Data Analytics for Secure and Resilient Grid Infrastructure

CIGRE U.S. Next Generation Network Webinar

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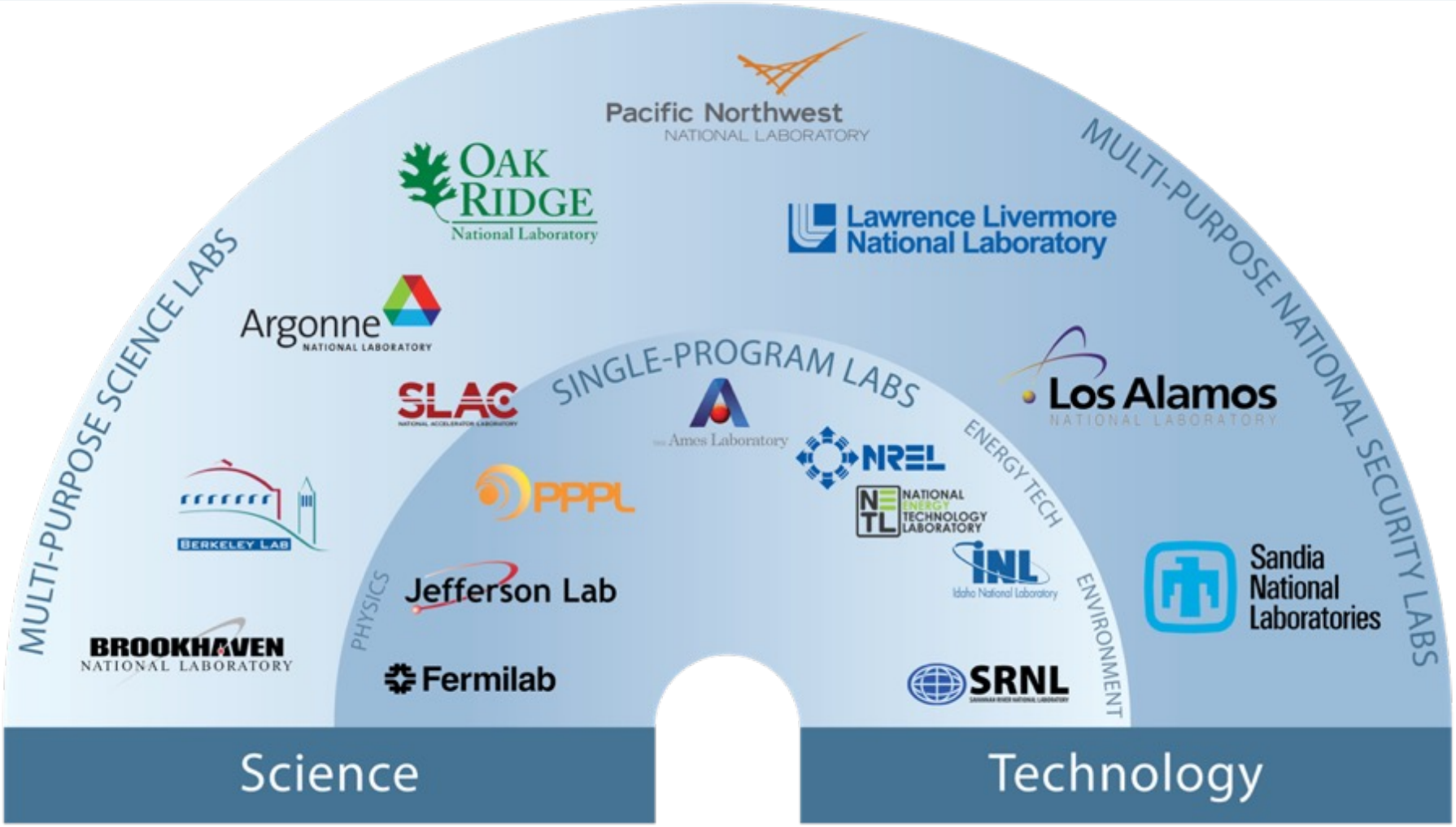
Introduction – Lawrence Livermore National Laboratory



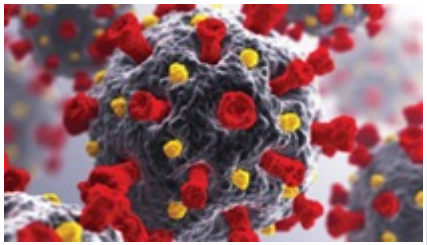
Introduction – LLNL

LLNL's mission: to strengthen national security through world-class science, technology, and engineering

Nuclear Deterrence

- Annual Assessment
- Stockpile modernization
- Advanced science and technologies
- NNSA enterprise agility and resilience

Threat Preparedness and Response



- Pandemic response tools / biosecurity
- Nuclear counter proliferation and counterterrorism
- Forensic science
- All-source intelligence

Climate and Energy Resilience

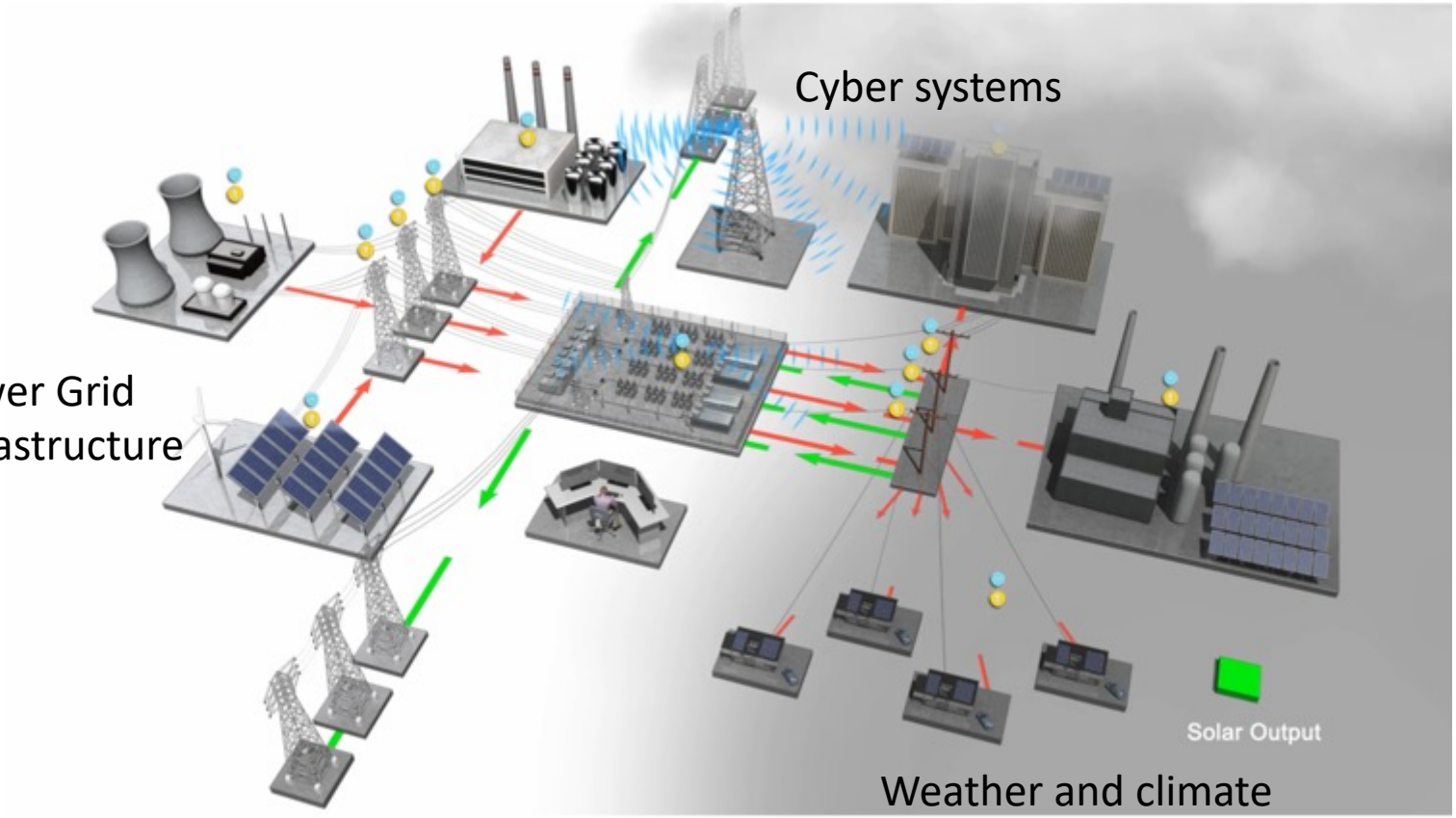
- High-fidelity climate impact assessments
- Reliable, secure, low-carbon energy
- Infrastructure sustainability
- Advanced materials and manufacturing

