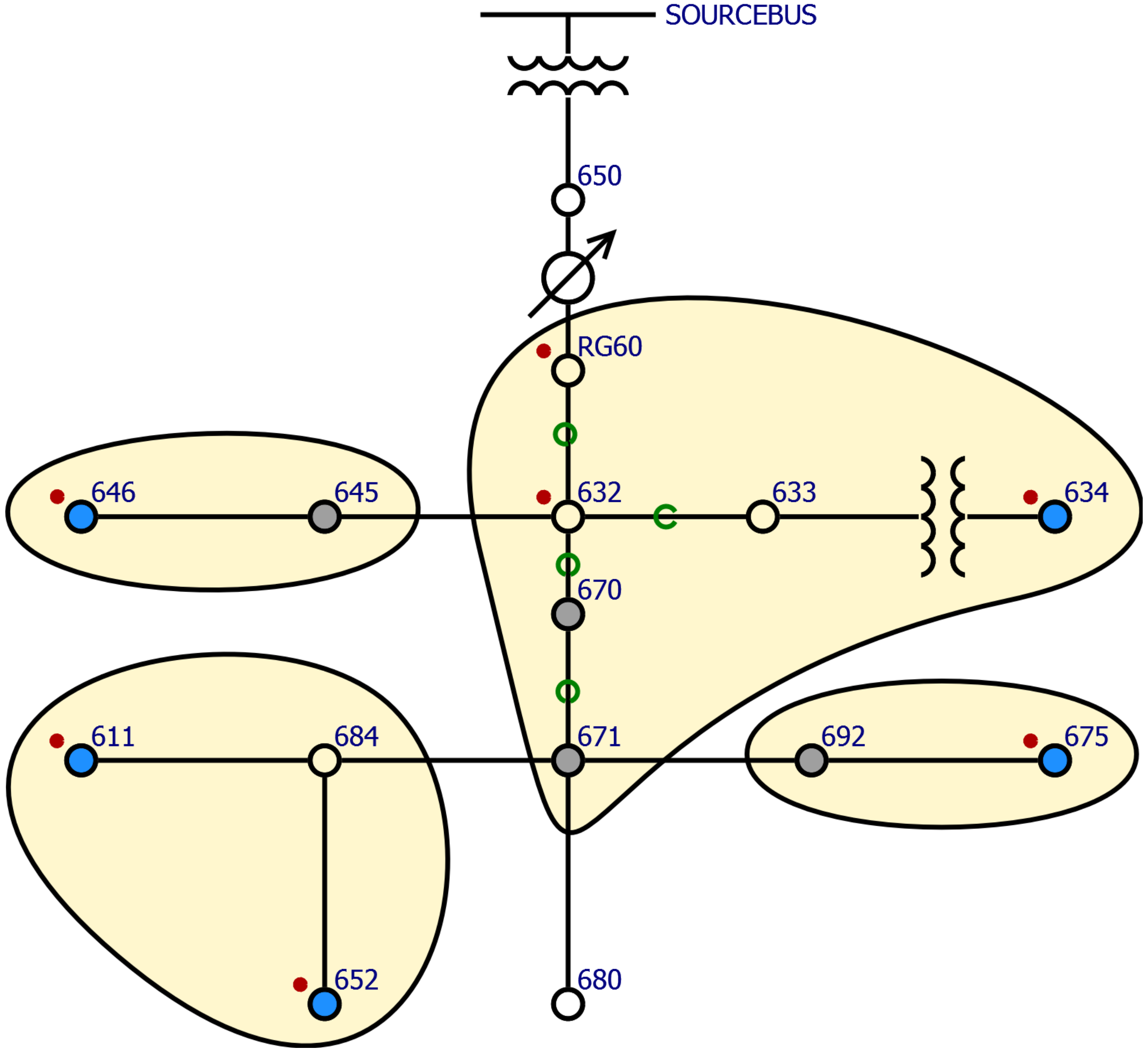
Quantifying Grid Visibility and Observability

- **Visibility Index:**
  - % of all possible measurement points that are measured and have communications
- **Observability Index:**
  - % of unmeasured points that can be estimated + % visibility



Increasing Observability with Optimized Sensor Placement





Visibility: 0.2374 Observability: 0.3957

Visibility: 0.3166 Observability: 0.7123

Thank you

Jim Ogle, PNNL
James.ogle@pnnl.gov

Power Sector Transmission & Distribution Data and Information

WEBINAR SERIES

Data Privacy for the Grid:

Toward a Data Privacy Standard for Inverter-Based and Distributed Energy Resources

Anna Scaglione, Professor, Cornell Tech, Cornell University

Robert Currie, Kevala, Inc.,
Sean Peisert, Lawrence Berkeley National Laboratory,
Aram Shumavon, Kevala, Inc., and
Nikhil Ravi, Cornell Tech.

U.S. DEPARTMENT OF ENERGY

Work supported by DoE Contract DEAC02-05CH11231.

U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY

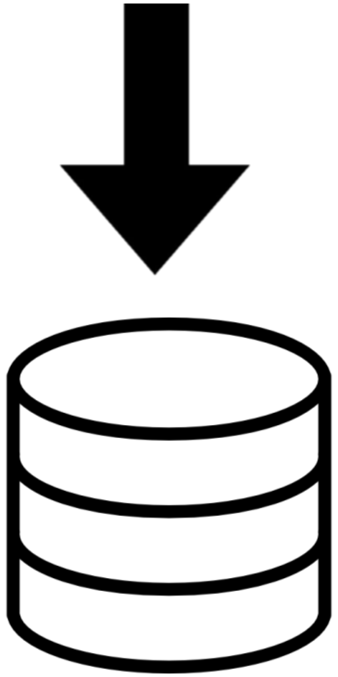
Los Alamos NATIONAL LABORATORY

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

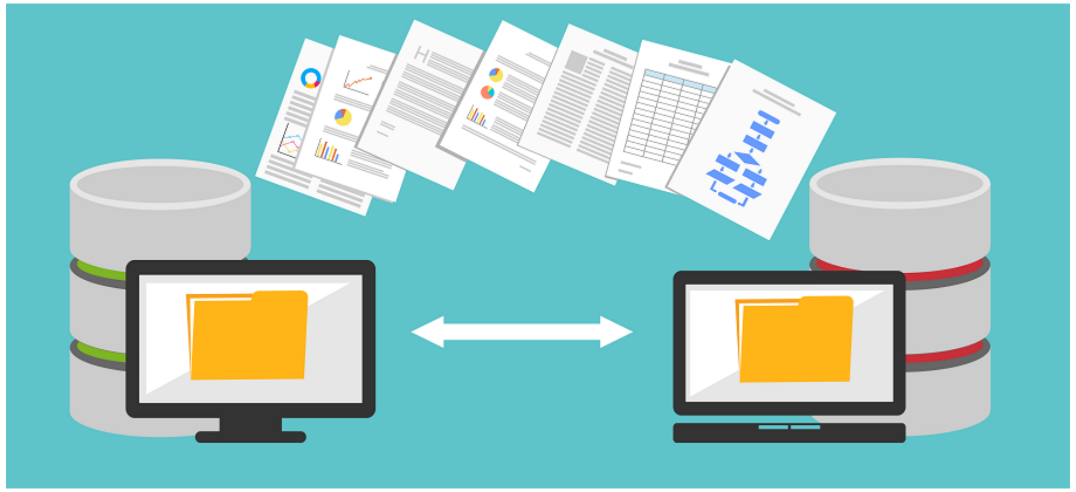
Changing Grid Dynamics

- Rapid growth in Distributed Energy Resources (DERs) and electrification of transportation and residential heating are transforming grid dynamics.
- **Large amounts of data** becoming available on customer demand, behavior, and technology adoption.



Integrating these data is vital for grid planning and operation…

Data sharing due to Increasing Governmental Oversight



- Regulators and governments are demanding more data sharing.
- Some recent developments include:
  - Integrated Energy Data Resource program in New York
  - Mandated use of the Common Information Model for sharing grid data in the United Kingdom
- Sharing data with regulators may be seen as "safe" from a national security perspective but can exacerbate privacy issues and regulatory scrutiny.

Why Is Confidentiality a Concern?

- Distribution-level data often include sensitive Personally Identifiable Information (PII) and reveal system configuration and assets.
  - Uniquely identify individuals and their activities within buildings.
  - Expose vulnerabilities that could be exploited by attackers to manipulate grid operations.
  - Data may be considered sensitive for business reasons.
  - Cyber-attacks
- Recent privacy laws like the General Data Protection Regulation (GDPR) in Europe and the California Consumer Privacy Act (CCPA) in the United States emphasize the need to protect data.

Presentation objective

- Exploring different approaches to addressing data security, with a primary focus on Differential Privacy (DP) as a statistical framework to protect data while allowing data sharing.

Current Practices In Grid Data Sharing

Balancing Confidentiality and Accessibility

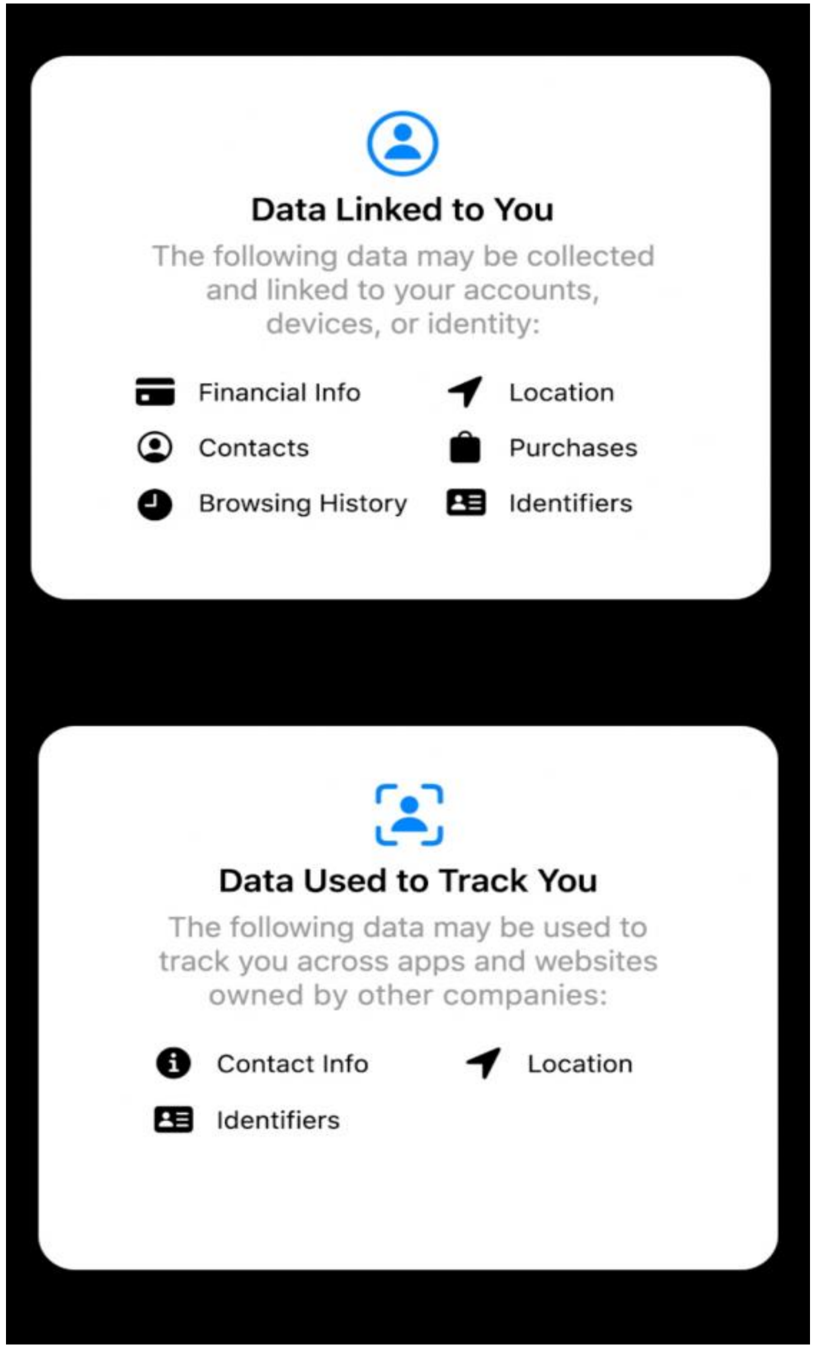
- **Accessibility of Grid Data:** Much of the electric grid data is already public, e.g. observing electrical lines, satellite imagery (e.g., Google Earth), or ground-level imagery (e.g., Google Street View).
- **Challenges in Restricting Access:** Attempting to restrict access to grid data may not effectively enhance security.
- **The Cat Is Out of the Bag:** Once public, data are difficult to reclassify as private
- NERC CIP does not yet provide a standardized way for utilities to securely share data

Privacy Risks and Limitations of Current Data Sharing Approaches

- **Traditional Anonymization**: Common anonymization approaches, like k-anonymity mask fields and aggregate data but are susceptible to linkage attacks from external sources.
- The "**15/15 Rule**" is an emerging *best practice* for sharing grid data:
  - aggregation of customer data is considered anonymous if it includes at least 15 customers with no single customer's data exceeding 15% of the total values.
- **The 15/15 Rule has no analytical privacy guarantee.**
  - aggregate queries and algebraic manipulations reveal individual values.
- **Sharing synthetic Data?** Sharing synthetic data that mimic real data trends does not guarantee privacy as it reproduces exactly ensemble averages

Potential Solutions

Transparency in Data Collection and Use



- Regulations (e.g. GDPR and CCPA) emphasize transparency when sharing occurs.
- **Transparency** → disclosing what data are shared, with whom, the purpose of sharing, data storage, and eventual deletion.
- Enhancing awareness among end consumers of data sharing purposes
  - Google and Apple "privacy nutrition labels" inform on data collection and purposes.
- Transparency also benefits the research community in vetting methods.

The electric utility industry could use a similar tailored approach for energy systems data.

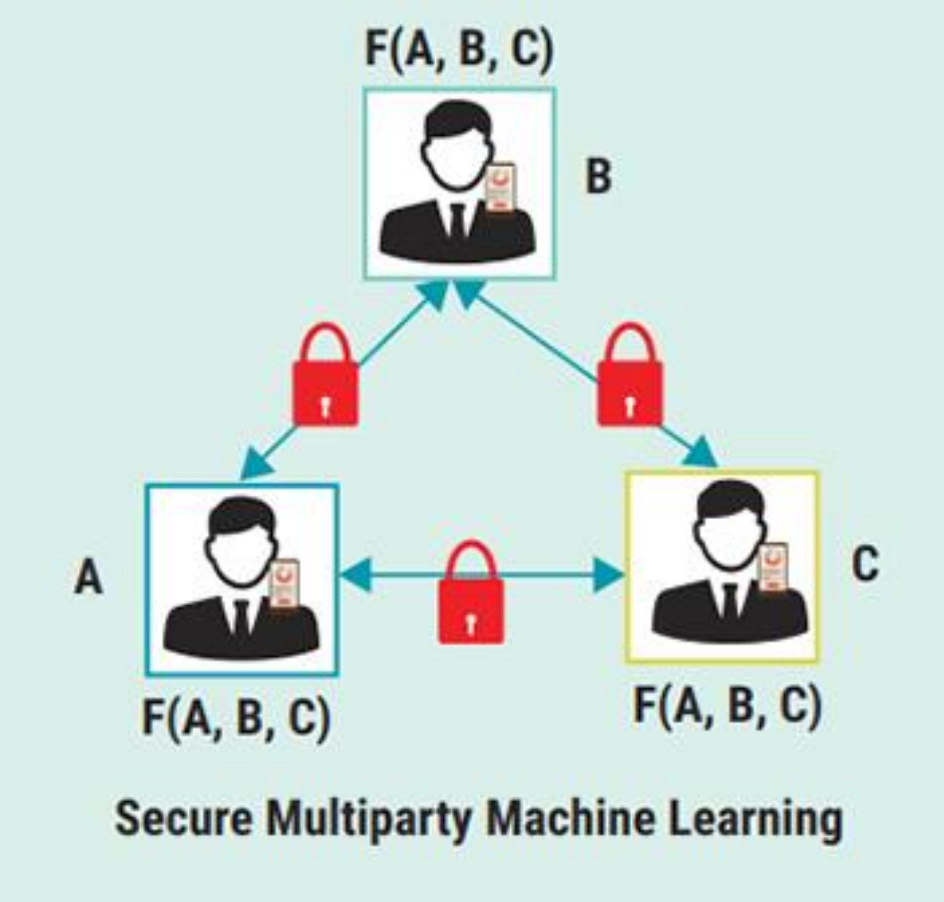
Sharing the “right” data

- **Efficient Resource Allocation:** Focusing on protecting non-sensitive data may divert resources from more critical security measures.
  - The notion that “more data sharing is better” isn't always advisable.
  - Shared data should be well-curated, understanding the associated privacy threat.

Trusted Execution Environments (TEEs)

- Secure multiparty computation via Trusted Execution Environments (TEEs)
  - ARM's Confidential Compute Architecture, Intel's Secure Guard Extensions, and AMD's Secure Encrypted Virtualization.
- The Linux Foundation's Confidential Computing Consortium, major cloud providers (AWS, Google Cloud, Microsoft Azure) support TEEs to enhance security
- TEE is suitable for modern data-driven computing like machine learning and graph analysis.
- These methods unfortunately still rely on trusting data recipients

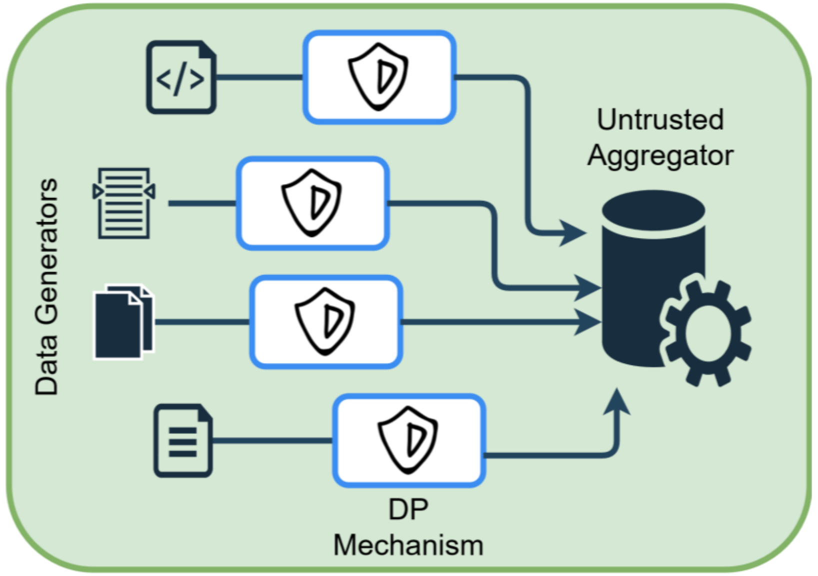
Enhancing Data Security with Multiparty Computation



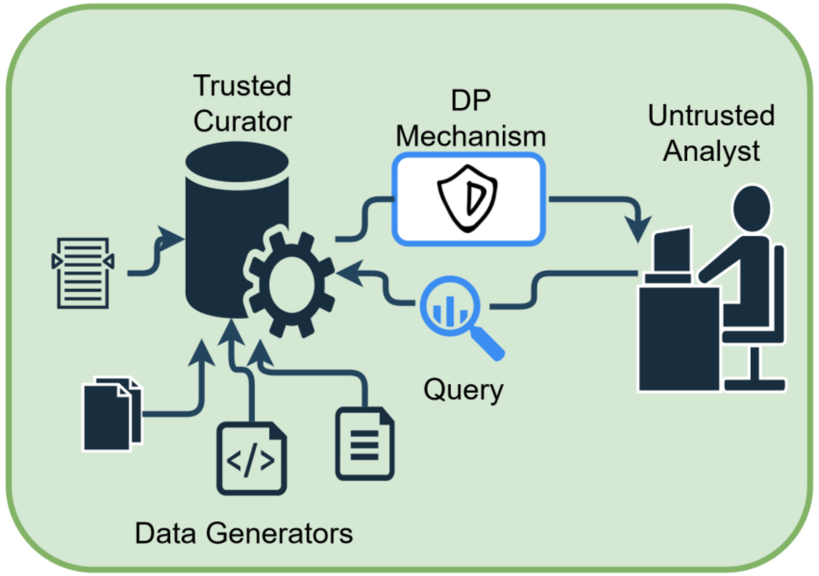
- Secure multiparty computation and **homomorphic encryption** enable computation over encrypted data, offering protection during data usage.
  - are applied in data analysis processes, including in finance and public sectors.
- While effective, these methods are generally slower than clear-text computation and may require custom code modification
- Striking a balance between technical controls and anonymization approaches while maintaining data utility can be complex.

Making Data Open with Statistical Safeguards

- **Successful Example of Differential Privacy methods:** The U.S. 2020 census successfully employed DP as a statistical safeguard. Tech giants like Apple, Google, and Microsoft use it to collect sensitive information while safeguarding privacy.
- Data sharing with **statistical protection raises tradeoffs between privacy and data utility**.
- We need to:
  - Balance the need for data sharing with the risk of exposing sensitive information.
  - Evaluate control mechanisms from multiple perspectives, including Legal, Technical, and Statistical Considerations

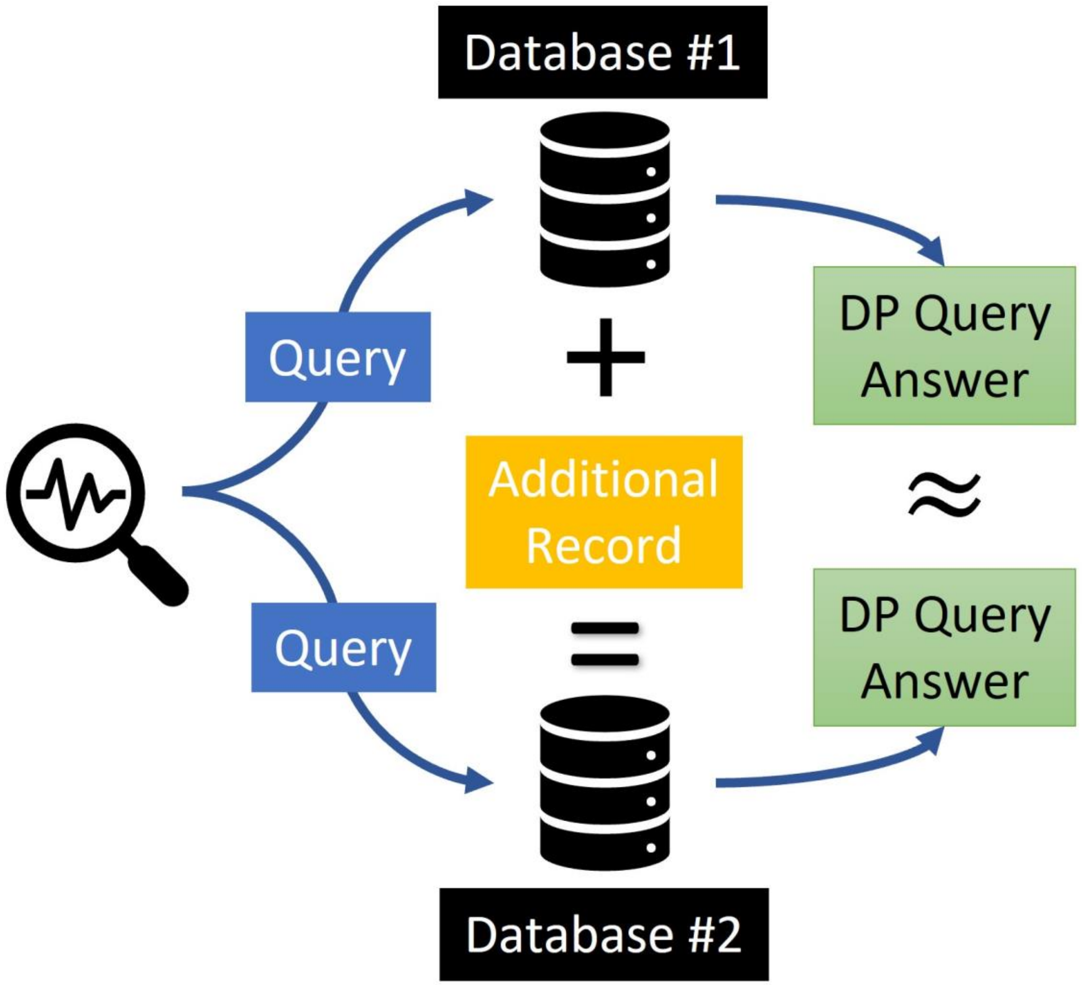


Local Privacy



Global Privacy

Differential Privacy: Protecting Privacy in Data Analysis



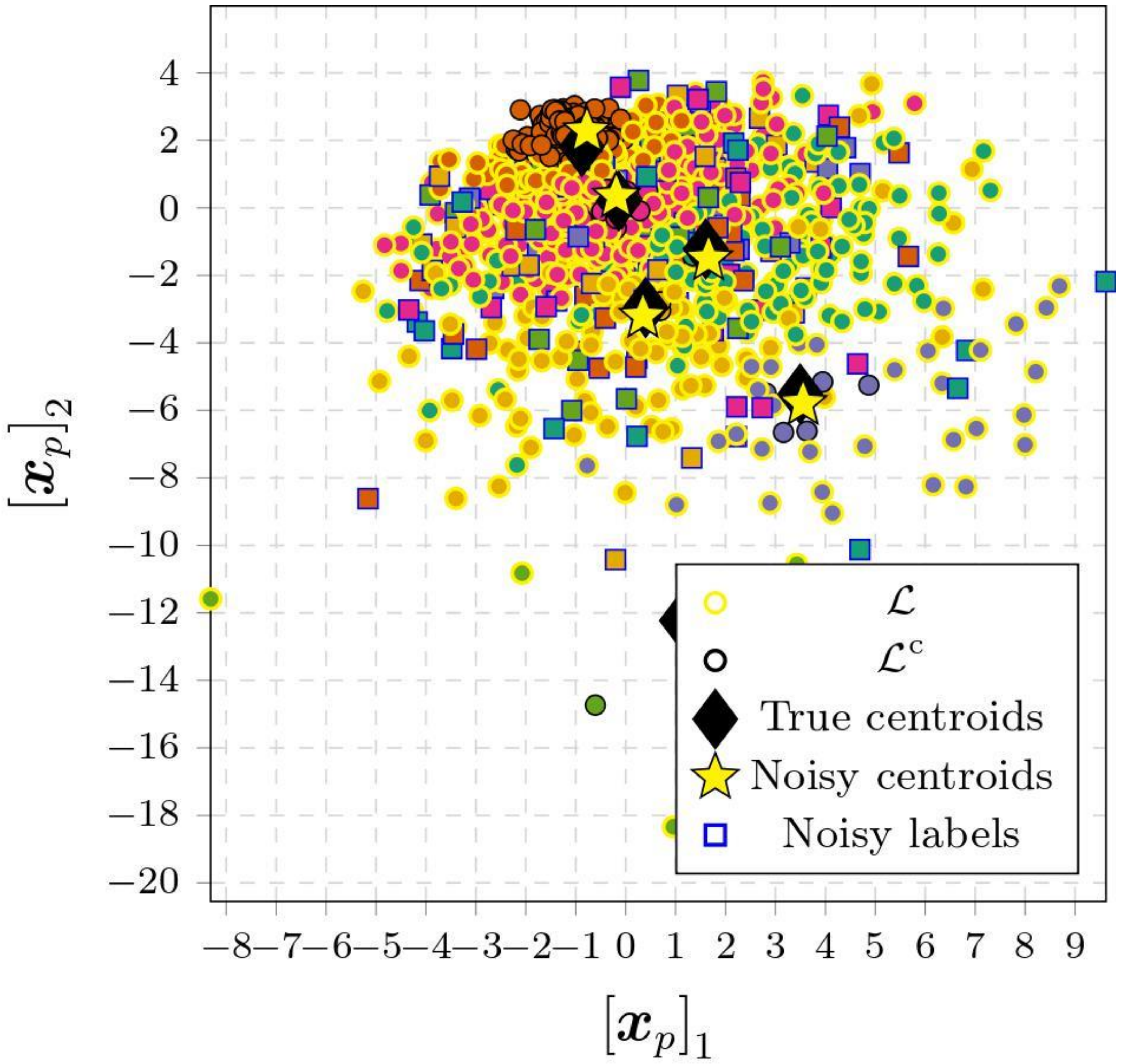
- **DP releases randomized answers to queries →** hard to guess sensitive data.
  - Common DP mechanisms include Laplacian and Gaussian mechanisms, which introduce noise to query results.
- **Privacy guarantees must apply to the ensemble of queries** in a session, which necessitates budget allocation to each query.
- DP is statistically sound and preserves privacy while enabling useful information sharing.

Caveats

- Achieving greater utility of noisy query answers may involve tailoring mechanisms to specific queries.
- Standards should define what and how data or queries can be shared with DP guarantees, considering data utility and privacy constraints.

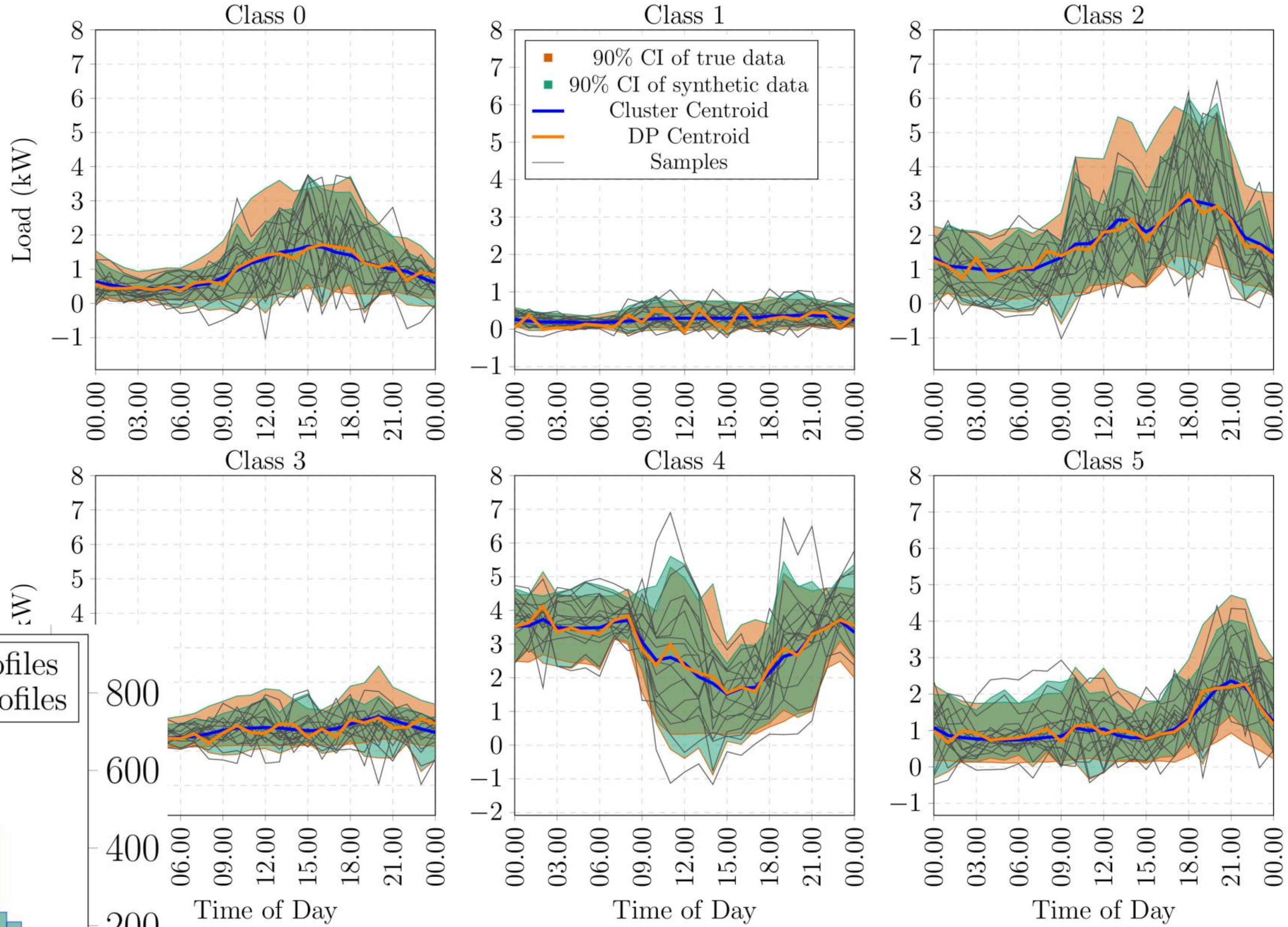
Use-case 1: DP K-Means Clustering

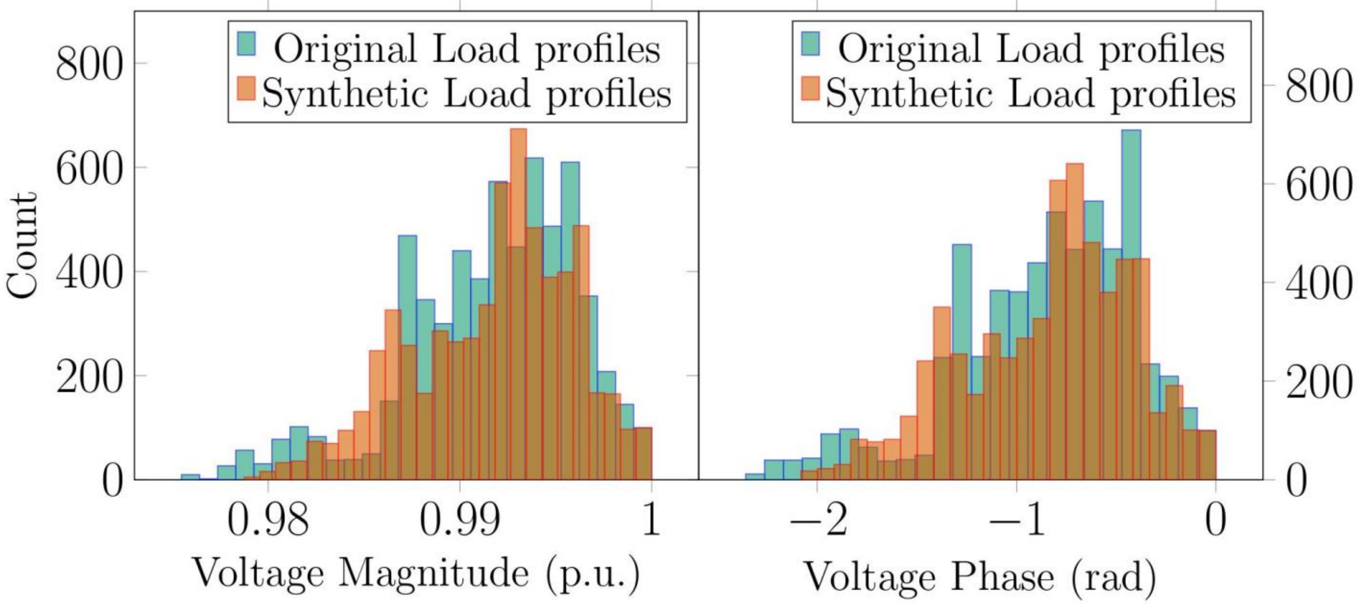
- DP can be strategically applied to clustering, as seen in the clustering results of daily load shapes in a real dataset.



