



# Distributed Waveform Analytics in the WaveApps Platform

April 14, 2025

Jim Follum, PNNL



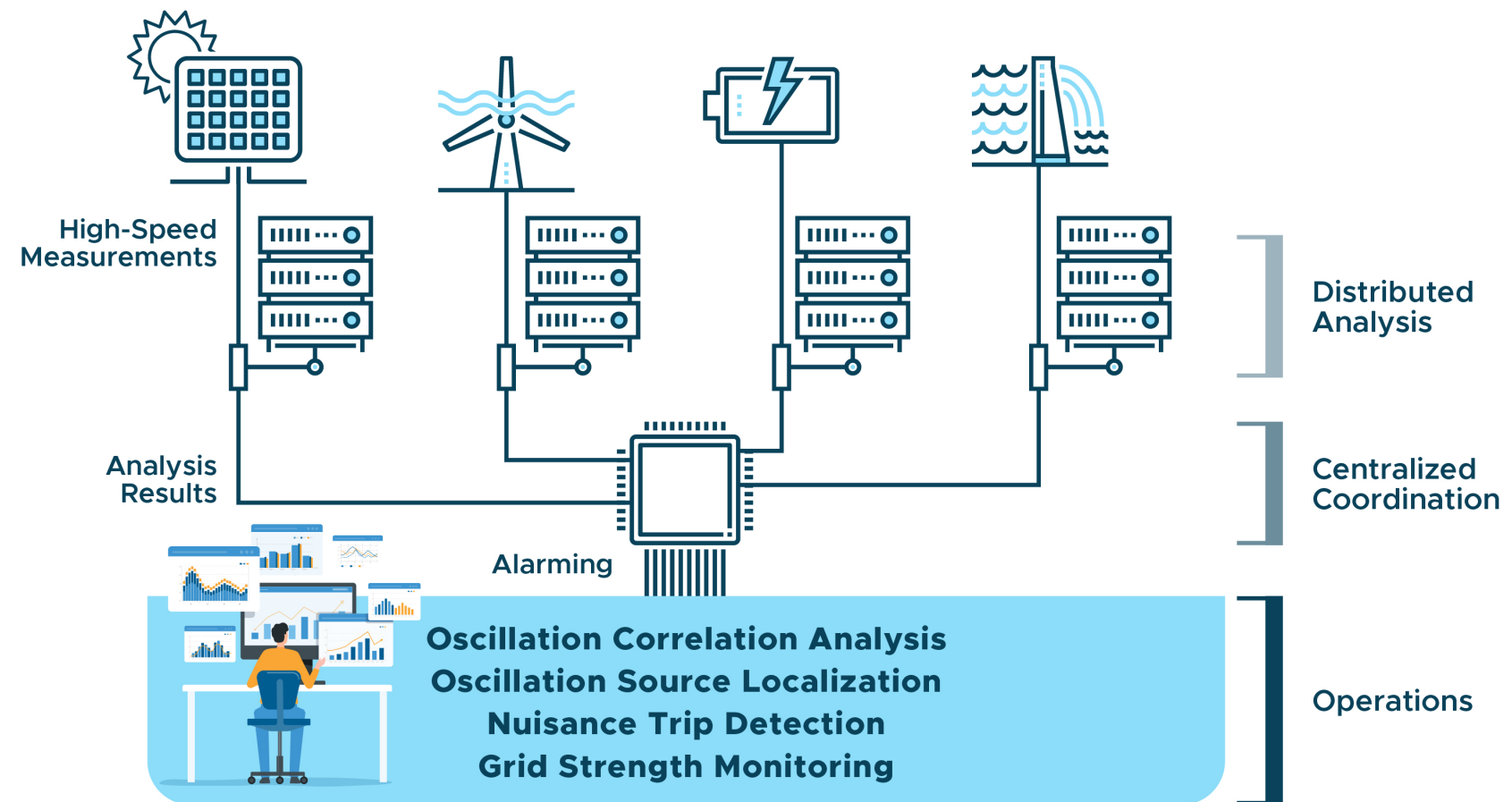
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PNNL-SA-222012



# Concept

- WaveApps is a distributed platform that enables wide-area monitoring based on point on wave (POW) data
- POW measurements are analyzed within substations by distributed instances
- Analysis results are then streamed to the central platform for coordination, alarming, and visualization
- Streaming will be comparable to a PMU, so existing networks can be used
- Four high-value applications will be developed and demonstrated
- Extensible to allow additional applications