Integrated Deterrence and Competition

- Emerging technologies R&D and assessments
- Strategic defense and conventional strike
- Space / cyber security
- Cognitive simulation / artificial intelligence

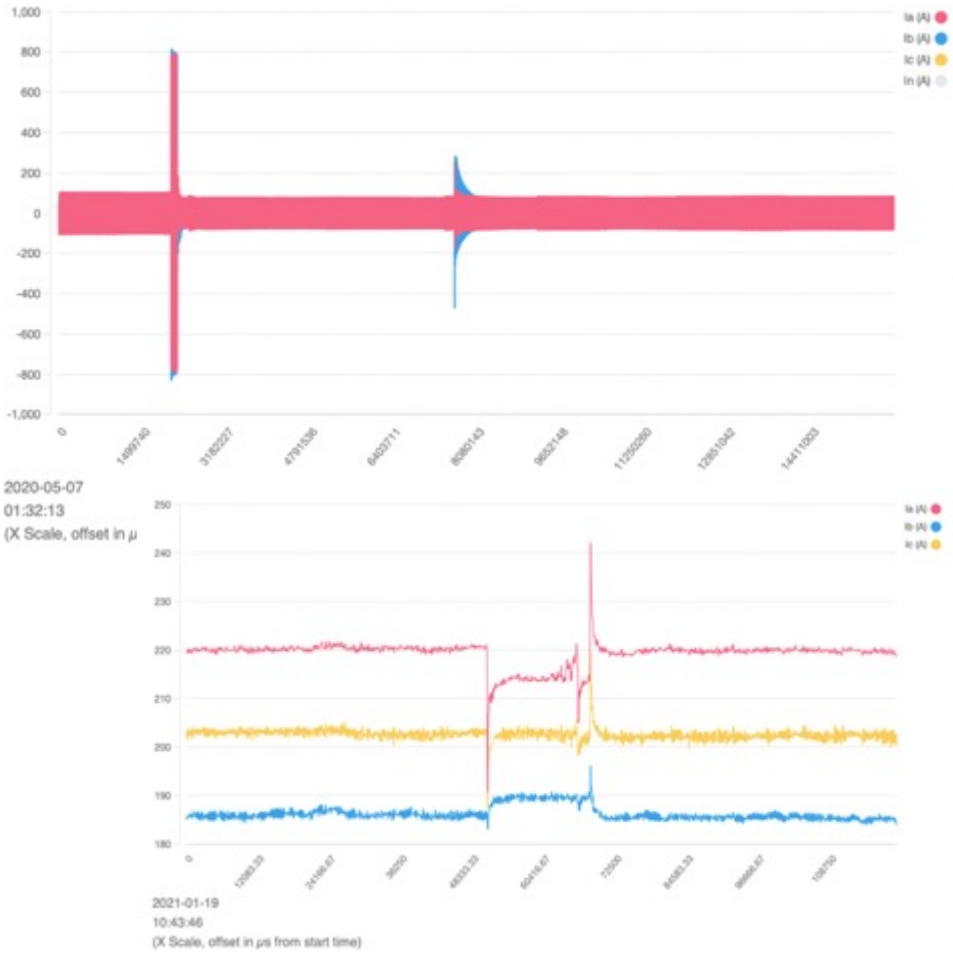
Security and resiliency of power grid infrastructure

- Increasingly interdependent on climate and cyber systems
  - Opportunities and challenges



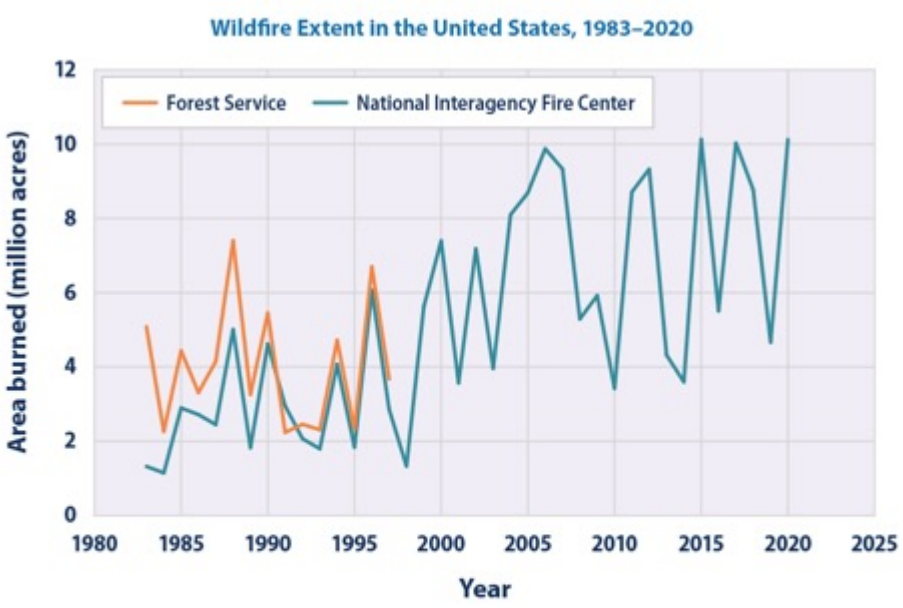
How can data science address grid security and resilience challenges?

- Increased situational awareness
  - New sensing and measuring instruments and data management
  - Leveraging/retrofitting existing sensors
- Preventative operation and planning
  - Planning and operation against extreme weather events
  - Preventative maintenance to minimize outages
- Discovery of contextual information from multiple sources of data
  - Wide area monitoring
  - Post-event forensic analysis
  - Localization of events



Data analytics for wildfire prevention

- Background
  - Fires caused by electric equipment → increasing concern across US



Data sources:
- NIFC (National Interagency Fire Center). 2021. Total wildland fires and acres (1983–2020). Accessed March 2021. www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html.
- Short, K.C. 2015. Sources and implications of bias and uncertainty in a century of U.S. wildfire activity data. Int. J. Wildland Fire 24(7):883–891.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

