



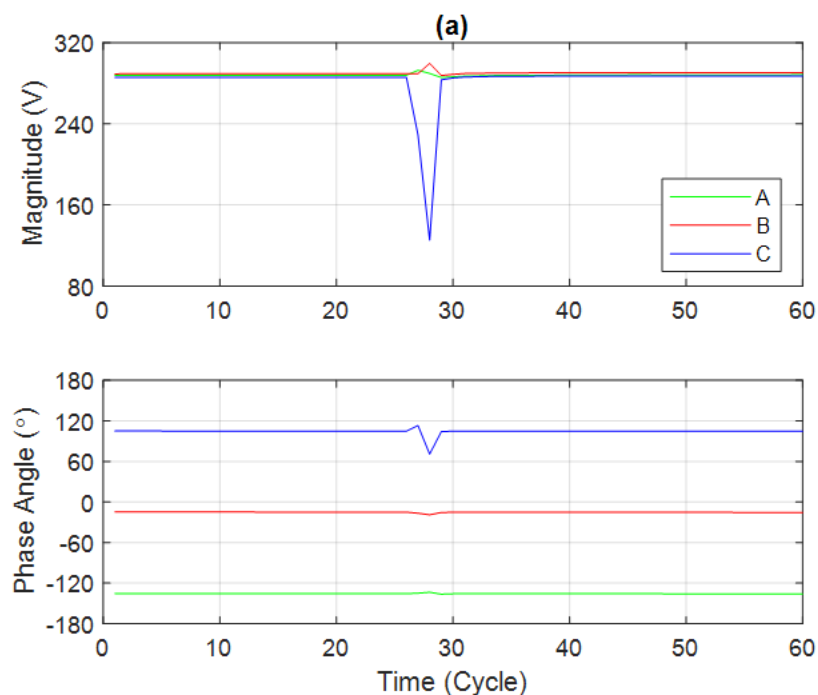
Analysis of Waveform Measurements from Utility Distribution Systems: Lessons Learned

NASPI Work Group Hybrid Meeting
September 24, 2025

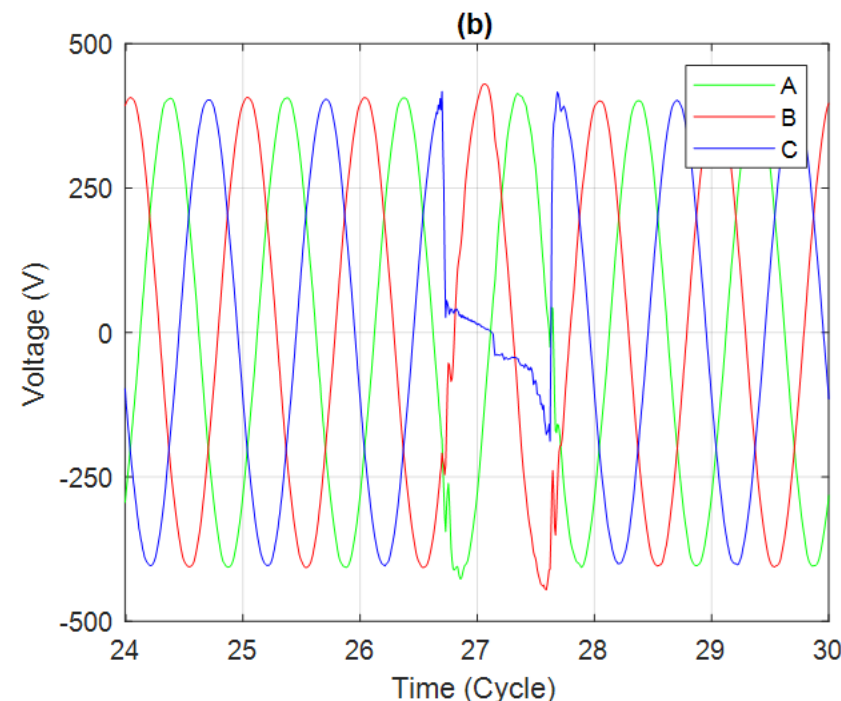
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Lawrence Livermore National Laboratory

Prepared by LLNL under Contract DE-AC52-07NA27344.