Use-case 2: Synthesizing Load Data

- DP can be used to generate differentially private synthetic load data, ensuring privacy while maintaining data utility.
- Synthetic load shapes were tested on distribution system test cases, and results show a good match with real data.





Take away message

- DP and TEEs offer data security through different means.
  - **DP** enables data sharing without exposing raw data → suitable for untrusted user access.
  - **TEEs** protect against untrusted computing providers through secure multiparty computation.
- Each approach can be deployed separately based on the risk model
- Both DP and TEEs are in production use but continue to evolve, becoming more usable and performant.
- In DP incorporating **domain expertise is vital** for defining analytical results that balance privacy and data query accuracy.
- Working with standards organizations, regulators, end users, and privacy experts is essential for advancing privacy-preserving methods.

Thank you

Anna Scaglione, Cornell Tech, Cornell University
as337@cornell.edu

Power Sector Transmission & Distribution Data and Information

WEBINAR SERIES

The Distribution PMU in Practice

Sherif Fahmy

Technical Sales Manager

Zaphiro Technologies

U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY

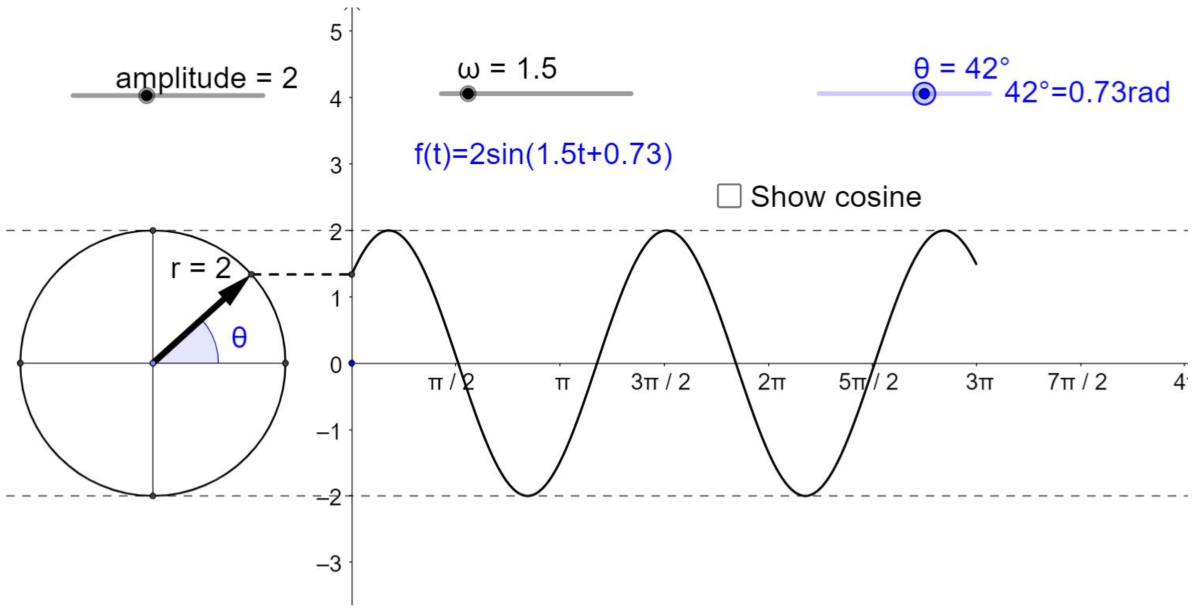
Los Alamos NATIONAL LABORATORY

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

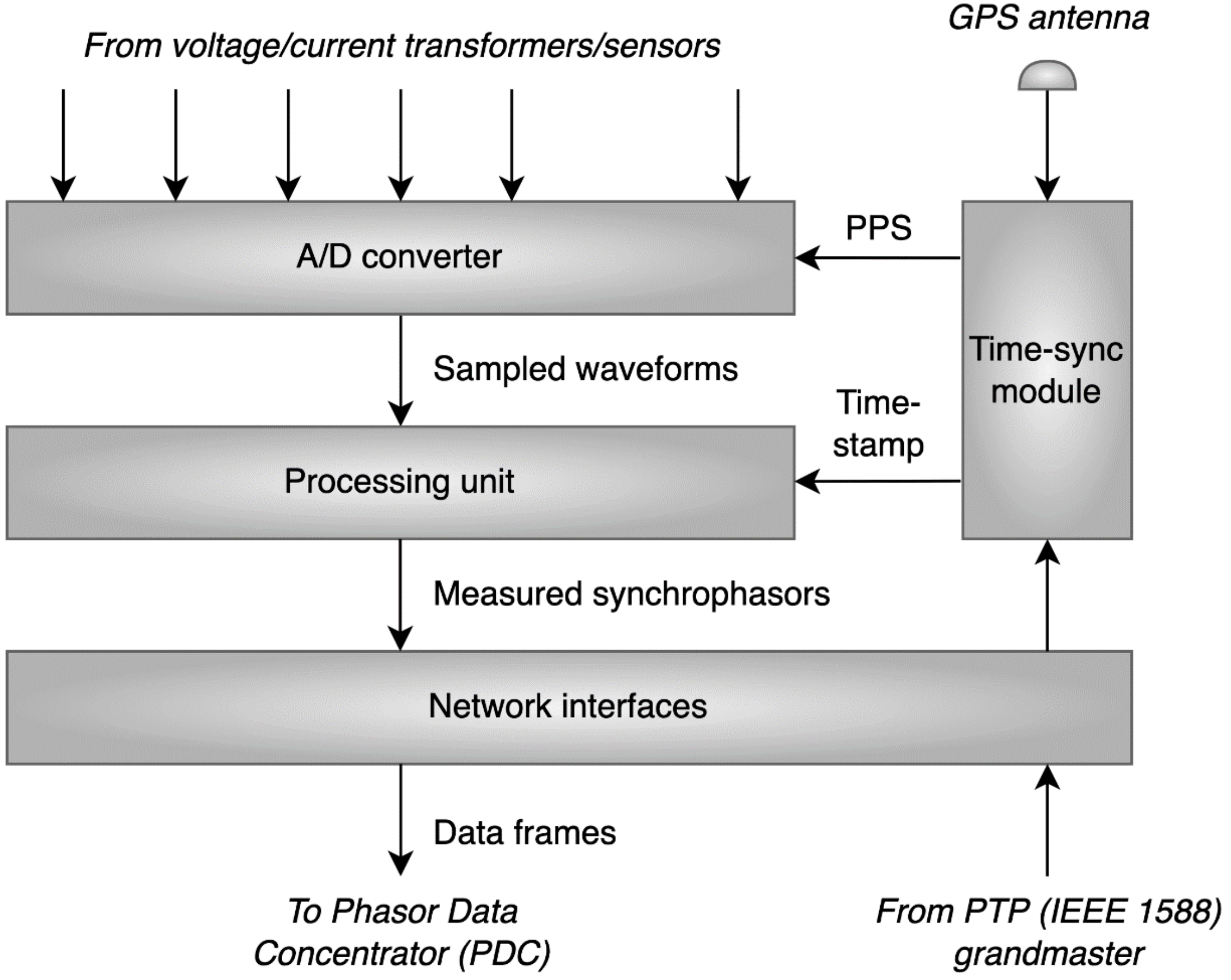
The basics

- **Phasor**: vector representation (amplitude and phase-angle) of an AC waveform

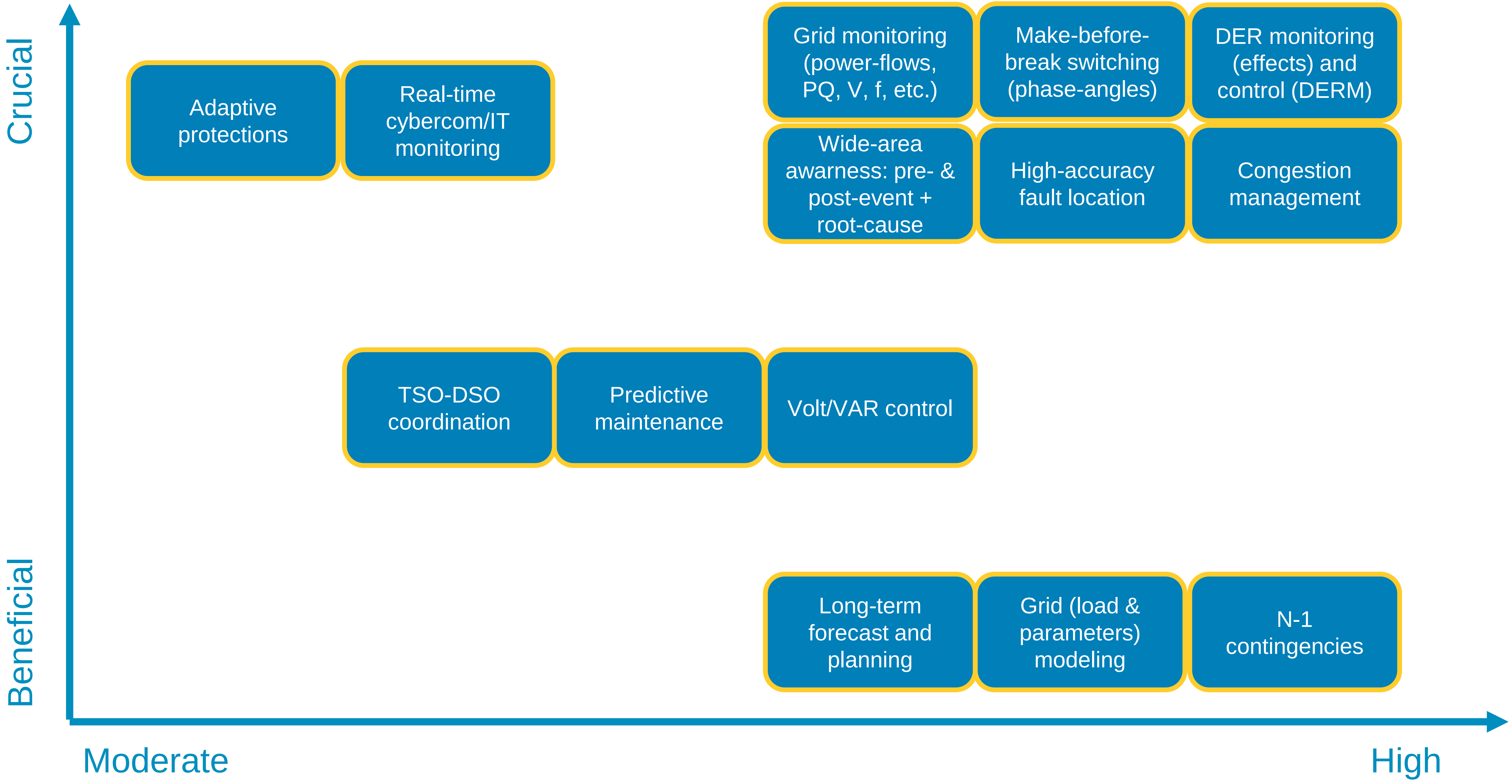


- **Synchrophasor**: phasor measurement synchronized to a common time reference (e.g., GPS) and reported at a high rate (50/60 Hz)
- **D-PMUs**: Distribution-PMU are adapted to distribution system characteristics such as small phase-angle differences

Phasor Measurement Unit (PMU)



Use-cases: Priority vs. Necessity of Synchronized Measurements



About Zaphiro

- **Smart grid** deep-tech company headquartered in Lausanne (CH), with IT subsidiary based in Milan
- **Synchrophasor**-based solutions to increase **distribution grids** observability, resiliency and efficiency
- **14** satisfied customers across the globe with repeating orders and over **180** SynchroSense devices installed in the field
- **Recently** closed a **9 million Series-A investment round** led by ABB Ventures and CDP Ventures

Customers selection

CLP 中電 China Light and Power | ROMANDE ENERGIE | Netze BW | unareti

KAHRAMAA كهرماء | SIL SERVICES INDUSTRIELS LAUSANNE | ComEd | Terna

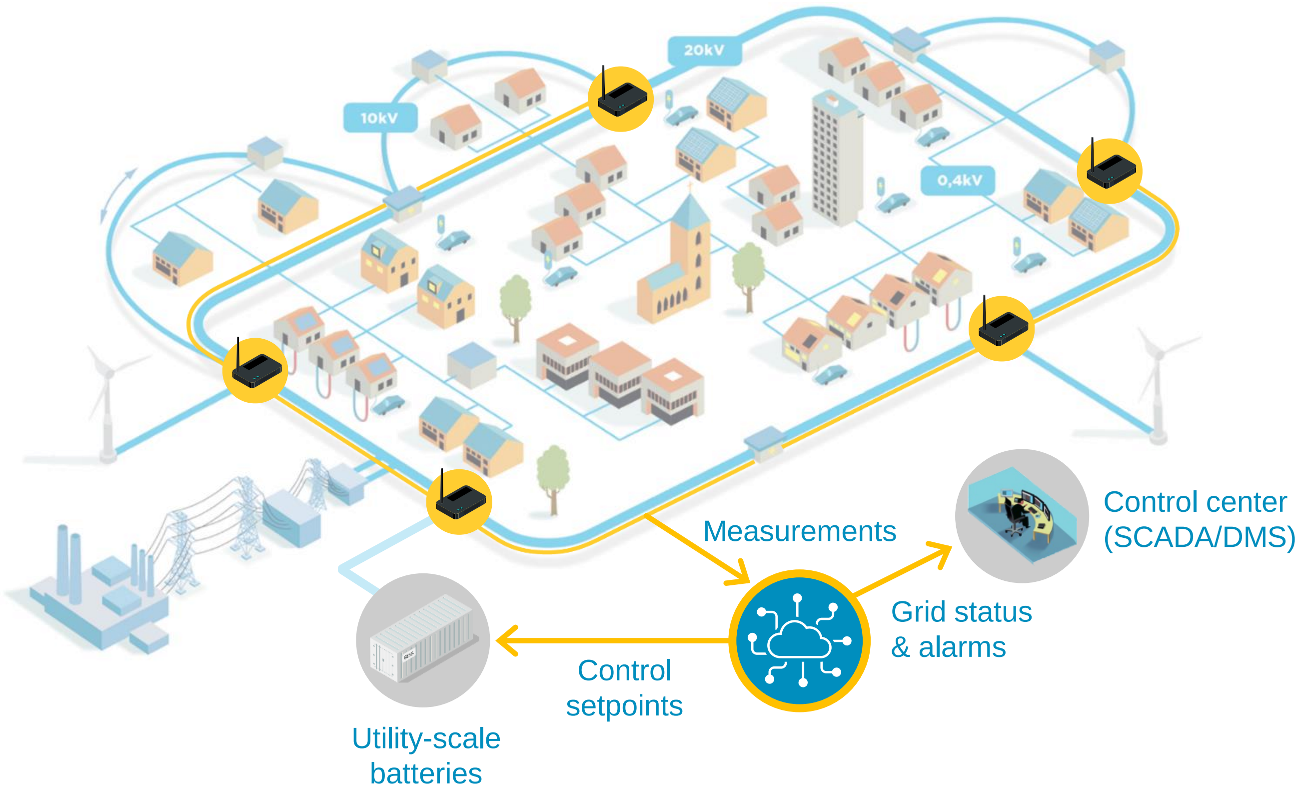
Partners selection

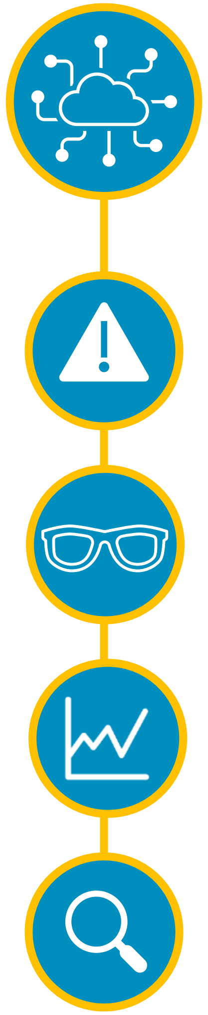
LEM Life Energy Motion | ERICSSON | ABB | NI

SynchroGuard

Zaphiro’s grid monitoring & automation solution based on D-PMU technology

SynchroSense: Patented D-PMU device
- Time-synchronized + high-speed measurements
- Ideal for substation retrofitting





Modular and scalable software platform:
- Full interoperability with 3rd party devices
- Empowered by patented algorithms
- Leverages grid model

Accurate fault location

→ Automated fault location to reduce the duration or even prevent blackouts

Real-time grid monitoring

→ Full grid visibility with only a few devices placed at strategic grid nodes

Online/Offline grid analytics

→ Advanced grid analytics for optimal grid operation, planning and predictive maintenance

Predictive maintenance and root cause analysis

→ Enabled by the detection of early asset failures such as incipient faults and congestions and the availability of the full grid state

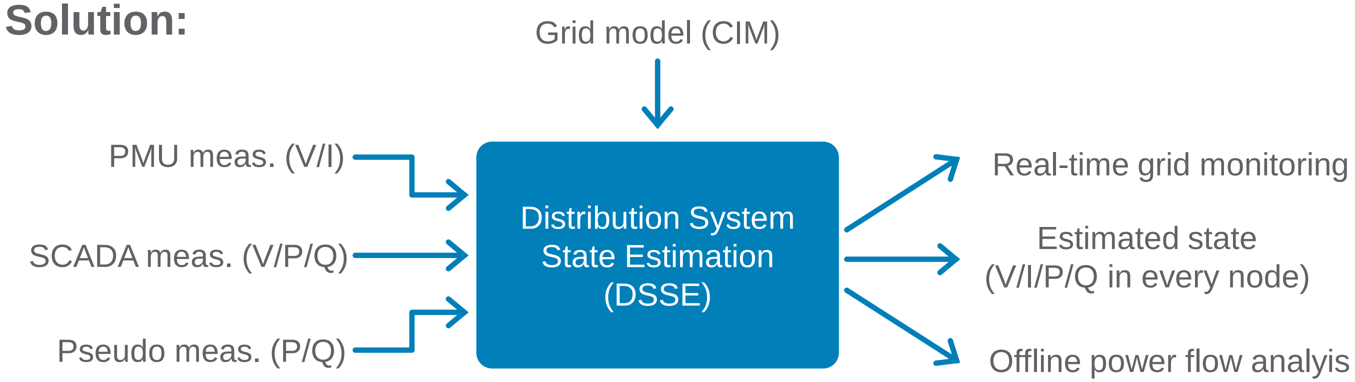
SynchroGuard

Reference deployment – State Estimation: Concept & Project Overview

Problems/Challenges:

- 46% renewable power share in Germany (2020)
- Lack of knowledge of voltage profiles, current/power flows and grid equipment stress in presence of high DER (Distributed Energy Resources) penetration

Solution:

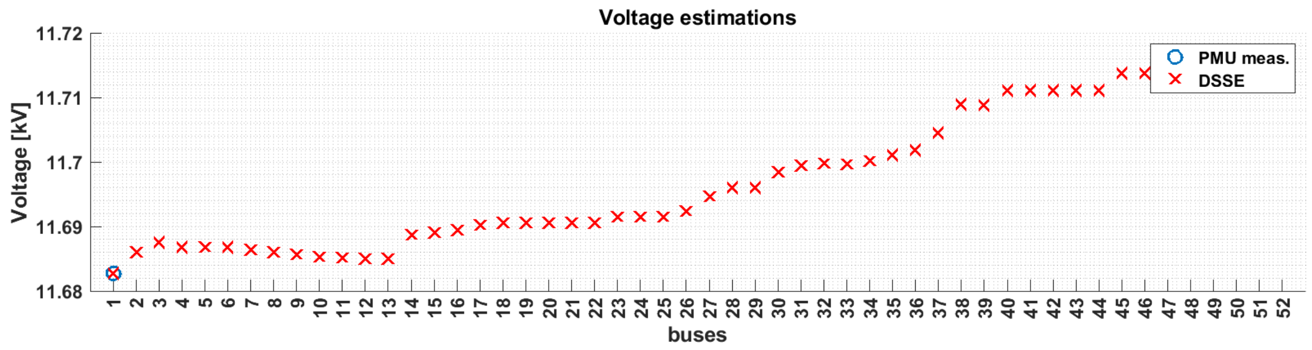


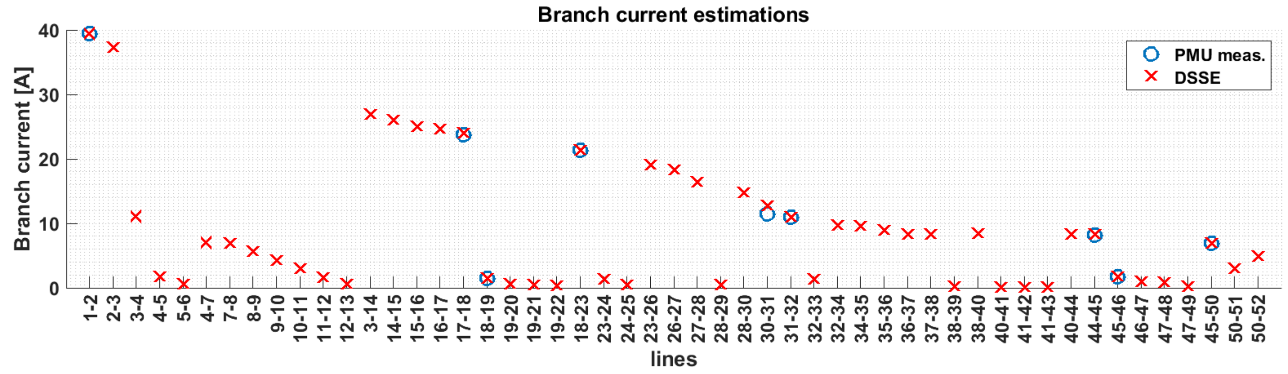
Benefits:

- Full grid visibility in real-time with only 10% measurement coverage
- 70% lower integration effort compared to other monitoring solutions

SynchroGuard

Reference deployment – State Estimation: Performance



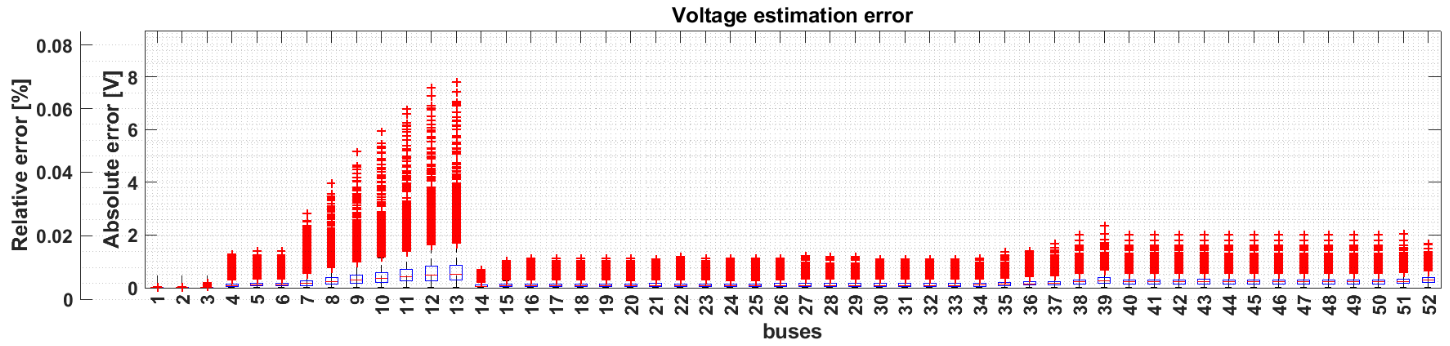


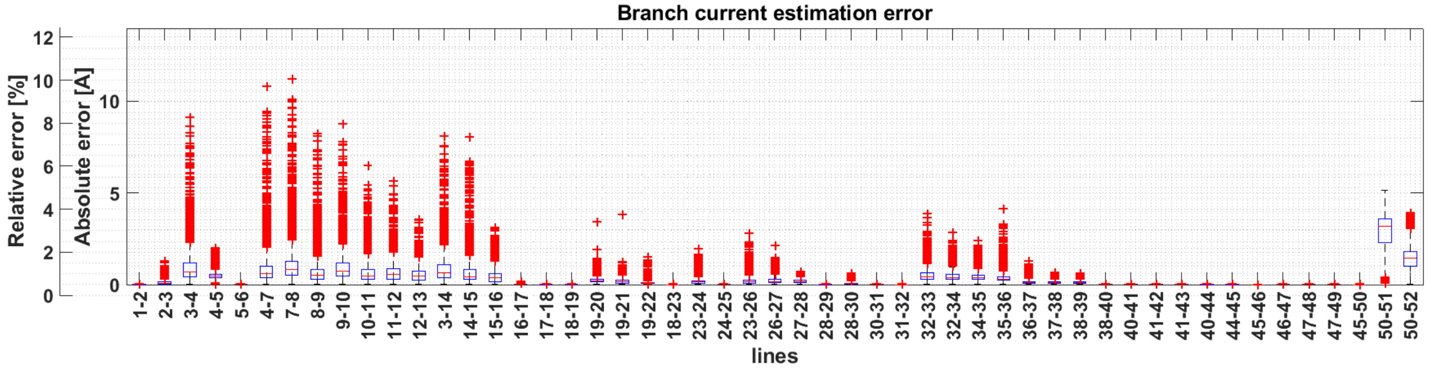
→ Full grid visibility (estimation of voltages, currents, active/reactive power flows at all liones & transformers) using few D-PMU measurements.

SynchroGuard

Netze BW

Reference deployment – State Estimation: Accuracy assessment

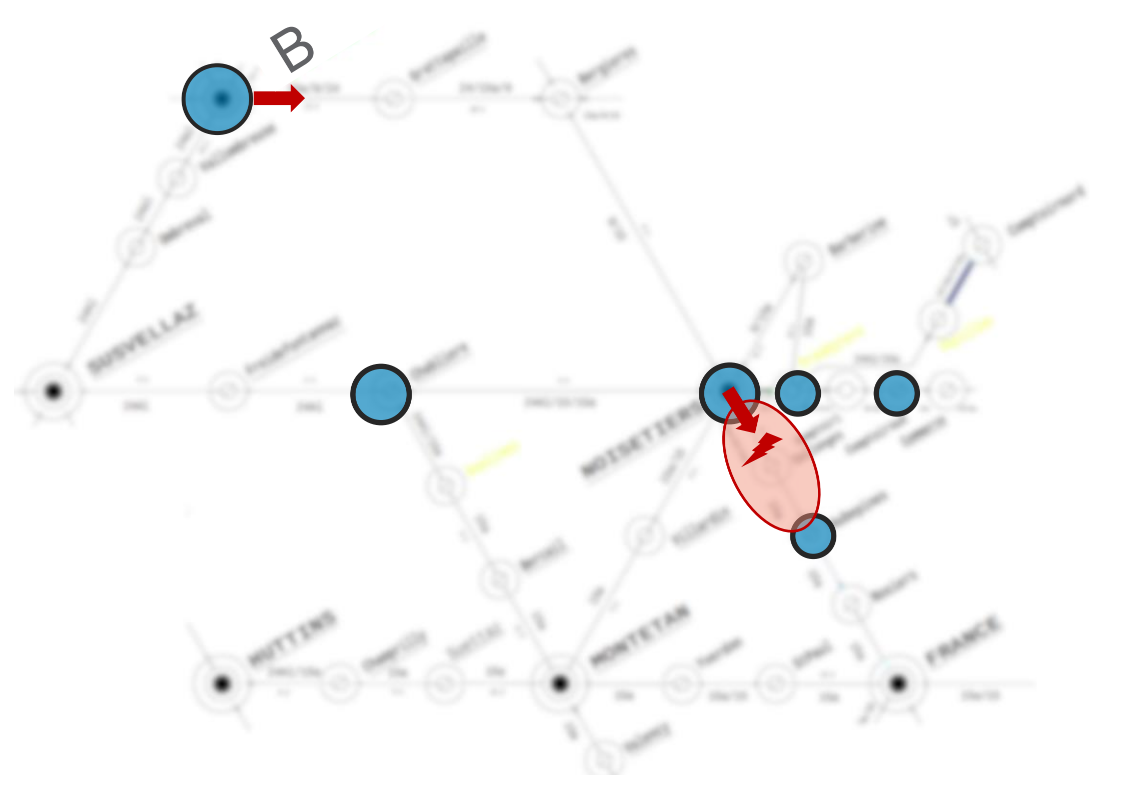


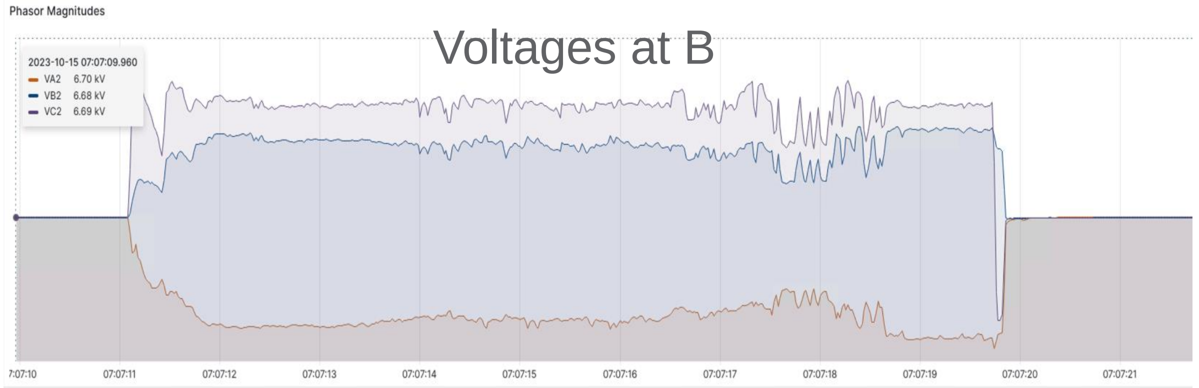


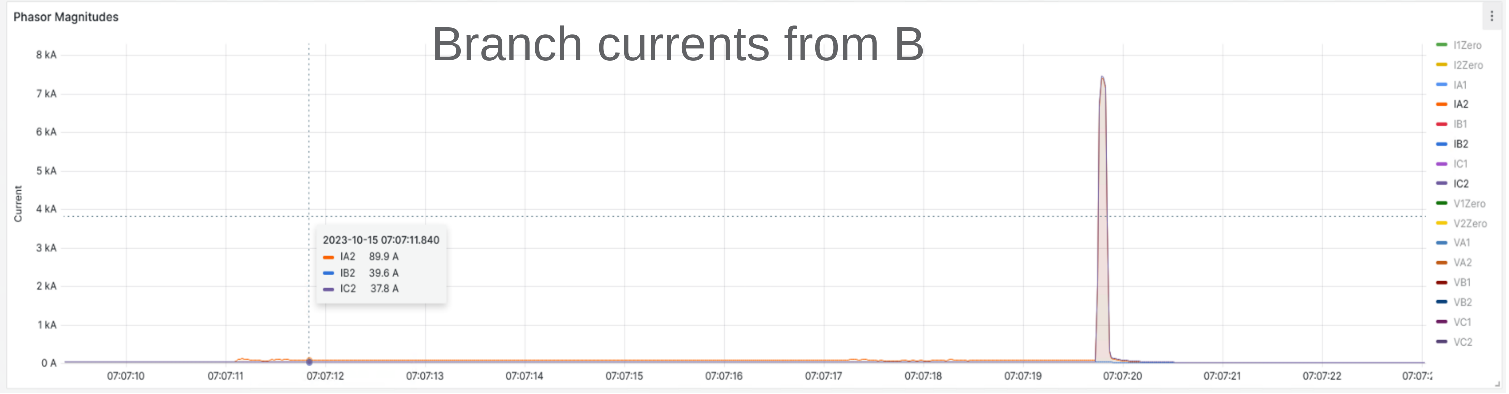
- → Voltage estimation errors <0.5% for grid stability monitoring
- → Accurate current/power flow (error <1.5 A for 95% of the cases) for line/transfomer congestion monitoring, Volt/VAR control, etc.