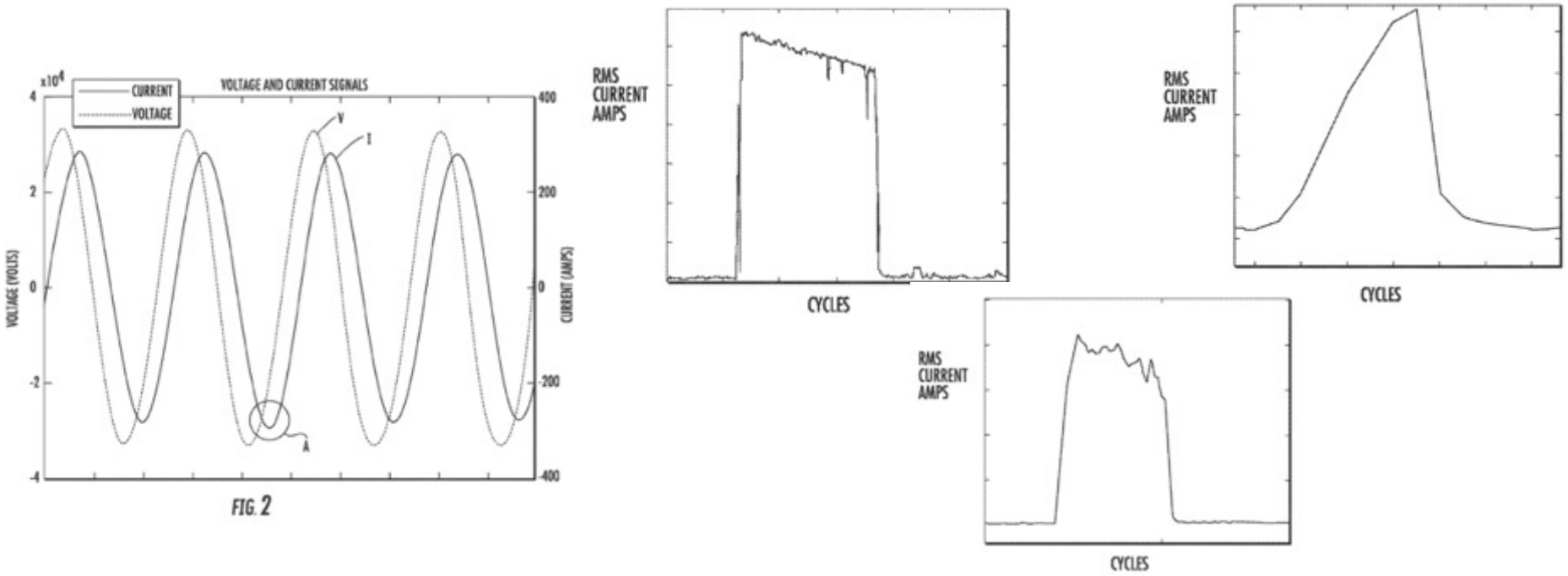
National Interagency Coordination Center, Wildland Fire Summary and Statistics Annual Report 2022

Arcing detection in distribution systems

- **Objective**
  : detect arcing on distribution systems to prevent fires caused by power equipment
- **Challenges**
  - Events are transient (a few cycles), fault-currents are low (tens of amps)
- **Questions**
  - What do arcing signatures look like?
  - What measurements/sensor devices are needed?
  - How do we identify arcing?
- **Approach**
  - Continuous measurements from high-resolution sensors
  - Capture anomalies and extract features from signal processing techniques
  - Identify low-current arcing from known signatures

Arcing faults

- Example measurements



Source: U.S. Patent US9046563B2
Arcing event detection

Detecting faults and measuring devices/systems/data

- Protection devices
  - Relays
  - Digital fault recorders
- Continuous measurements
  - SCADA
  - AMI (advanced metering infrastructure)
  - PMU (phasor measurement unit)
  - Point-on-wave (POW)
- Event records
  - Outage and maintenance records
  - Device activation records

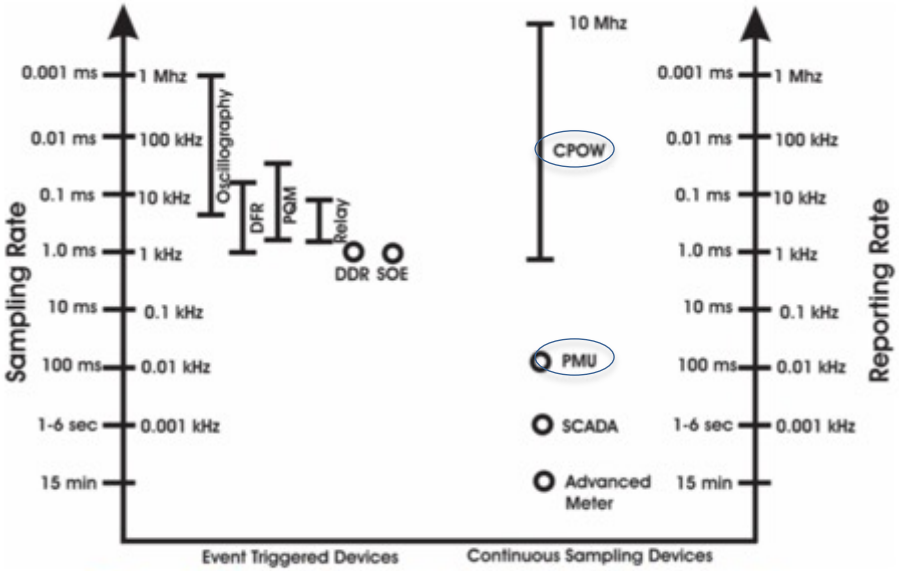


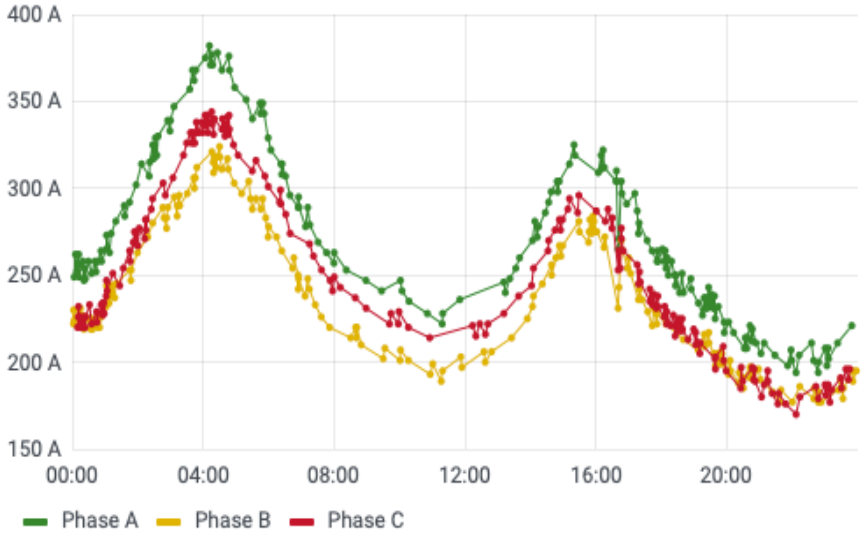
Figure 18: Grid monitoring devices by resolution and data continuity[1].

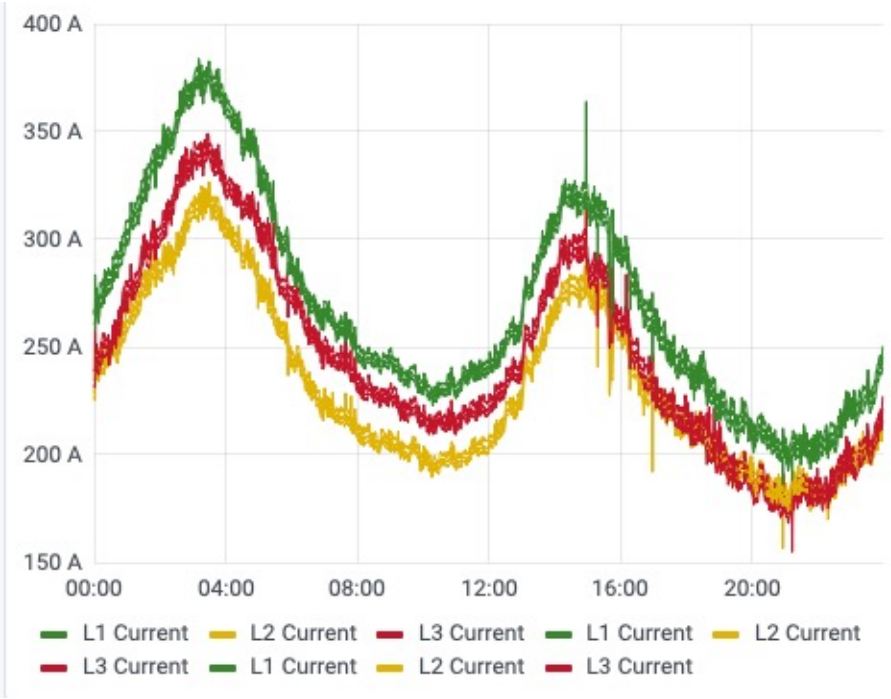
Silverstein, Alison, and Jim Follum. 2020. "High-Resolution, Time-Synchronized Grid Monitoring Devices." NASPI