# Team Roles

## Project Lead



## Platform Development



## Application Development



## Field Demonstration




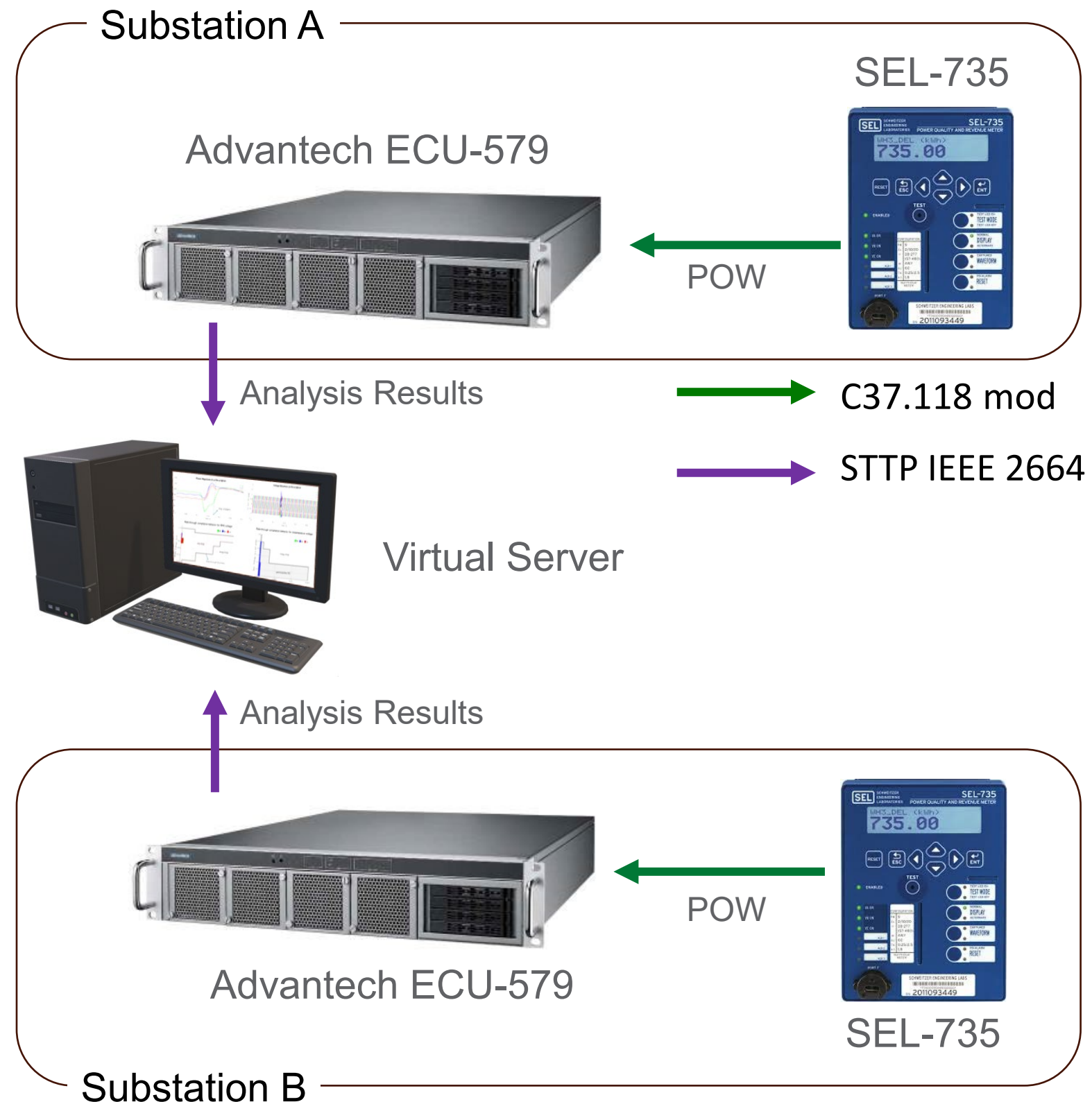
## Advisors





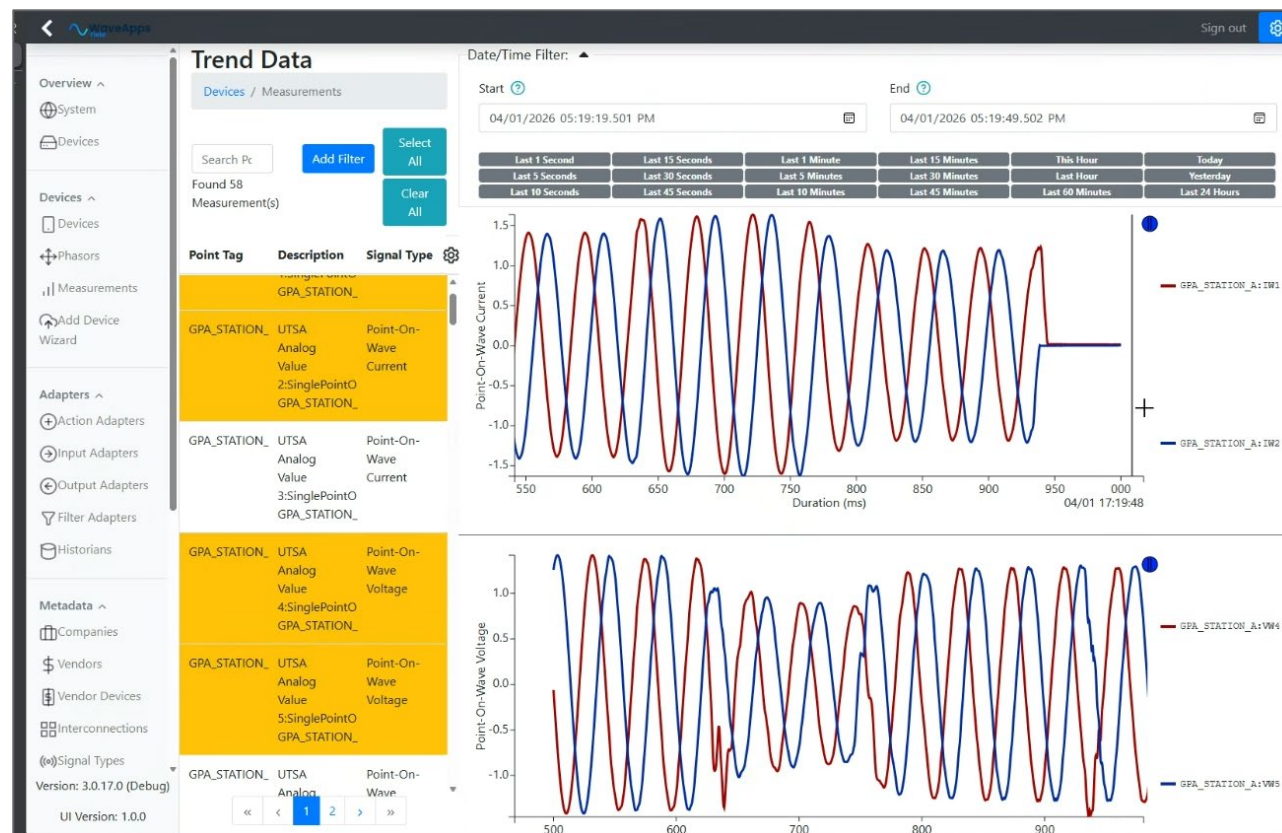
## Hardware & Network

- SEL-735 streams 3 ksps POW over manufacturer-modified C37.118 protocol
- Advantech ECU-579 substation computer runs  WaveApps
- Results transmitted via the Streaming Telemetry Transport Protocol (STTP) to virtual server hosting  WaveApps

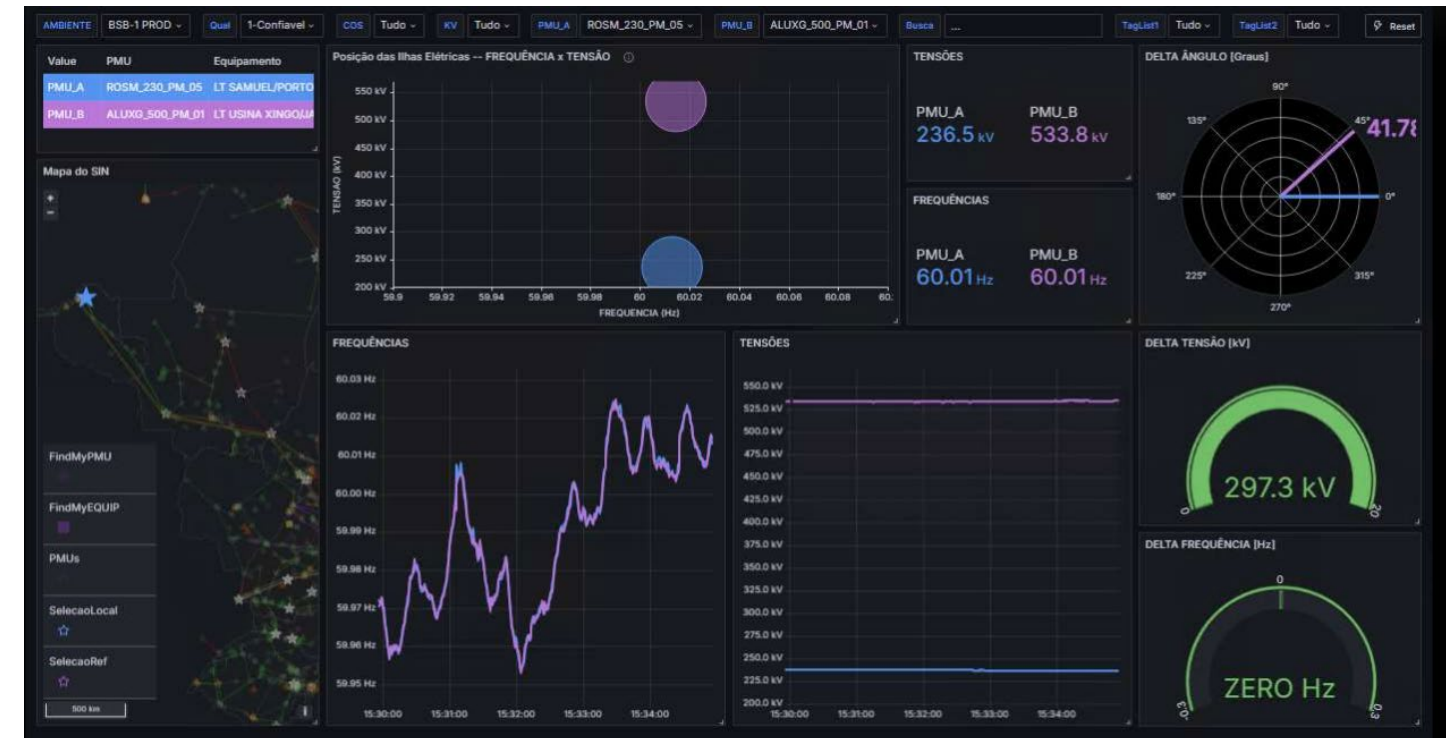


# Platform Design

- Modular- adapter based
  - Deploy applications separately
  - Manage applications independently



Early-stage web-based management interface



Concept for Grafana-based result visualization





# Applications

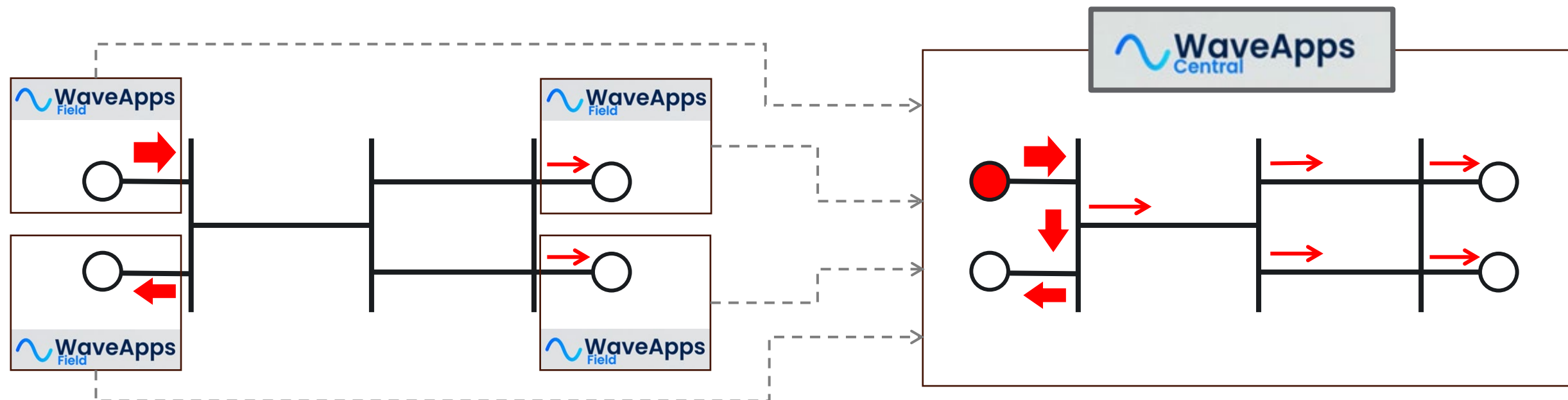


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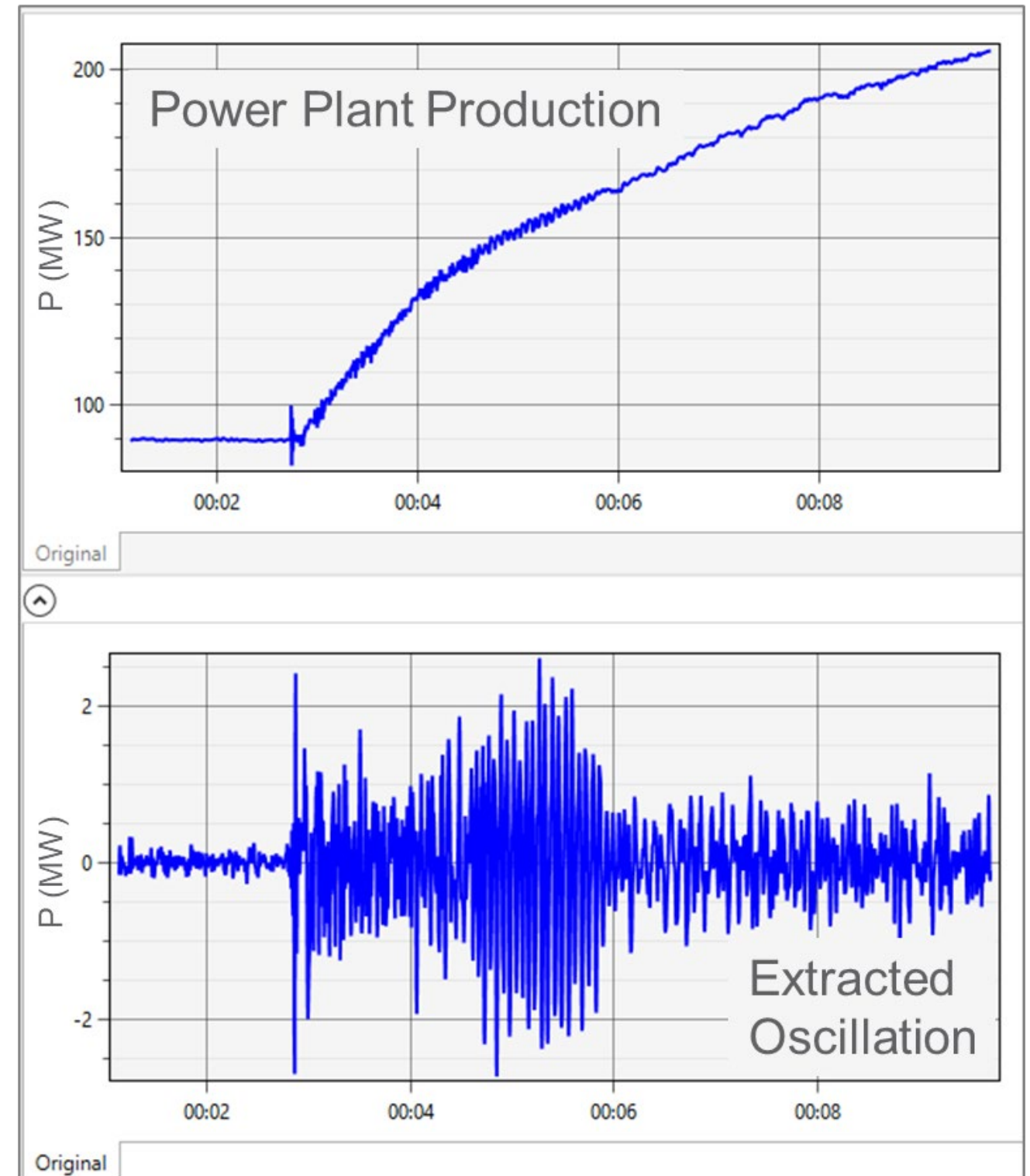
# Oscillation Source Localization