SynchroGuard

Reference deployment – Fault Location







D-PMU

Measured direction of fault current

Identified fauled area

Benefits of D-PMU based faulted localization

- Low-current L1-g fault identified in real-time.
- Faulted area provided in real-time.
- Subsequent high-current L1-L3 fault identified and localized with **12m*** accuracy
- Fault data (waveforms+phasors) registered for post-event analysis.

*verified via on-field measurments

SynchroGuard

SERVICES INDUSTRIELS LAUSANNE

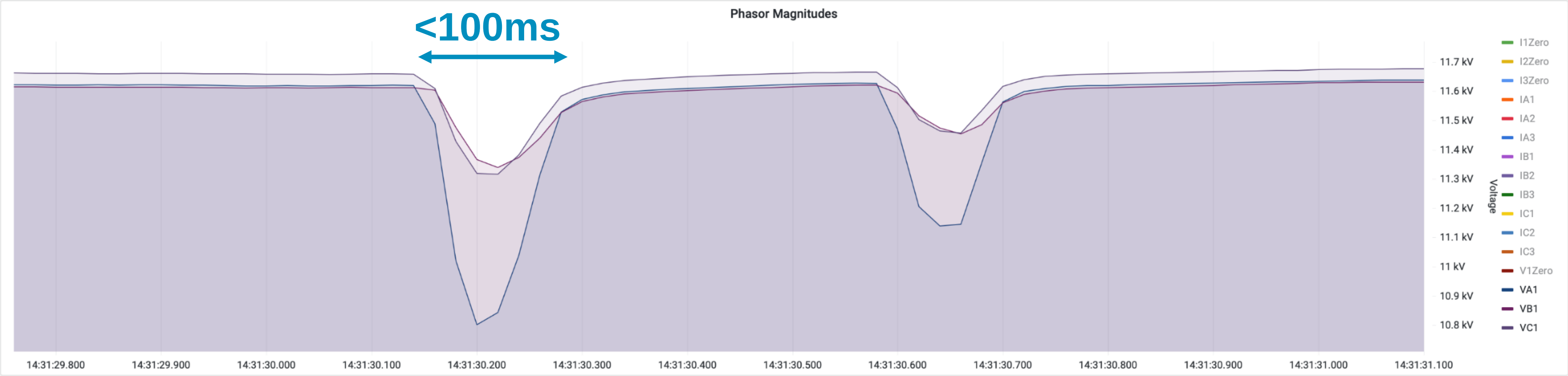
Reference deployment – Voltage Dips Detection

Monitoring / Event analysis

Type: All · Event: Voltage dip + Transformer congestion · Severity: All · Location: 14-CO + Franklin · Last 30 days

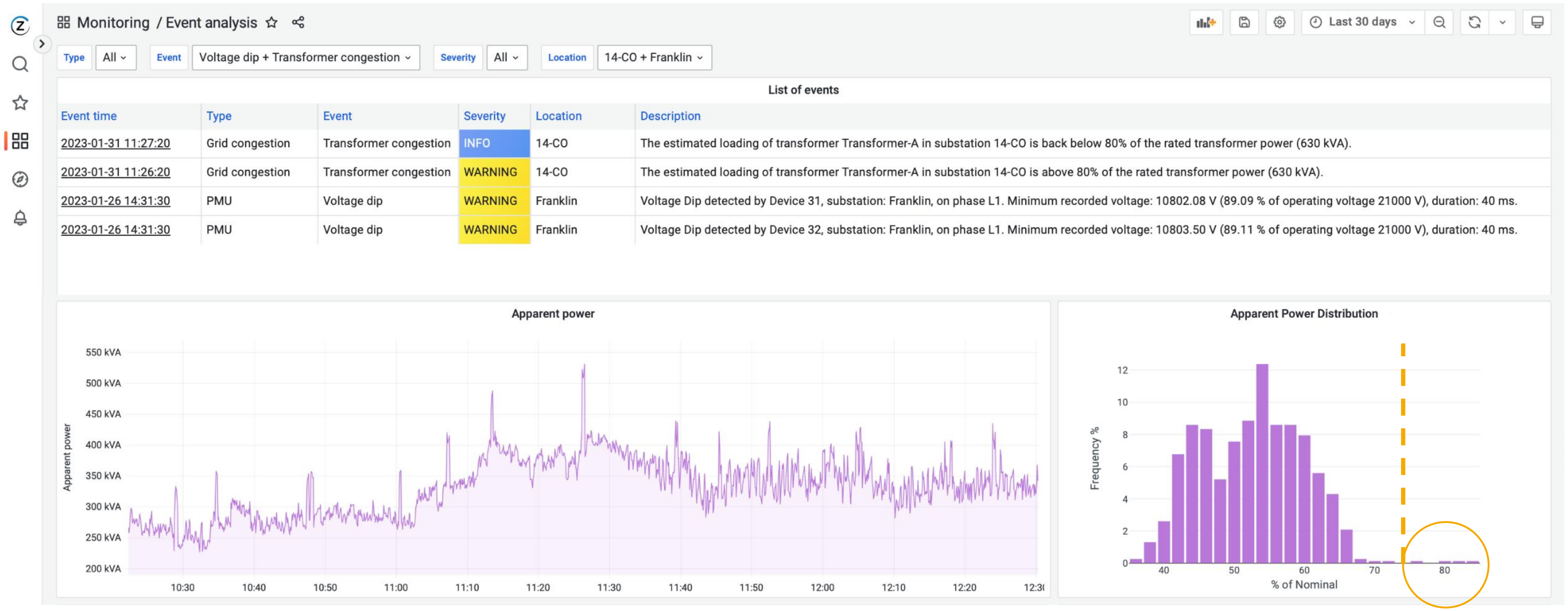
List of events

Event time	Type	Event	Severity	Location	Description
2023-01-31 11:27:20	Grid congestion	Transformer congestion	INFO	14-CO	The estimated loading of transformer Transformer-A in substation 14-CO is back below 80% of the rated transformer power (630 kVA).
2023-01-31 11:26:20	Grid congestion	Transformer congestion	WARNING	14-CO	The estimated loading of transformer Transformer-A in substation 14-CO is above 80% of the rated transformer power (630 kVA).
2023-01-26 14:31:30	PMU	Voltage dip	WARNING	Franklin	Voltage Dip detected by Device 31, substation: Franklin, on phase L1. Minimum recorded voltage: 10802.08 V (89.09 % of operating voltage 21000 V), duration: 40 ms.
2023-01-26 14:31:30	PMU	Voltage dip	WARNING	Franklin	Voltage Dip detected by Device 32, substation: Franklin, on phase L1. Minimum recorded voltage: 10803.50 V (89.11 % of operating voltage 21000 V), duration: 40 ms.



SynchroGuard

Reference deployment – Transformer Congestion



Event time	Type	Event	Severity	Location	Description
2023-01-31 11:27:20	Grid congestion	Transformer congestion	INFO	14-CO	The estimated loading of transformer Transformer-A in substation 14-CO is back below 80% of the rated transformer power (630 kVA).
2023-01-31 11:26:20	Grid congestion	Transformer congestion	WARNING	14-CO	The estimated loading of transformer Transformer-A in substation 14-CO is above 80% of the rated transformer power (630 kVA).
2023-01-26 14:31:30	PMU	Voltage dip	WARNING	Franklin	Voltage Dip detected by Device 31, substation: Franklin, on phase L1. Minimum recorded voltage: 10802.08 V (89.09 % of operating voltage 21000 V), duration: 40 ms.
2023-01-26 14:31:30	PMU	Voltage dip	WARNING	Franklin	Voltage Dip detected by Device 32, substation: Franklin, on phase L1. Minimum recorded voltage: 10803.50 V (89.11 % of operating voltage 21000 V), duration: 40 ms.

Detected congestion on unmonitored transformer

Final thoughts

A proposal to integrate D-PMUs in the current IT/OT environment of a utility company

Typical data sources (IEDs)


Remote Terminal Units (RTUs)


Fault Passage Indicators (FPIs)

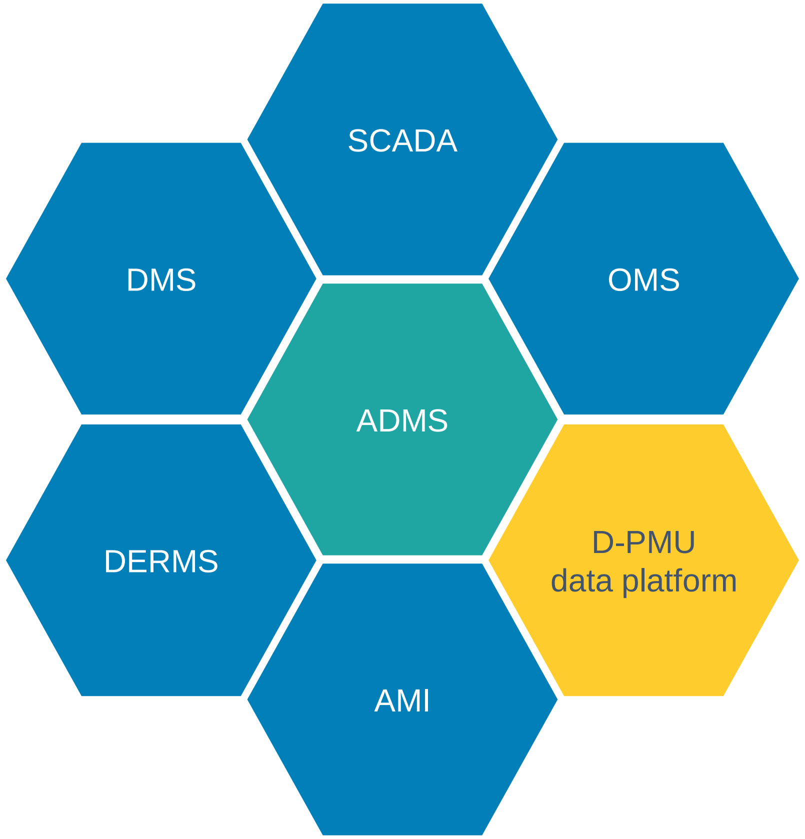

Protection relays


Energy (smart) meters


Power Quality (PQ) meters


Distribution Phasor Measurement Unit (D-PMU)

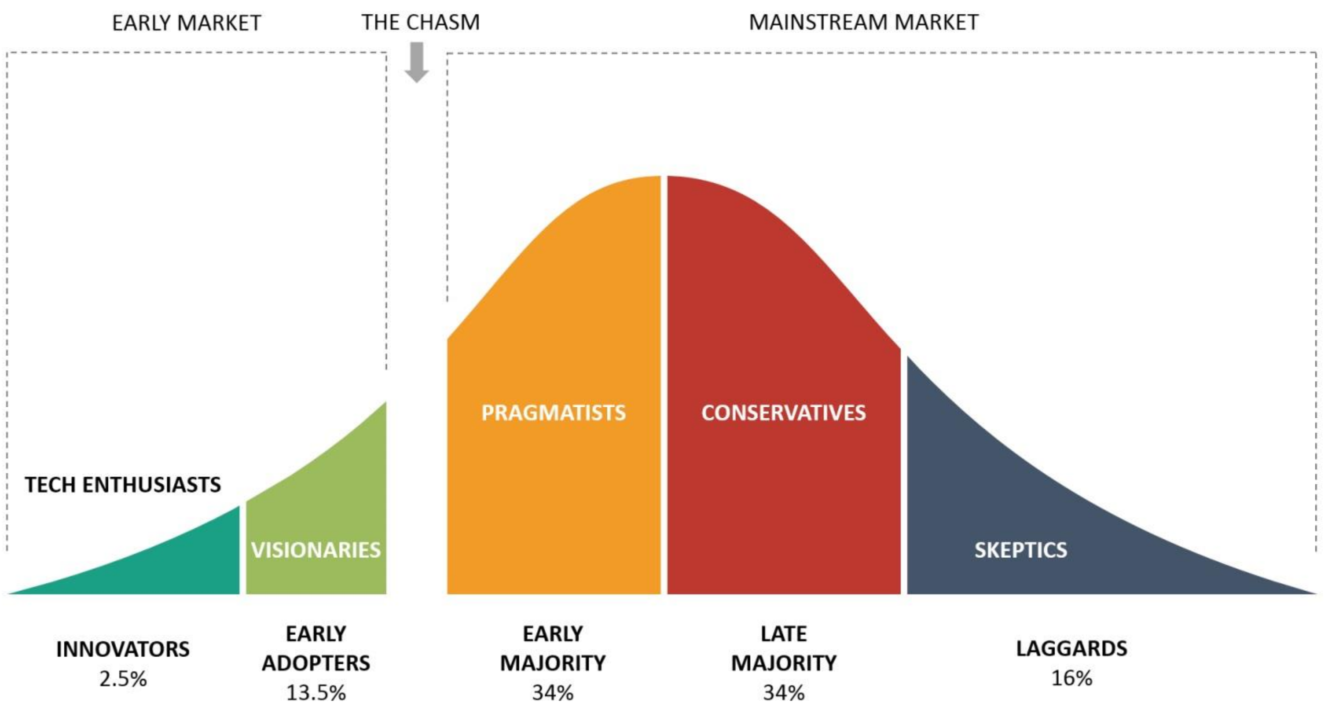
Control room integration



Final thoughts

What do we need for D-PMUs to "cross the chasm"

1. A new D-PMU Std. designed around the core D-PMU use cases and applications, able to clarify the requirements and ambiguity around D-PMU technology
2. More industry involvment to increase the amount of D-PMU vendors and cut-down the costs of today's D-PMU devices
3. A research community focused on the development of novel and impactful D-PMU applications able to justify the investment on D-PMU technology



Thank you

Sherif Fahmy, Zaphiro Technologies
sherif.fahmy@zaphiro.ch

Power Sector Transmission & Distribution Data and Information

WEBINAR SERIES

Distributed Intelligent Sensor Platform

Teja Kuruganti, Jamie Lian, Jin Dong, Ben LaRiviere – Oak Ridge National Laboratory

Linquan Bai – University of North Carolina, Charlotte

U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY

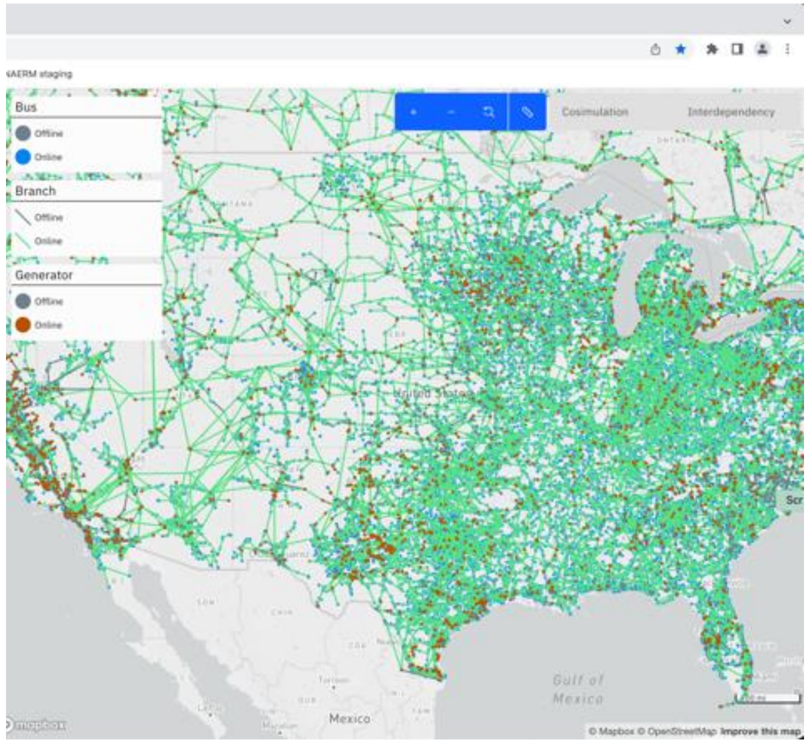
Los Alamos NATIONAL LABORATORY

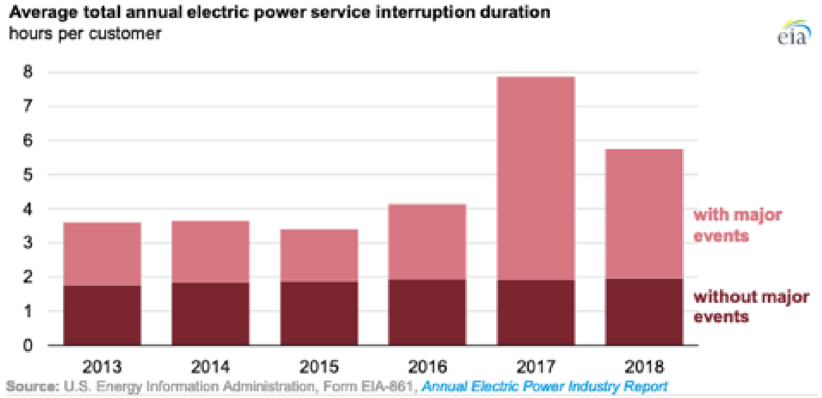
OAK RIDGE National Laboratory

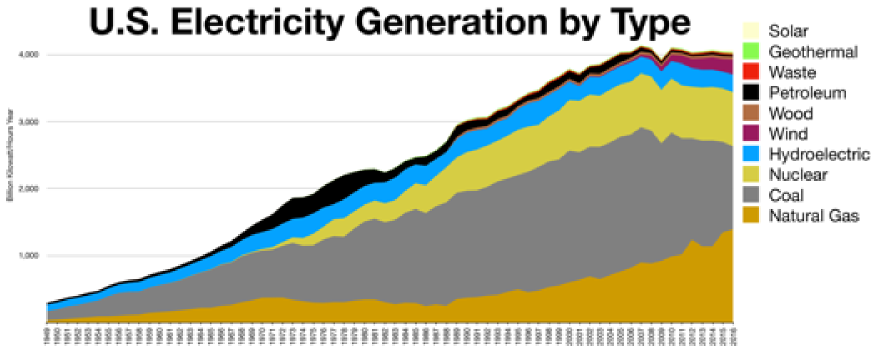
Pacific Northwest NATIONAL LABORATORY

Grid Transformation: Three key drivers

- **Decarbonization** - high penetration of renewable generation sources in the grid.
- **Resilience to Threats** (natural and intentional) - flexible and adaptive to proactively mitigate threats
- **Changing Demand Patterns** - efficient electrified transportation and economic growth.

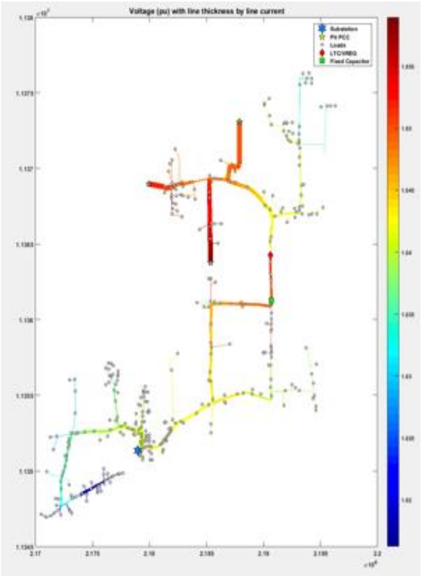






Sources: EIA

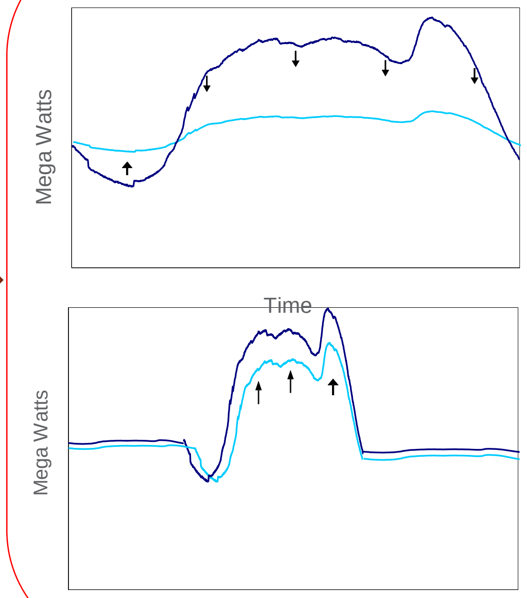
Improve Resilience – Engaging Distribution Resources



Distribution reconfiguration/controls

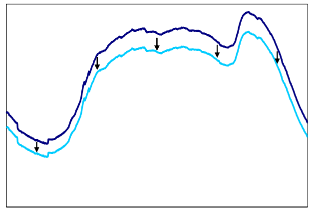
Source: Southern Company

Coordinate demand side resources

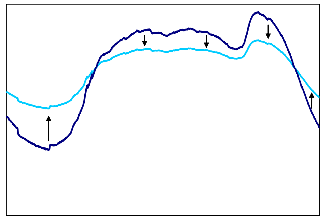


Reduce Energy Intensity and Increase Energy Efficiency

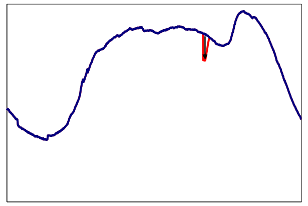
Increase Load Flexibility and Improve Grid Resiliency



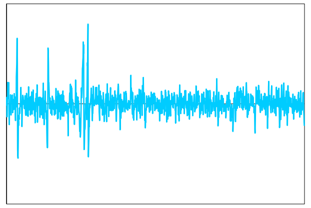
Capacity



Load Shaping



Reliability

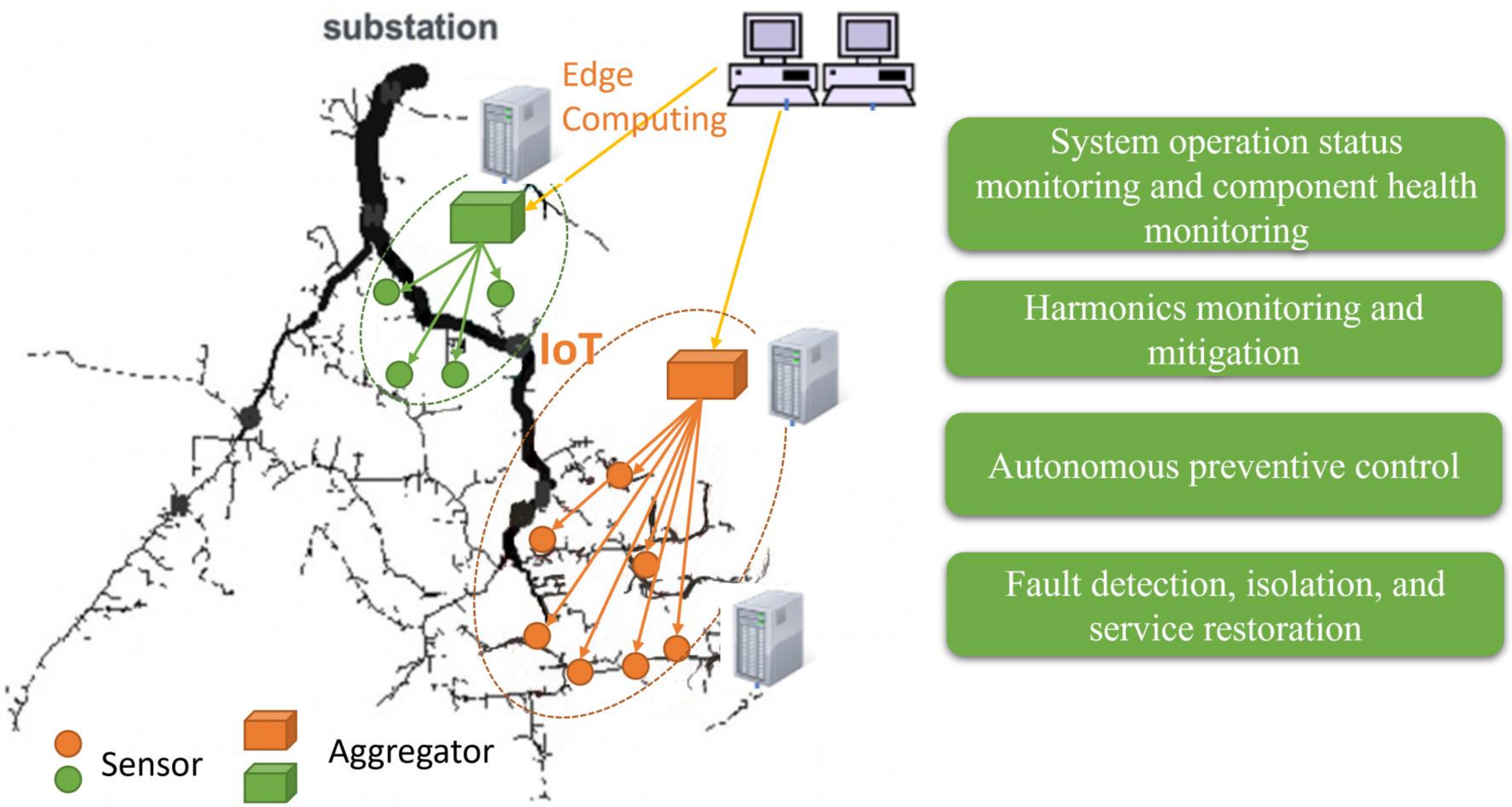


Regulation

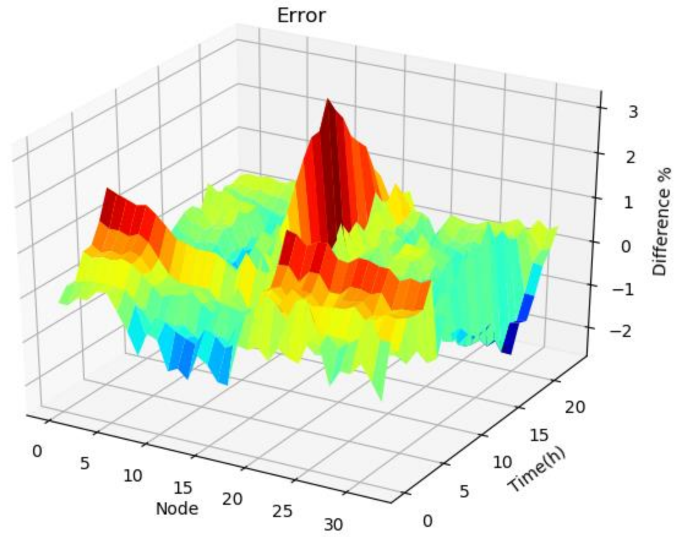
Advancing Distribution-level Monitoring and Control

Develop a solution that synergistically combines low-cost sensors and distributed data analytics to enable distribution-scale situational awareness for operations and planning

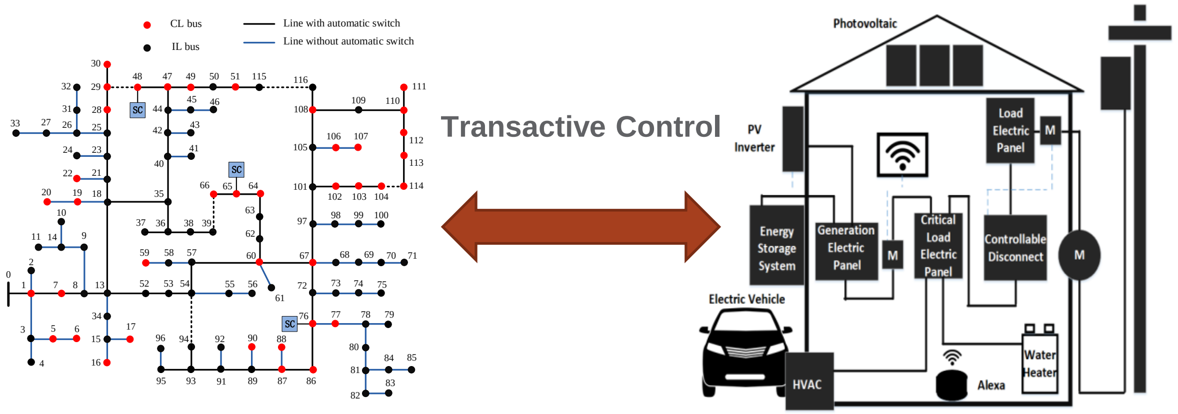
- Design advanced, low-cost sensors at the edge
- Develop Robust, reliable communication architecture
- Perform scalable data collection and analytics

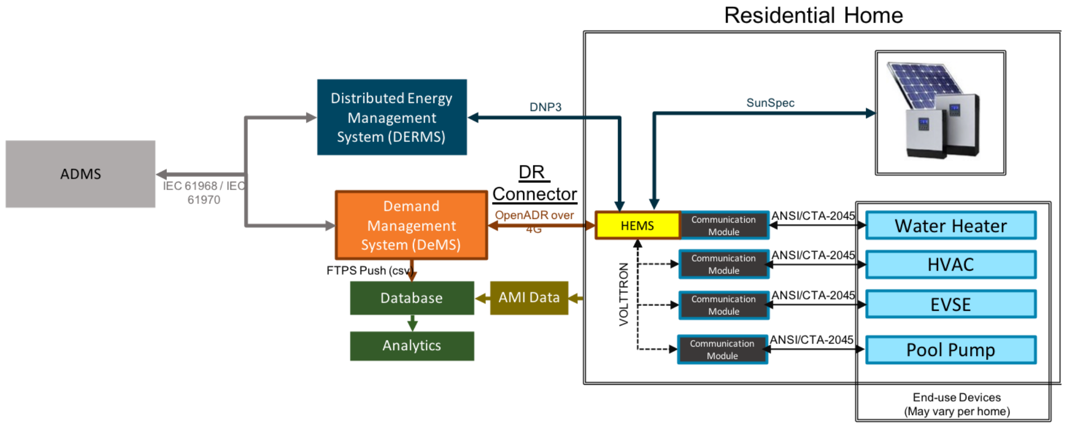


Key challenges to Address Scalability



- **Models** - Online learning-driven models
  - Models that enable observability and controllability
  - Forecast energy-use based on disturbances and constraints
- **Controls** - Grid-interactive Controls
  - Utilize open communication standards
  - Optimize resources for demand reduction and grid support
- **System Integration** – Overlay Architectures
  - Coordinate power flow, operations and economics – DLMP
  - Integration – System of systems



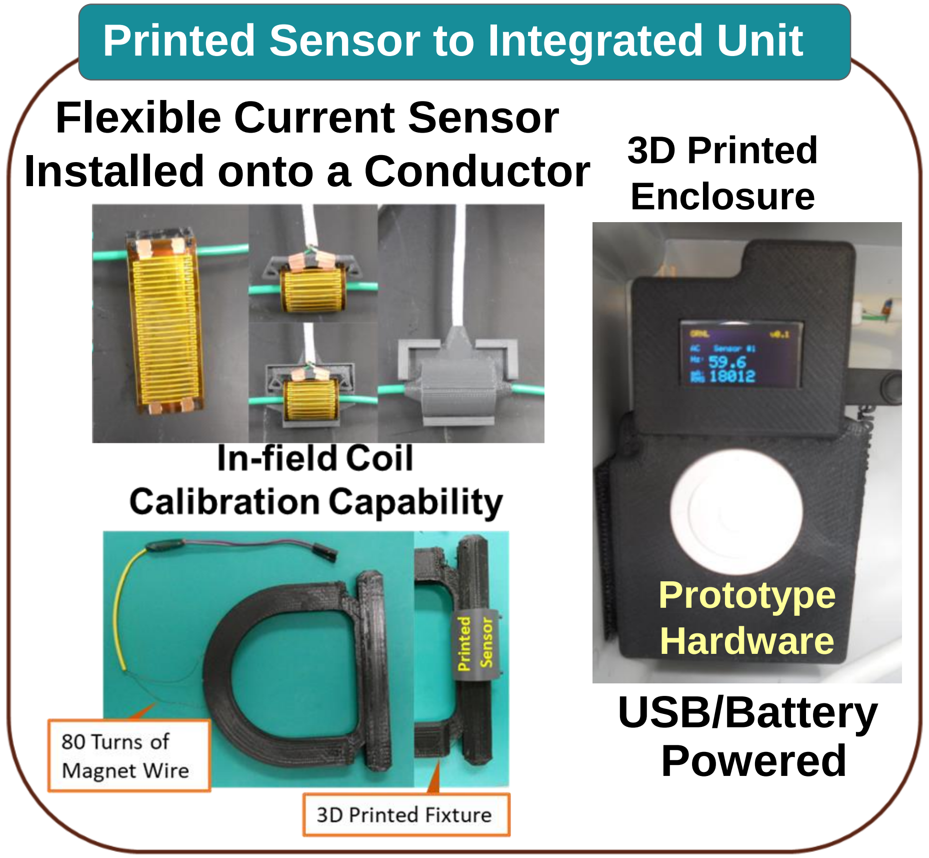


Enabling Distributed control

- **Sensor-enabled Visibility:** Real time precise DC/AC *I, V, P* - measurements - tradeoff among cost, bandwidth, power loss, and accuracy.