Data management and visualization

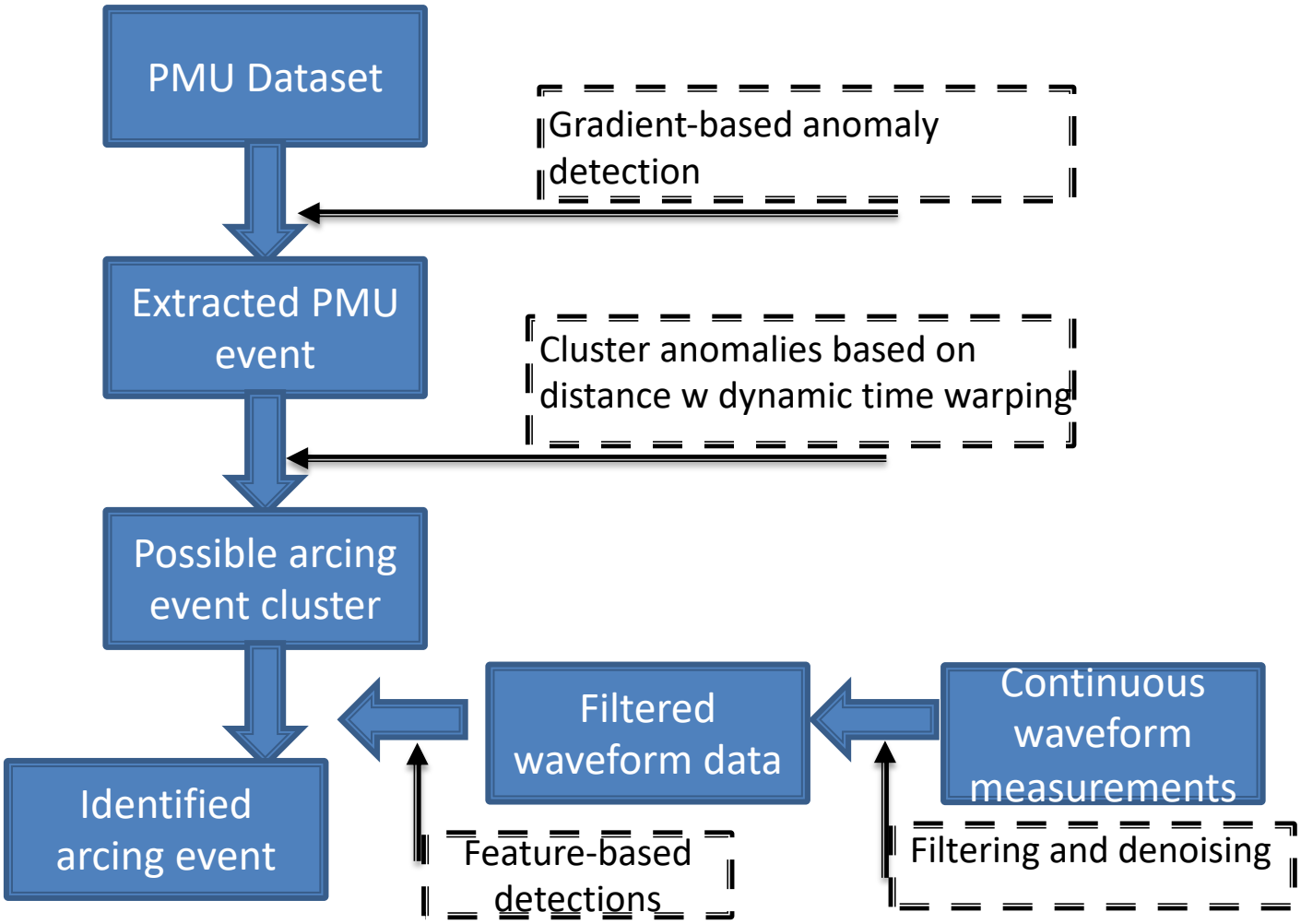
- Data storage needs per month
  - microPMU: ~25 GB per device
  - Continuous POW: ~750 GB
  - Cellular connection from device storage
- Database setup and data visualization
  - Data formats and conversion (.dat, COMTRADE)
  - PostgreSQL-based TimescaleDB
  - Grafana for visualization
- Measurement verification and calibration
  - PT/CT ratios
  - Verification with existing measurement data (e.g., SCADA)

SCADA vs. PMU (distribution)





Overview of analytics



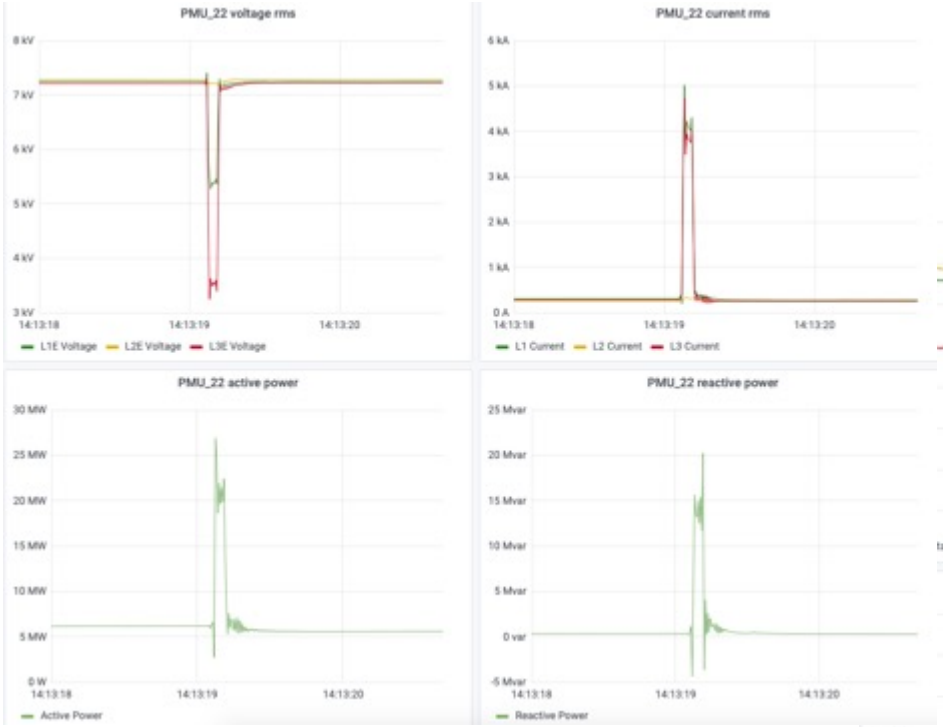
Gradient-based anomaly detection

- Filter events based on a set threshold
  - PMU datasets: three-phase voltage magnitudes and phase angles, current magnitudes and phase angles, active and reactive power
  - Filtering w separate variables either missed a lot of events or captured too many events when threshold set low
  - Normal bounds of the reduced order set by a “normal” day + epsilon