- Dissipating Energy Flow (DEF)
  - Well-established PMU-based method developed and used by ISO-NE
  - Traces the **flow of dissipating energy** back to the source
- A POW-based version has been developed to address oscillations at frequencies too high for PMU-DEF, enabling timely and actionable mitigation



# Oscillation Correlation Analysis

Supports root cause analysis  
of IBR-induced oscillations  
and early identification of  
latent configuration issues



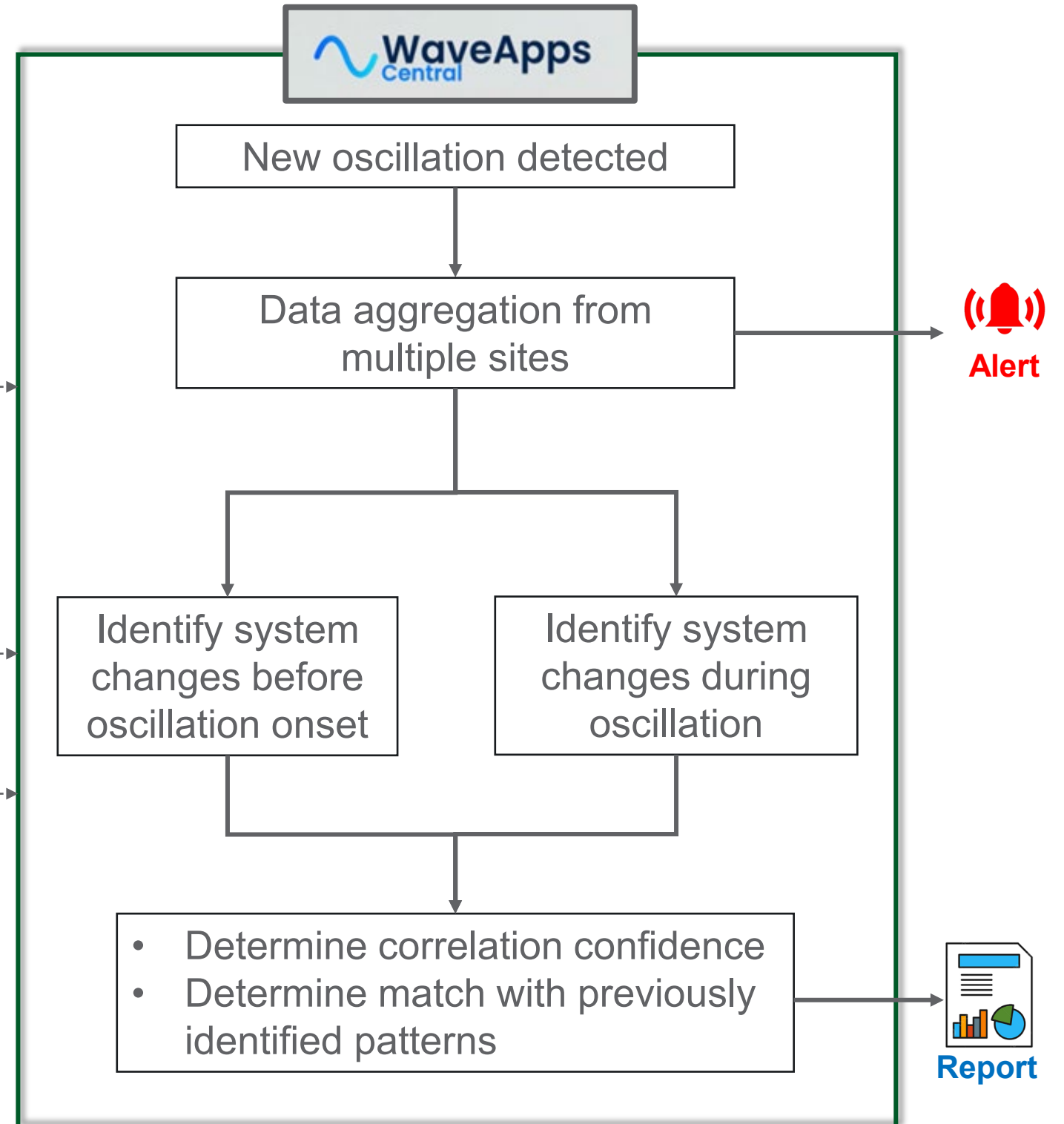


# Oscillation Correlation Analysis

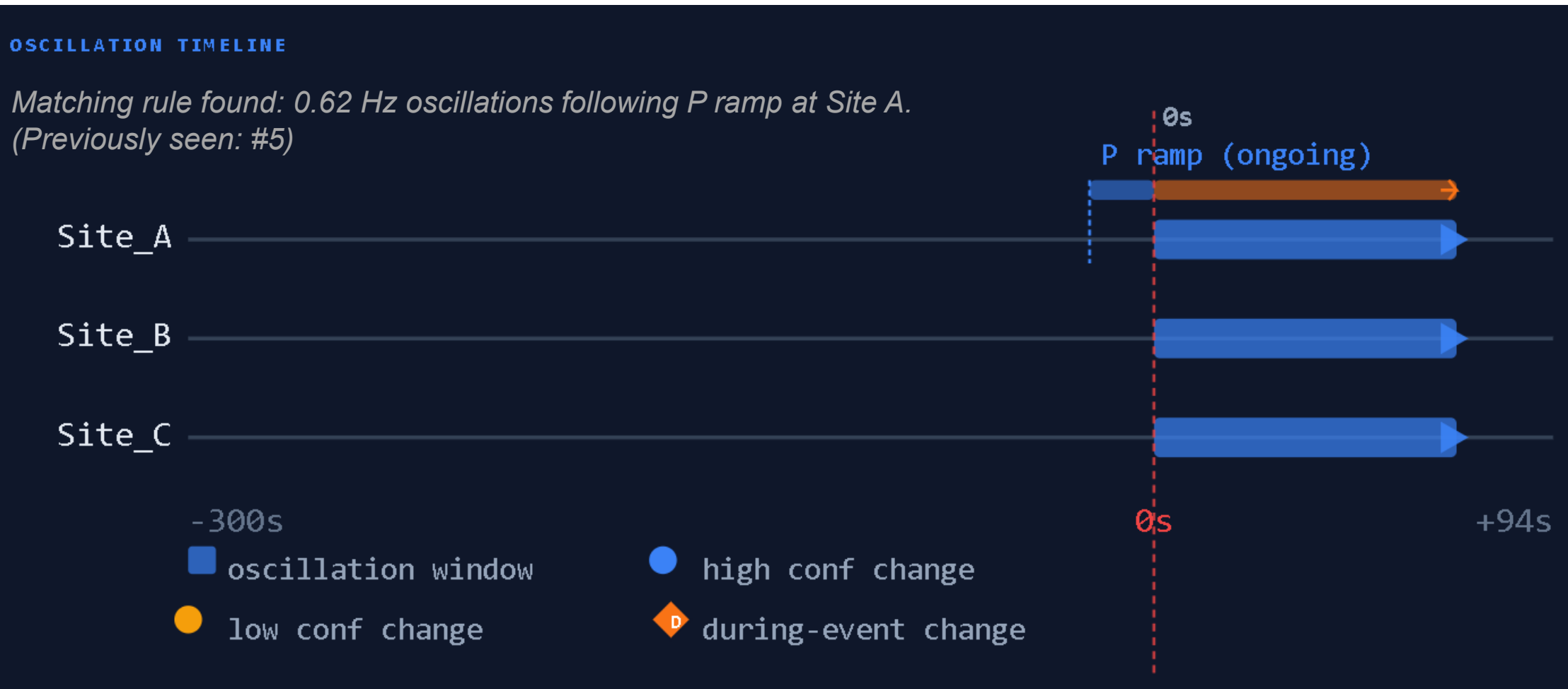


Streamed every second

- System conditions
- Oscillation detection and characterization
- System change detection