- **Utility-to-Edge Federated Architecture:** Beyond SCADA system architecture to support hundreds of data sources at times with varying computational complexity.

- **Data Management and Analytics:** Real-time edge-utility data processing and analytics to demonstrate utilization of sensor data, computational and communication efficiency, and timeliness of information for operations



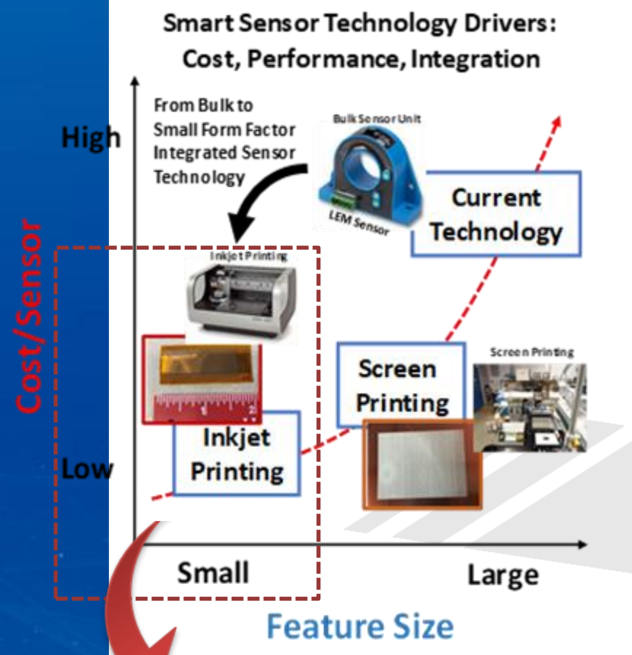
Source: Oak Ridge National Laboratory

Source: University of Tennessee, Knoxville

Direct-Write Current Sensor Unit

Monitoring the Electrical Characteristics of Behind-the-meter (BTM) Equipment

Smart Sensor Technology Drivers
Cost, Performance, Integration



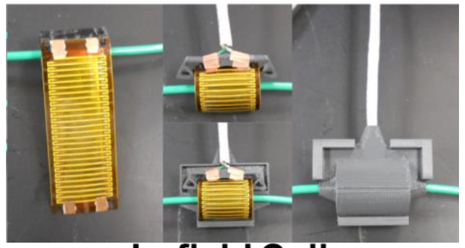
Flexible Current Sensor Development: Core Components

- Flexible Substrate
- Thin Permalloy
- Printed Conductor
- Integrated Prototype
- Performance Evaluation

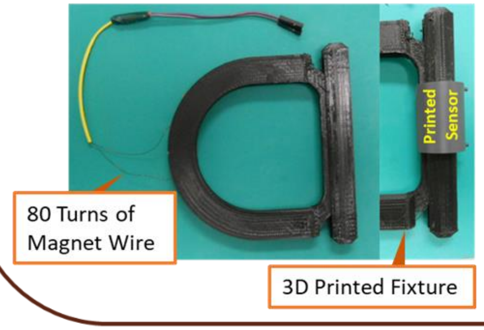
Core Enabling Components	Key Characteristics
Flexible Substrate	Polyimide sheets: **7.5-100µm**
Permalloy	Thickness: **12.5µm**, Permeability>60,000
Direct-Write Conductor	Additive Printing: Line-width control ~**10µm**

Printed Sensor to Integrated Unit

Flexible Current Sensor Installed onto a Conductor



In-field Coil Calibration Capability

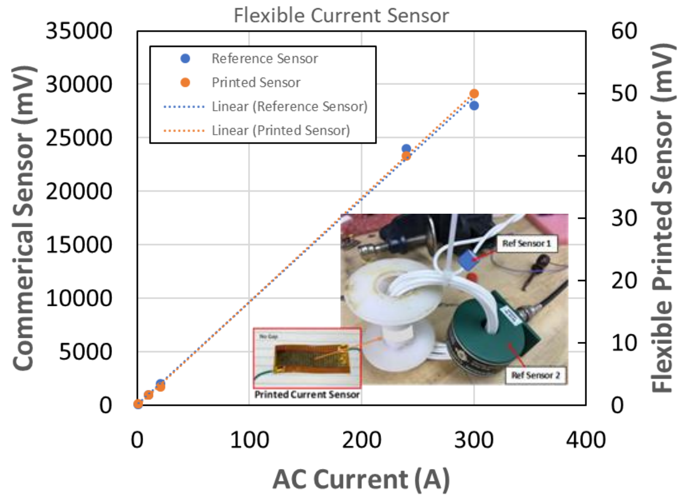


3D Printed Enclosure

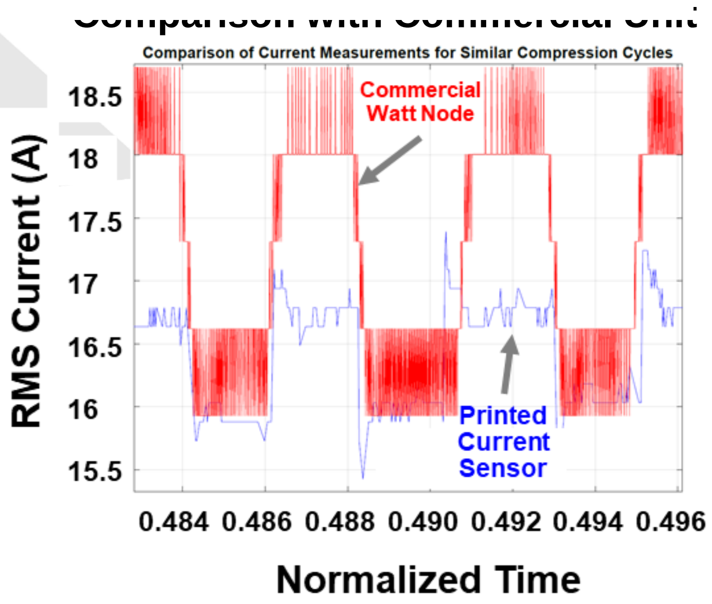
USB/Battery Powered

Performance Evaluation

Linear Sensor Response



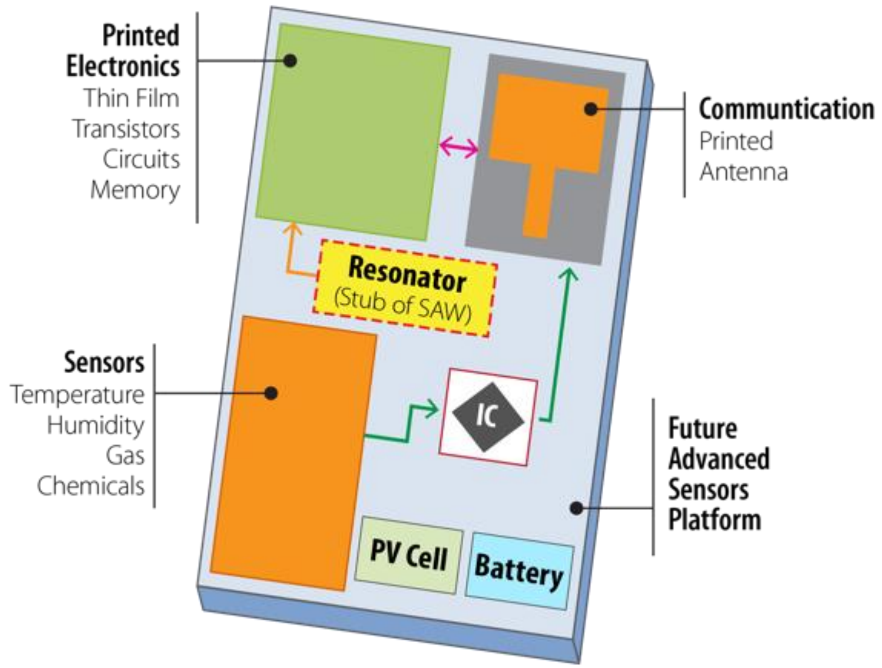
Comparison with Commercial Unit

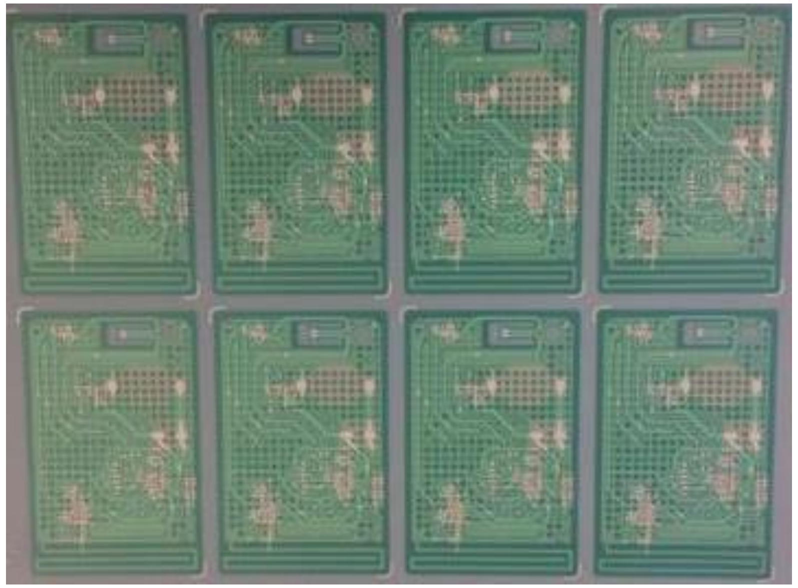


Low-Cost Wireless Sensor Platform

Increasing accessibility to affordable information

- Goal – develop low-cost, easy to deploy sensors
- Peel-and-stick wireless sensor, measuring 4.75’ x 3’ x 0.23’
- Uses additive techniques on thin-film, flexible, and light-weight substrates
- Contains photovoltaic cells that harvest energy from artificial indoor light and powers a rechargeable battery
- The platform includes integrated circuitry for sensor signal processing, onboard computation, wireless communication and an antenna



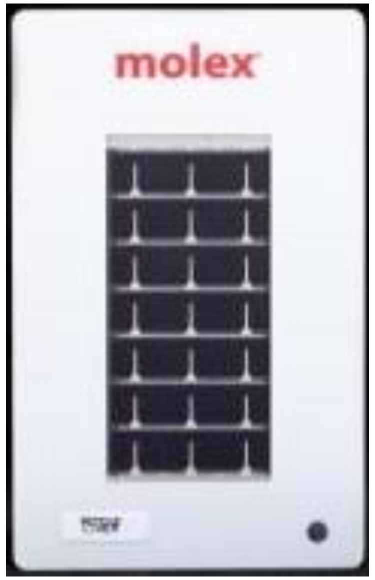


Print components on flexible substrates

Back

Front

Add discrete components using pick-and-place



Samples for OEMs

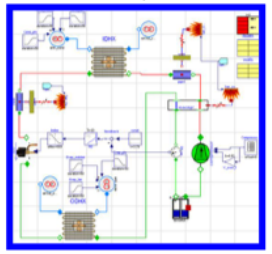
The ultra-low power smart sensors collect and send data to a receiver, which can capture data from many different peel-and-stick nodes and provide information to the controls for the energy-consuming systems. The more information received, the better the building’s energy management. Both new construction and retrofitted buildings can benefit from ORNL’s smart sensors.

Distributed Control Design

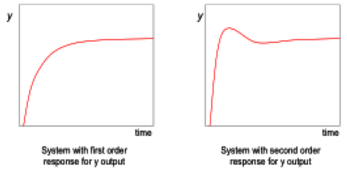
System Characterization

Disturbances

Virtual System



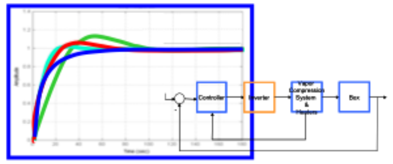
Control parameters



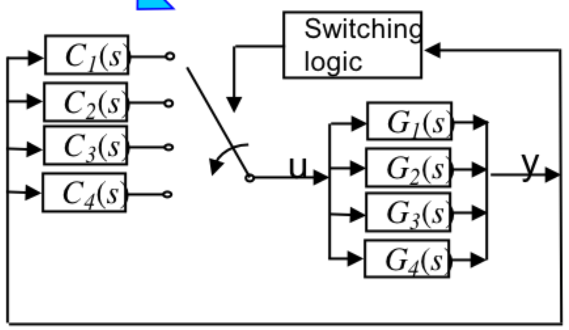
System Dynamics

Learning

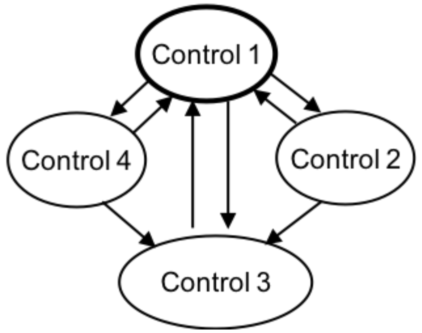
Control Design



Objective and constrain handling

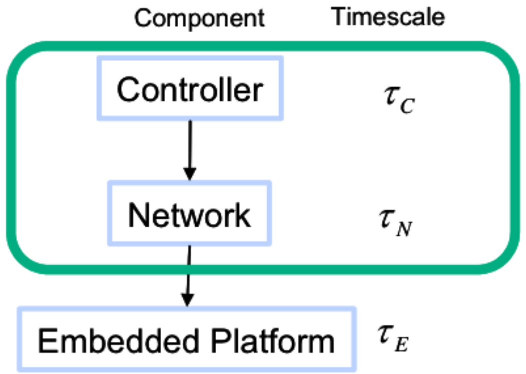


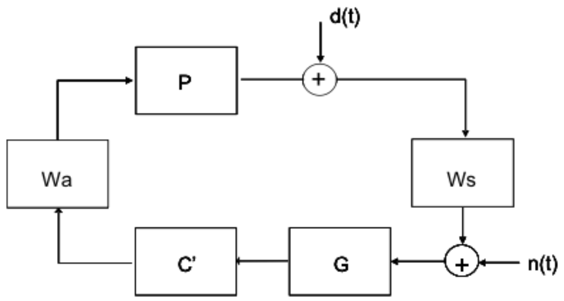
Hybrid control analysis



Optimization

Control over Network



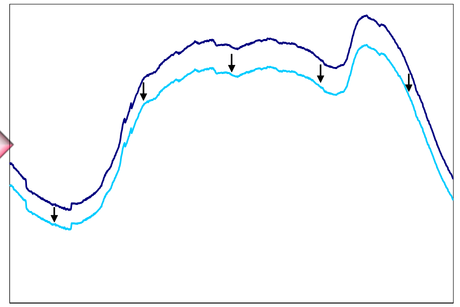


Networked Controls

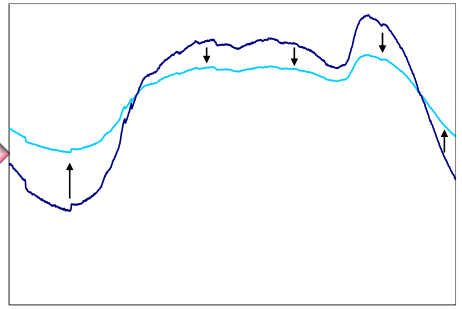
- No time-scale separation
- Network and controller design have system-level effects
- Co-design Communication, Controls – Deterministic

Control

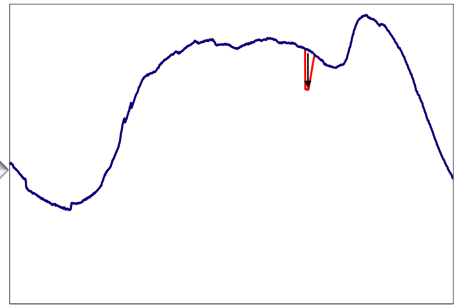
Capacity Management



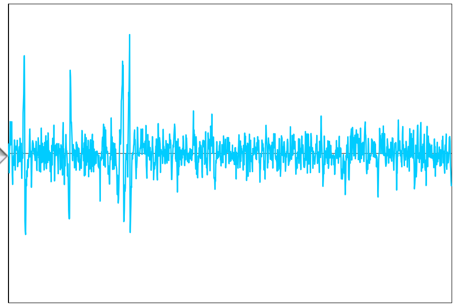
Adaptive Load Shape



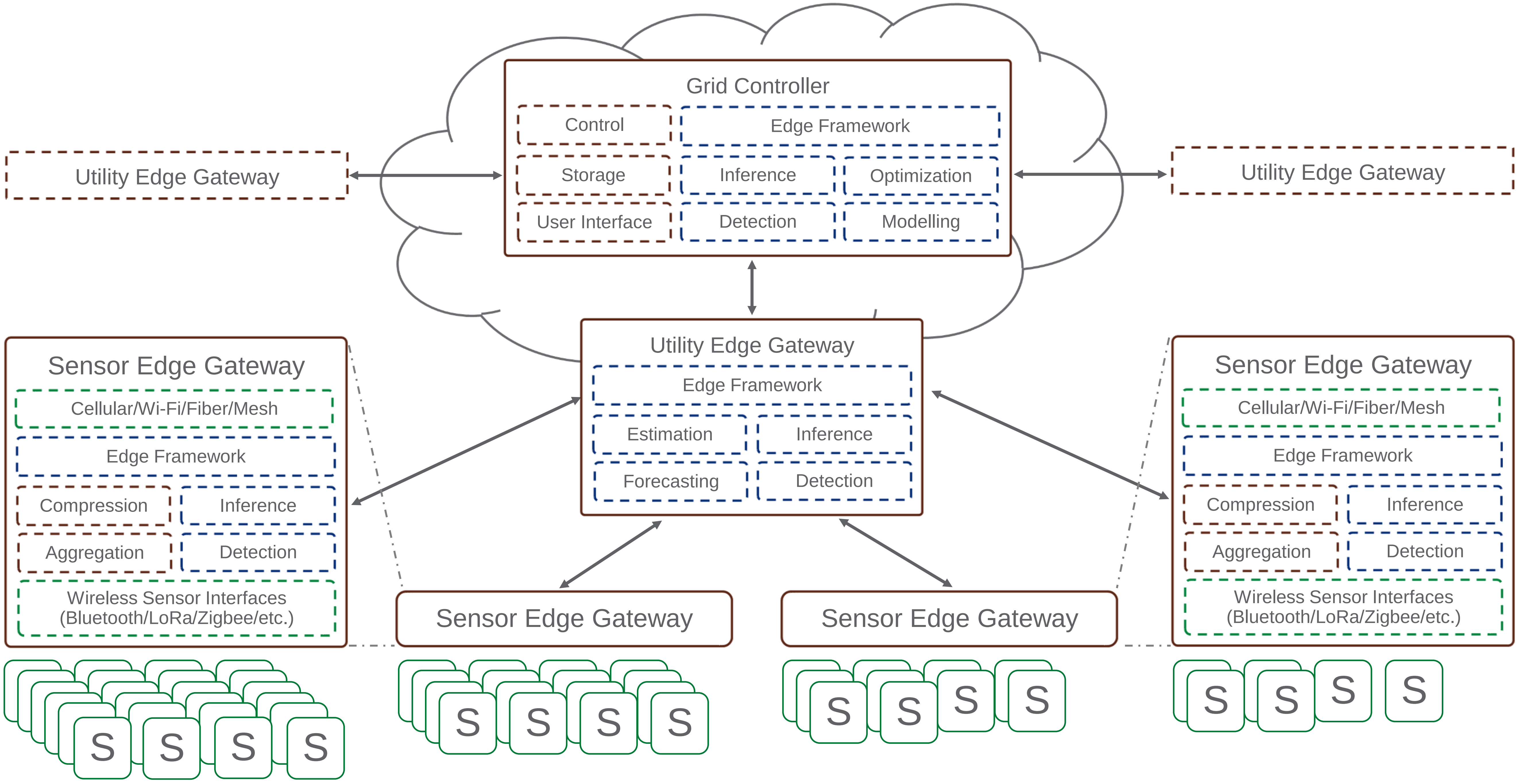
Reliability response



Regulation response

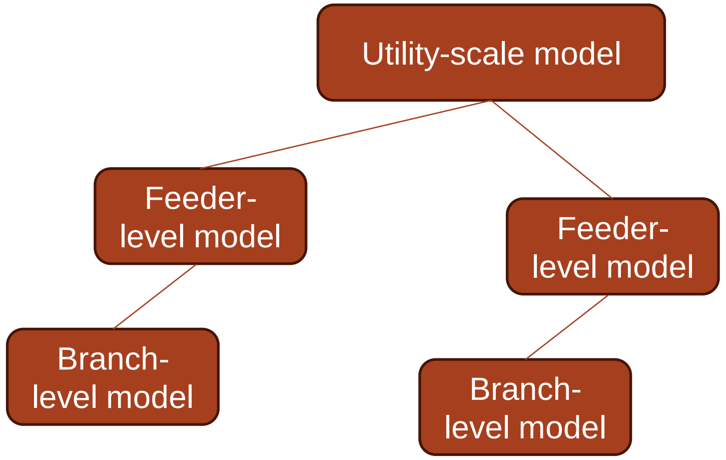


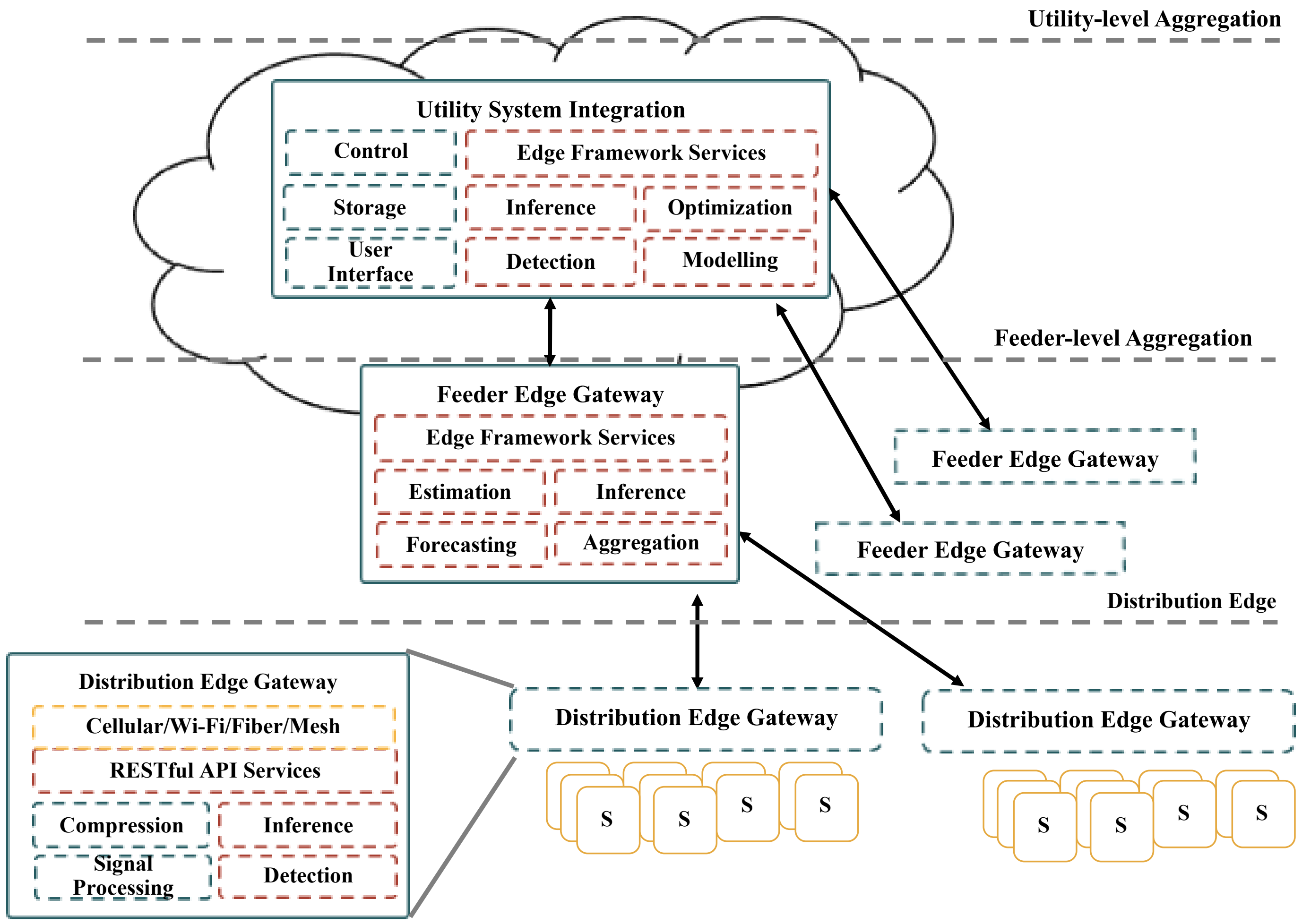
Framework for Distributed Control

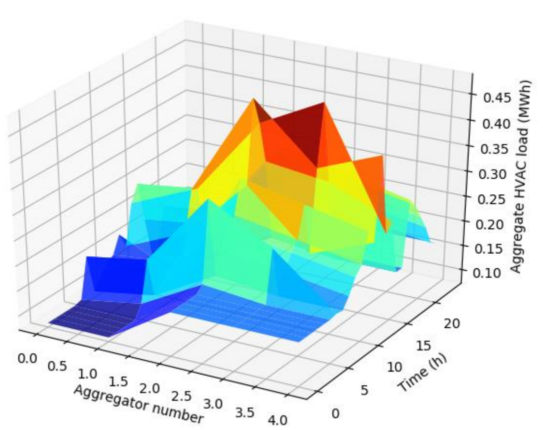


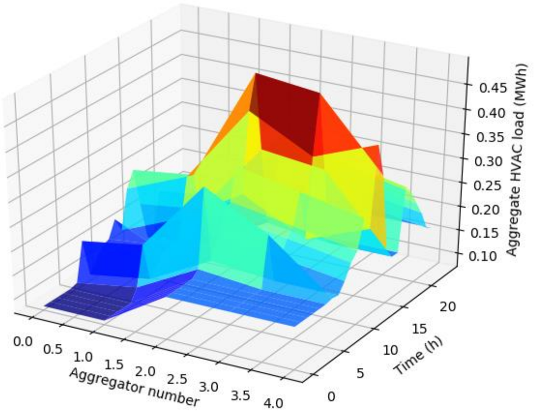
Use case – Learning-driven VVO

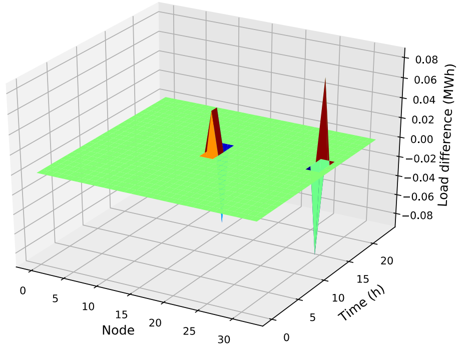
- Cloud-based global model for entire network
- Local/segment model for Branches







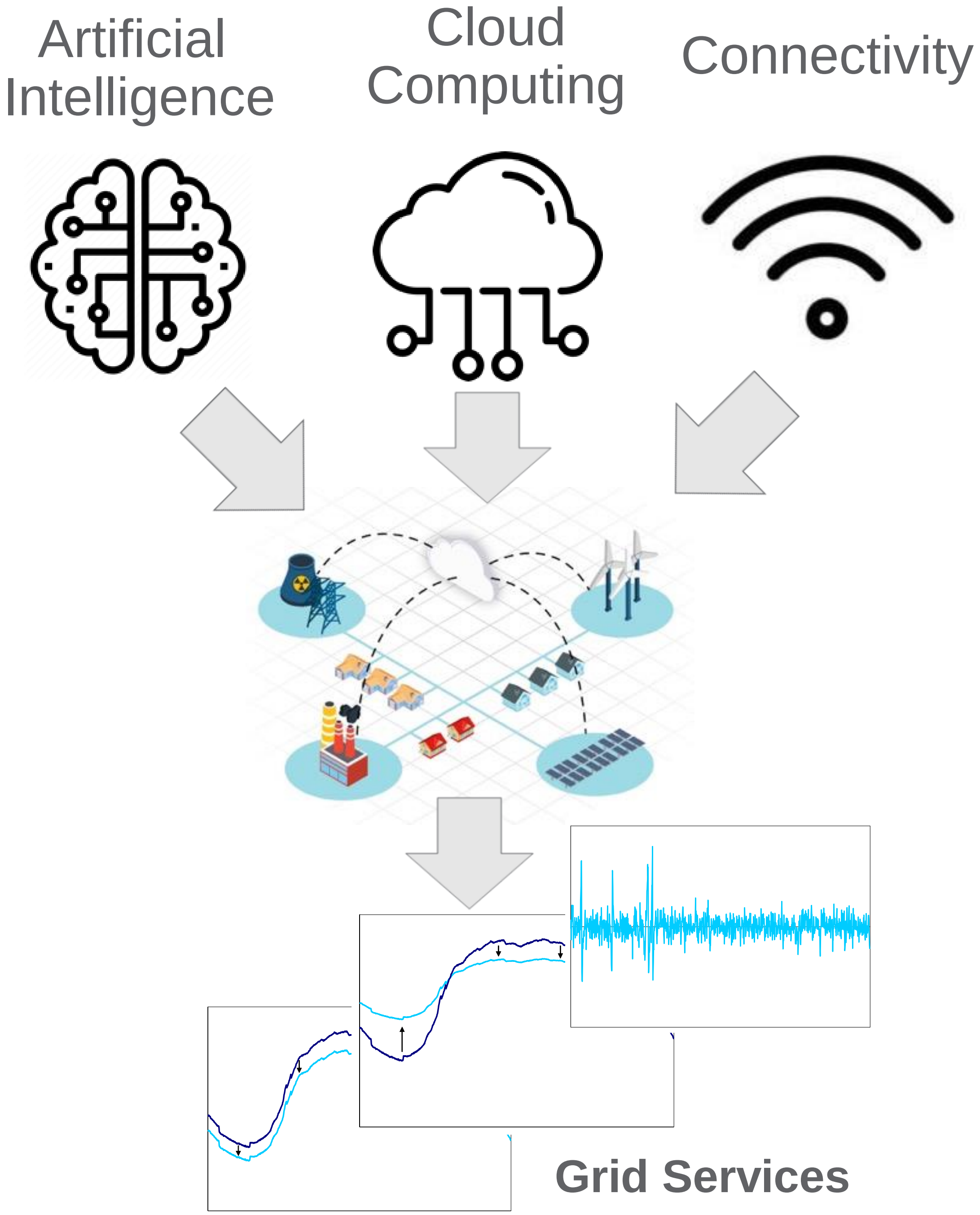




Scaling Edge-to-Utility Architecture

- **Technology convergence drives opportunity -** AI, Cloud, and 5G
    - Wide-area situational awareness
    - Predictive modeling and simulation
    - Proactive decision-making for improving resilience