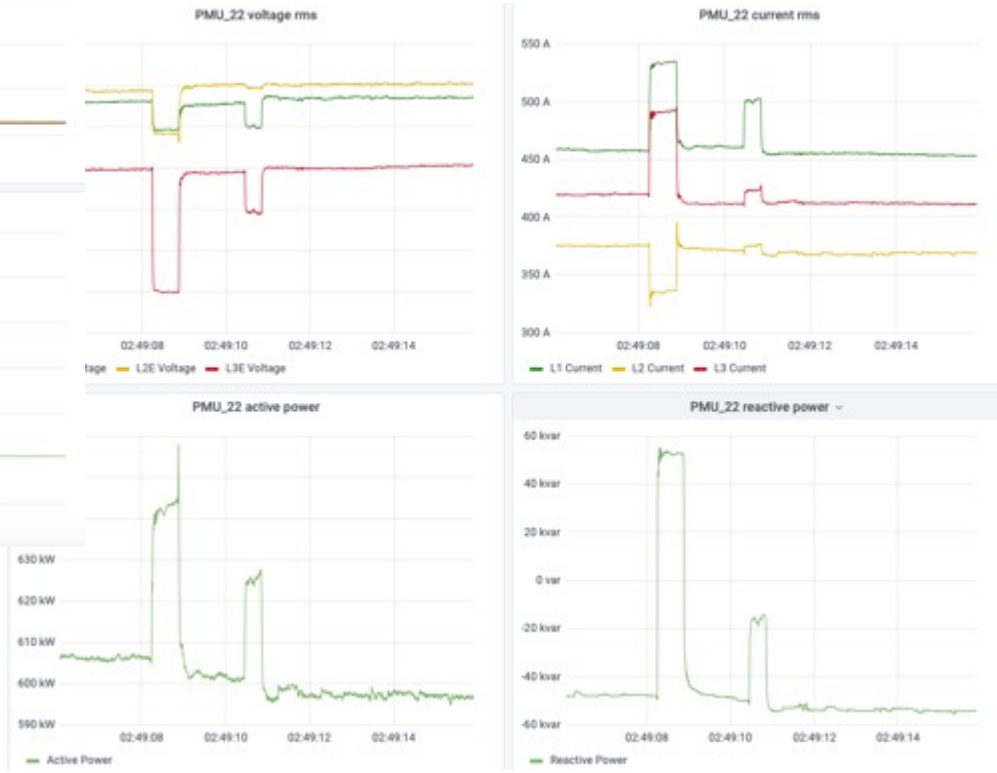
Eliminate non-arcing events

- Voltage regulation (cap bank switch, tap changes)
- Fuse and reclosers
- Motor start inrush

Example of anomalies captured



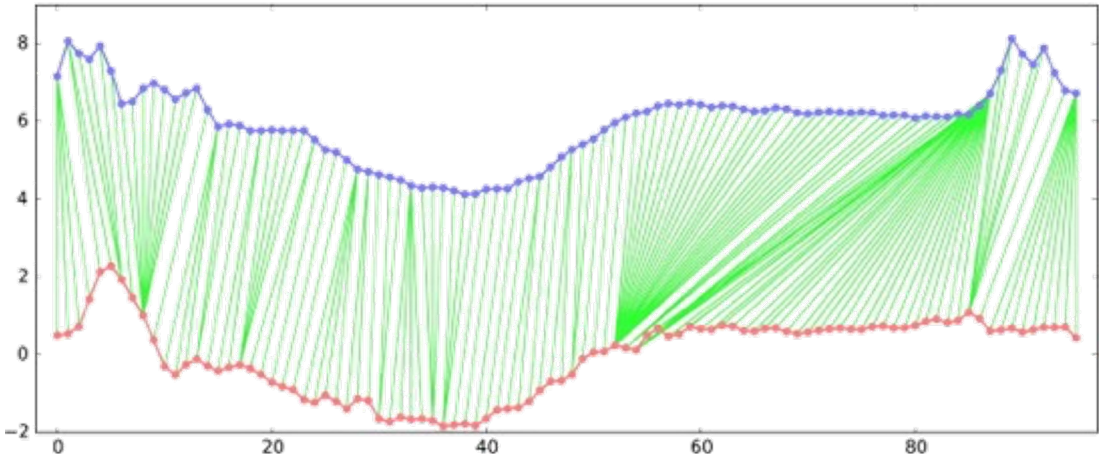
Recloser open



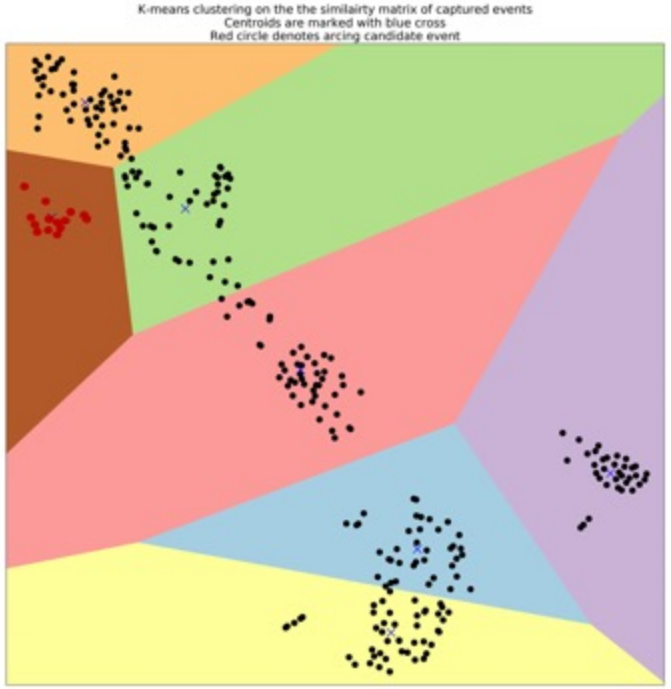
Vegetation. Fuse. Tree came down and took out wire and pole

Clustering of events

- Dynamic time warping
  - Calculate similarity between the captured events
- *k*-means clustering
  - Find optimal number of clusters with elbow method