The Grid's “New” Eye – Waveform Measurements



Phasor representation



Waveform (point-on-wave) representation

Picture credit: Hamed Mohsenian-Rad, UC Riverside

Source: IEEE Power & Energy Society Technical Report “Synchro-Waveform Measurements and Data Analytics in Power Systems,” PES-TR127, December 2024

Synchro-Waveforms and Waveform Measurement Units (WMUs)

- Terminology
 - Synchro-waveforms (comparable to synchro-phasors)
 - [Synchronized] Waveform Measurements
 - [Synchronized] [Continuous] Point-on-Wave Measurement
- Technology/Enabling devices = WMUs
 - Power Quality Meters
 - Digital Fault Recorders
 - PMUs with Waveform Capture
 - etc...
- When to use waveforms?*

- Useful for capturing subcycle/few-cycle transients
- Use cases include IBR monitoring and model validation, load modeling and characterization (esp. harmonics), asset condition monitoring



SEL



PMI



Schneider



Candura



NuGrid



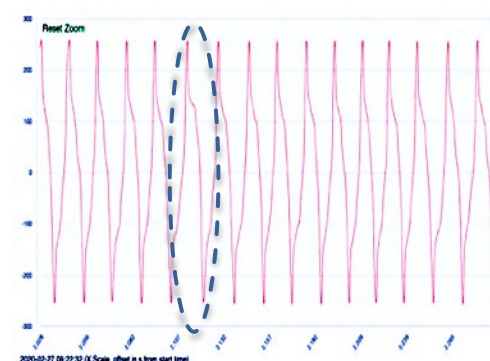
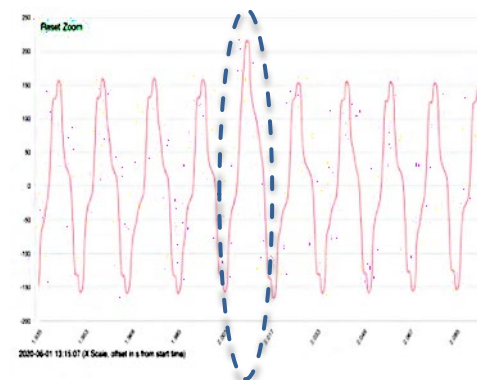
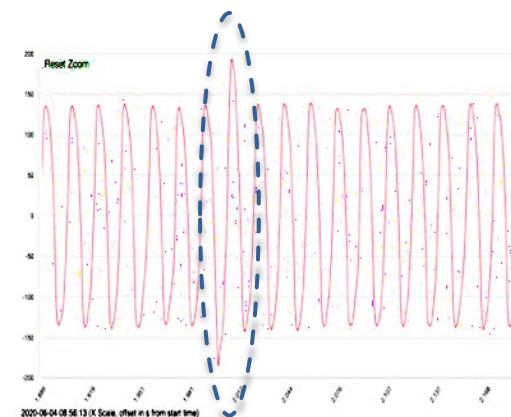
GridSweep

Examples of WMUs

*J. Follum et al., Phasors or Waveforms: Considerations for Choosing Measurements to Match Your Application, April 2021, NASPI
https://www.naspi.org/sites/default/files/reference_documents/pnnl_31215_follum_phasors_waveforms.pdf