- **Key challenges**
    - ***Scalable data management and communications*** - Federating large numbers of IoT-driven end-use devices
    - ***Virtualized network architectures***: Information-centric networking (ICN) to maximize the utilization of the communication infrastructure
    - ***Scalable and robust distributed control***: Robust wide-area distributed feedback control systems through low-latency communications
    - ***Federated learning***: Tools that utilizes highly granular spatiotemporal data from networks of devices to learn about the system



Thank you

Teja Kuruganti
Oak Ridge National Laboratory
kurugantipv@ornl.gov

Power Sector Transmission & Distribution Data and Information

WEBINAR SERIES

Incorporating multiple physical measurements for grid insights

Hall Chen

CTO

Gridware

U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY

Los Alamos NATIONAL LABORATORY

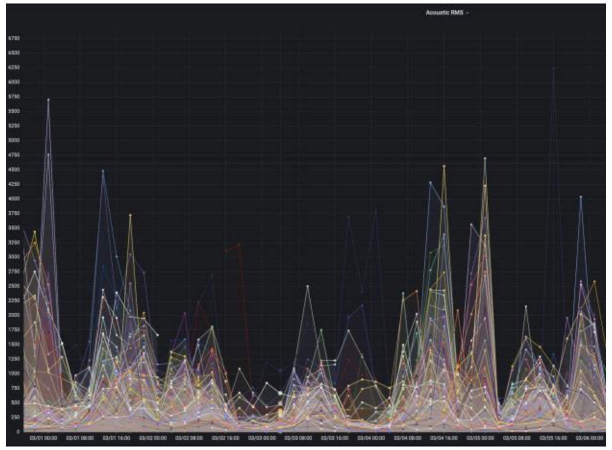
OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

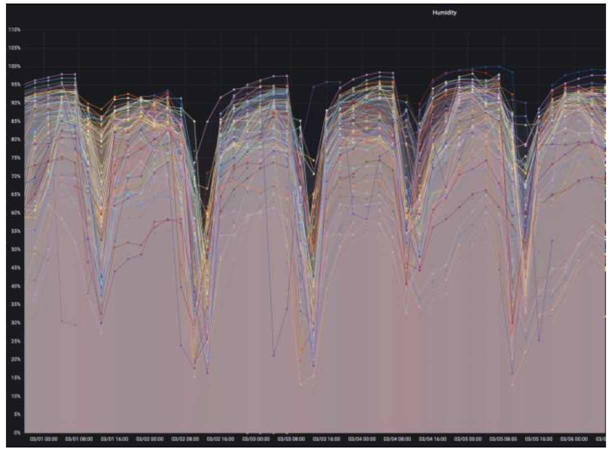
The grid is electrical, but faults don't have to be

System wear-out mechanisms
are a function of environmental stimulus

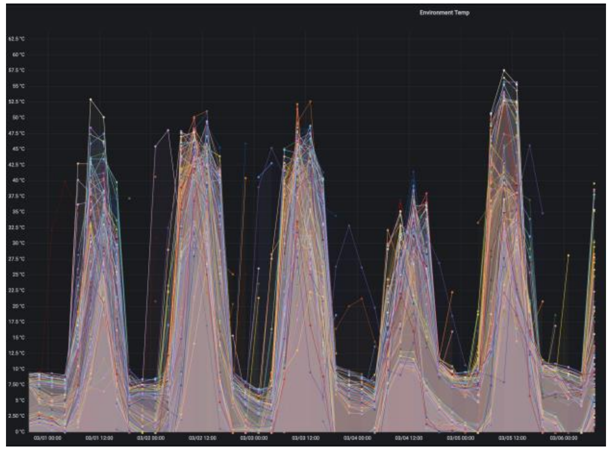
Wind

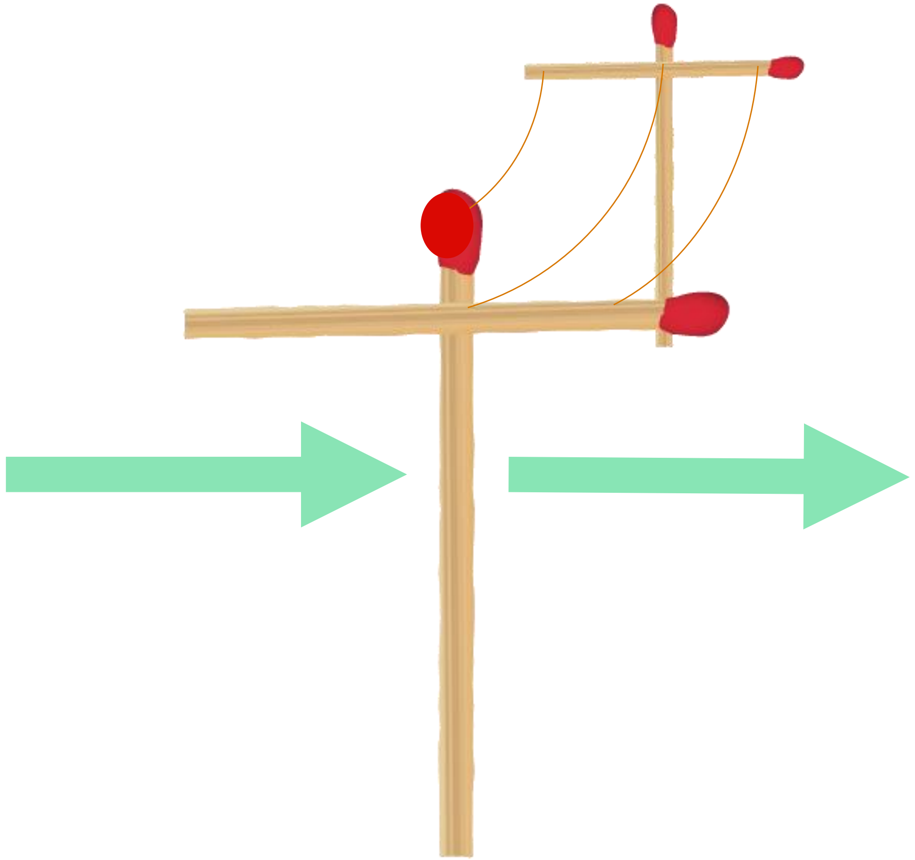


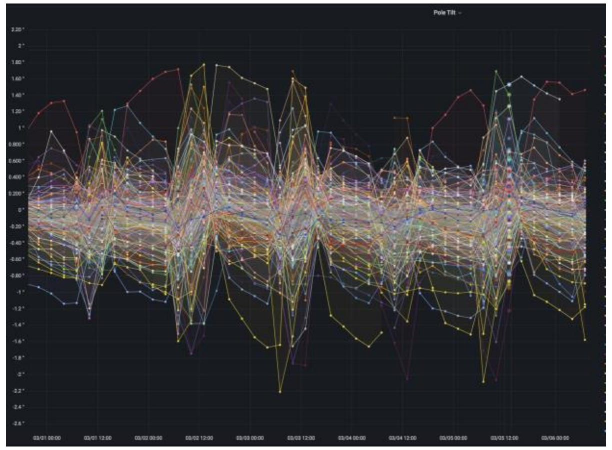
Humidity

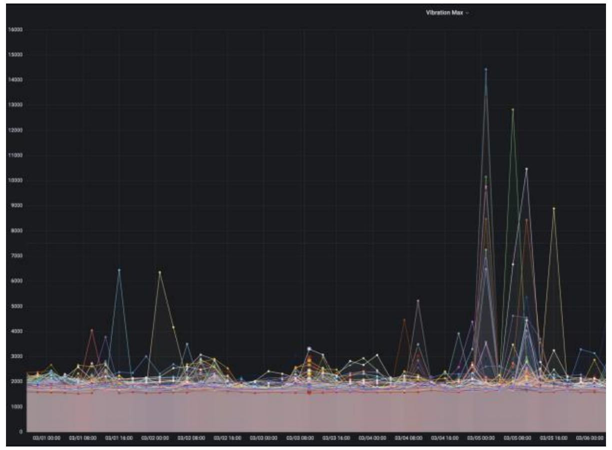


Temperature





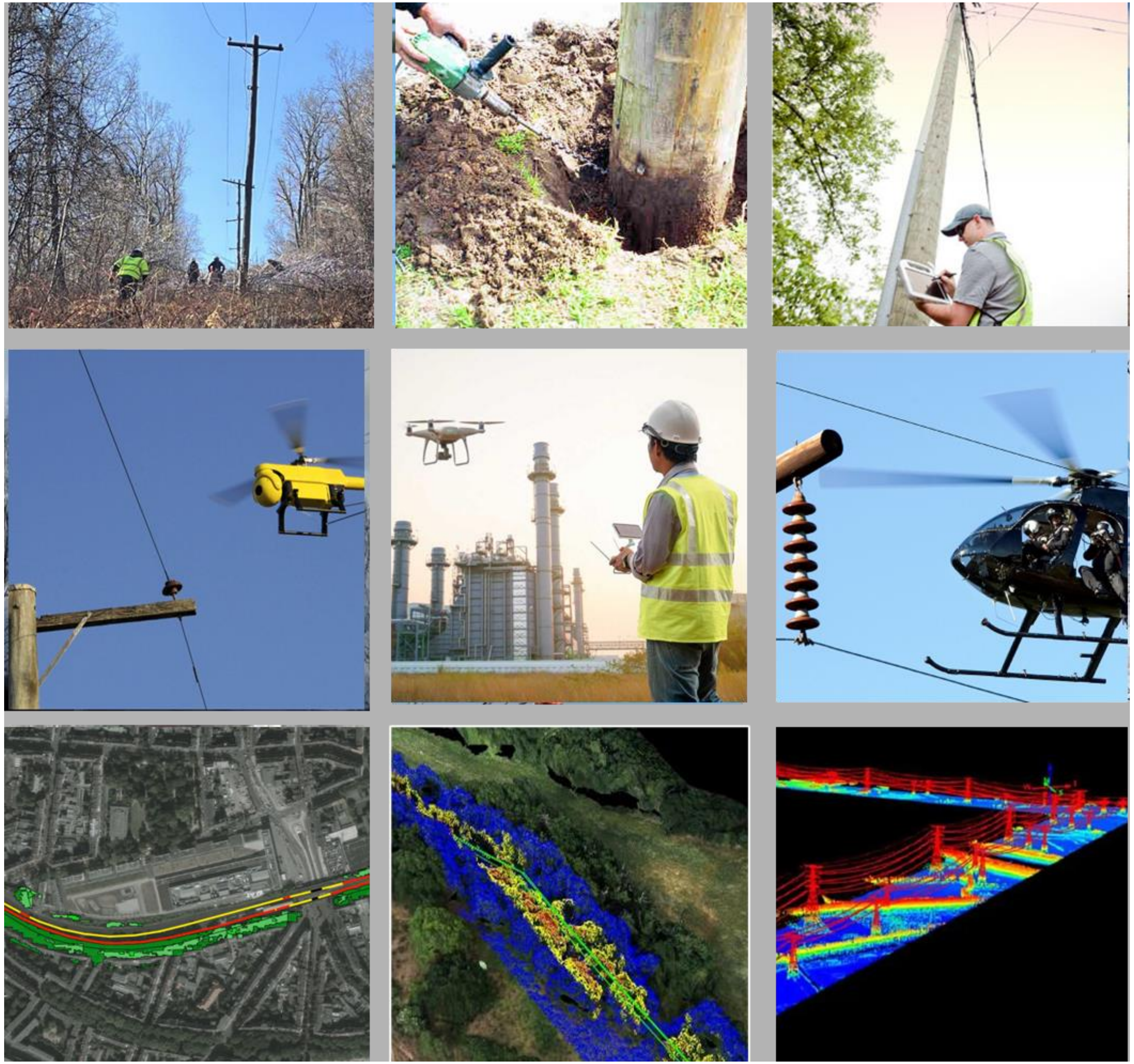




The need for high spatial-resolution environment measurement capabilities

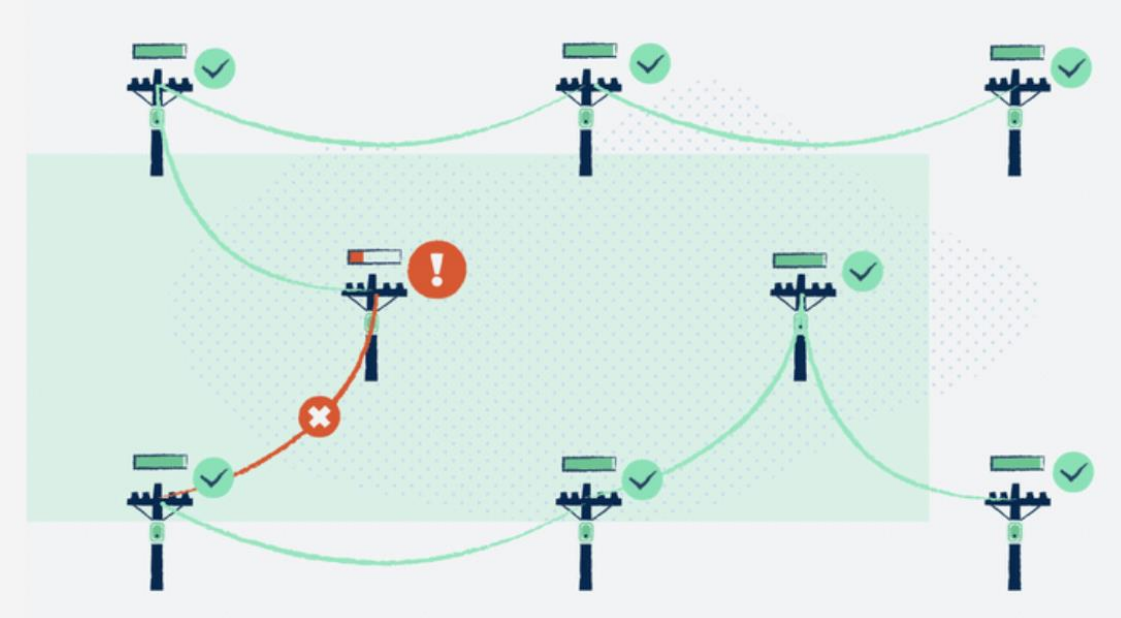
Better yet, also measure the way grid equipment responds to the environment

We currently solve this with point-in-time inspections



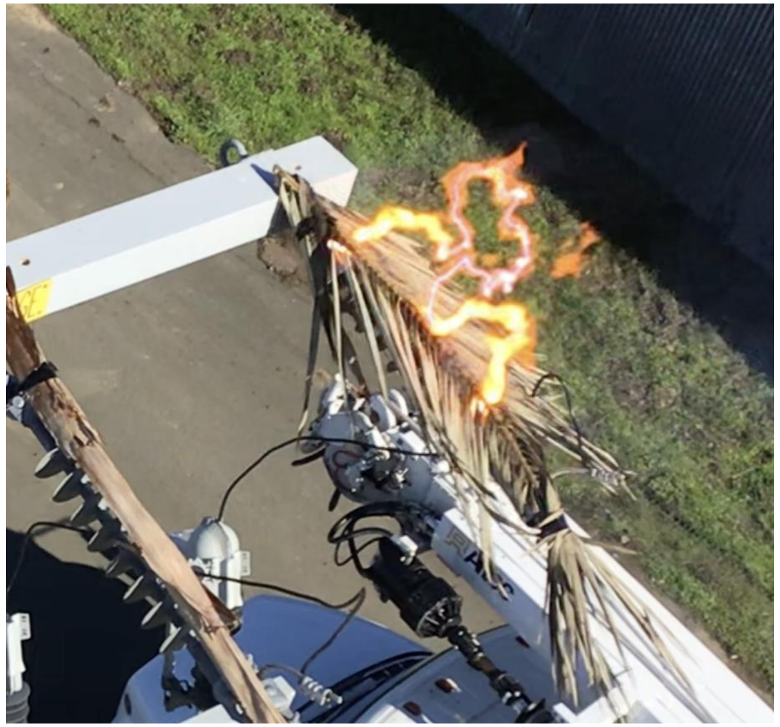
Denser instrumentation enables grid resilience and modernization with surgical precision

Vegetation Contact	Pole Energization / Leakage
Conductor Clash / Partial Discharge	Loss of Phase / Lines Down



A full-scale distribution test circuit for accelerated life and wear-out testing

- Class 2 55’ poles
- 200’ 4 wire spans
- 12.5kV generation
- Pole-top transformers



Hardware with multi-domain physical sensing

Mechanical sensors
Vibration, Acceleration, Tilt, Microphone, Ultrasonic

Wireless communications
Cellular, Mesh, Private LTE, Satellite

Environmental sensors
Temperature, Humidity, Pressure, RF, E/H Field, Wind Speed, Wind Direction

Intelligent Microcontroller
Machine learning core, Cryptographic engine

Optical sensors
Cameras, IR, UV, Visible light

Solar + Battery
10-min installation, no pause to operation, 10-15 year lifespan

Thank you

Hall Chen, Gridware
hallchen@gridware.io

Power Sector Transmission & Distribution Data and Information

WEBINAR SERIES

The trustworthiness and quality of data

Artis Riepnieks
Electrical Engineer
Pacific Northwest National Laboratory

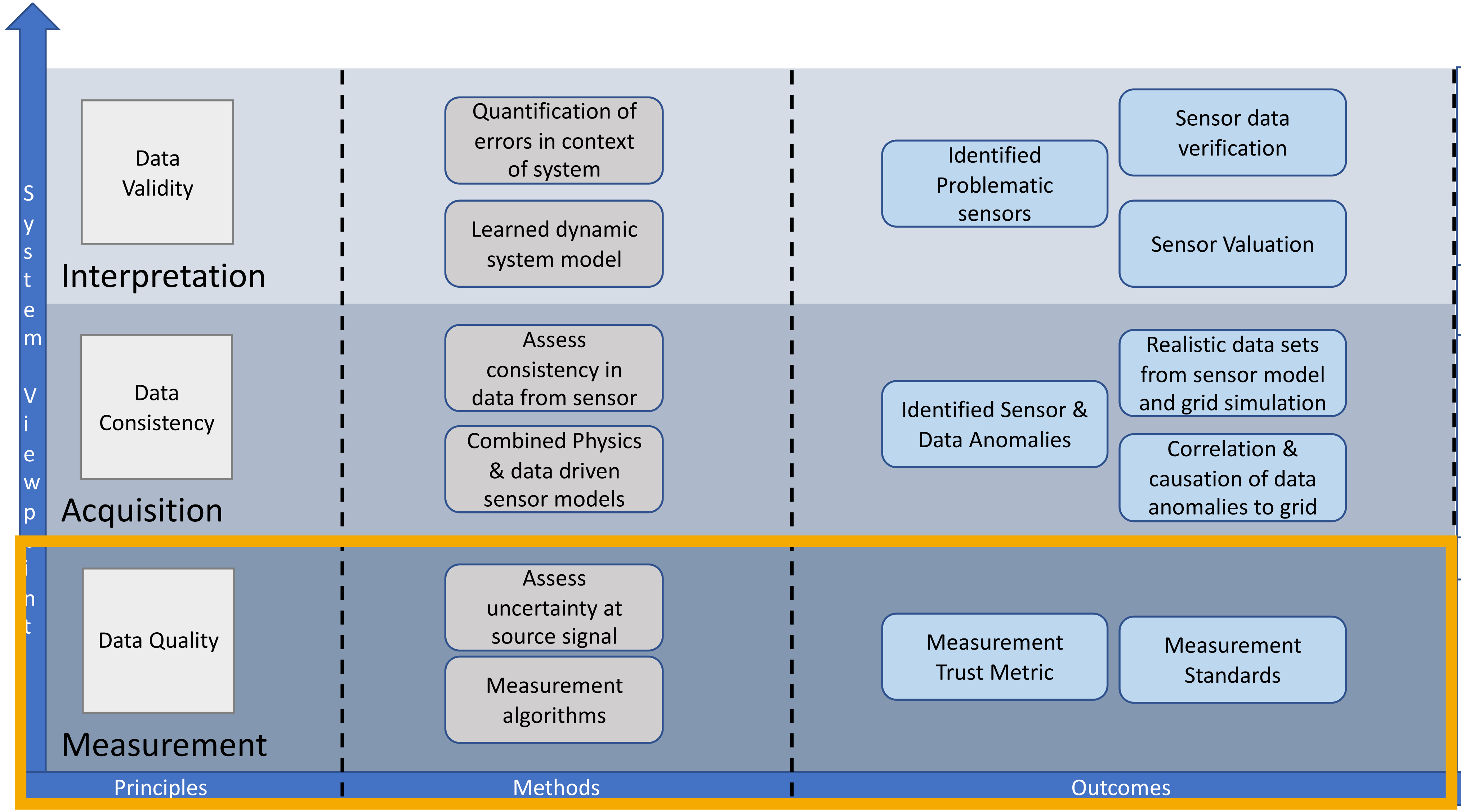
U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY

Los Alamos NATIONAL LABORATORY

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

Quality data starts at the source



Definitional uncertainty

Bureau of Weights and Measures (BIPM) Guide to the Expression of Uncertainty in Measurement (GUM)

- Three sources, according to GUM:

  (1) Incomplete definition of the measurand

  (2) Imperfect realization of the definition of the measurand

  (3) Nonrepresentative sampling*

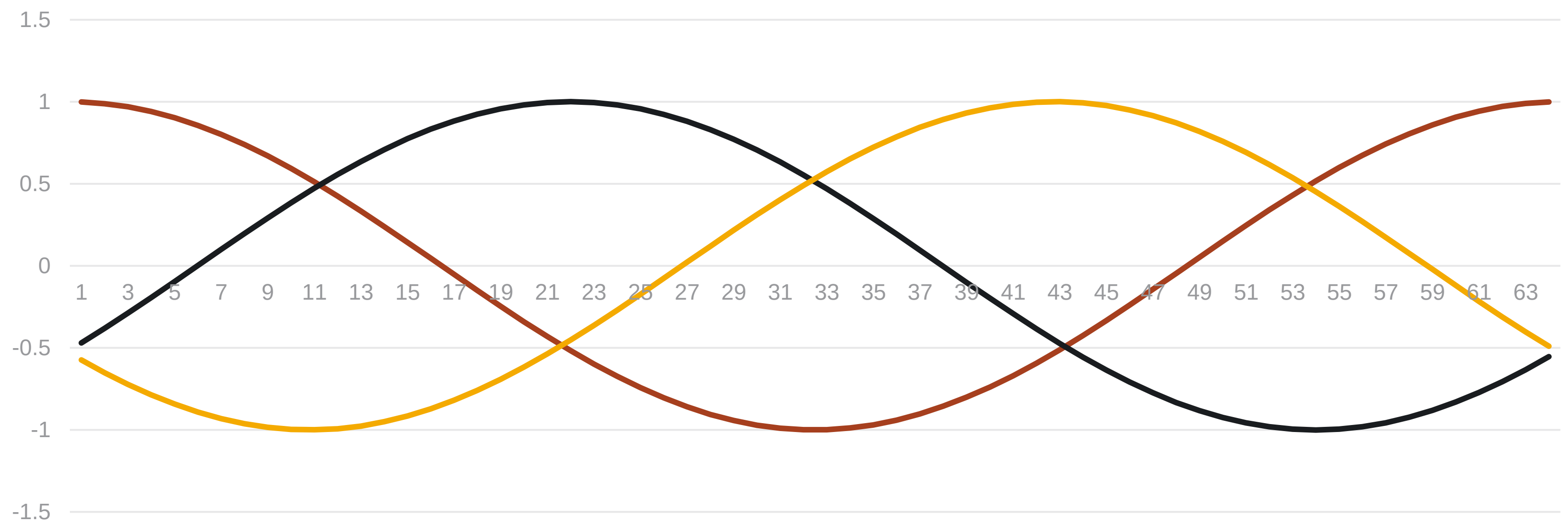
https://www.bipm.org/en/committees/jc/jcgm/publications

* Sample signifies the piece of the measurand selected for measurement

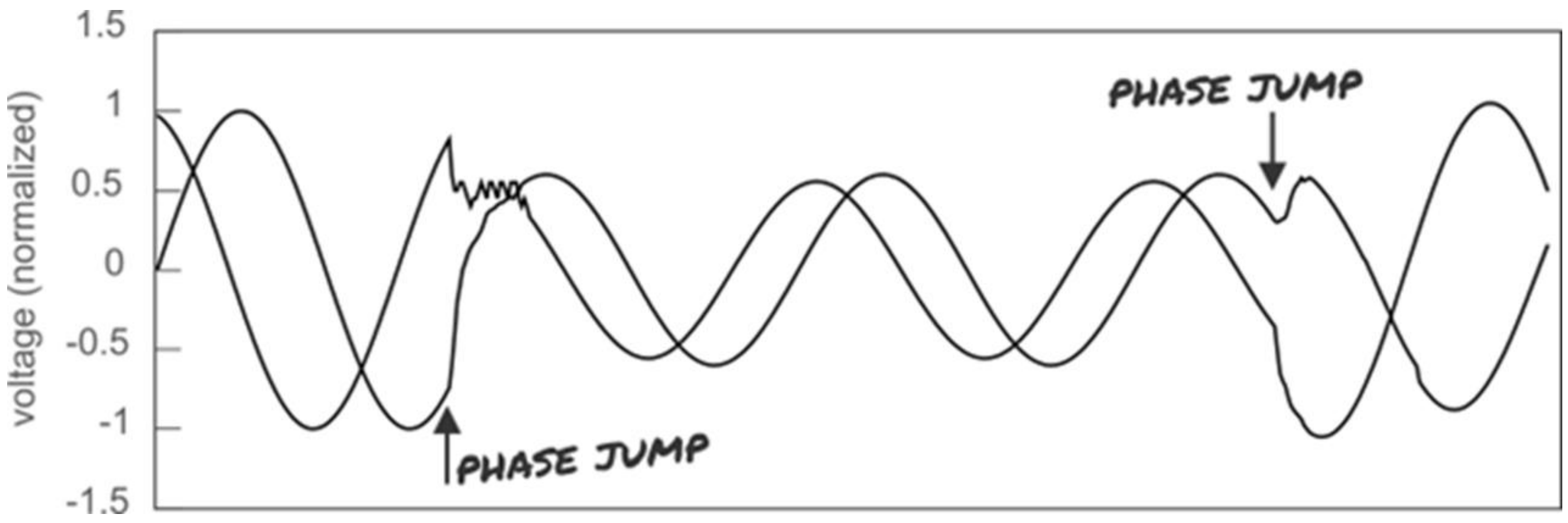
Definitional uncertainty (cont.)

As tested:

$$v_A(t) = V_A(cos\omega t + \varphi_{AV})$$



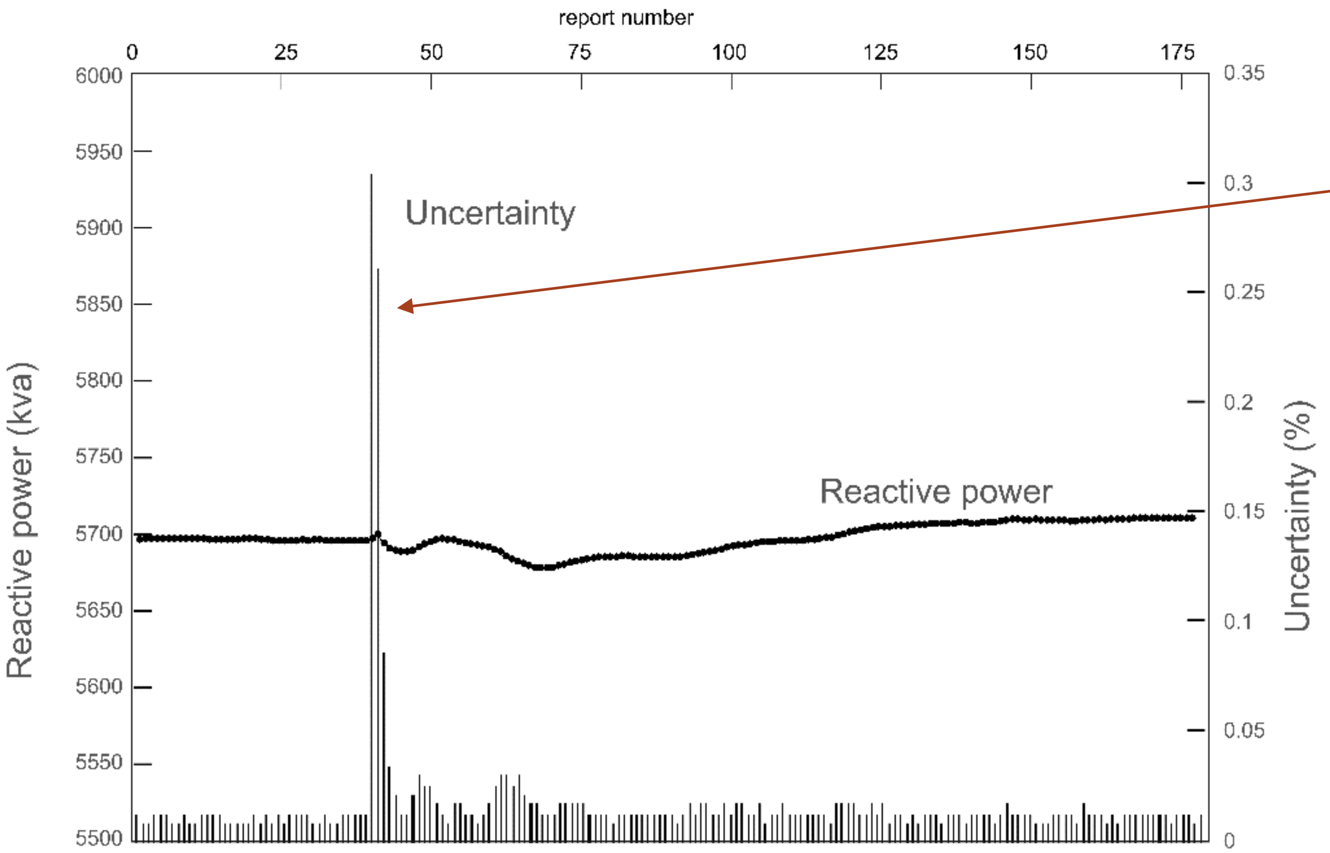
In the field environment:



"Blue Cut Fire" event waveforms

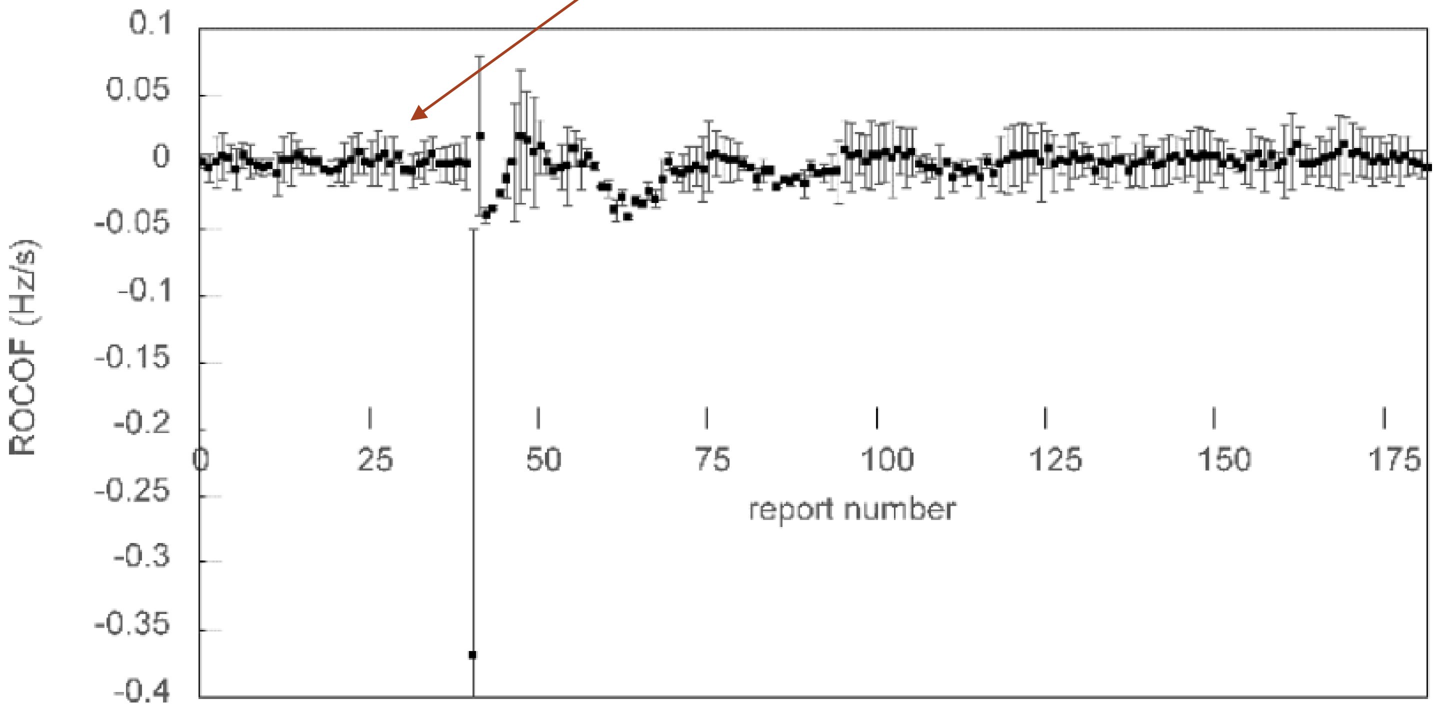
Source: https://www.nerc.com/pa/rrm/ea/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_Interruption_Final.pdf

Mark data that’s unfit for purpose



“No Trust” flag

Trustworthiness metric in form of error bars

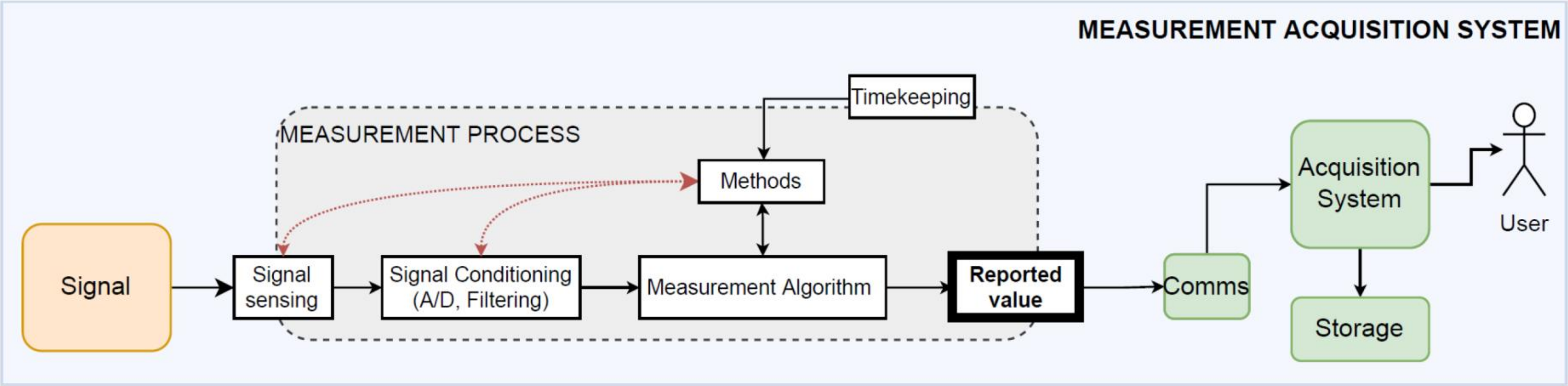


A. Riepnieks and H. Kirkham, "An Introduction to Goodness of Fit for PMU Parameter Estimation," in IEEE Transactions on Power Delivery, vol. 32, no. 5, pp. 2238-2245, Oct. 2017,
A. Riepnieks and H. Kirkham, "Measuring during a fault," 2020 IEEE Power & Energy Society General Meeting (PESGM), Montreal, QC, Canada, 2020, pp. 1-5,

A measurement standard for the future

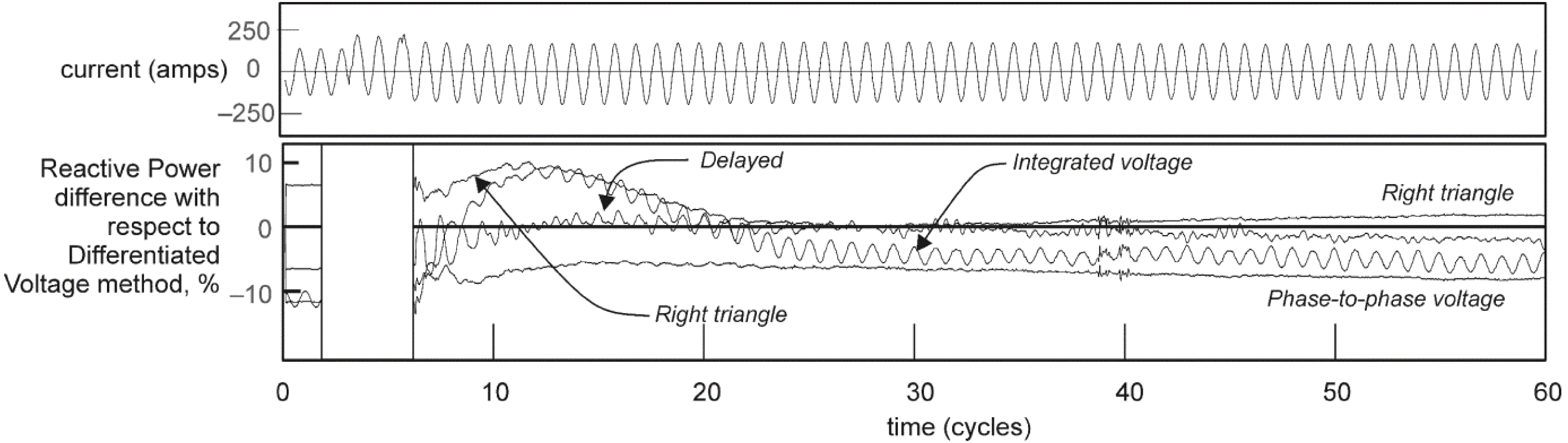
IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions *(expected to be published in 2024)*

- Defines measurement process requirements
- Provides workable solutions
- Indicates the necessary consensus requirements for measurement interoperability and consistency:
  - ✓ Signal limitations
  - ✓ Filtering
  - ✓ Measurement algorithms
  - ✓ Necessary metadata



A Riepnieks, J Follum, K Mahapatra, K Chatterjee “Limitations in Advanced Measurement Systems: An Overview for Power Systems“, Report, Pacific Northwest National Laboratory. March, 2023, PNNL-34131

How are you measuring?



- 5 Reactive power measurands
- Singe cycle measurements
- Sliding window
- 10%-15% difference in reported values

H. Kirkham and A. Riepnieks, "A Future Standard for Reactive Power Measurement,"
2020 IEEE Power & Energy Society General Meeting (PESGM), Montreal, QC, Canada, 2020, pp. 1-4, doi: 10.1109/PESGM41954.2020.9281774.

Thank you

Artis Riepnieks, PNNL
Artis.riepnieks@pnnl.gov

PNNL-SA-191987

Power Sector Transmission & Distribution Data and Information

WEBINAR SERIES

Sensor Data Anomaly Detection

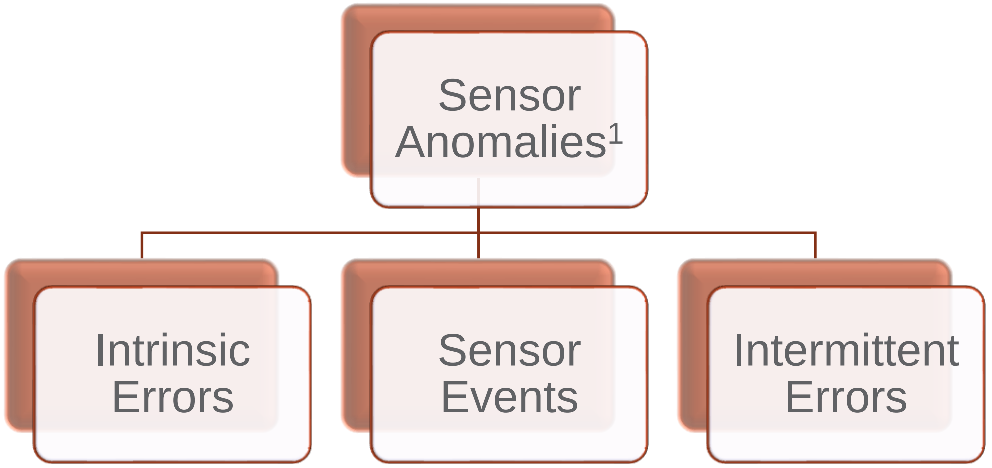
Dr. Kaveri Mahapatra
Power Systems Research Engineer
Pacific Northwest National Laboratory

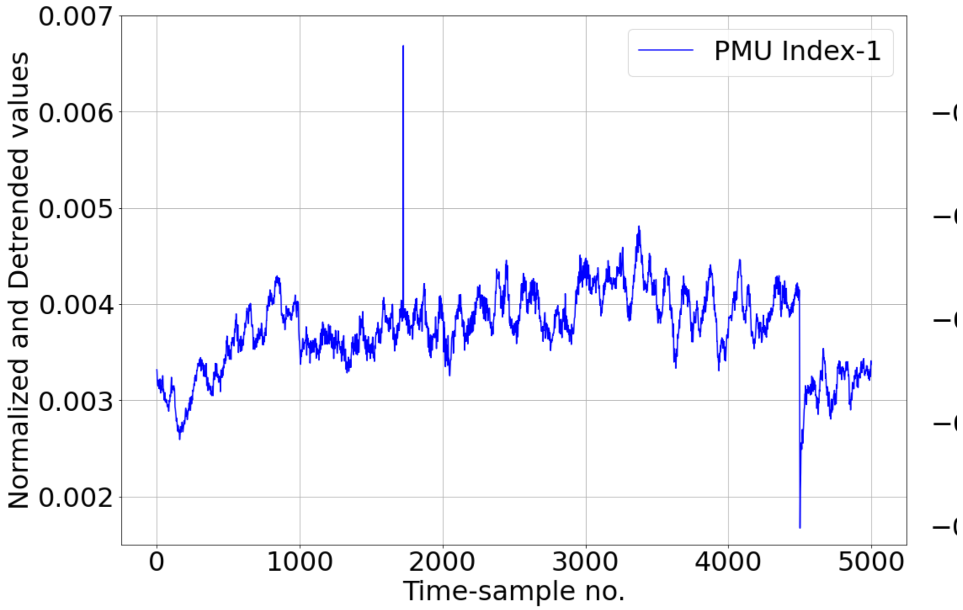
U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY
Los Alamos NATIONAL LABORATORY
OAK RIDGE National Laboratory
Pacific Northwest NATIONAL LABORATORY

SENTIENT Products Outline

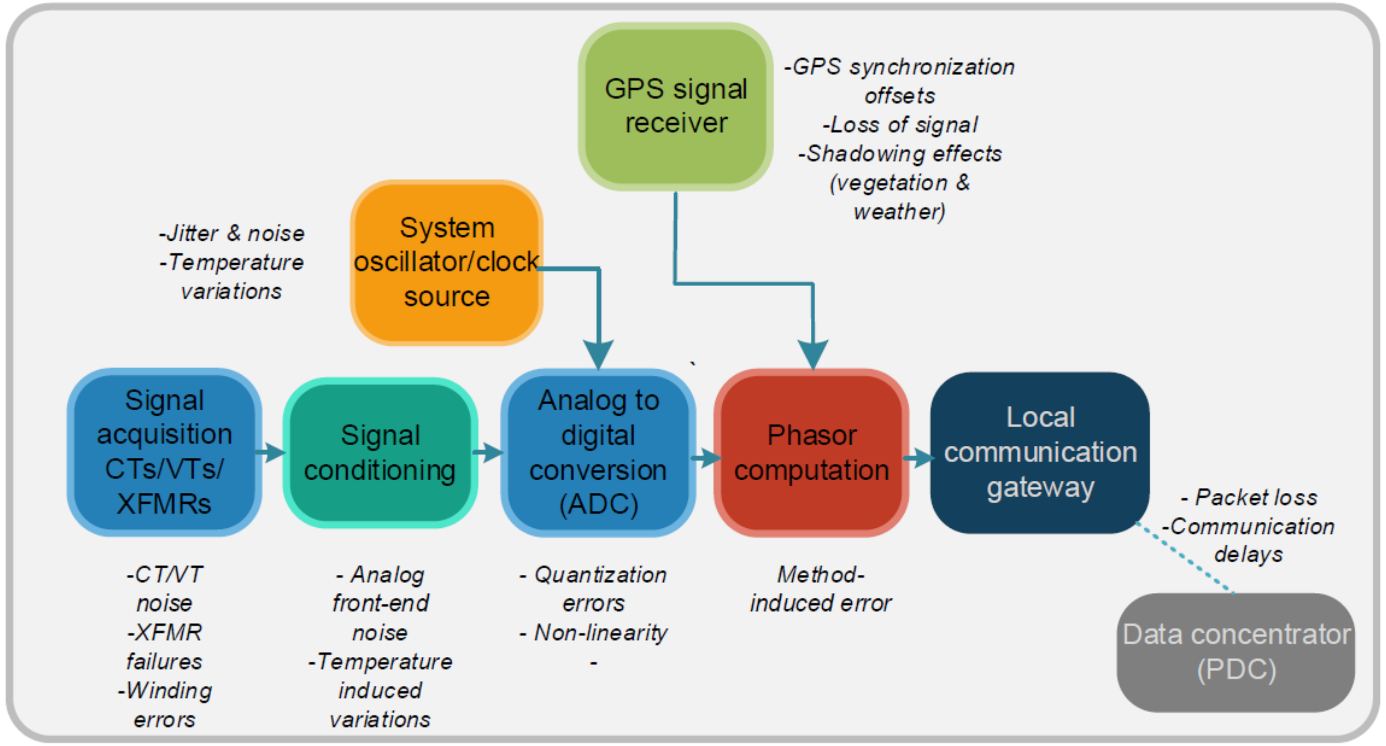
- Sensor Events & Anomaly Detection Software (FY23)
  - Centralized algorithms
  - Distributed algorithms, edge computing
  - Both transmission and distribution system-focused
- Sensor Noise Emulation Platform (FY22)
  - Publicly distributing phasor data without any sensitivities
  - With heterogeneous data extraction capability

Sensor Anomalies?





" A spatial-temporal point whose non-spatial attribute values are significantly different from those of other spatially and temporally referenced points in its spatial or/and temporal neighborhoods is considered as a spatial-temporal outlier[2]"



- Current Transformer (CT), Potential Transformer (PT)
- Phasor Measurement Unit (PMU)
- Digital Fault Recorder (DFR), Digitaal Disturbance Recorders (DDR)

[1] Gaddam, Anuroop, Tim Wilkin, and Maia Angelova. "Anomaly detection models for detecting sensor faults and outliers in the IoT-a survey." *2019 13th International Conference on Sensing Technology (ICST)*. IEEE, 2019.
[2] Branch, Joel W., et al. "In-network outlier detection in wireless sensor networks." *Knowledge and information systems* 34 (2013): 23-54.

Sensor Data Anomalies & Data Integrity

What causes these?

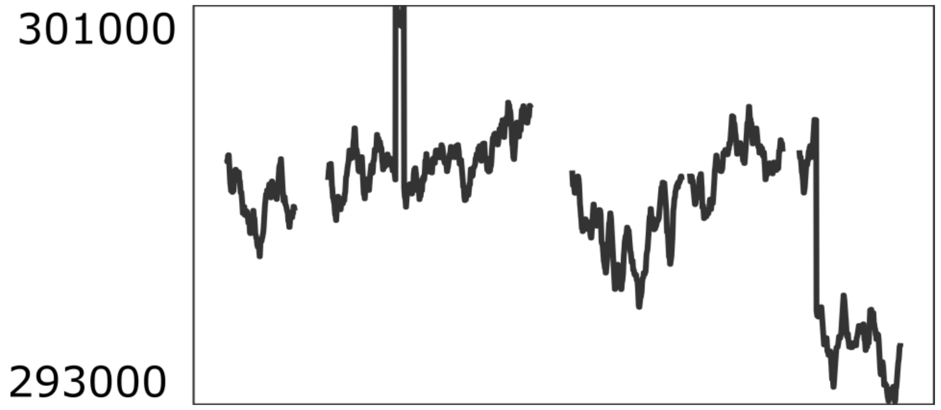
1. Sensing instruments maloperation
2. Bad calibration
3. Outdated sensing algorithms
4. Communication errors
5. Cyber intrusions
6. GPS issues
7. Aging sensors
8. Unused infrastructure assets
9. No sensor/comm firmware updates

Focus on existing works

1. Data quality
2. Supervised detection
3. Slow offline methods
4. Computationally expensive

Challenges remaining still…

1. **Sensor HEALTH Monitoring**
2. Lack of trustworthy labeled data
3. Time-varying color noise patterns
4. Need for ultra-fast inference speeds
5. Lack of model agnostic methods
6. Lack of quantifying uncertainty
7. Data volatility
8. High-volume data processing
9. Multimodal data processing



What can it impact?

Data pipeline to applications

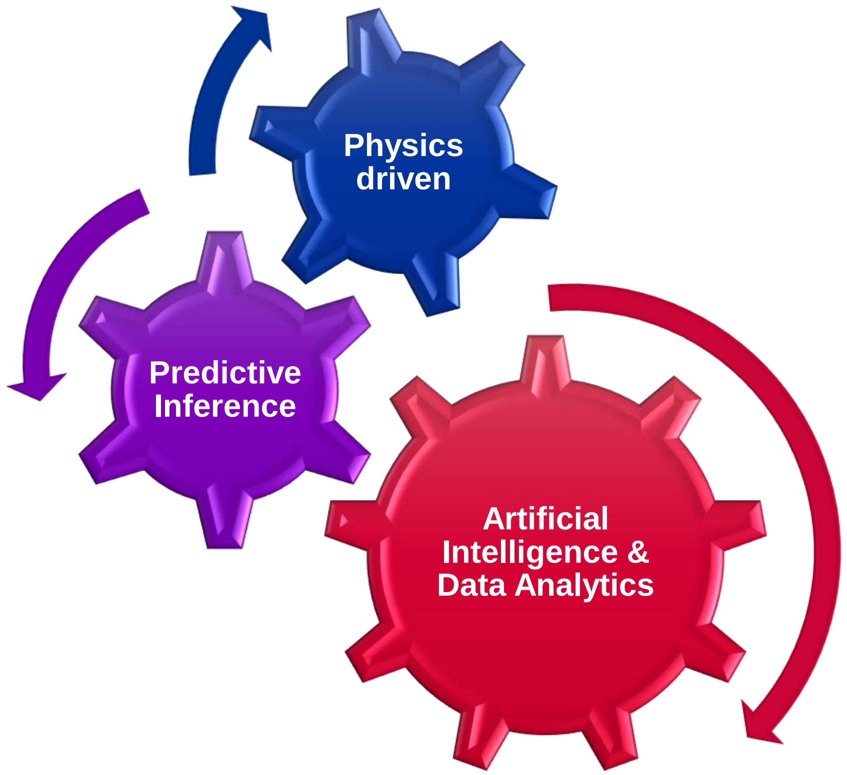
1. Situational Awareness
    1. Oscillation monitoring
    2. Oscillation source localization
    3. System observability
2. Wide area damping control using PMUs
3. Wide area protection using PMUs
4. High-fidelity Modeling
5. Control room operations
6. Heterogenous data aggregation

What advancements is it blocking?

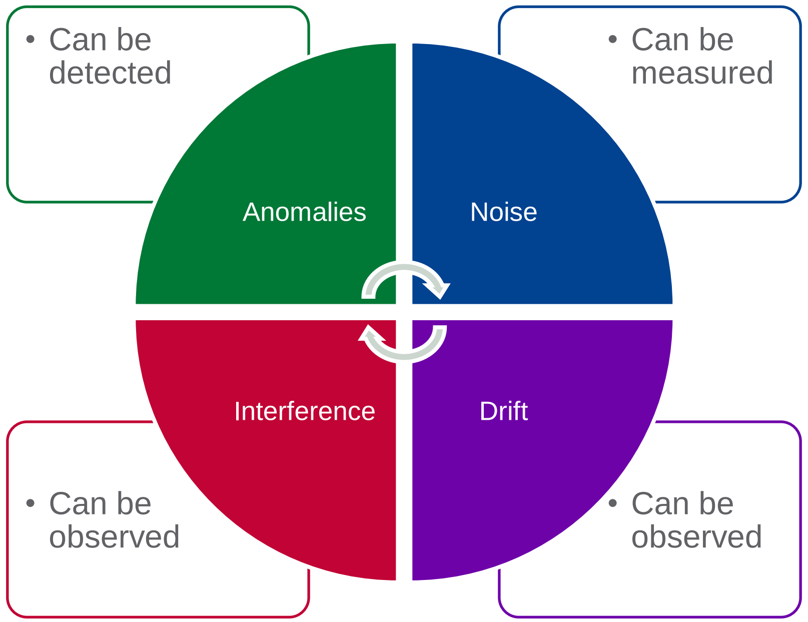
1. Automated capabilities
2. Digital twin platforms
3. Data-driven algorithms
4. IBR data analytics
5. Co-simulation
6. Co-optimization

SENTIENT Anomaly Detection Software

- Sensor Anomaly Detection and Failure Prediction Platform
- Open-source set of tools for sensor data:
  - Preprocessing power grid multimodal data
  - Anomaly/Event Detection
  - Event tracking and localization
  - Data imputation
  - Interpretation (error cause attribution)
  - Centralized and distributed computing algorithms
- Additional features
  - Supports single- and multi-sensor analyses
  - Handles large volumes of high-frequency data
  - Capable of high-speed online and offline processing
  - Compatibility with real-time application software in loop simulations

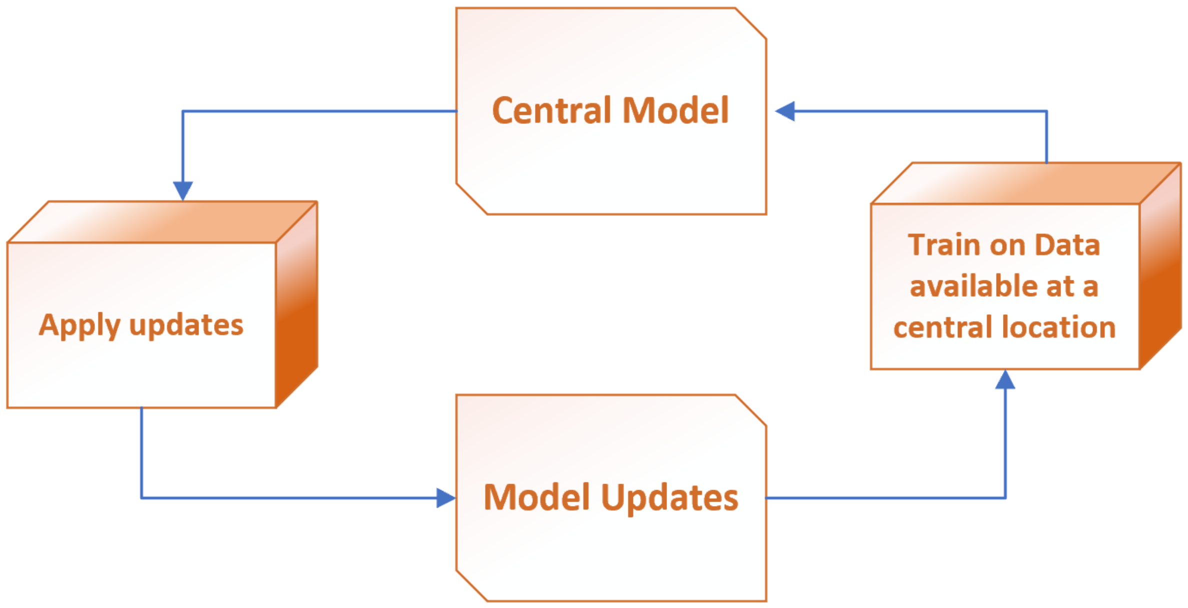


Monitoring Sensor Health

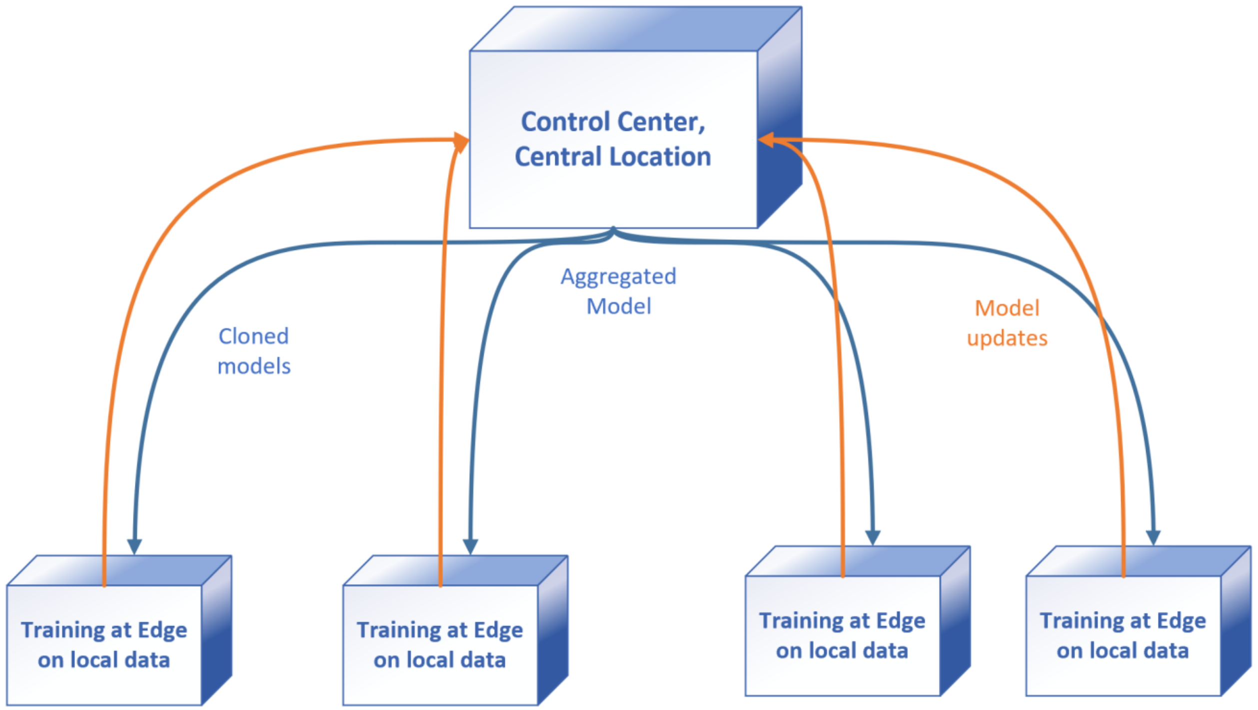


Sensor Events & Anomaly Detection Software Overview

Centralized Architecture



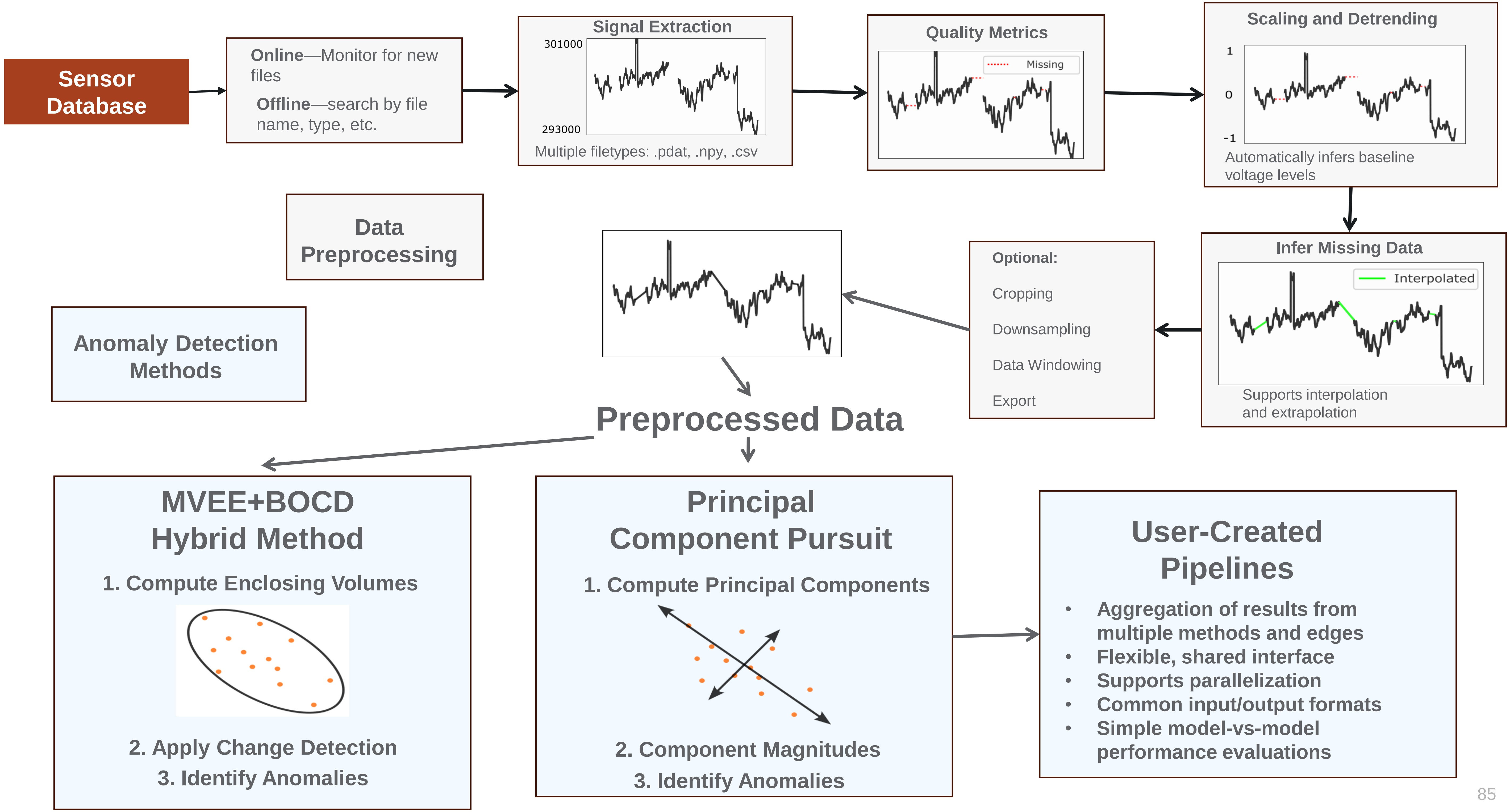
Distributed/ Federated



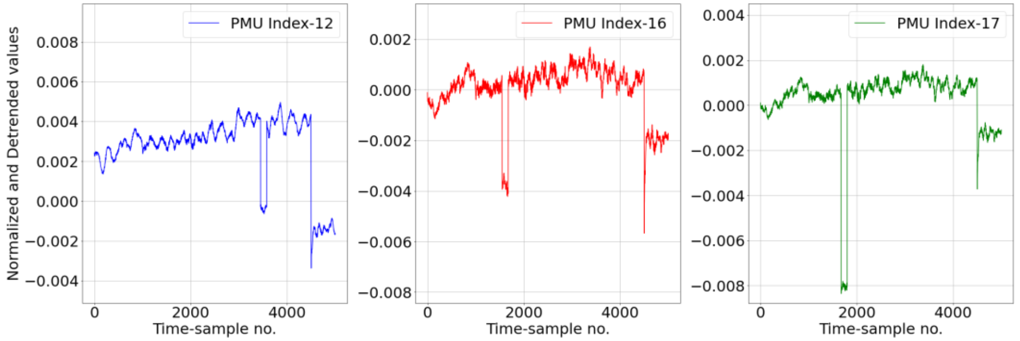
Hossain, Ramij R., Kaveri Mahapatra, and James P. Ogle. "Model Agnostic Bayesian Framework for Online Anomaly/Event Detection in PMU Data." *2023 IEEE Power & Energy Society General Meeting (PESGM)*. IEEE, 2023.