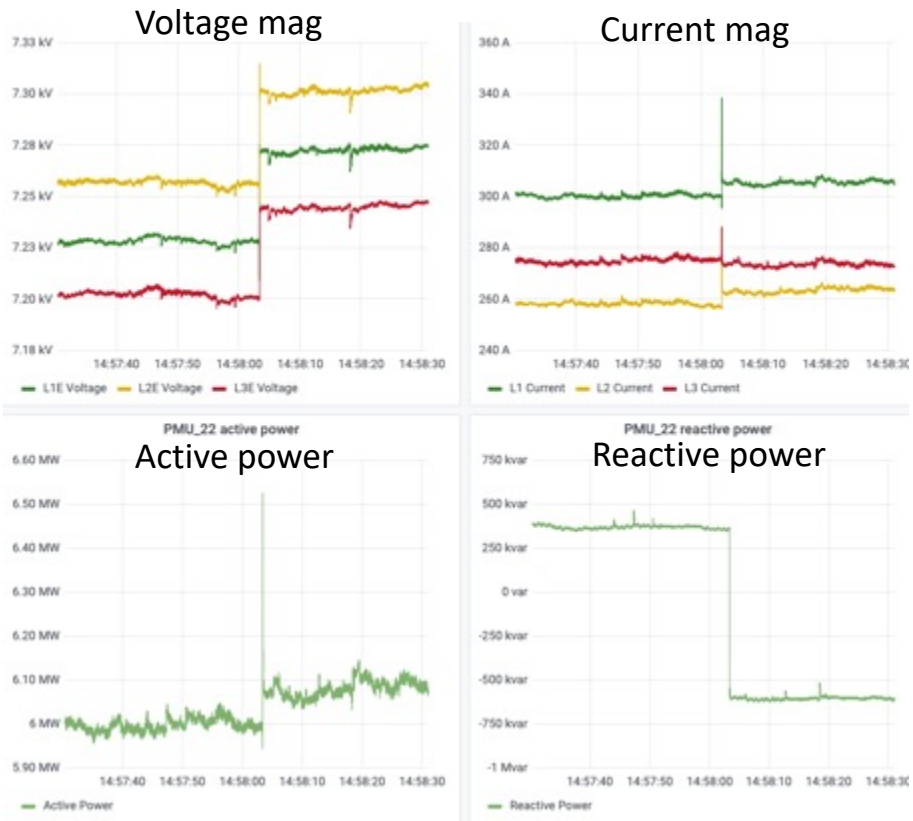


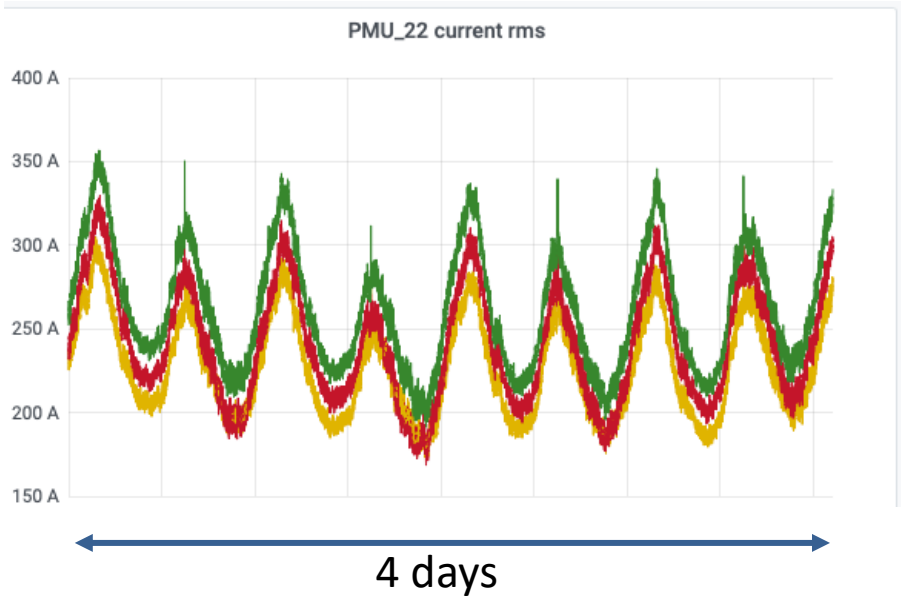
Zheng Zhang, Ping Tang, Rubing Duan, Dynamic time warping under pointwise shape context, Information Sciences, Volume 315, 2015



Analysis of captured events – example

- Voltage step change and current transients





Probable arcing events – example

Voltage

Current

75% match w/ known arcing signatures

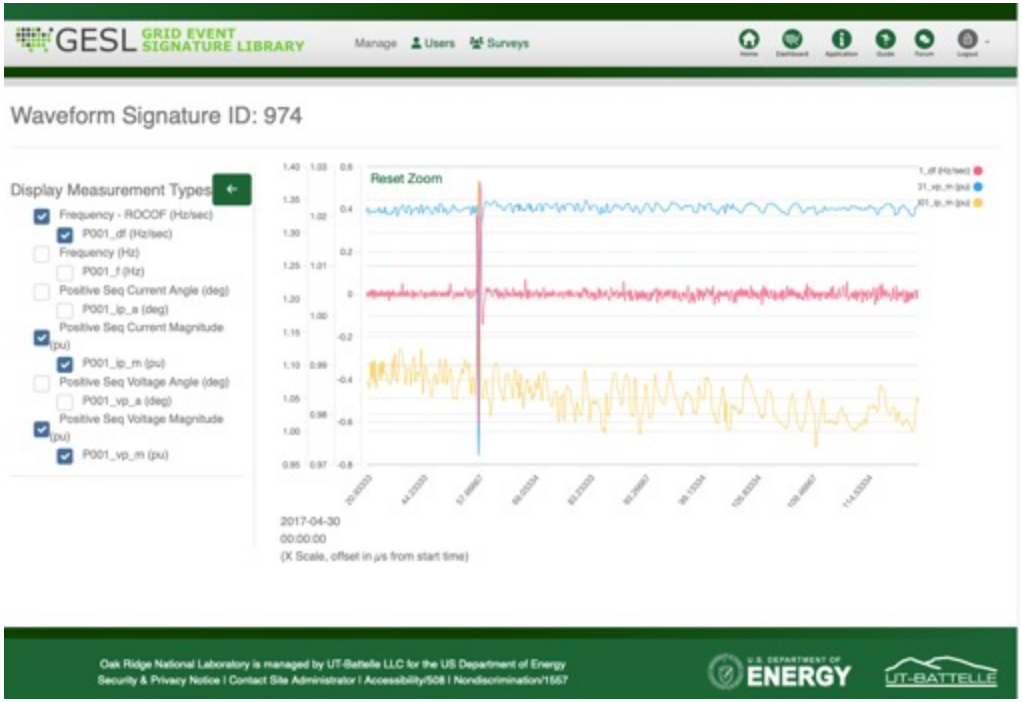
→ Further investigation/validation with point-on-wave measurements

Supervised learning of waveform arcing events

- Electric grid waveform signature library
  - Repository of labeled grid signatures including arcing faults
    - DOE ORNL/LLNL signature library
      https://gesl.ornl.gov
- Feature extraction of arcing signatures for classifier training
  - Fast Fourier transform (FFT)
  - Wavelet transform
  - Noise attenuation
    → wavelet shrinkage denoising
- Apply different classifiers to find the best fit

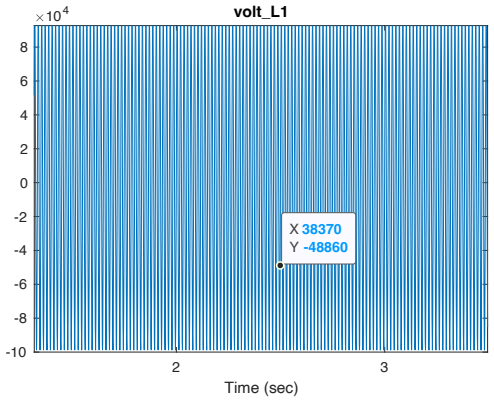
Supervised learning of arcing events

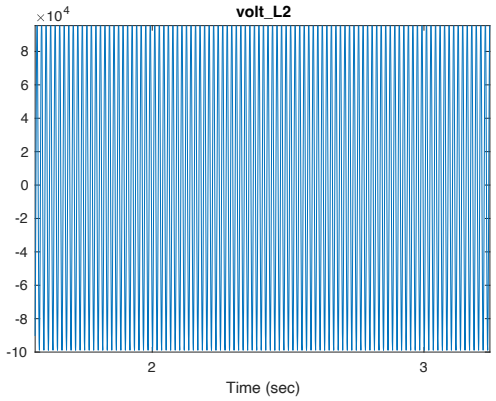
- DOE Grid Event Signature Library
  - Publicly available data repository being developed by Oak Ridge National Laboratory and LLNL https://gesl.ornl.gov
  - Library of disturbance measurement signals (voltage, current, frequency, etc.) captured from a variety of sensors and entities
- Used for “ground truth” arcing training datasets in this work

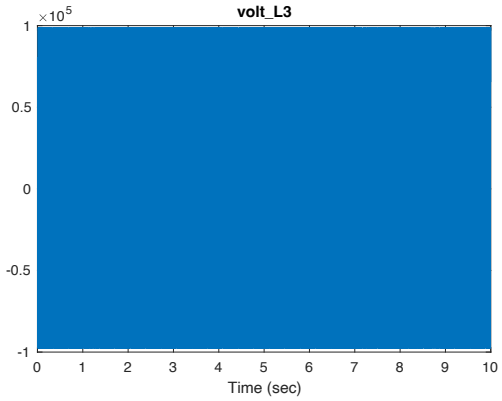


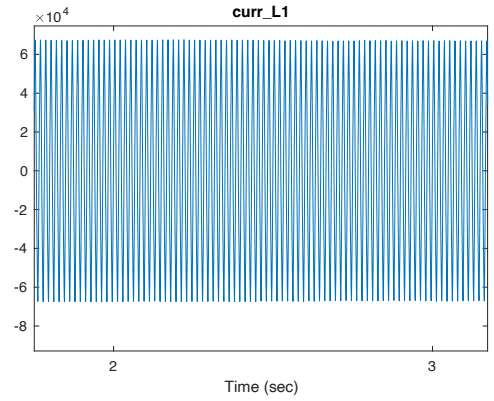
Filtering waveform signatures

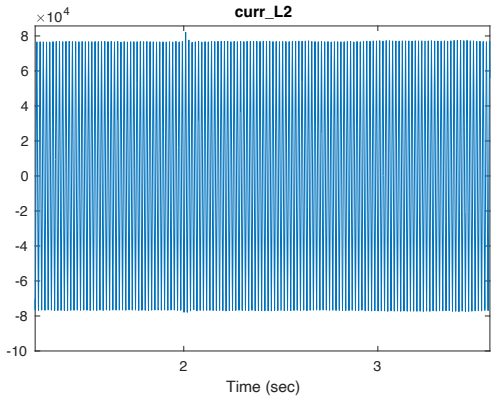
- Waveform measurement of arcing event

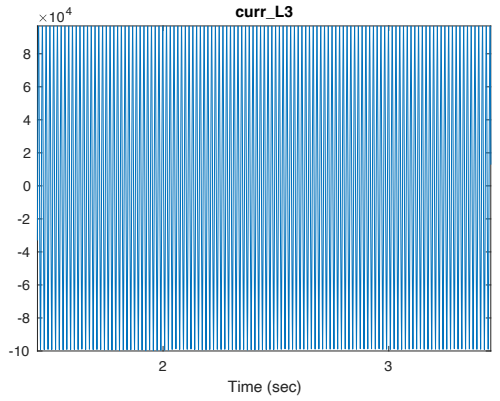






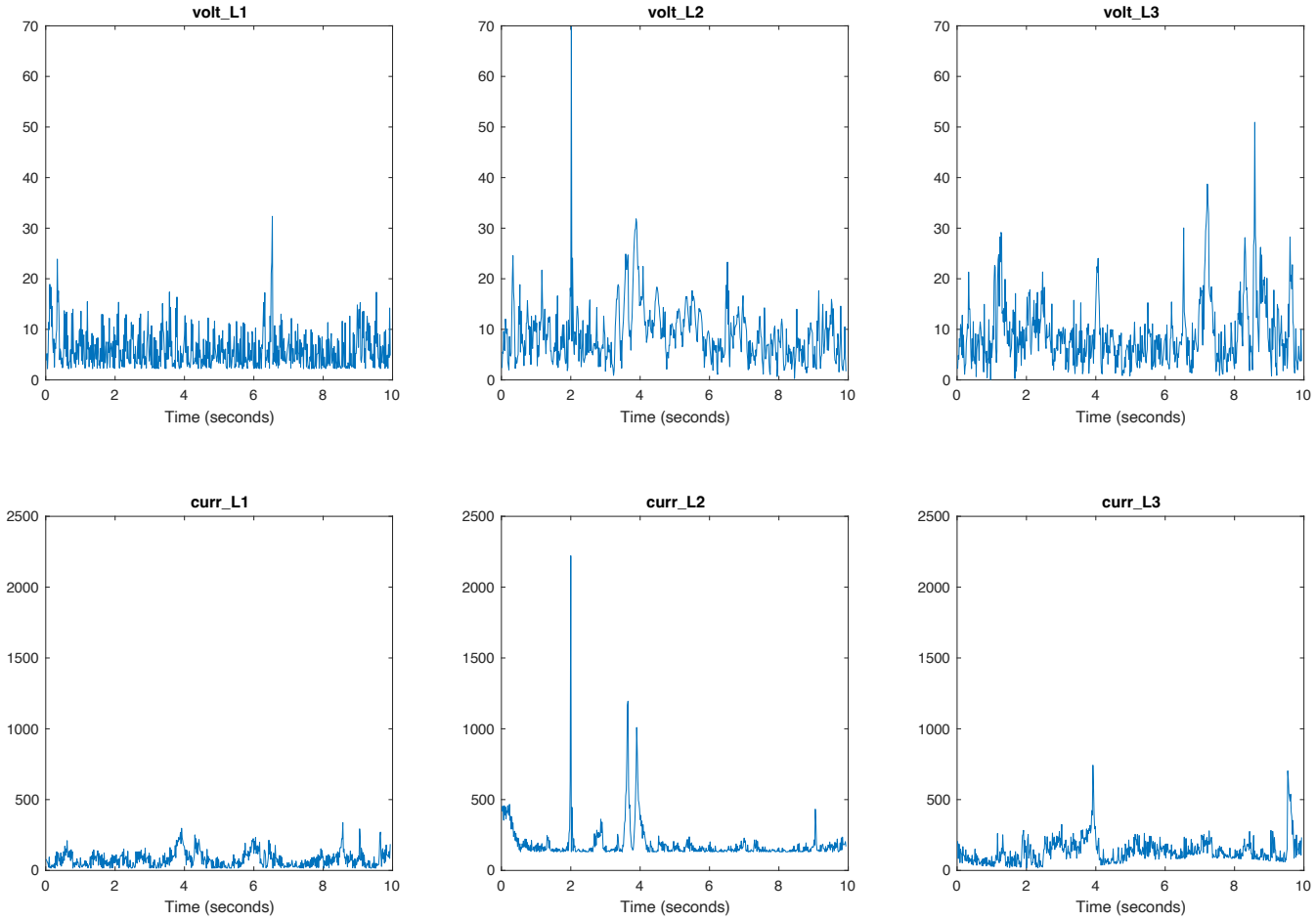






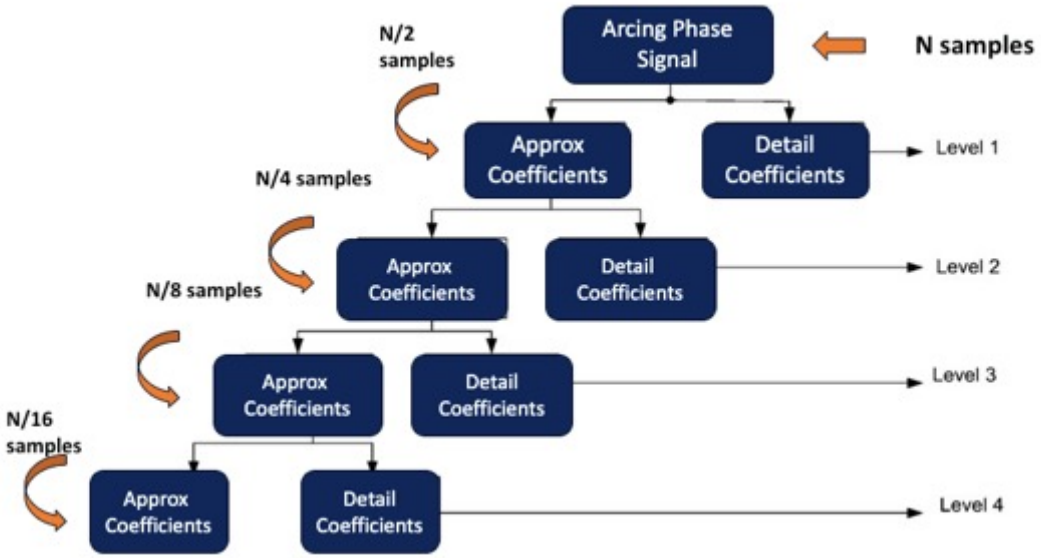
Filtering waveform signatures

- Filtered waveform data of arcing event

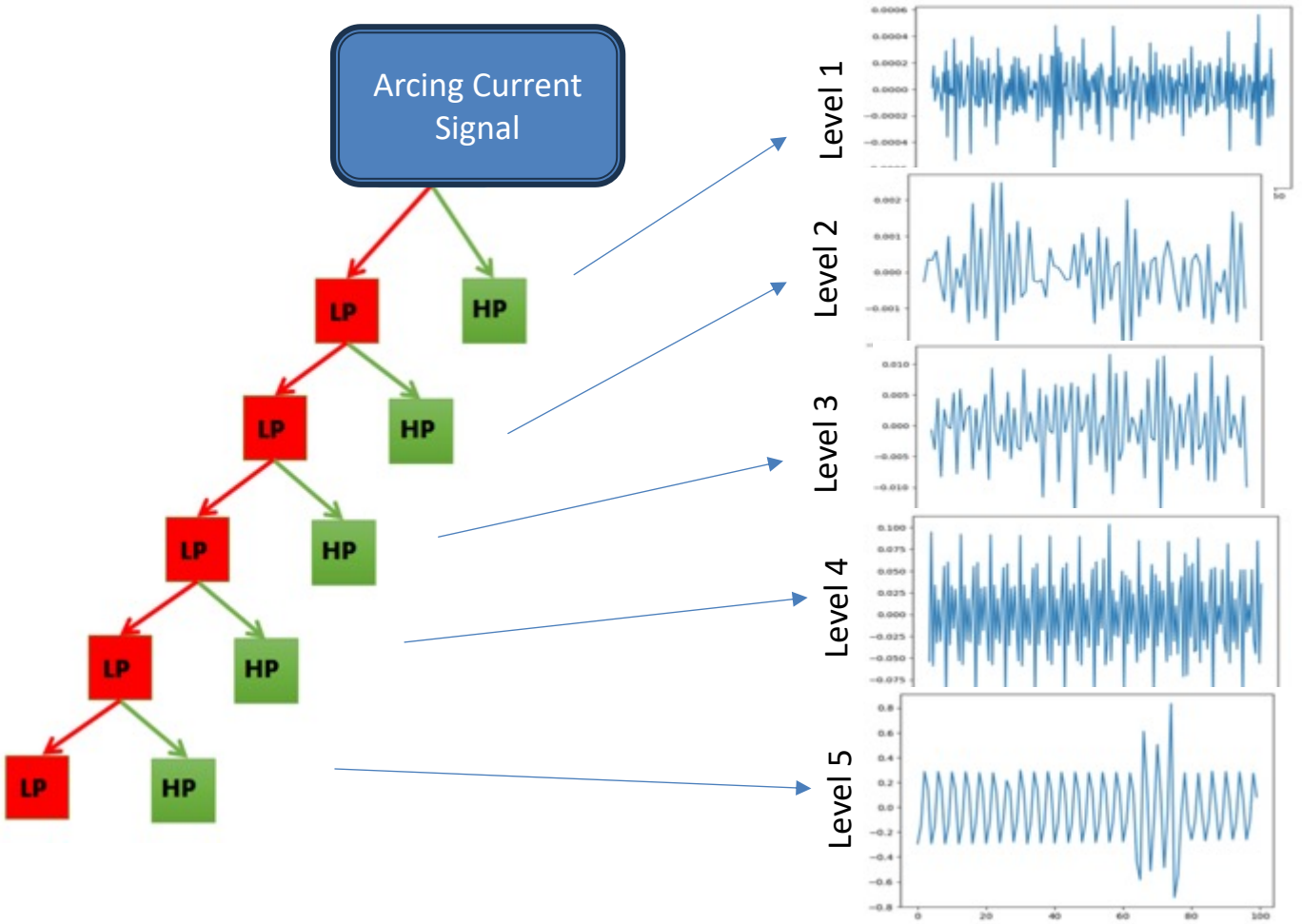


Discrete wavelet transform

- Flexibility in frequency and time domain feature extraction
- Approximation coefficients (smooth low-frequency components) --> coarse-scale trends in signal
- Detail coefficients (high frequency components) --> subtle fine-scale variations

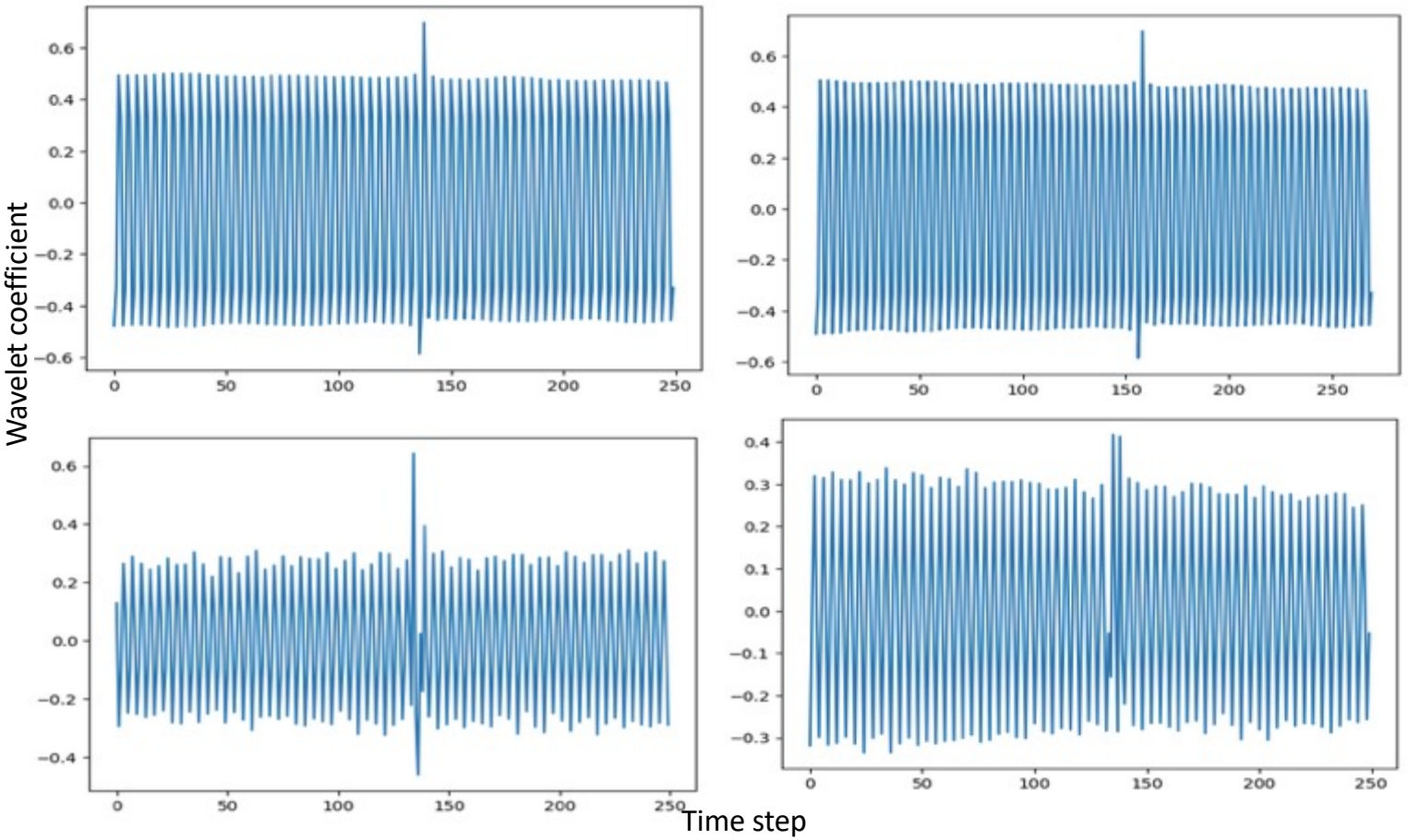


Wavelet transform on arcing signature



Increased prominence of localized variations as signal is filtered

Arcing features from wavelet transform



Four unique arcing signatures being decomposed to its detail 4 DWT coefficients

Summary and work in progress

- Data analytics for evolving grid infrastructure
  - Opportunities and challenges
- Arcing detection for fire prevention
  - Unsupervised anomaly detection and clustering from high-resolution measurements
  - Ground-truth datasets for training – Grid Event Signature Library
  - Feature extraction with waveform signatures
- Work in progress
  - High-resolution simulation of arcing on distribution systems
  - Classifier training with waveform features
  - Optimal sensor placement
  - Locating incipient faults

Acknowledgment for arcing detection

- LLNL team
  - Apoorv Pochiraju, Christabella Annalicia, Indrasis Chakraborty, Pedro Sotorrio, Joseph Guensche
- DOE Office of Electricity
- Oak Ridge National Laboratory
- Utility partners – PG&E, SCE

Thank you!

Questions? Comments?

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