Example Use Case – Low-current Arcing Detection in Distribution Systems

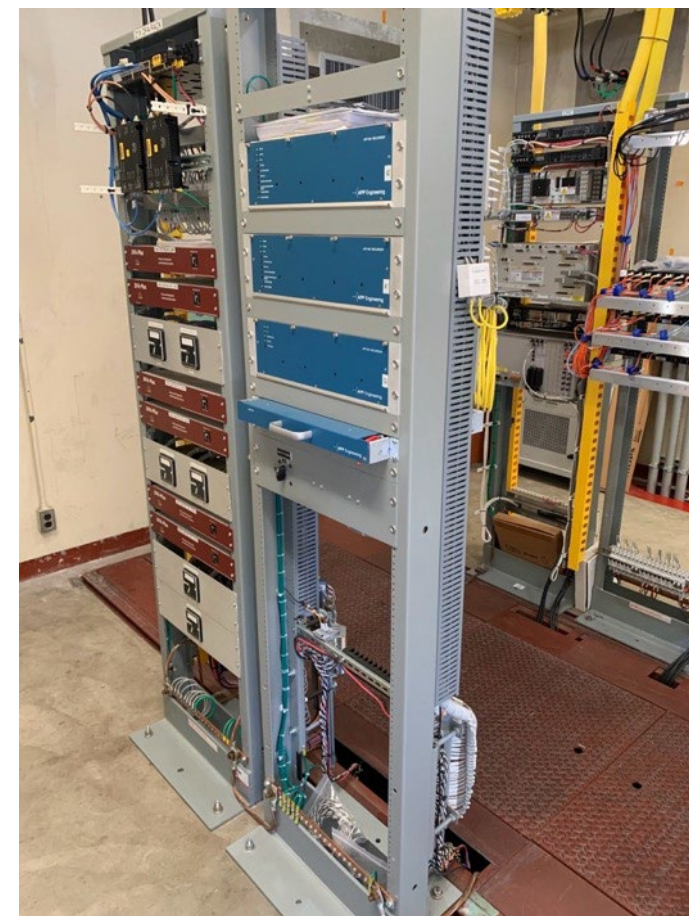
- Characteristics of arcing
 - Slightly elevated peaks on phase current
 - “Shoulders” on mid-cycles
 - Duration can be a few to several cycles
 - No consistent frequency components
- Phasor representation not adequate to detect these