M. Shinkle, K. Mahapatra, T. Chen, J. Ogle, SENTIENT Anomaly Detection Platform: Online Detection of Sensor Events and Anomalies via Federated Learning, (pending patent)

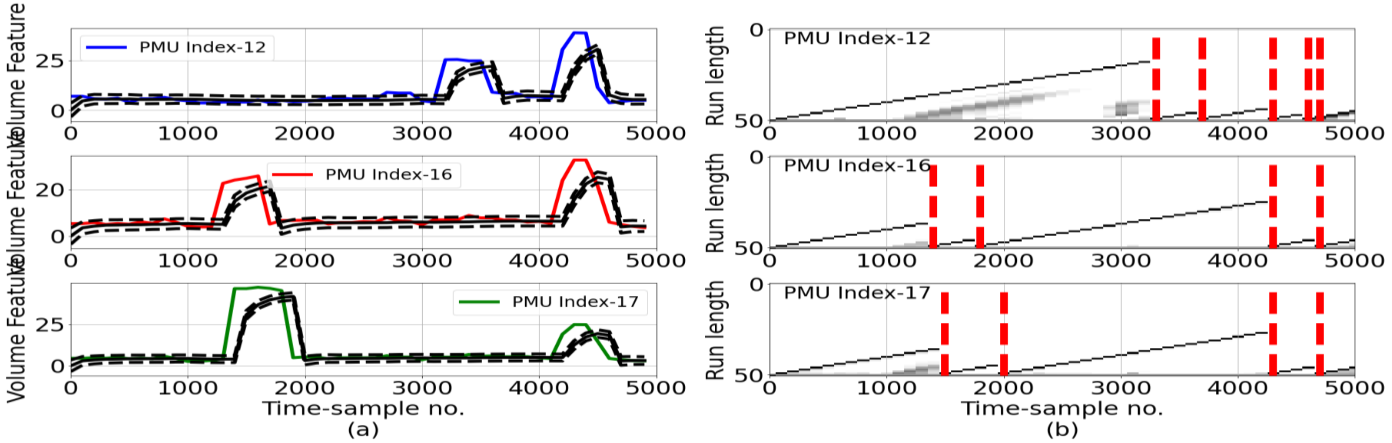
SENTIENT—Anomaly Detection Processes

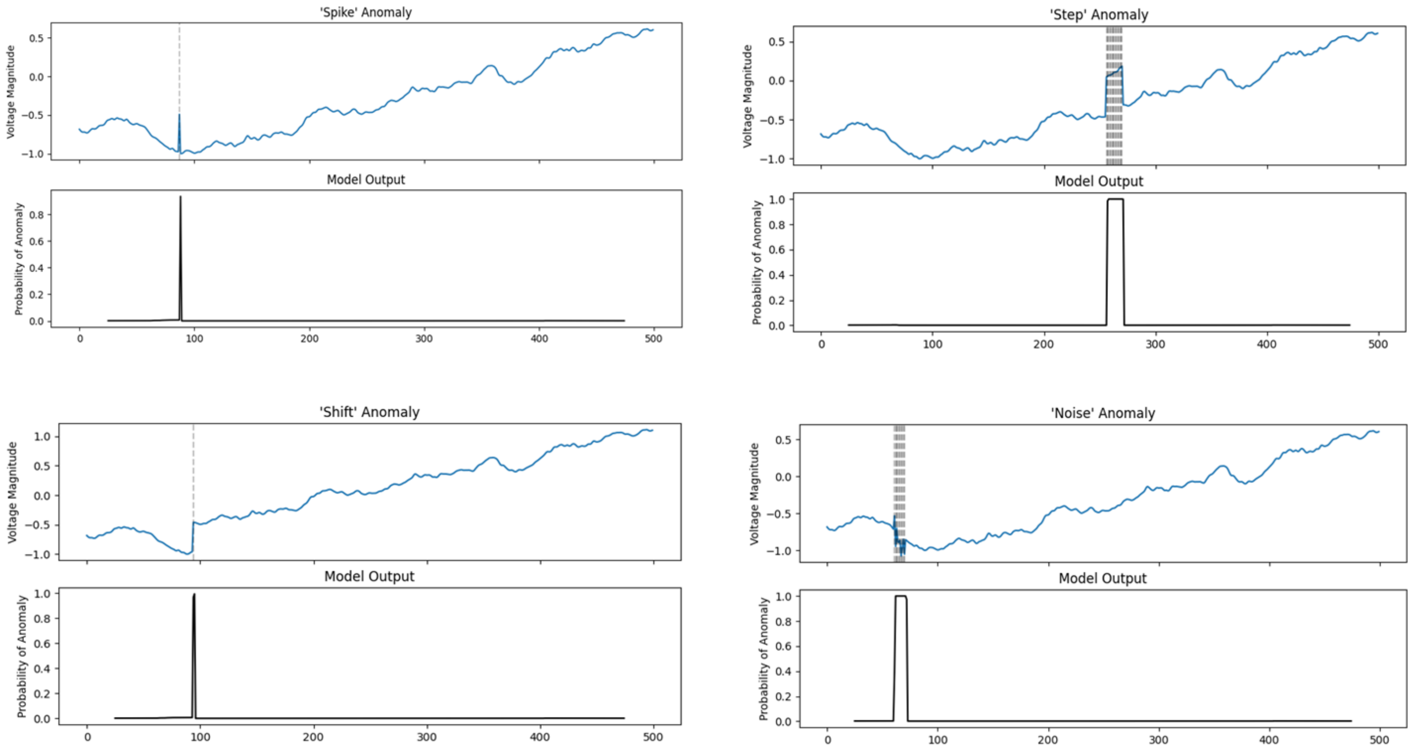


Anomaly Detection Performance

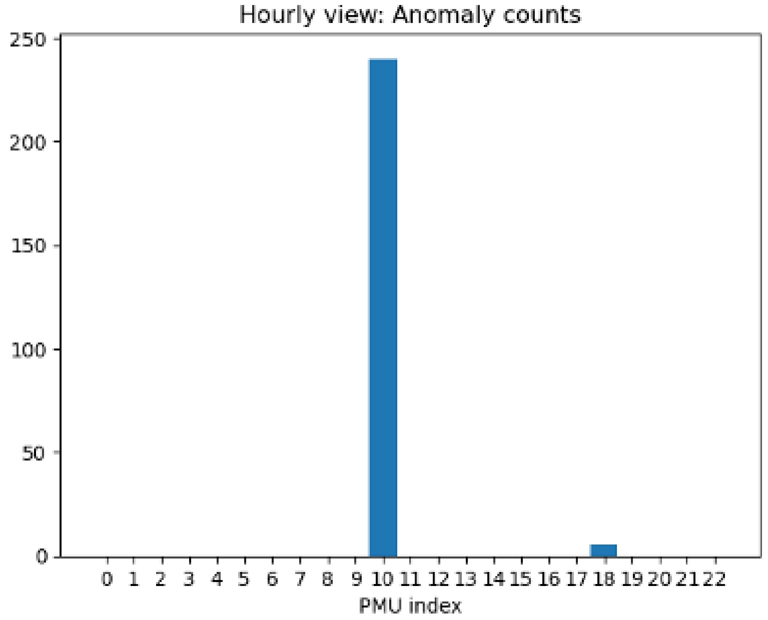


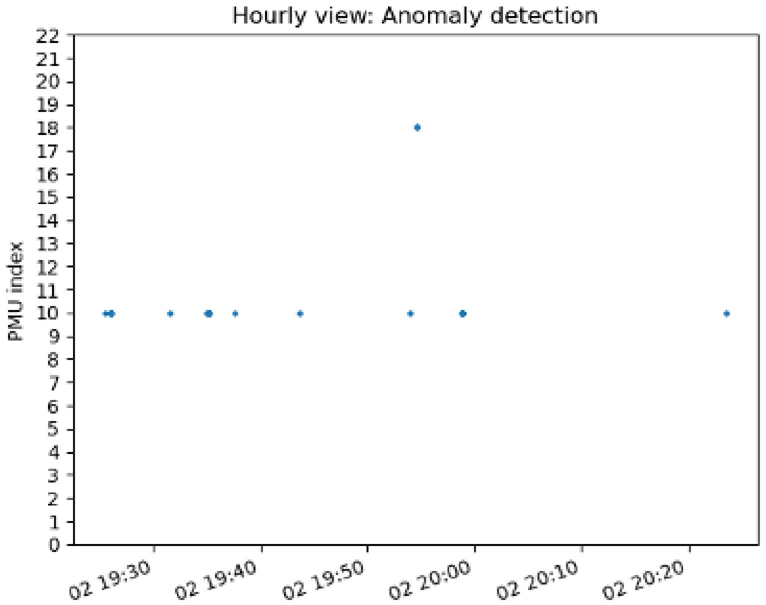
- Sample-wise anomaly location and duration
- Works for diverse types of anomalies
- **99.6%** accuracy on synthetic anomalies in the centralized aggregation
- **99.4%** accuracy on a federated platform
- Suitable for online monitoring
  - 150,000+ samples/second on standard laptop hardware

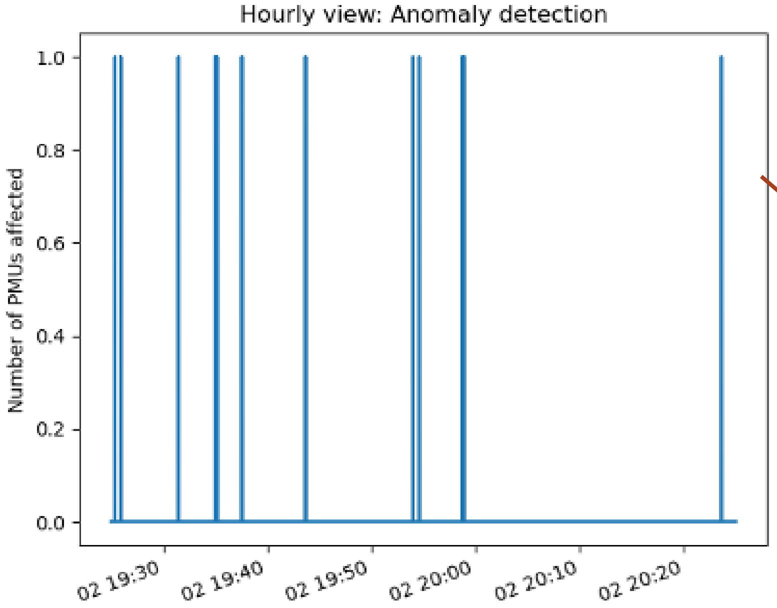


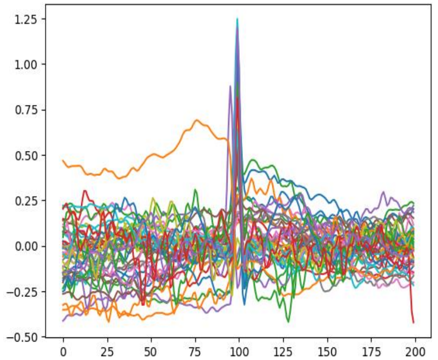


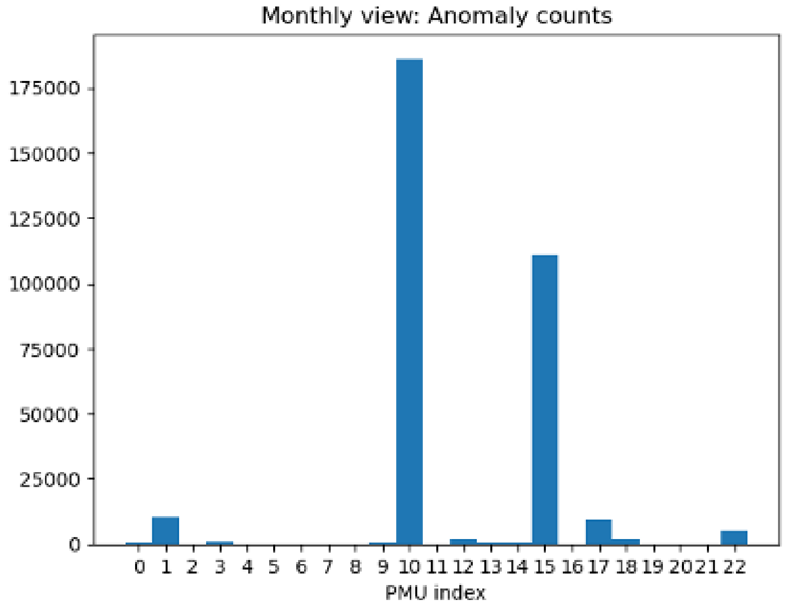
Results on field measured data: Long term trends

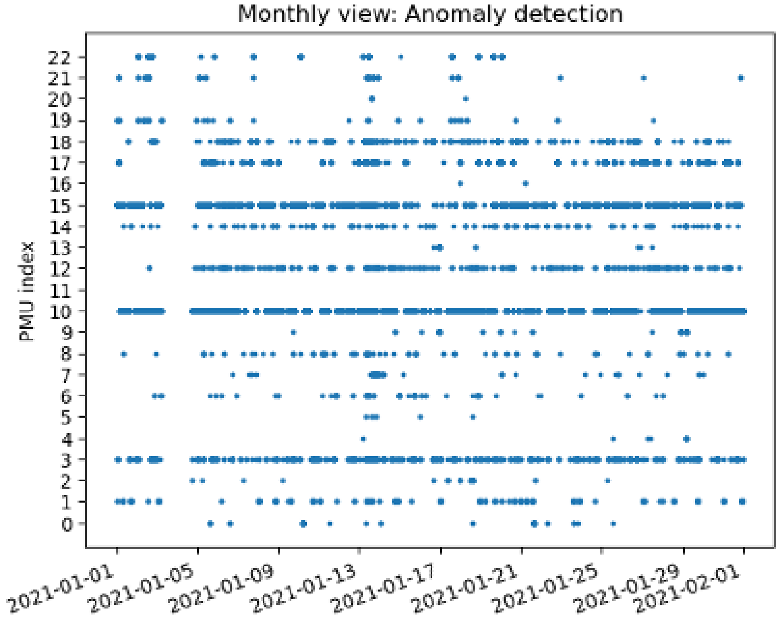


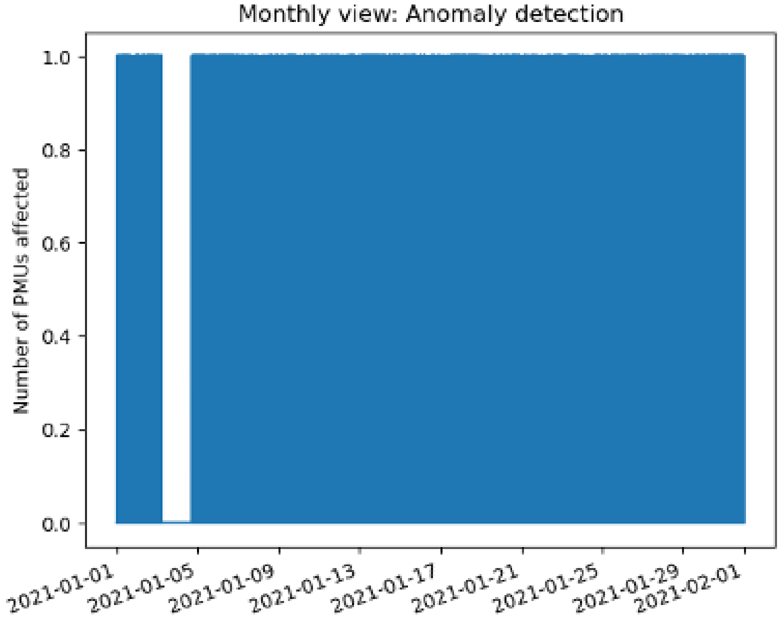






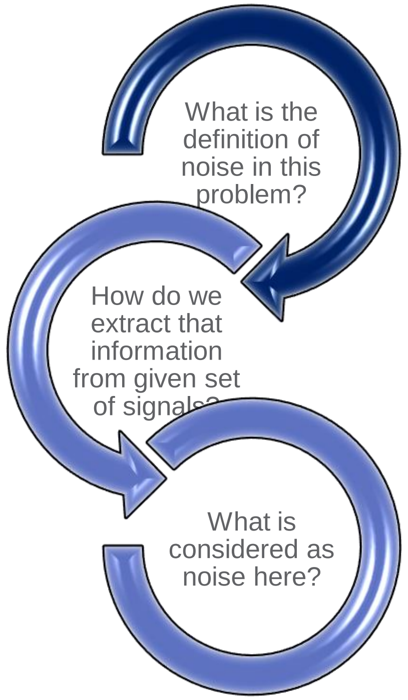


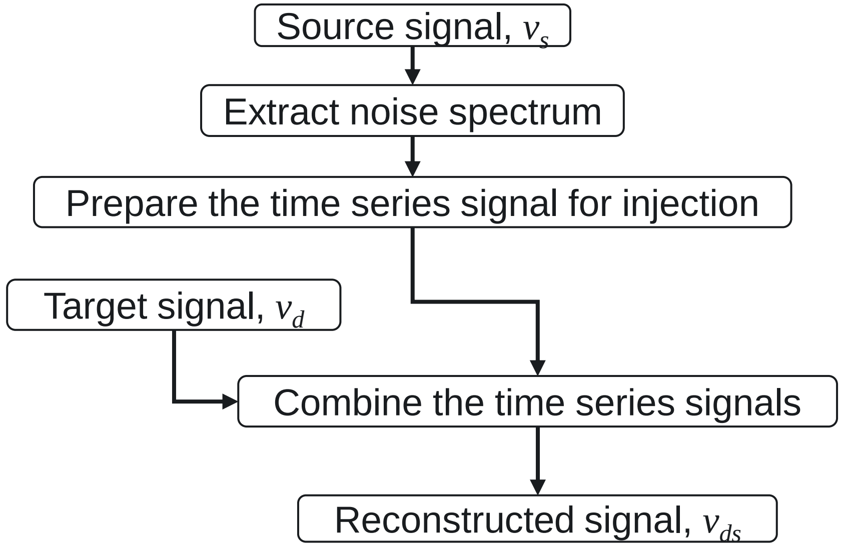




Create Synthetic Measurement Signals

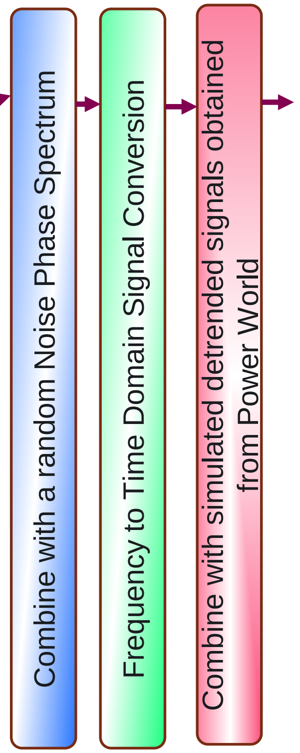
Accurate Noise Emulation Problem Formulation

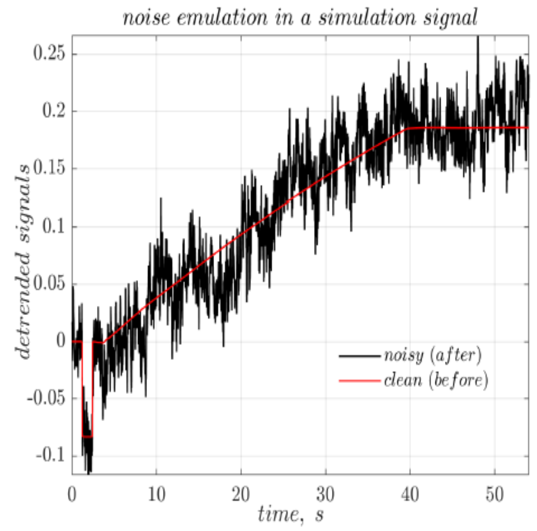




Clustering example in 2D*

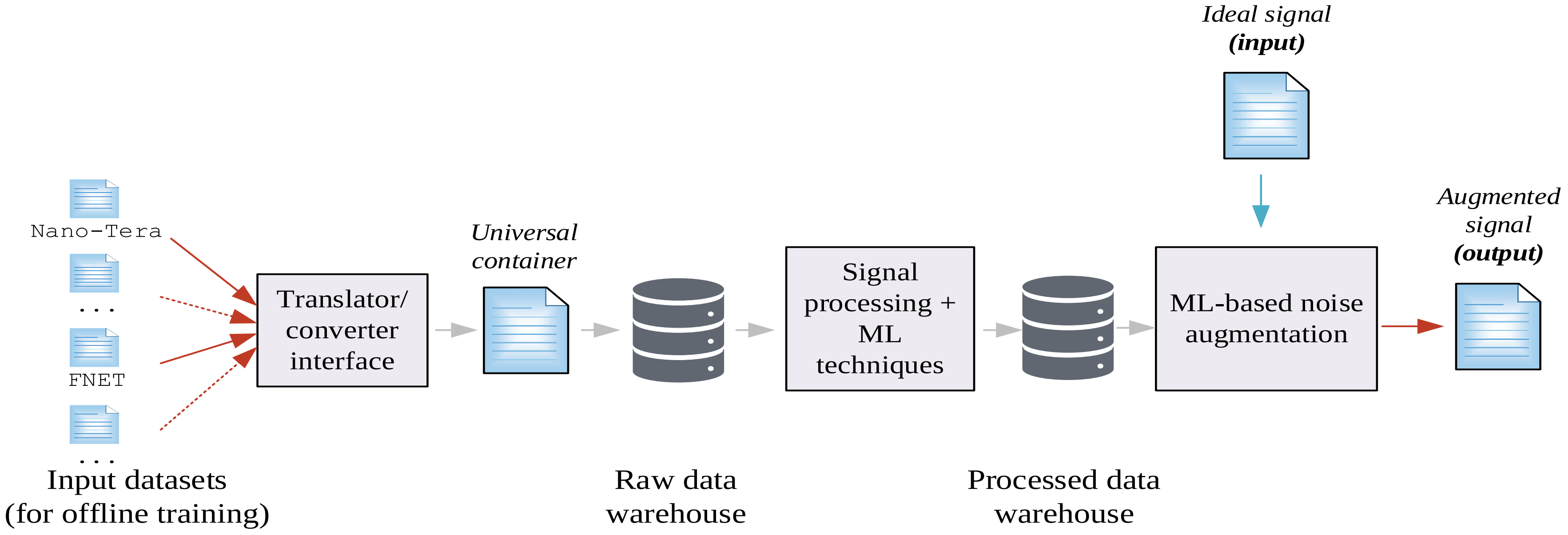
Three cluster with cluster centers



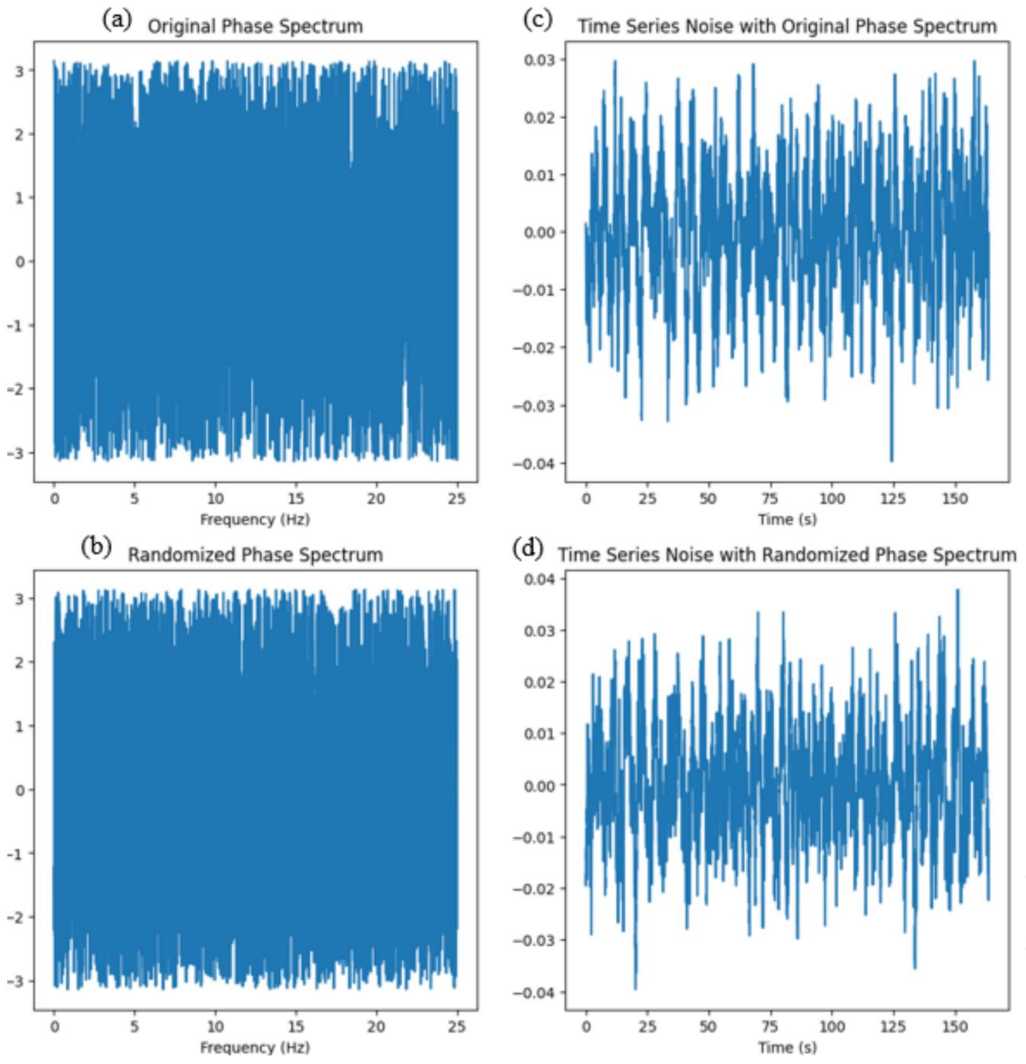


A detrended voltage phasor signal obtained from a Power World contingency simulation is shown in red. The resulting waveform after manual noise emulation process from a field PMU signal (NanoTera) is shown in black and contains similar frequency content as the field PMU signal and with randomized noise phase

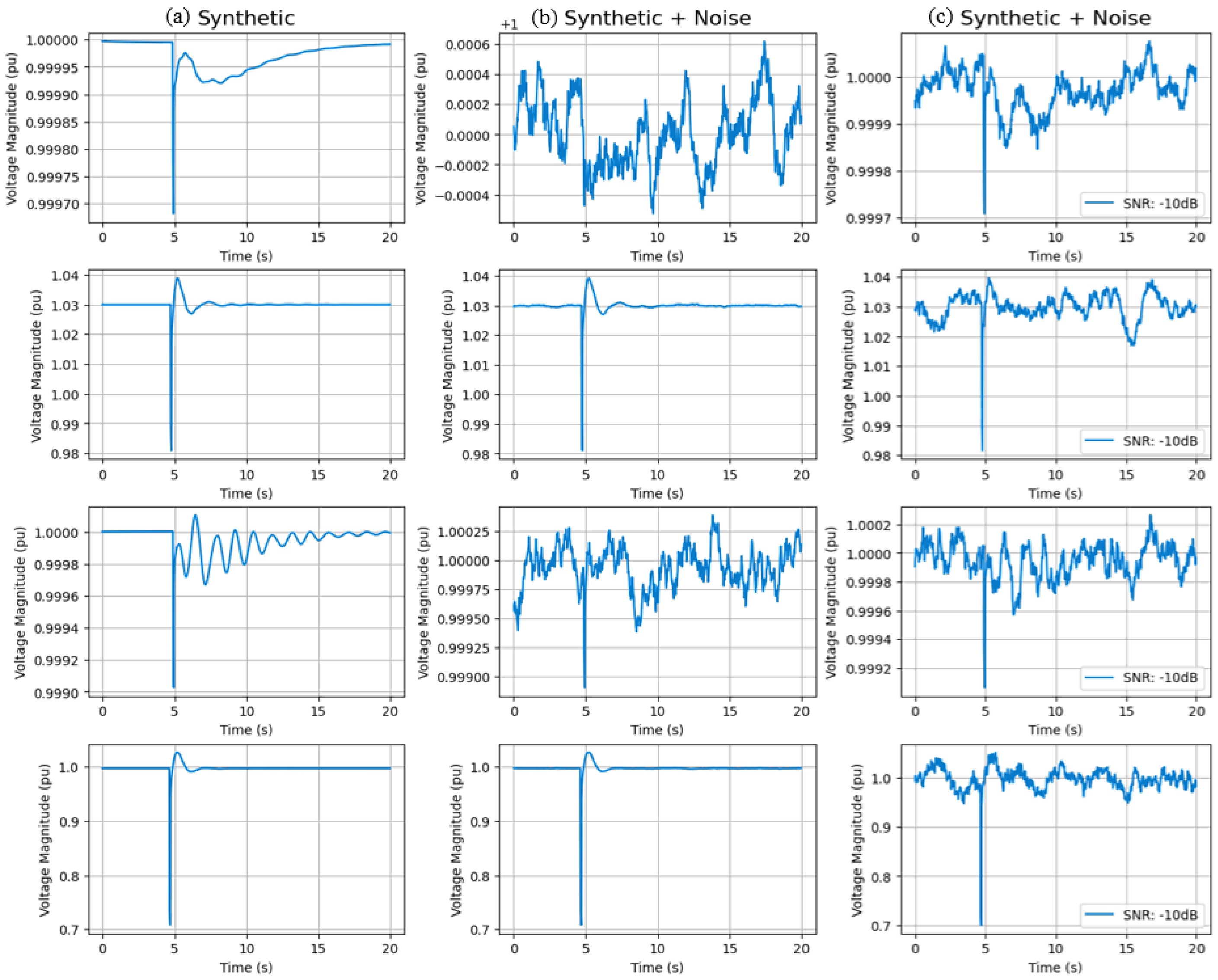
SENTIENT Synthetic Data Generator



SENTIENT Noise Emulation Software



With a variation of SNR



Lassetter, Austin R., Mahapatra, Kaveri, et al. "Data-Driven PMU Noise Emulation Framework using Gradient-Penalty-Based Wasserstein GAN." *2022 IEEE Power & Energy Society General Meeting (PESGM)*. IEEE, 2022.