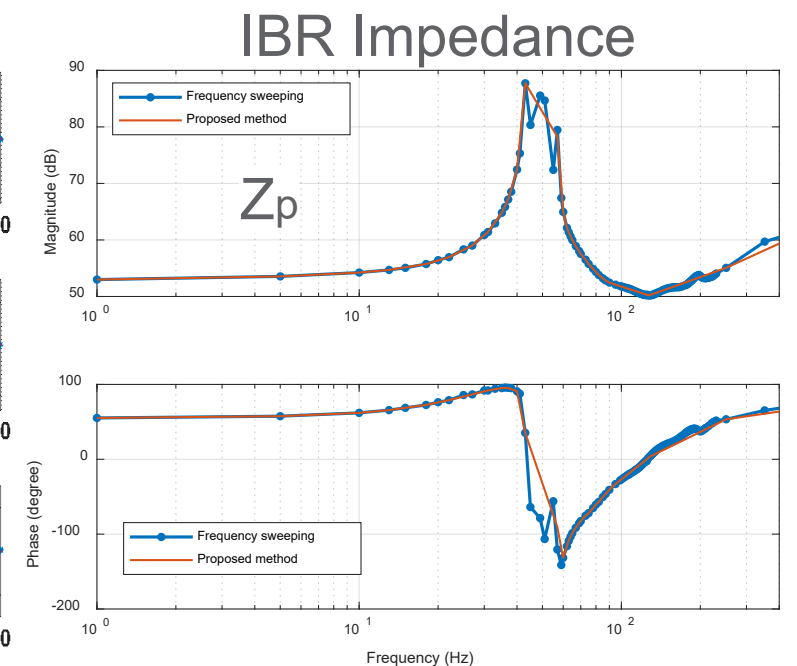
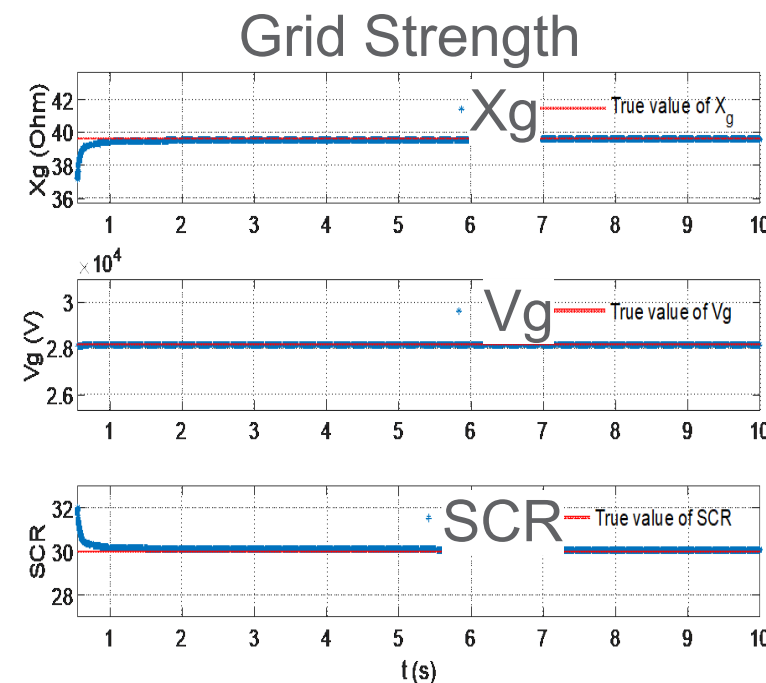
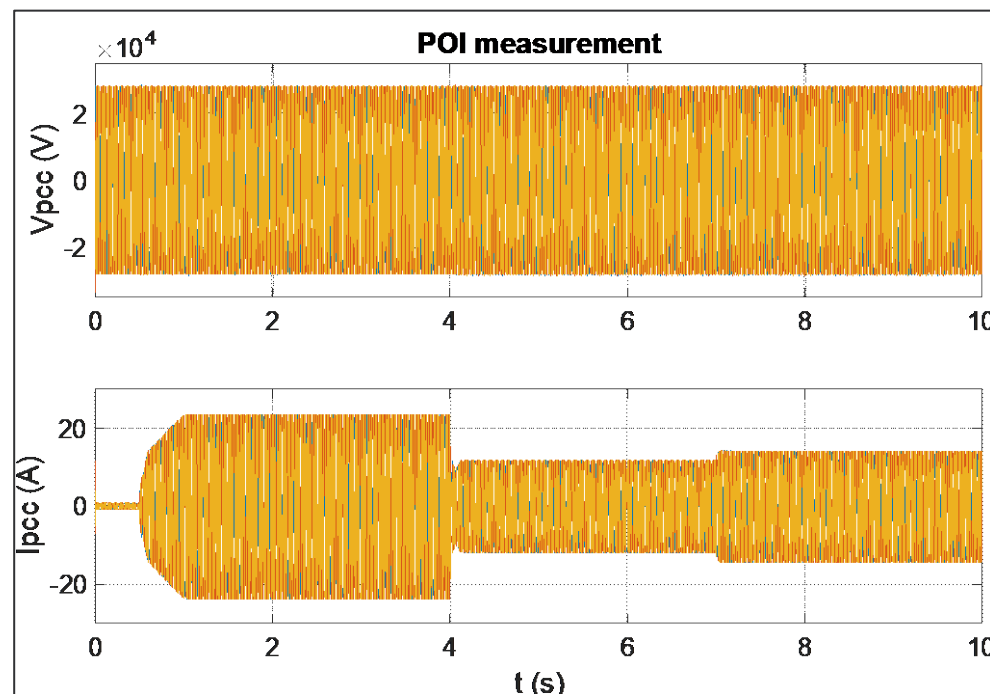


# Example: Oscillation following Generation Change



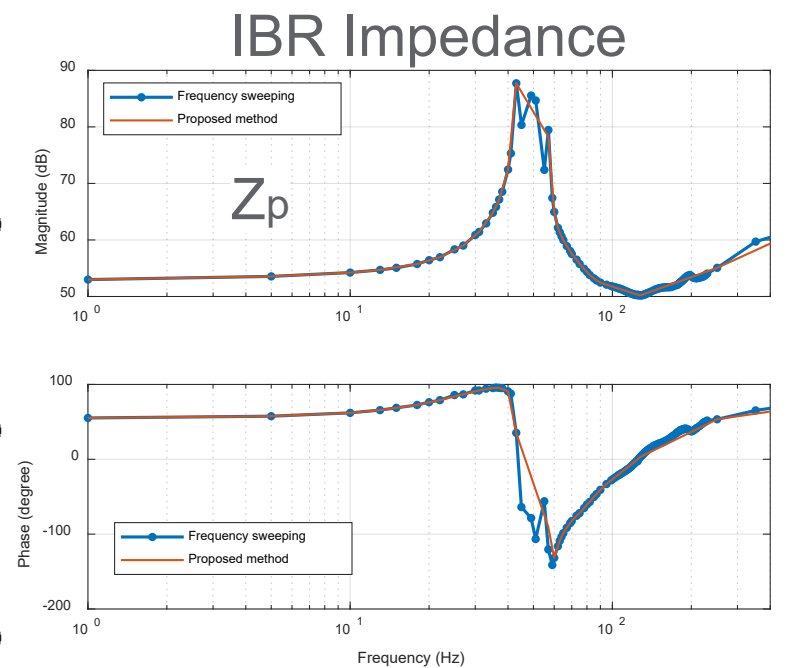
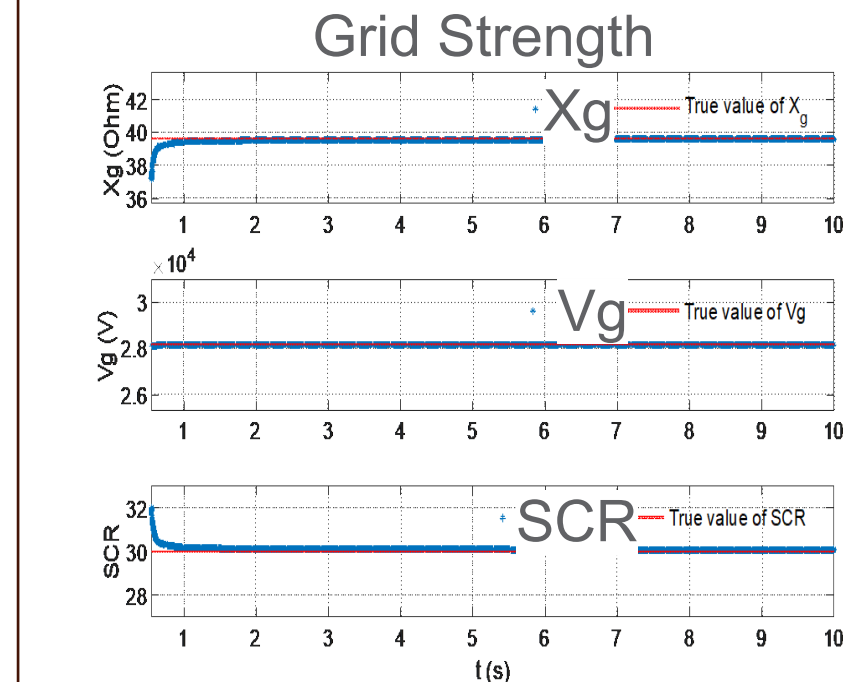
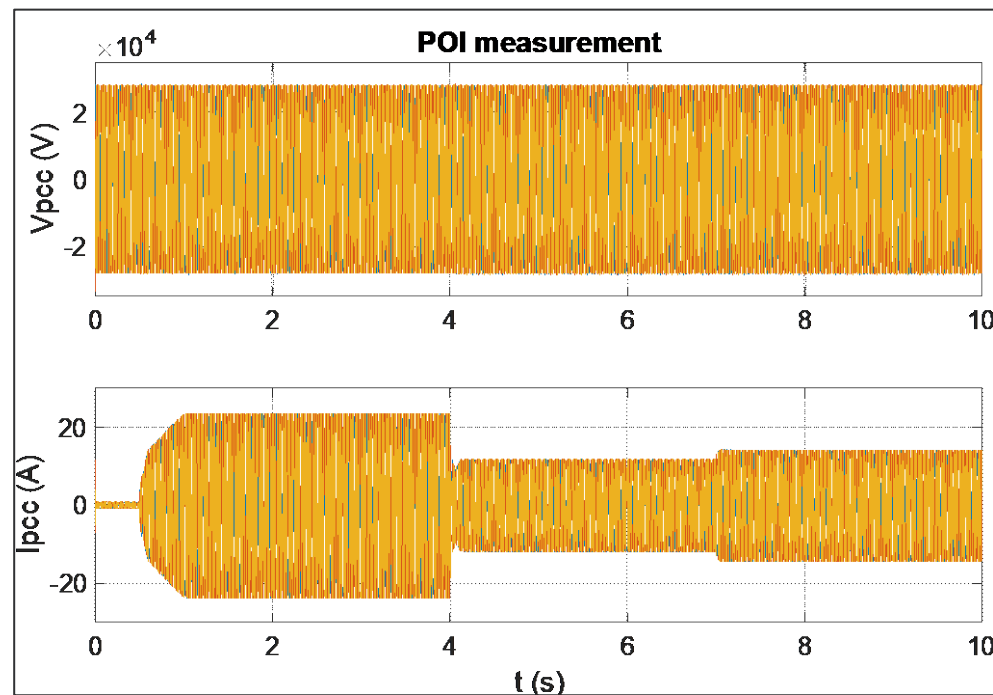
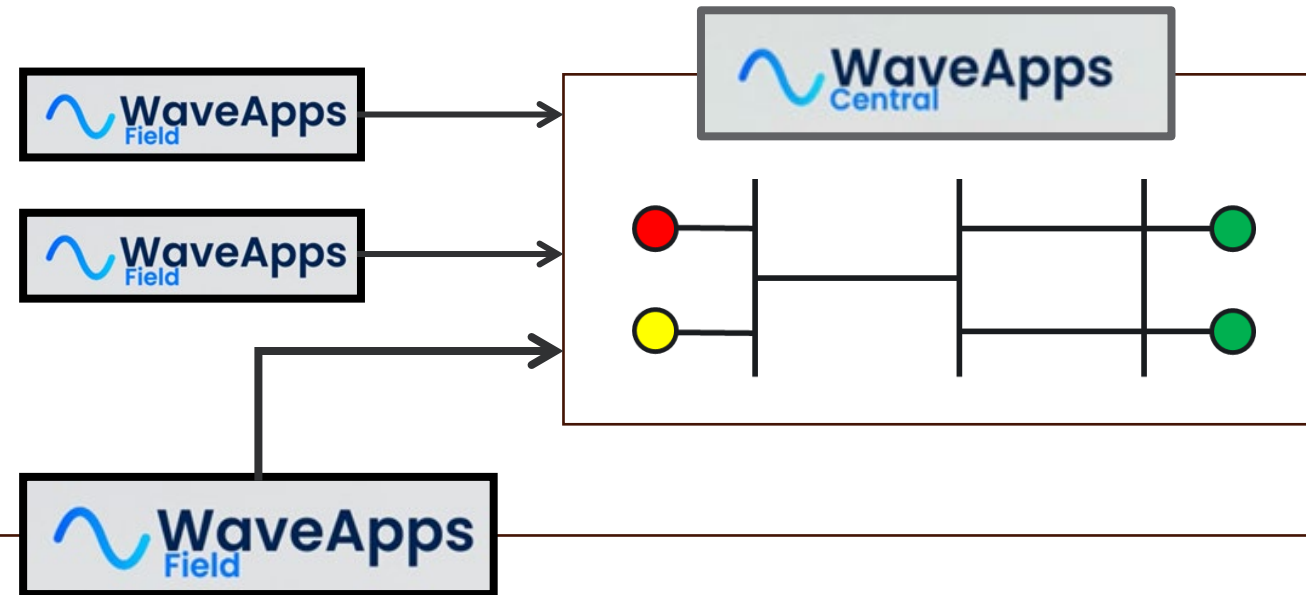
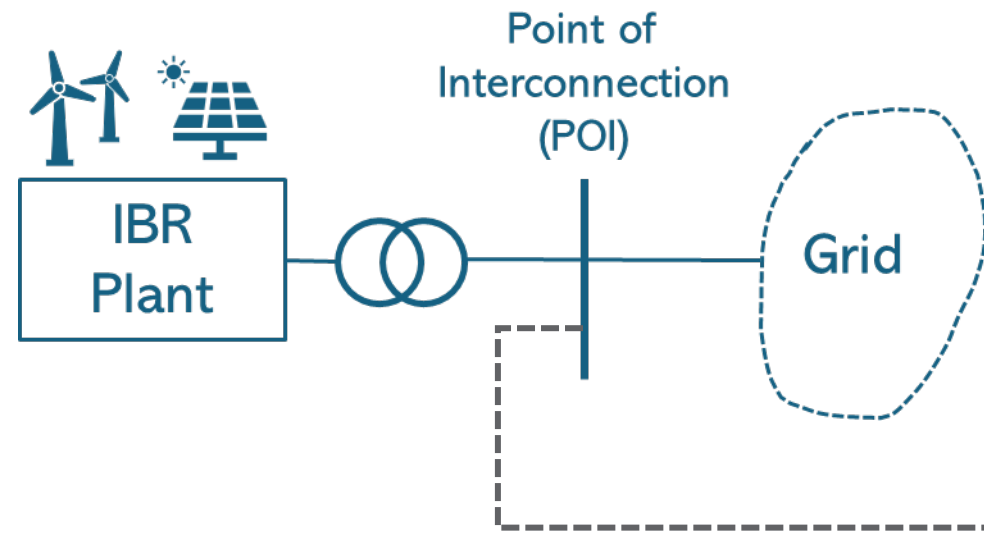
# Grid Strength Monitoring

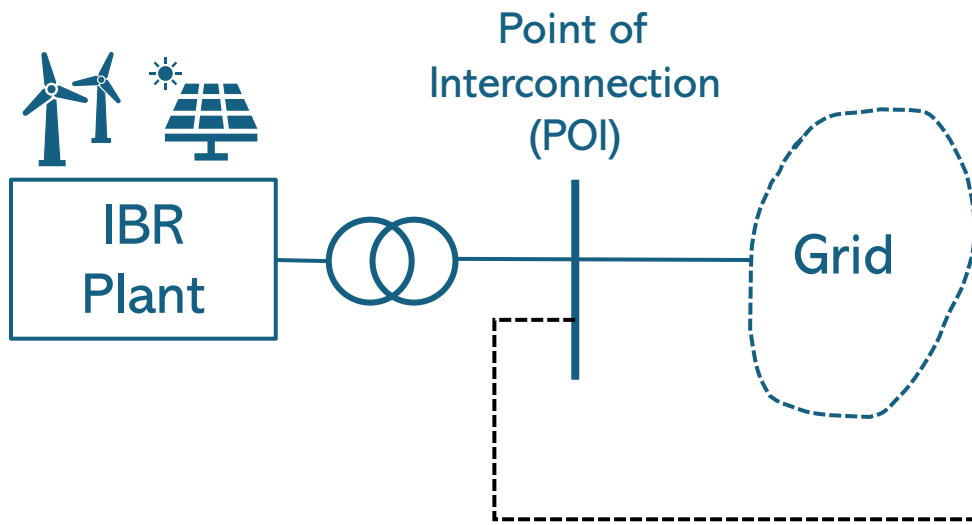
- Wide spectrum grid and IBR impedance monitoring
  - Grid impedance monitoring at fundamental frequency
  - Small signal impedance estimation at POI – Both of grid impedance and IBR impedance
- Provides system operator with:
  - Grid strength monitoring capability – P and Q transfer limits, voltage stability, etc.
  - Sub-synchronous oscillation prediction and stability margin estimation





# Grid Strength Monitoring





Waveform Measurements:  $v_{abc}, i_{abc}$

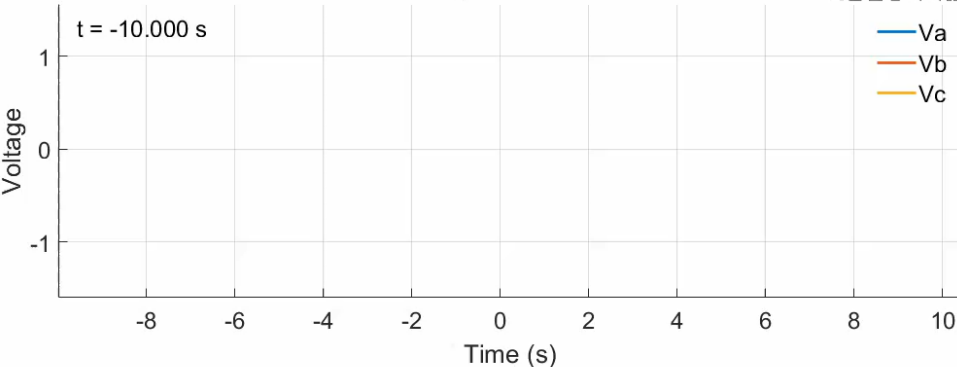
# Nuisance Trip Detection

WaveApps  
Field

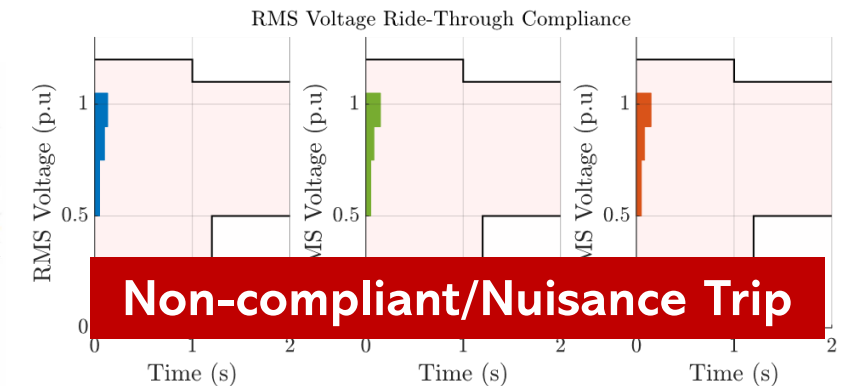
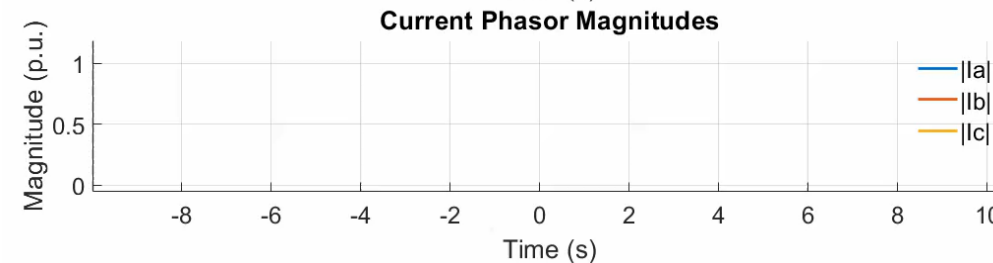
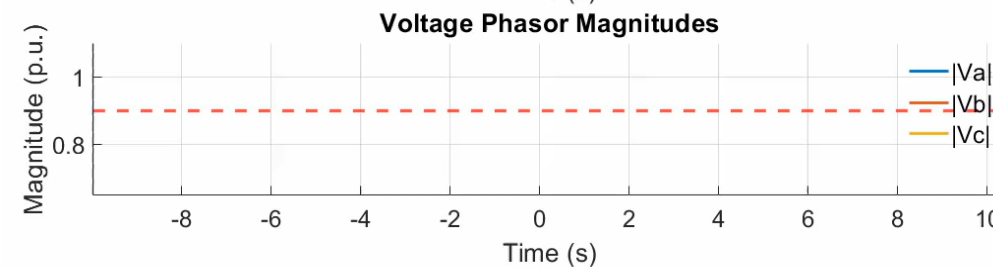
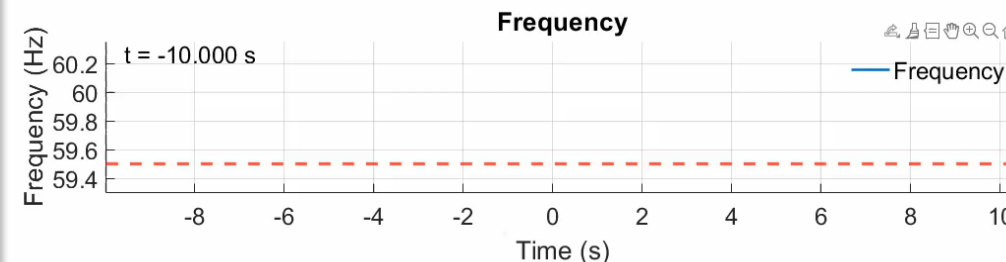
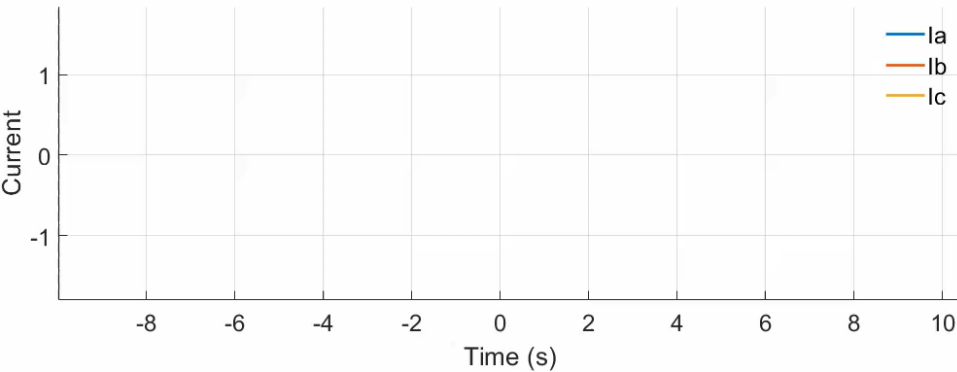
Phasor Estimation,  
Event Detection, and IBR Status Identification

IEEE-2800 Compliance Determination  
(using phasors and waveforms)

Voltage Waveforms



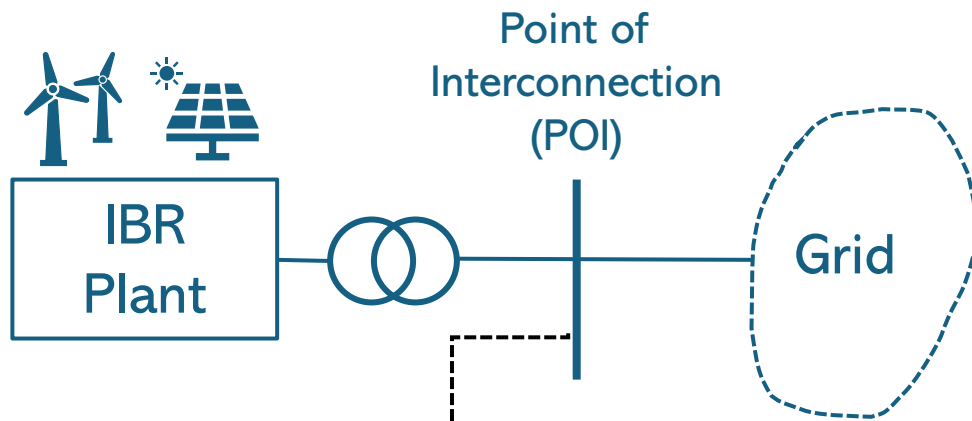
Current Waveforms



Automated Event Report with  
Compliance Justification

IBR_Compliance.IBR1	
Field	Value
Status	'trip'
Compliance	"does not comply with IEEE-2800 r
Justification	1x9 cell
Standard	'IEEE-2800'

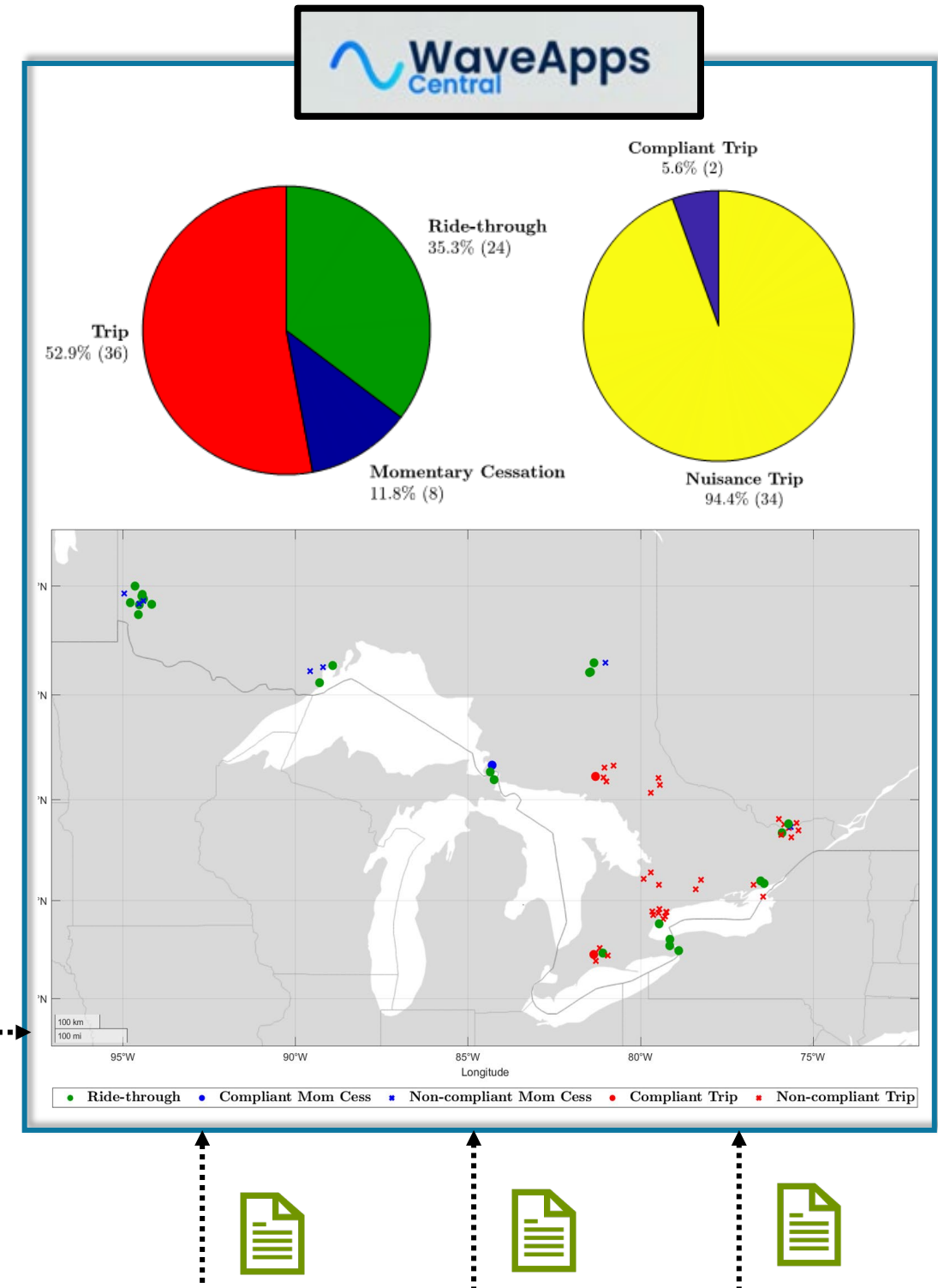
# Nuisance Trip Detection



WaveApps  
Field

## Automated Event Report with Compliance and Compliance Justification

IBR_Compliance.IBR1	
Field	Value
Status	'trip'
Compliance	"does not comply with IEEE-2800 ride-through requirements"
Justification	1x9 cell
Standard	'IEEE-2800'



From Other WaveApps Field Instances





# Demonstrations



PNNL is operated by Battelle for the U.S. Department of Energy



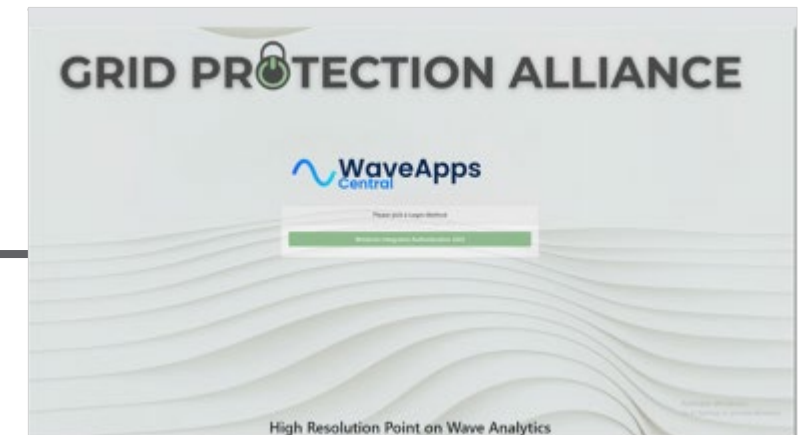
# Lab Demonstration



**WaveApps Field**  
Local Instance at Richland, WA



**WaveApps Central**  
Central Instance at Chattanooga, TN



# GRID PROTECTION ALLIANCE



Please pick a Login Method

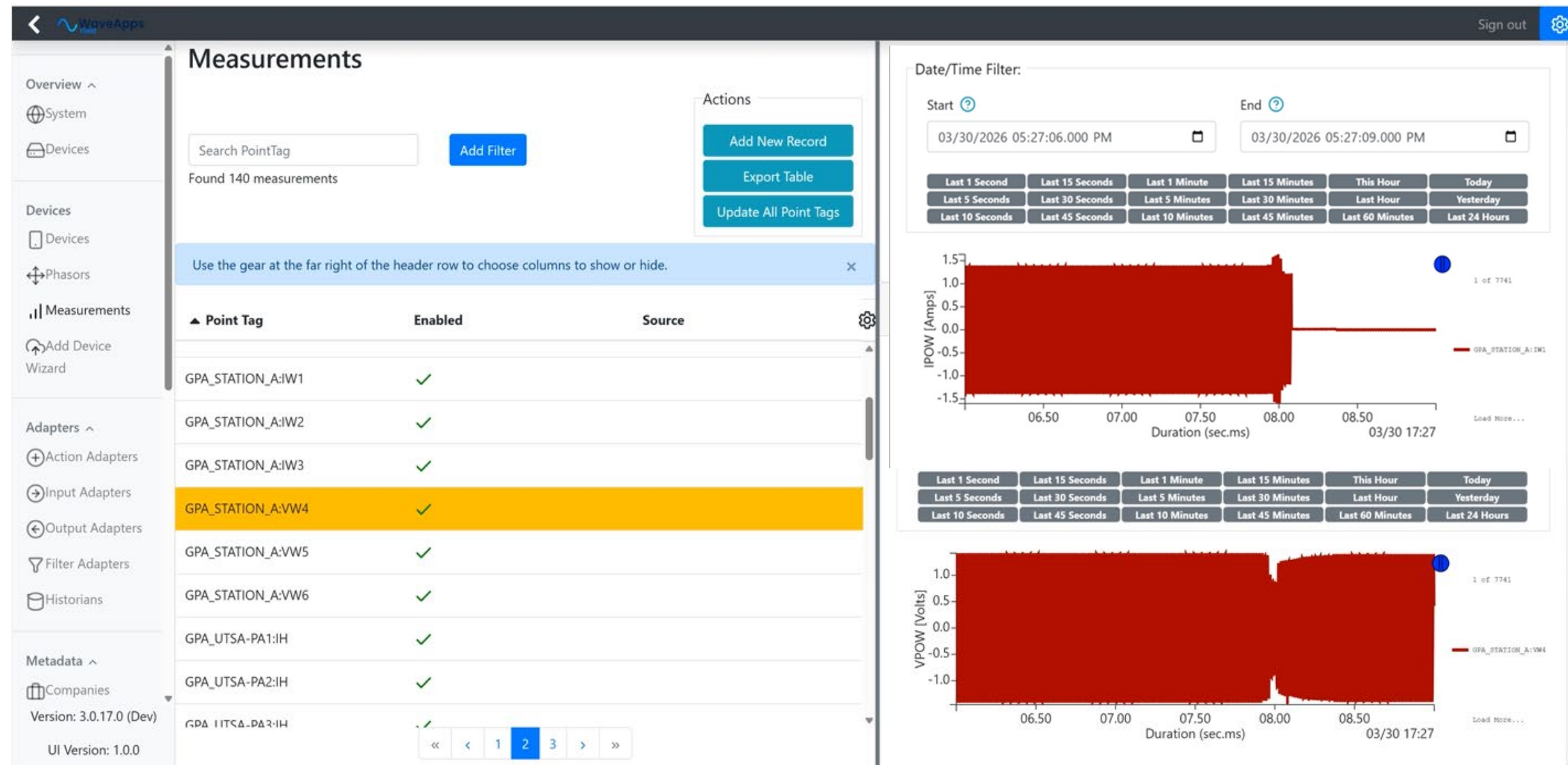
Windows Integrated Authentication (AD)

High Resolution Point on Wave Analytics



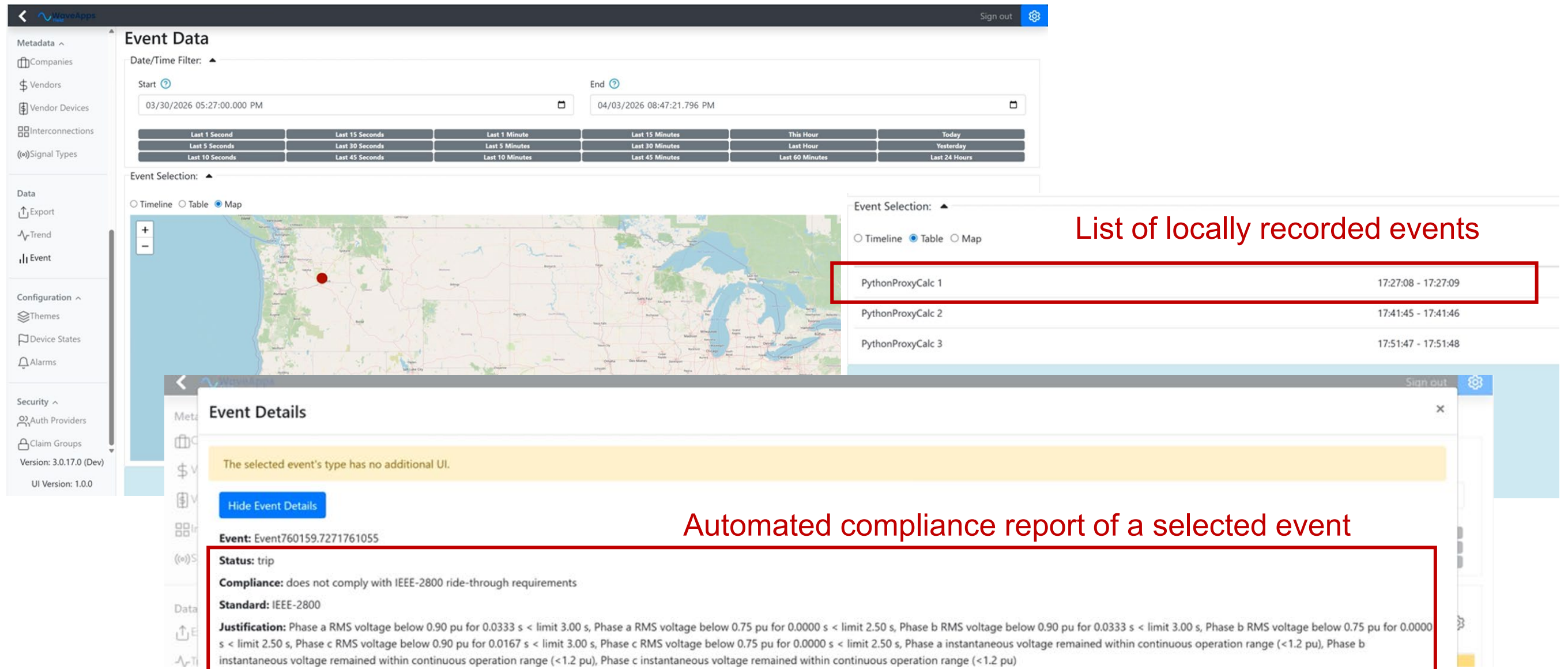
# WaveApps Field Instance

Continuous voltage and current waveform measurements played into WaveApps Field from a local file



# WaveApps Field Instance

- Detects trip and momentary cessation events
- Determines compliance to IEEE 2800 and/or NERC PRC-029-01 ride-through requirements



The screenshot displays the WaveApps Field Instance interface. The left sidebar contains navigation menus for Metadata (Companies, Vendors, Vendor Devices, Interconnections, Signal Types), Data (Export, Trend, Event), Configuration (Themes, Device States, Alarms), and Security (Auth Providers, Claim Groups). The main area is titled 'Event Data' and includes a 'Date/Time Filter' with start and end date pickers. Below the filter is a grid of time range buttons (Last 1 Second, Last 5 Seconds, Last 10 Seconds, Last 15 Seconds, Last 30 Seconds, Last 45 Seconds, Last 1 Minute, Last 5 Minutes, Last 10 Minutes, Last 15 Minutes, Last 30 Minutes, Last 45 Minutes, This Hour, Last Hour, Last 60 Minutes, Today, Yesterday, Last 24 Hours). The 'Event Selection' section shows a map view with a red dot indicating an event location. To the right of the map is a table of locally recorded events.

**List of locally recorded events**

Event Name	Time Range
PythonProxyCalc 1	17:27:08 - 17:27:09
PythonProxyCalc 2	17:41:45 - 17:41:46
PythonProxyCalc 3	17:51:47 - 17:51:48

The 'Event Details' panel is open, showing a message: 'The selected event's type has no additional UI.' Below this is a 'Hide Event Details' button. The event information is as follows:

**Event:** Event760159.7271761055

**Status:** trip

**Compliance:** does not comply with IEEE-2800 ride-through requirements

**Standard:** IEEE-2800

**Justification:** Phase a RMS voltage below 0.90 pu for 0.0333 s < limit 3.00 s, Phase a RMS voltage below 0.75 pu for 0.0000 s < limit 2.50 s, Phase b RMS voltage below 0.90 pu for 0.0333 s < limit 3.00 s, Phase b RMS voltage below 0.75 pu for 0.0000 s < limit 2.50 s, Phase c RMS voltage below 0.90 pu for 0.0167 s < limit 3.00 s, Phase c RMS voltage below 0.75 pu for 0.0000 s < limit 2.50 s, Phase a instantaneous voltage remained within continuous operation range (<1.2 pu), Phase b instantaneous voltage remained within continuous operation range (<1.2 pu), Phase c instantaneous voltage remained within continuous operation range (<1.2 pu)

**Automated compliance report of a selected event**

# GRID PROTECTION ALLIANCE



Please pick a Login Method

Windows Integrated Authentication (ADI)

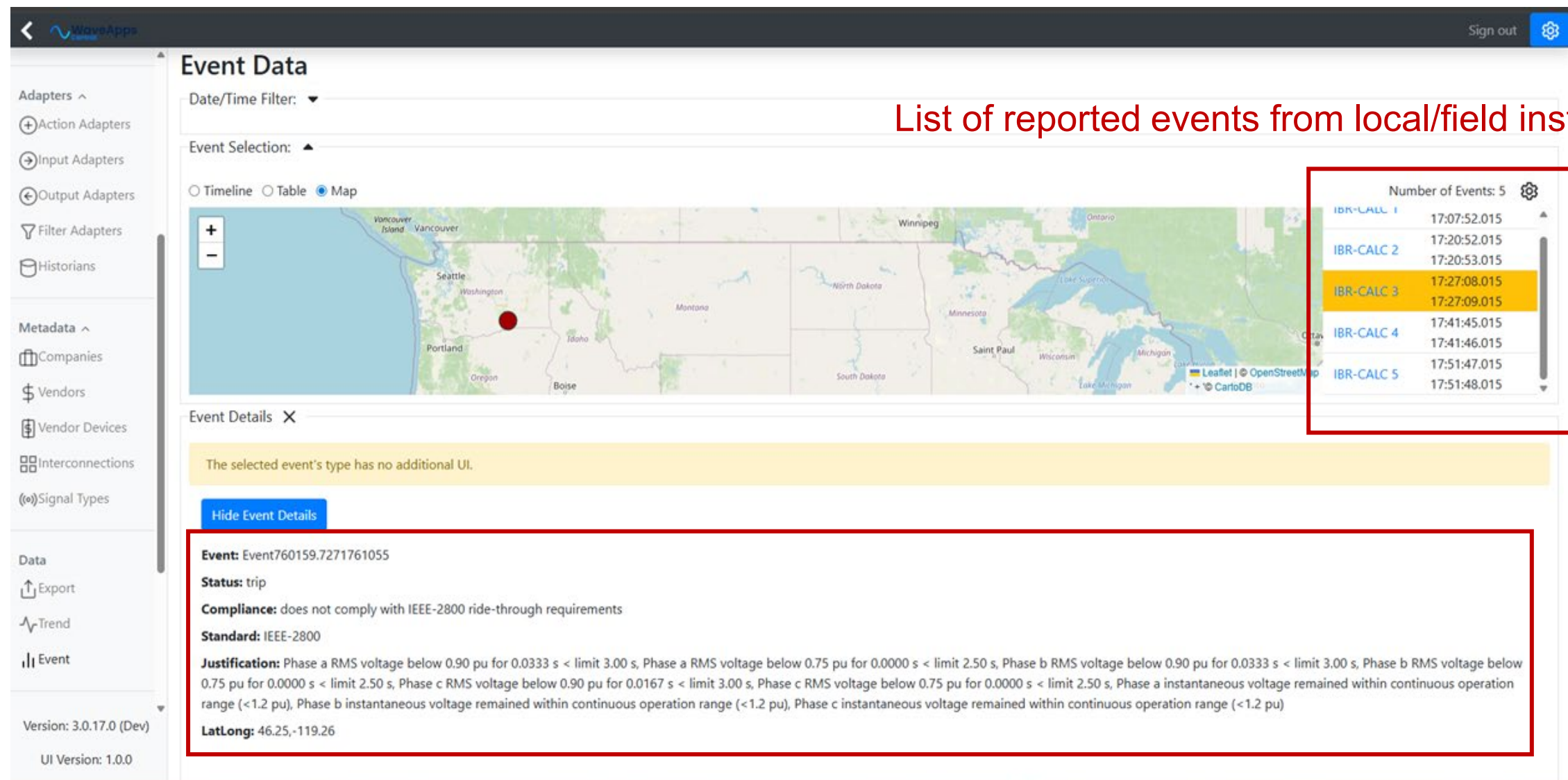
Activate Windows  
Go to Settings to activate Windows.

High Resolution Point on Wave Analytics



# WaveApps Central Instance

- Events and compliance reports received from the local/field instance are logged
- Visualization modules being developed



The screenshot displays the WaveApps Central Instance interface. On the left is a sidebar with navigation options: Adapters (Action, Input, Output, Filter, Historians), Metadata (Companies, Vendors, Vendor Devices, Interconnections, Signal Types), Data (Export, Trend, Event), and Version information (3.0.17.0 Dev, UI 1.0.0). The main area is titled 'Event Data' and includes a 'Date/Time Filter' dropdown and an 'Event Selection' section with 'Timeline', 'Table', and 'Map' views. The 'Map' view is active, showing a map of the Pacific Northwest with a red dot indicating an event location near Seattle. A red box highlights a list of reported events from the local/field instance, showing five entries with IDs and timestamps. Below the map, the 'Event Details' section is expanded, showing details for Event760159.7271761055, including its status, compliance status, standard, justification, and location.

List of reported events from local/field instance

Number of Events: 5	
IBR-CALL 1	17:07:52.015
IBR-CALC 2	17:20:52.015
IBR-CALC 3	17:27:08.015
IBR-CALC 4	17:41:45.015
IBR-CALC 5	17:51:47.015

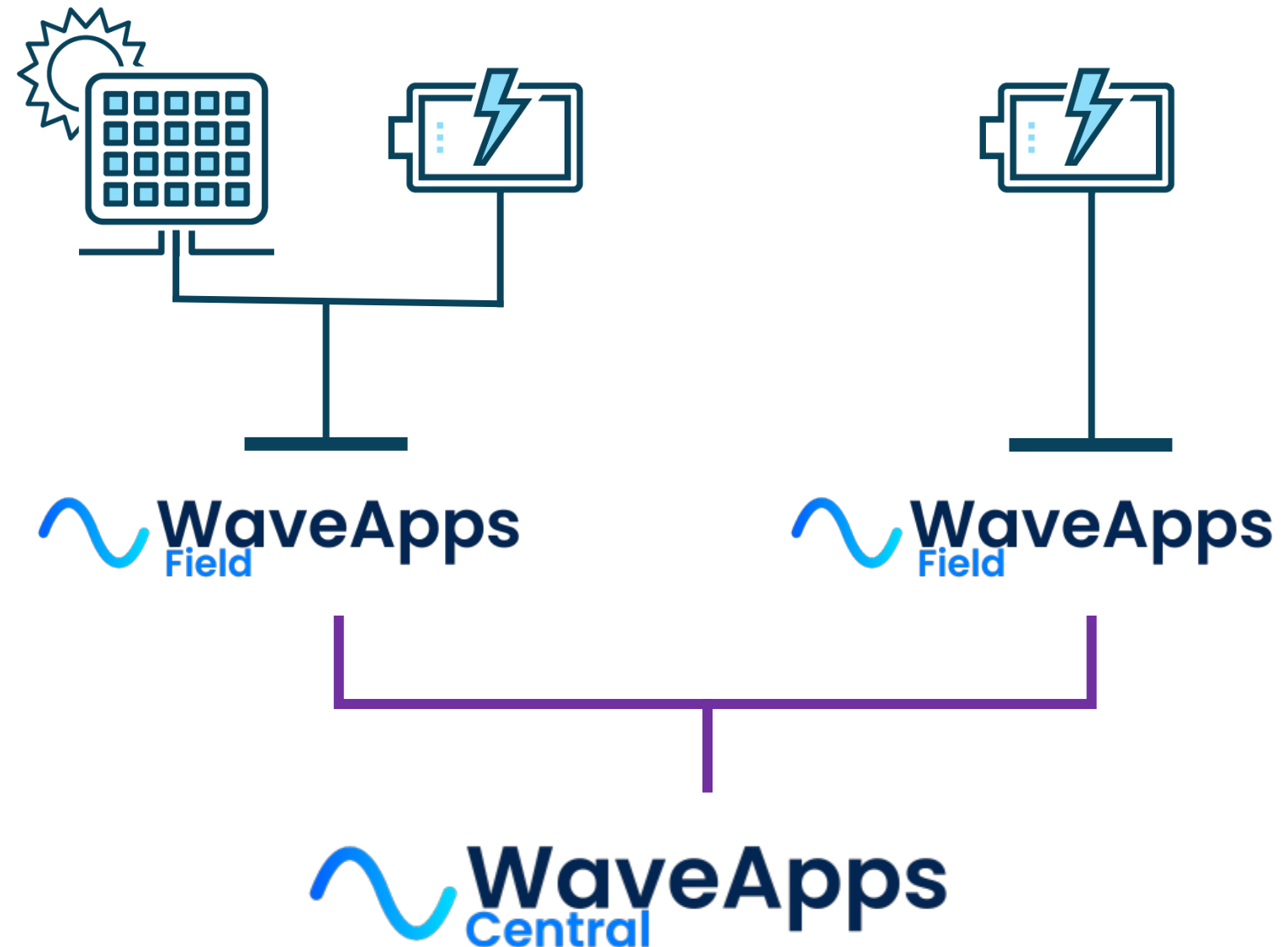
**Event Details**

The selected event's type has no additional UI.

**Event:** Event760159.7271761055  
**Status:** trip  
**Compliance:** does not comply with IEEE-2800 ride-through requirements  
**Standard:** IEEE-2800  
**Justification:** Phase a RMS voltage below 0.90 pu for 0.0333 s < limit 3.00 s, Phase a RMS voltage below 0.75 pu for 0.0000 s < limit 2.50 s, Phase b RMS voltage below 0.90 pu for 0.0333 s < limit 3.00 s, Phase b RMS voltage below 0.75 pu for 0.0000 s < limit 2.50 s, Phase c RMS voltage below 0.90 pu for 0.0167 s < limit 3.00 s, Phase c RMS voltage below 0.75 pu for 0.0000 s < limit 2.50 s, Phase a instantaneous voltage remained within continuous operation range (<1.2 pu), Phase b instantaneous voltage remained within continuous operation range (<1.2 pu), Phase c instantaneous voltage remained within continuous operation range (<1.2 pu)  
**LatLong:** 46.25,-119.26

# Field Demonstration Plan

- 6-month demonstration is scheduled to begin by June 30, 2027
- Hosted by Salt River Project (SRP)
- WaveApps Field will be deployed at two substations
  - Co-located PV and BESS
  - BESS
- Results from the four example applications will stream to WaveApps Central



## Summary and Next Steps

- The WaveApps platform will address a gap in utilities' ability to monitor high-frequency oscillations and other high-speed behaviors
- A distributed architecture enables POW-based analytics while limiting communication requirements
- The initial set of four applications will be extensible to meet emerging needs
- Looking forward:
  - Platform finalized
  - Algorithms translated to applications
  - Field demonstration at Salt River Project



# Acknowledgment and Disclaimer

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# Thank you