Sub-transients Hide Below the Cycle—Waveforms Reveal Them

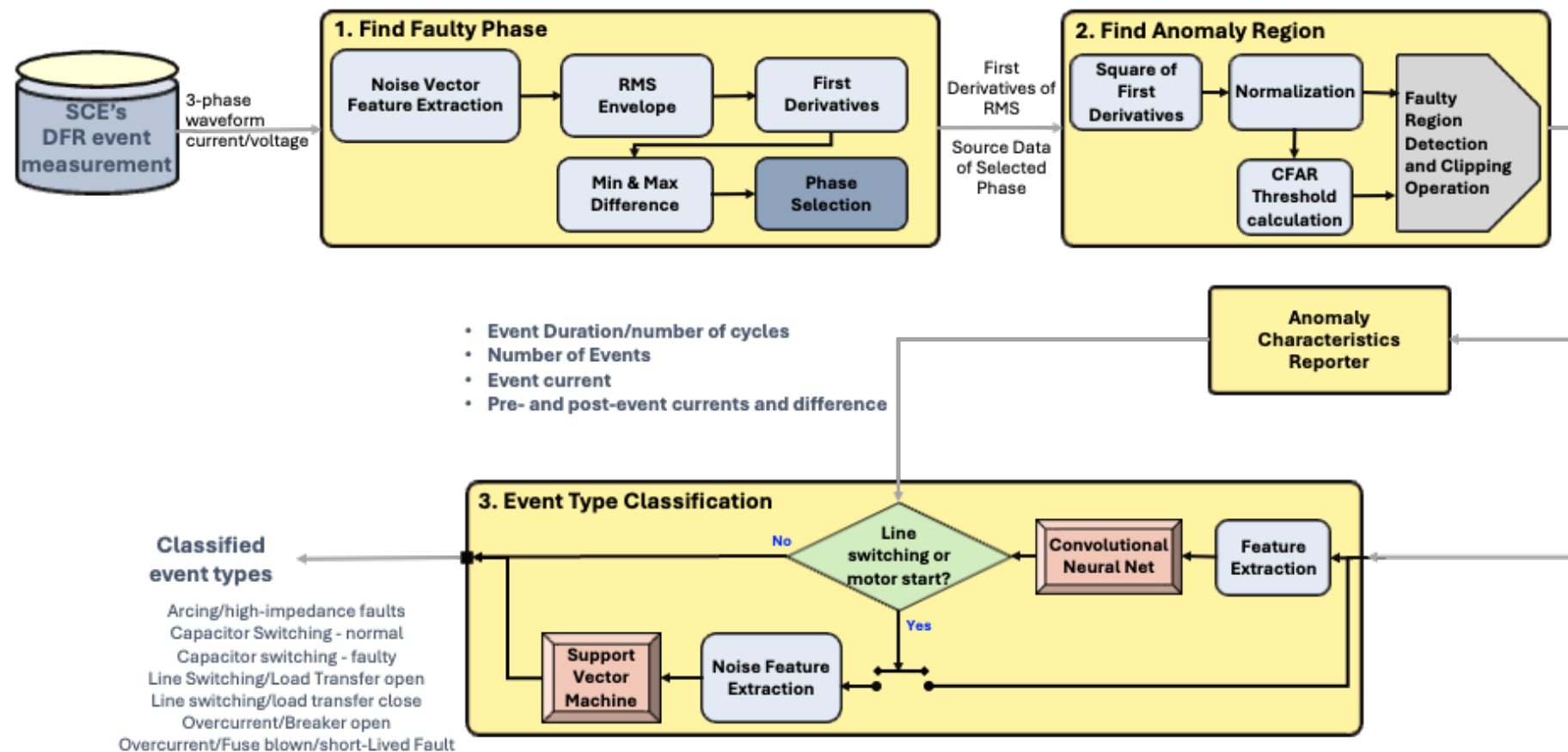
Waveform Data Used

- Digital Fault Recorder
 - Continuous and event data with trigger settings
 - RMS limits, frequency, 0/+/- sequence, THD, etc.
 - 960 to 9,600 samples per second recording
- Distribution Fault Anticipation System
 - 15,360 samples per second event data
 - Events labeled by proprietary algorithm



Digital fault recorder at a distribution substation
Photo courtesy of Southern California Edison

Multi-event Classification with Waveform Measurements



Signal Processing Detects Anomalies, Logic Connects What They Are

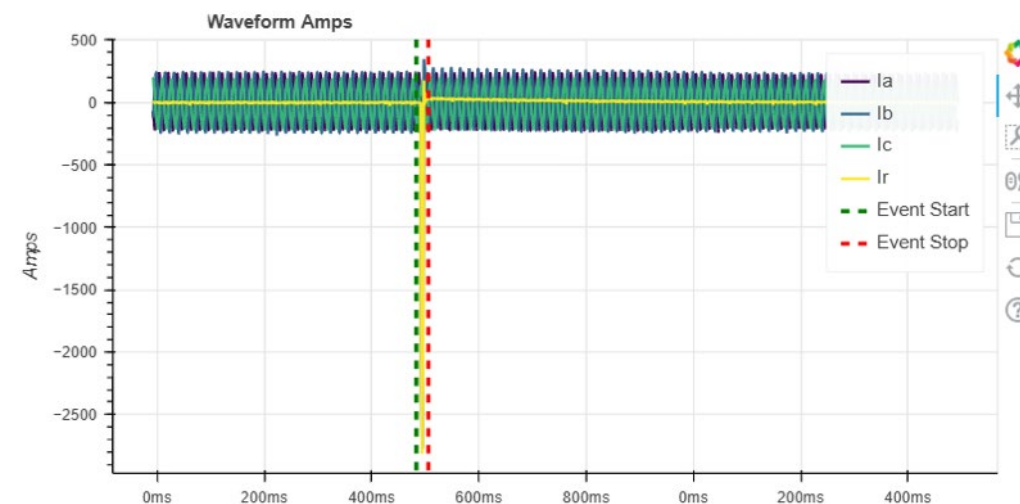
Waveform Analytics – From Dashboard To Control Room

- Next steps after event classification
 - Validation of identified events
 - Actionable information for operators
- Other datasets helpful for these
 - SCADA
 - Device status with time stamps
 - AMI (smart meters)
 - Events (outage, low voltage, etc.) and locations
 - Outage records
 - Time, location, weather, equipment involved, cause, # of customers impacted

Waveform Plotting

Plot DFR event waveform with detected events.

No AMI events matching waveform anomalies in this time window.

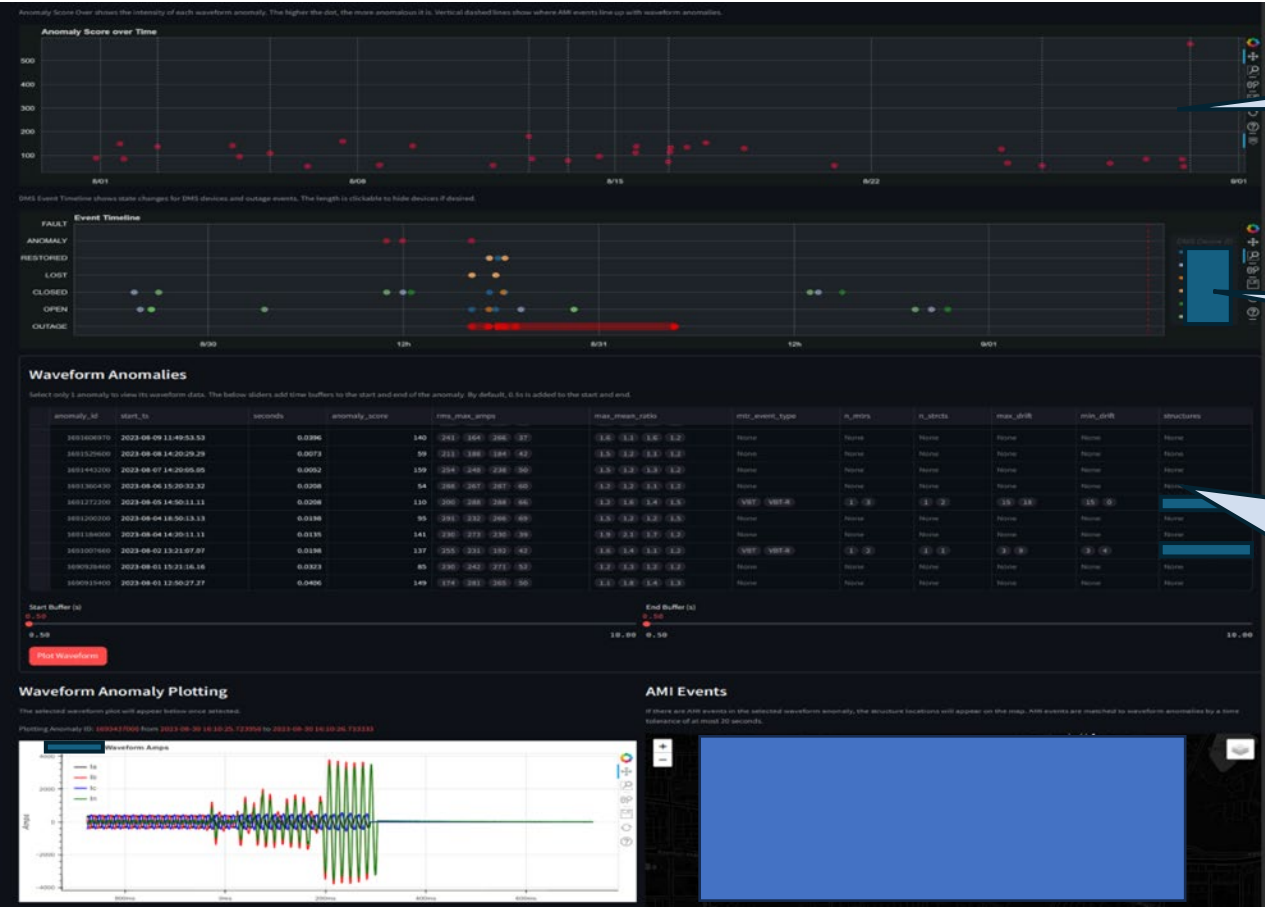


Classification: short-lived fault

Integration Can Turn Data into Decisions

Data Integration Example

– SCE’s Distribution Waveform Analytics Platform



Anomaly Score shows intensity of anomalies occurring on a circuit over time.

Event timeline shows the time correlation of waveform anomalies, SCADA events, and outages that have occurred on a circuit.

Chart shows features associated with waveform anomalies and allows users to select waveform anomalies for plotting. The selected waveform plots below in addition to AMI event locations that correlate with waveform anomalies will appear on the circuit map.

This project is part of the Electric Program Investment Charge (EPIC) funded by the California utility customers under the auspices of the California Public Utilities Commission.

Next Steps and Conclusion

- Waveforms reveal sub-cycle phenomena invisible to other measurements
 - Signal processing techniques effectively extracts fast transient dynamics
- However, waveform data alone lacks operational context for actionable insights
 - Multi-vendor waveform systems resist integration
 - Standardized data integration frameworks are essential
- Waveform synchronization requirement varies by application and cost
 - Traveling wave applications require more precise synchronization vs. event classification applications, for example

Acknowledgment

- DOE Office of Electricity
 - Sandra Jenkins, Grid Control and Communications
- Southern California Edison
 - Michael Balestrieri, Hamed Valizadeh Haghi
- Oak Ridge National Laboratory
 - Ali Riza Ekti, Ozgur Alaca



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Questions?

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