Summary of SENTIENT software tools

- Anomaly detection software is dedicated to the detection, characterization, and localization of any abnormality in the incoming sensor datasets with high accuracy
- Anomaly detection software is designed with parallelization for both online and offline testing environments of the sensor datasets and processes data at an extremely fast speed for both PMU, micro-PMU and POW data rates for online applications using those
- Sensor health monitoring platform keeps track of concurring data patterns in the incoming datasets thus helping identify problems with the data acquisition layers
- Sensor health monitoring platform helps maintaining a clean data infeed for the online control and protection algorithm
- Noise emulation platform can generate realistic synthetic signals from simulated fake power system model datasets
- Detection and Characterization of the problems in incoming data over time would help maintain a clean data feed into EMS applications relying on high-speed measurements – PMU-driven state estimation, dynamic state estimation
- Identify data acquisition problems: identifying and localizing cyberattack vs device maloperation
- Maintain clean data infeed to robust wide-area monitoring, protection and control methods using PMU data sets

Thank you

Kaveri Mahapatra, PNNL
Email- Kaveri.Mahapatra@pnnl.gov

Power Sector Transmission & Distribution Data and Information

WEBINAR SERIES

High Fidelity at The Distribution System

Panayiotis (Panos) Moutis

Assistant Professor, City College (CCNY) of the University of New York (CUNY)

Distribution Task Team Co-Lead, North American Synchrophasor Initiative (NASPI)

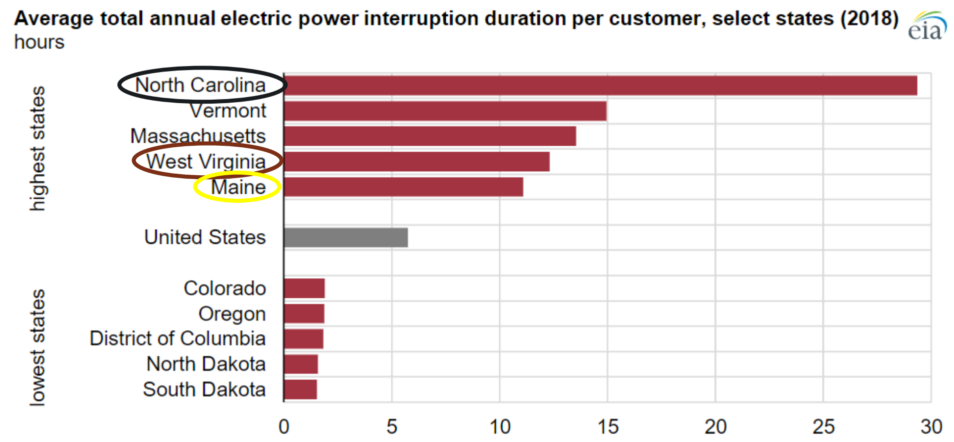
U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY

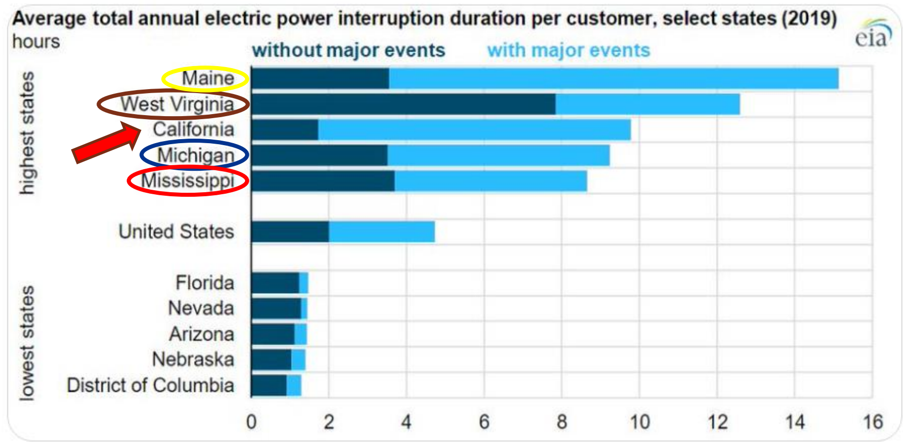
Los Alamos NATIONAL LABORATORY

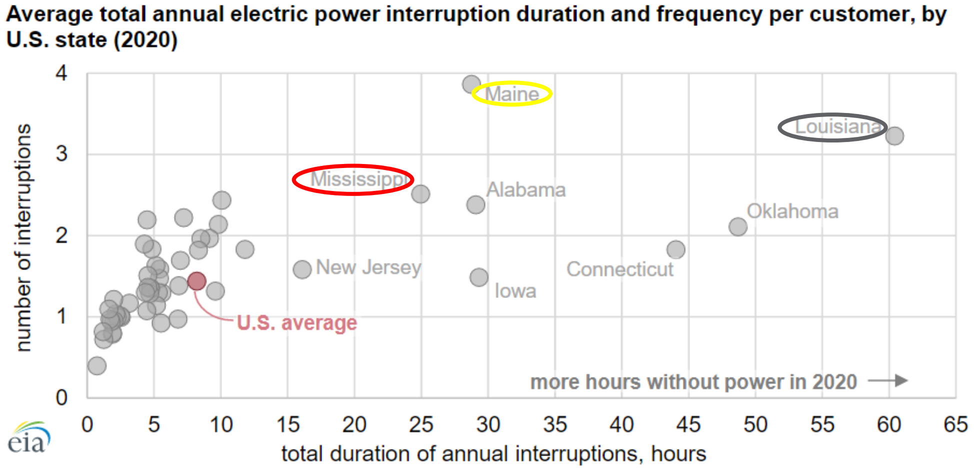
OAK RIDGE National Laboratory

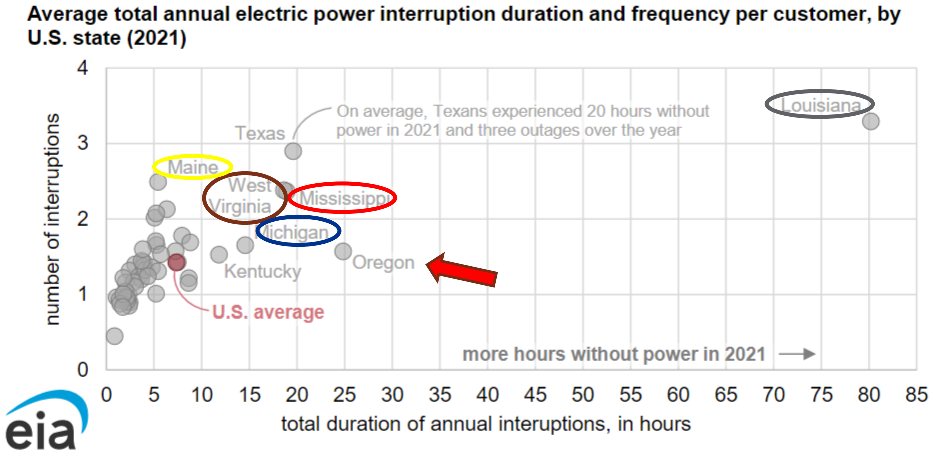
Pacific Northwest NATIONAL LABORATORY

Why am I here?









2022 US Census Bureau Median Family Income

Rank	STATE	Household Income (increasing)
1	MISSISSIPPI	$57,148
2	WEST VIRGINIA	$58,126
3	NEW MEXICO	$60,728
4	LOUISIANA	$61,042
5	ARKANSAS	$61,212
6	KENTUCKY	$61,790
7	ALABAMA	$63,401
8	OKLAHOMA	$66,786
9	TENNESSEE	$66,989
10	SOUTH CAROLINA	$67,922
11	IDAHO	$68,818
12	INDIANA	$69,505
13	MISSOURI	$69,614
14	FLORIDA	$69,884
15	NORTH CAROLINA	$70,000
16	MICHIGAN	$70,163
17	OHIO	$70,209
18	GEORGIA	$71,504
19	MONTANA	$71,836
20	MAINE	$72,988
21	NEVADA	$73,083
22	ARIZONA	$73,262
23	TEXAS	$74,636
24	PENNSYLVANIA	$74,805
25	SOUTH DAKOTA	$74,820

The distribution grid is NOT OK!..

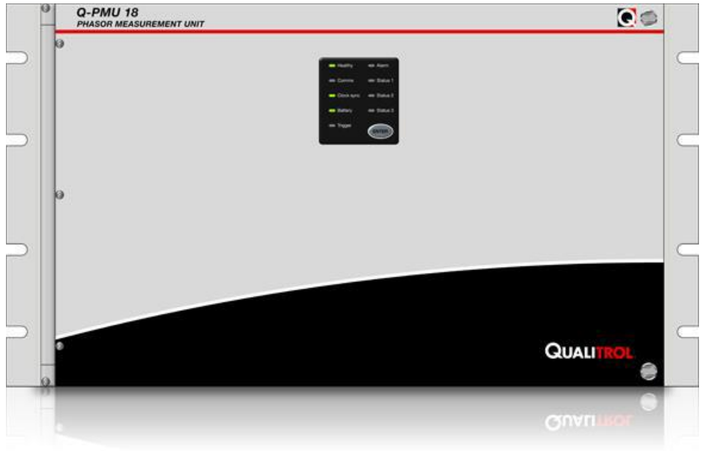
<u>Why</u> are distribution grids is failing?

- Little maintenance of ageing equipment (incl. vegetation control)
  - Reasons for faults left unchecked
- No digital models, poor monitoring+automation (TX “rolling” blackouts)
- Designed to retain functionality under (some) faulty conditions
  - (Some) Faults go unnoticed until several pile up, but <u>all</u> must be cleared
- Renewables arbitrarily installed & passively operated
- Not properly restructured business

Much of the grid built per the “fit & forget” or “fail gracefully” strategies…

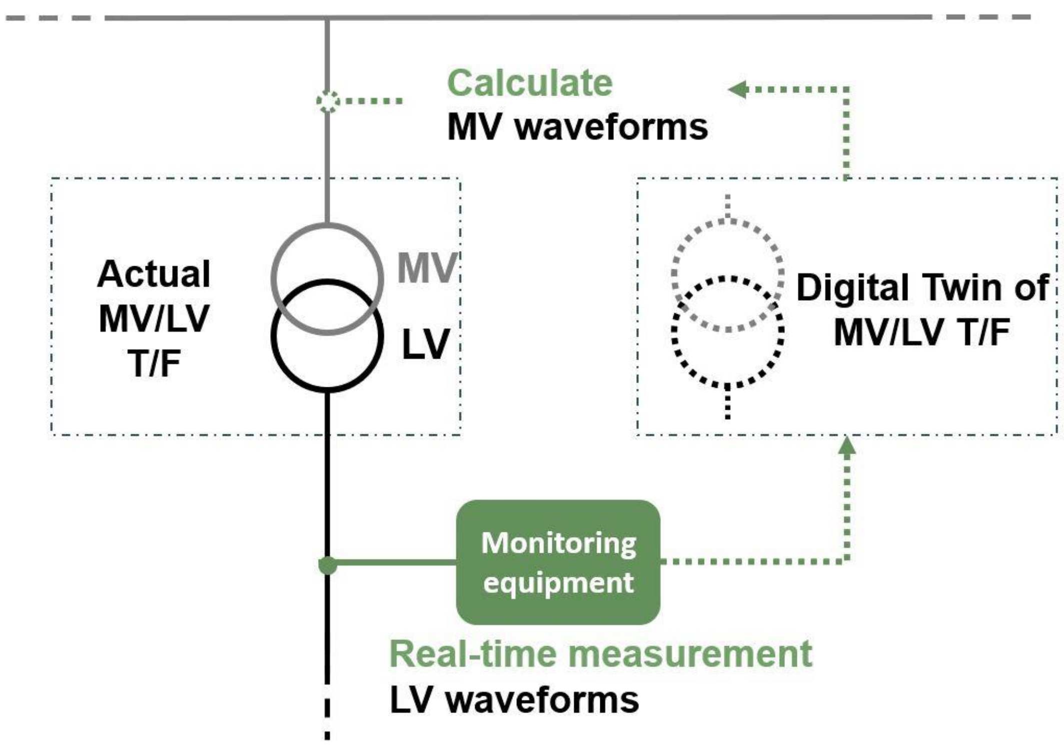
High accuracy, high granularity monitoring value case

- Devices capturing the time-varying signals of voltage & current
- “Phasor Measurement Unit” (PMU) capturing phase angle and magnitude
- “Point on Wave” (PoW) capturing sub-cycle signal detail
- Standardized equipment (e.g. IEEE Std C37.118)
- Considering expanding standardization for distribution system uses
- Much improved costs in the last few years



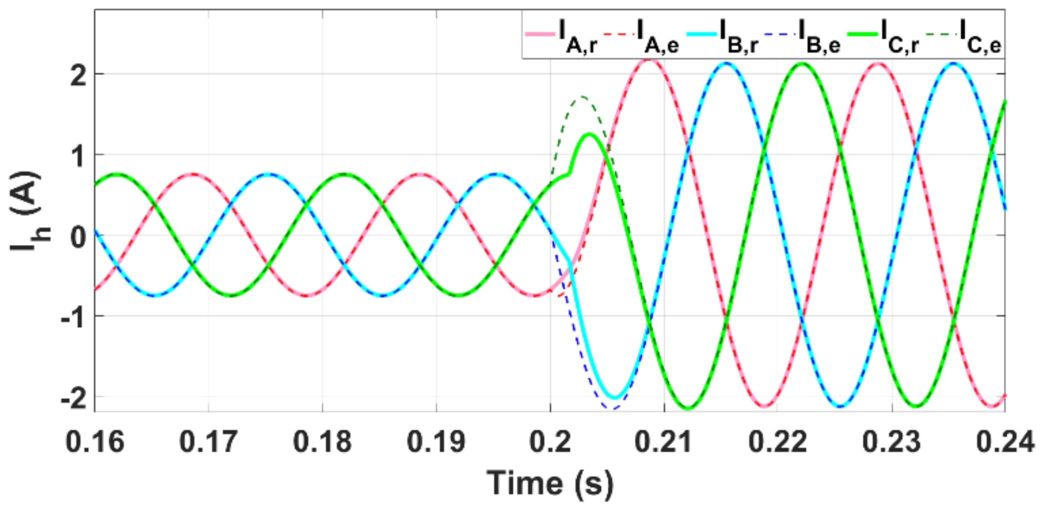
Value proposition for distribution grid monitoring

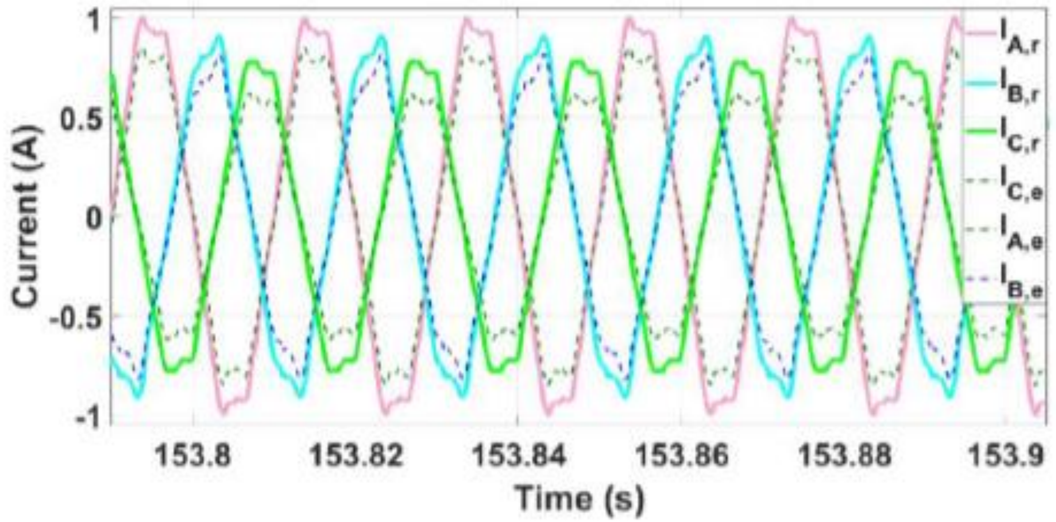
- The idea of the digital twin of a distribution transformer (T/F)
- The value of distribution T/F digital twin:
  - Sensing on Low voltage (LV)
  - MV is estimated/twinned
  - Detect:
    - Faults
    - Power Quality
    - Inverse current
  - Minimum disruption compared to other methods



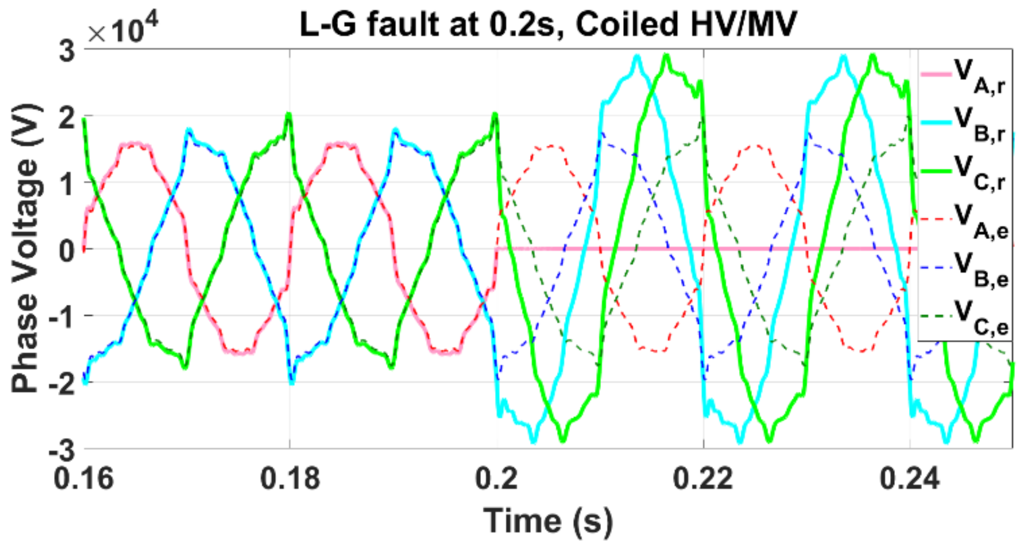
Distribution grid monitoring with transformer sensing (1/2)

- Monitoring normal conditions and high-harmonics content



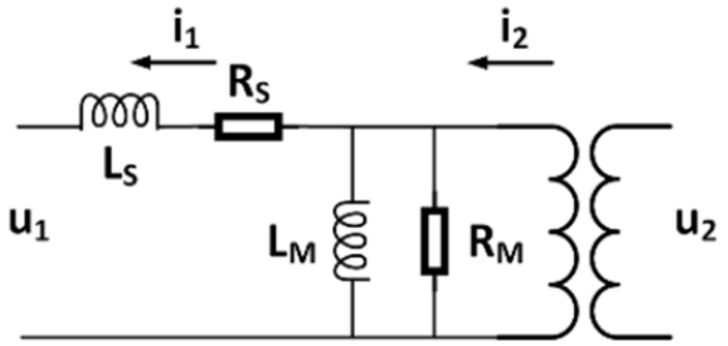


- Transient monitoring of faults, excl. ground-faults, i.e. back to the drawing board or do we *redesign distribution*?



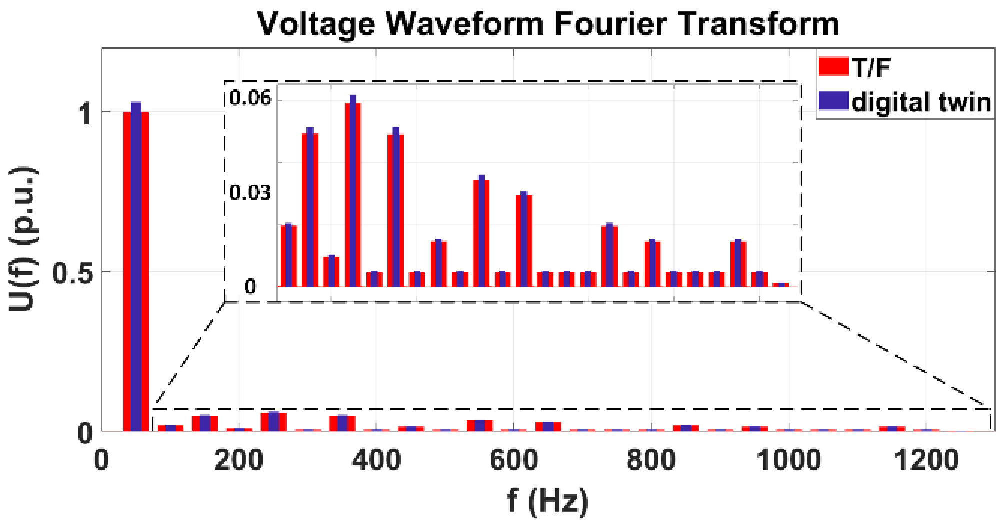
Distribution grid monitoring with transformer sensing (2/2)

- Transformers are low-pass filters



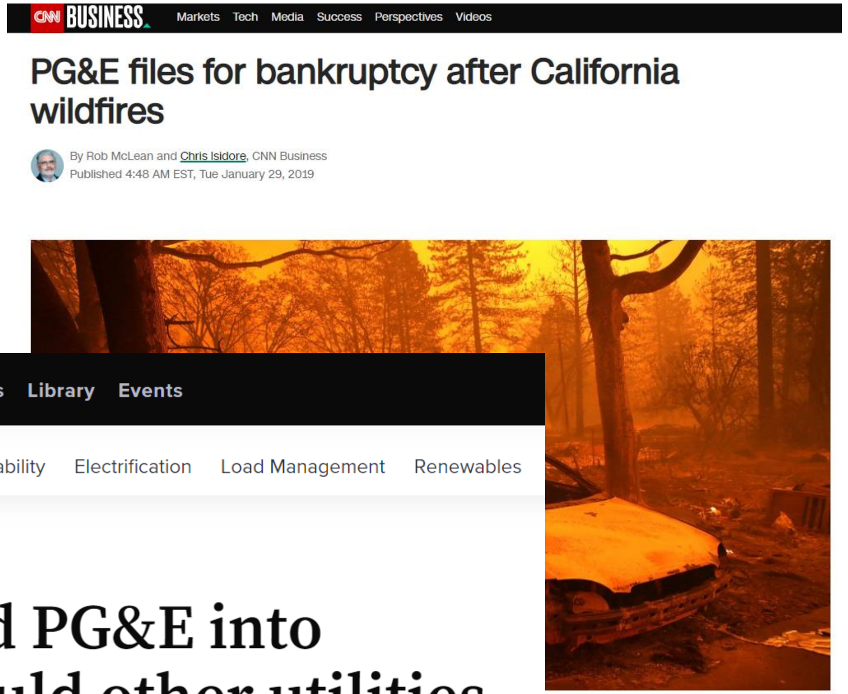
- Will circuit nature of transformer the accuracy of harmonics monitoring?

- No significant loss



More info: **Moutis P**, Mousavi O. (2020). Digital Twin of Distribution Power Transformer for Real-Time Monitoring of Medium Voltage from Low Voltage Measurements. IEEE Transactions on Power Delivery (IEEE).

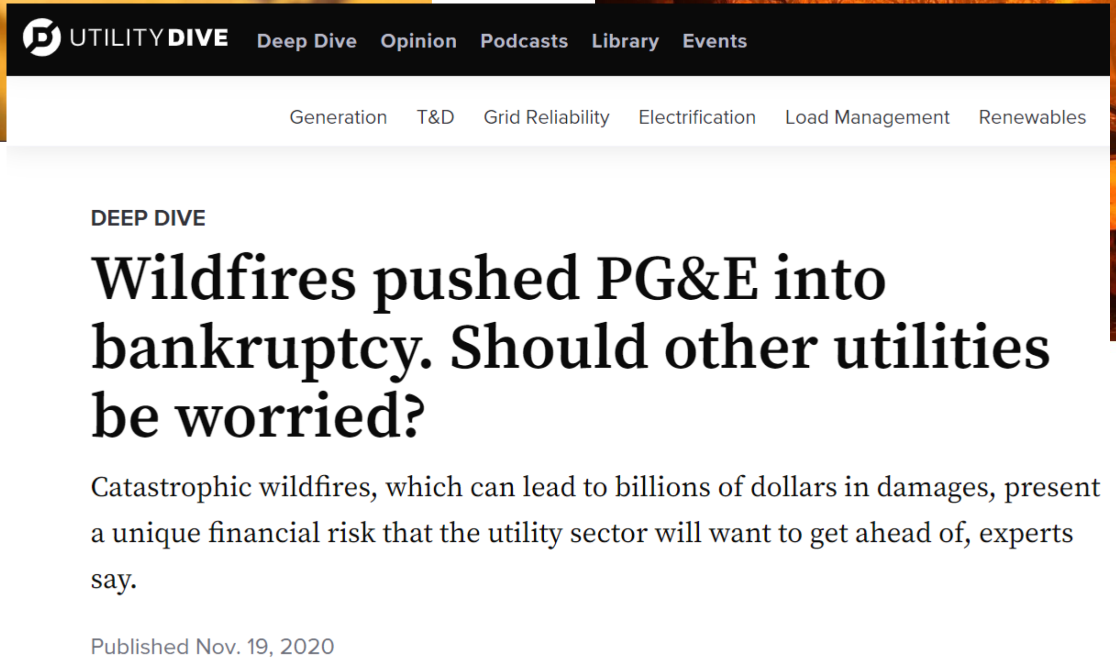
From culpability to conservatism...



CNN BUSINESS Markets Tech Media Success Perspectives Videos

PG&E files for bankruptcy after California wildfires

By Rob McLean and Chris Isidore, CNN Business
Published 4:48 AM EST, Tue January 29, 2019



UTILITY DIVE Deep Dive Opinion Podcasts Library Events

Generation T&D Grid Reliability Electrification Load Management Renewables

DEEP DIVE

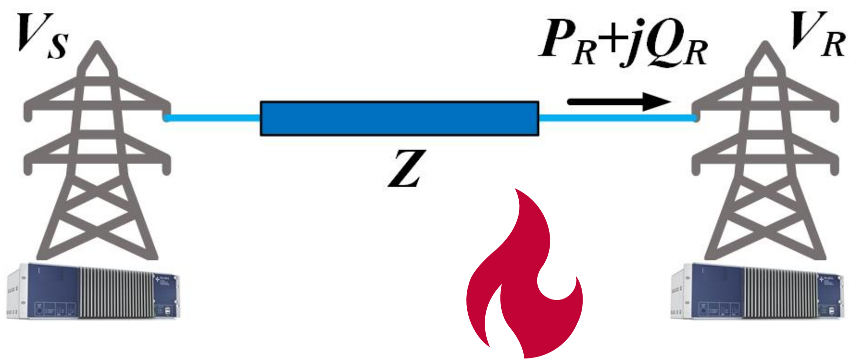
Wildfires pushed PG&E into bankruptcy. Should other utilities be worried?

Catastrophic wildfires, which can lead to billions of dollars in damages, present a unique financial risk that the utility sector will want to get ahead of, experts say.

Published Nov. 19, 2020

Value proposition for conductor sensing for fire detection

- Impedance includes resistance (affected by temperature) & reactance



$$Z(T_c) = R(T_c) + jX = |Z(T_c)|cos\delta(T_c) + j|Z(T_c)|sin\delta(T_c)$$

$$R(T_C) = R_{ref} \cdot \left[1 + \alpha\left(T_c - T_{c,ref}\right)\right]$$

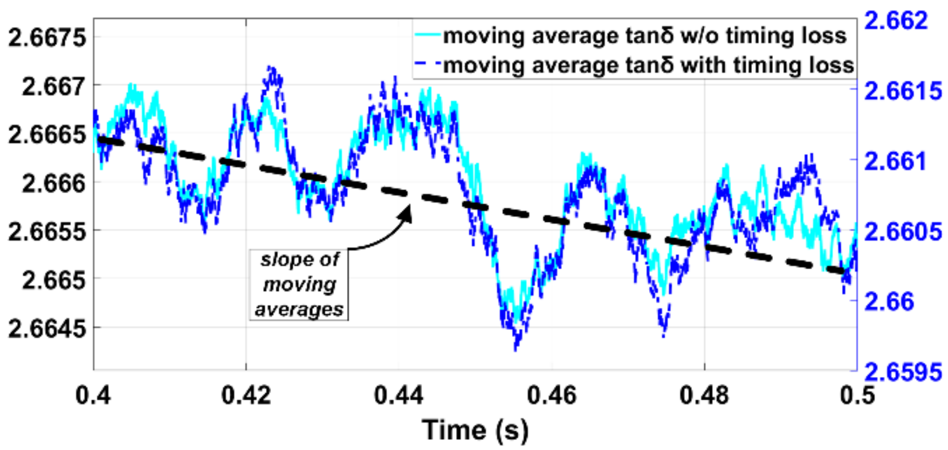
$$\frac{dT_c}{dt_T} = \frac{1}{m \cdot C_p}[R(T_c) \cdot I^2 + q_s - q_c(V_w, T_s, T_a,) - q_r(T_s, T_a)]$$

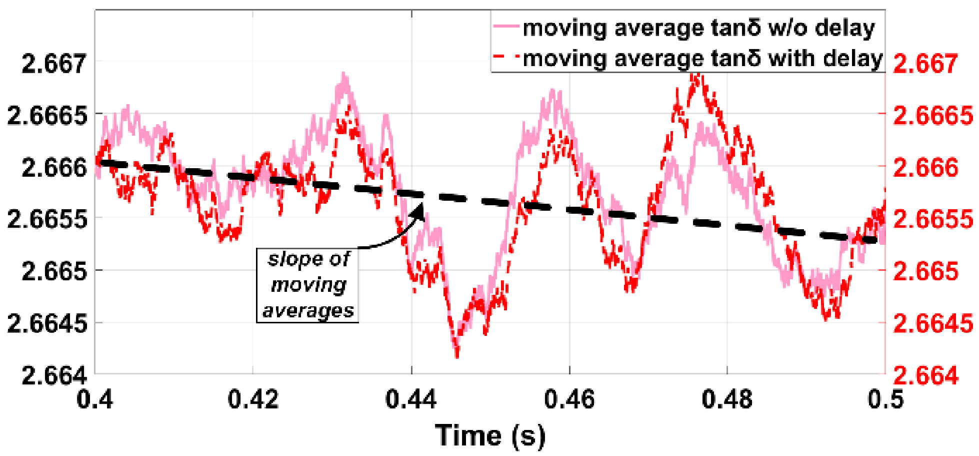
More info: **Moutis P.**, Sriram U. (2022). PMU-Driven Non-Preemptive Disconnection of Overhead Lines at the Approach or Break-Out of Forest Fires. IEEE Transactions on Power Systems.

Condition monitoring & effectiveness

- Conditions to detect approaching forest fire in <0.1s:
  - Burning for at least 60 s at most 5 m from the conductor,
  - V_w<1.35m/s and line loading >90% and
  - Burning for at least 10 s at most 10 m from the conductor, T_s<57°C, line loading>50%.

Control type & conditions	*Δtanδ*			
	TP	TN	FP	FN
Control 1 with ΔT_c>2.87°C	99.32	0.29	0.29	0.10
Control 2 with ΔT_c>2.87°C and V_{err}<0.003%	89.13	0.00	0.00	10.87





Path Forward as from NASPI DisTT Roadmap of Projects

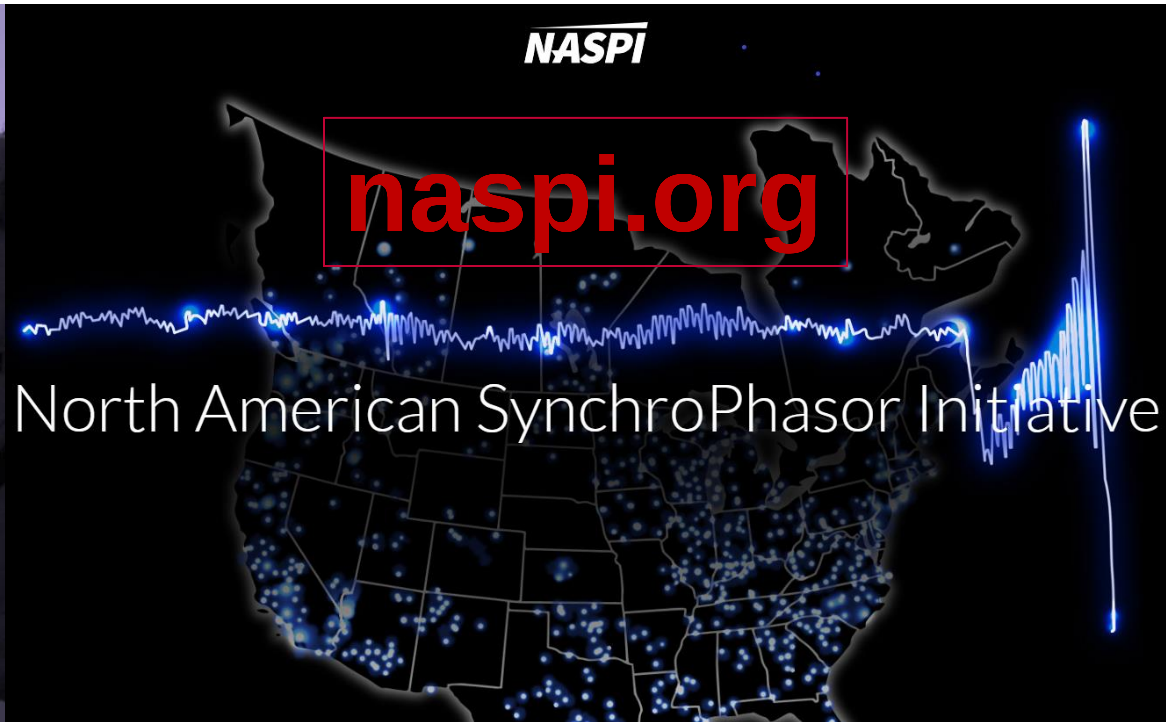
1. Train the (utility) **Champion** on Distribution Sync'd measurement uses
2. Effects of Inverter-Based Resources (IBR) & DERs on **sync'd measurement requirements**: on going IEEE effort to identify requirements (Ken Martin)
3. Value propositions for sync'd measurements in **IBR & DER-rich grids**
4. Value **counter-propositions** for sync'd measurements; "holding a hammer" does not make everything we see a "nail"

Others: IT & TelCom challenges, Sync'd measurement visualization & new metrics

Thanks for your attention!

Questions, please?

http://panay1ot1s.com



Thank you

Panos Moutis, CCNY & NASPI
pmoutis@ccny.cuny.edu

Power Sector Transmission & Distribution Data and Information

WEBINAR SERIES

Concluding Remarks

U.S. DEPARTMENT OF ENERGY OFFICE OF ELECTRICITY

Los Alamos NATIONAL LABORATORY

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY