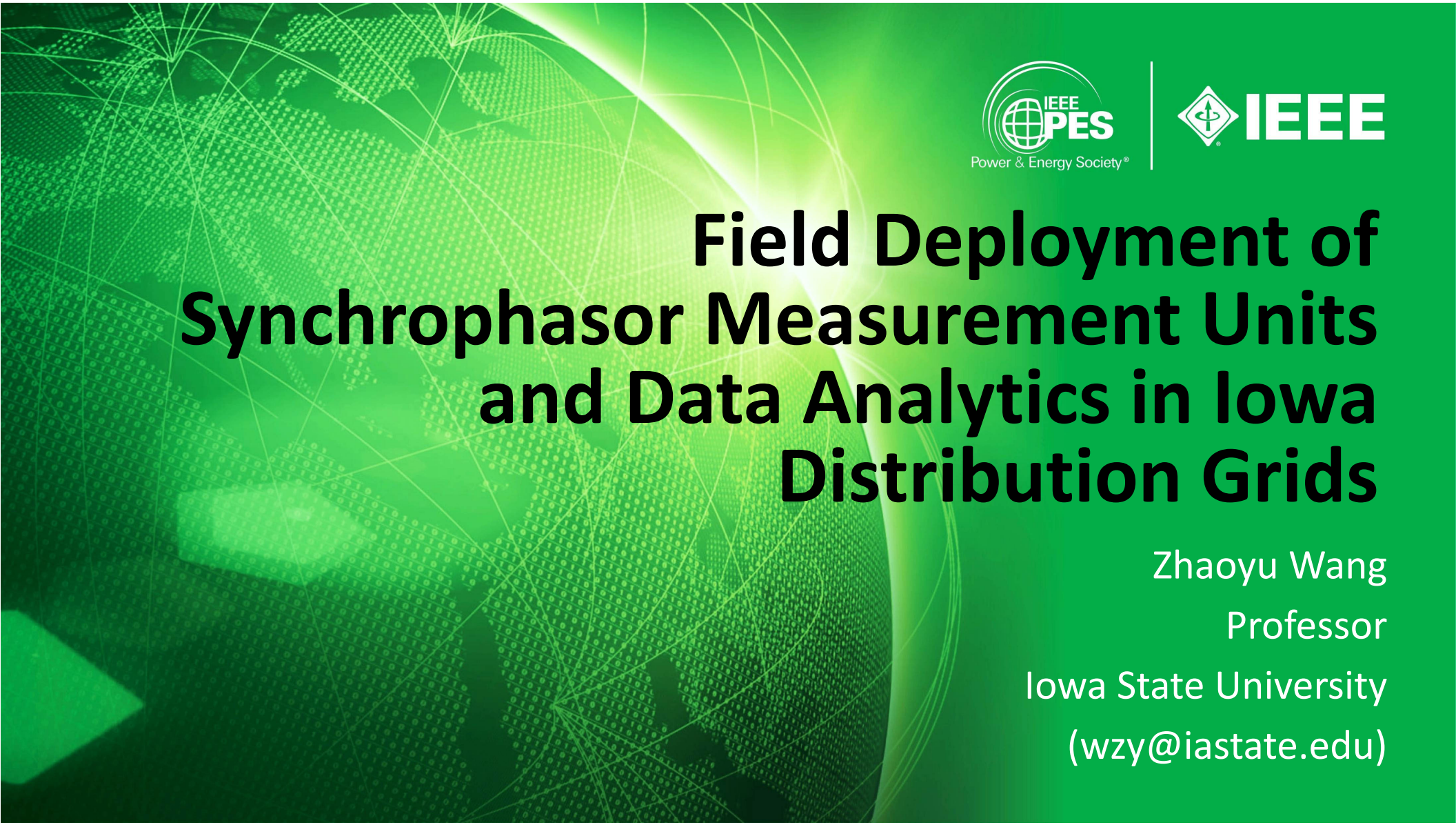

Field Deployment of Synchrophasor Measurement Units and Data Analytics in Iowa Distribution Grids

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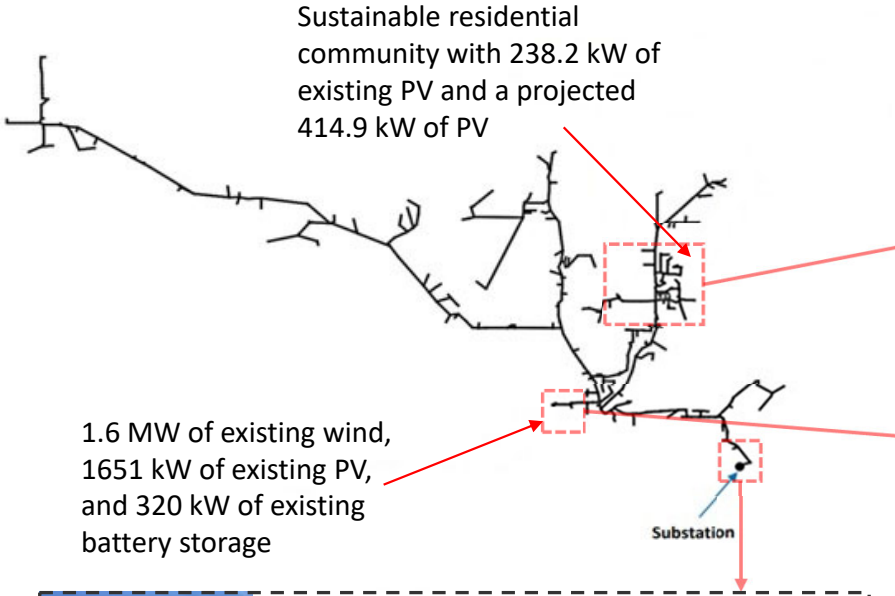
μ-PMU Field Deployment - Overview

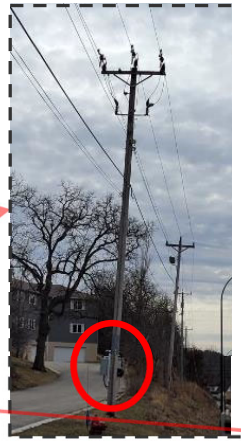
- Demonstrate field deployment of μ-PMUs in power distribution systems and provide big data tools for analysis.
- Collaborate with Alliant energy to deploy three μ-PMUs on one feeder with high DER penetration areas:
  - The upstream substation has two transformers (69/13.8 kV) supplying 5 feeders.
  - Primary voltage: 13.8 kV-LL
  - Maximum load on feeder: 5 MW
  - Total DER: 4.45 MW
  - Total wind: 1.65 MW
  - Total solar: 1 MW solar farm; 3.2 MW distributed solar
  - Future energy storage system: 2.5 MW, 2.9 MWh
- Grid model is available in Synergi software.

µ-PMU Field Deployment - Location



Feeder Head µ-PMU:

Positioned at the beginning of the feeder, this micro-PMU serves as a crucial monitoring point directly interfacing with the substation.



Storage-Centric µ-PMU:

This location monitoring battery storage facility, distributed solar generation, and future utility-scale solar developments.

- 3.2 MW distributed Solar
- 2 MW battery storage system

High Renewable Integration µ-PMU:

This location features a diverse mix of renewable energy sources.

- 1 MW solar farm
- 1.65 MW wind turbines
- 56-60 kW battery storage system

µ-PMU Field Deployment - Components

- Main components of the µ-PMU:
  - **µ-PMU main module** for uninterruptedly synchrophasor collection
  - **PQube 3 main module** for event/outage collection
  - G&W outdoor electronic current and voltage sensor
  - Uninterruptible power supply (UPS)
  - Digital signal processor
  - GPS receiver
  - Ethernet connection or cellular modem
  - Enclosure for hardware
  - Server/Platform for data transmission and collection.

µ-PMU Field Deployment - Components

µPMU Main Module

UPS

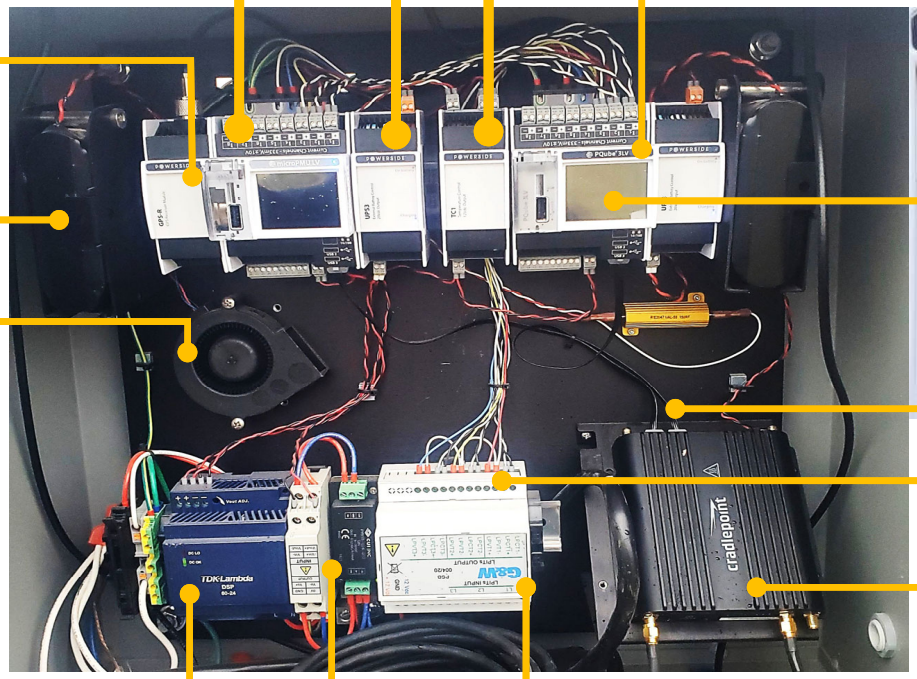
Temp Control

PQube 3 Main Module

GPS Receiver Module

Emergency Battery Unit

Cooling Fan



PQube 3 Voltage, Current and Frequency Reading

Data Transmission Port

Voltage/Current outputs are separated for each phase, connected to the PQube

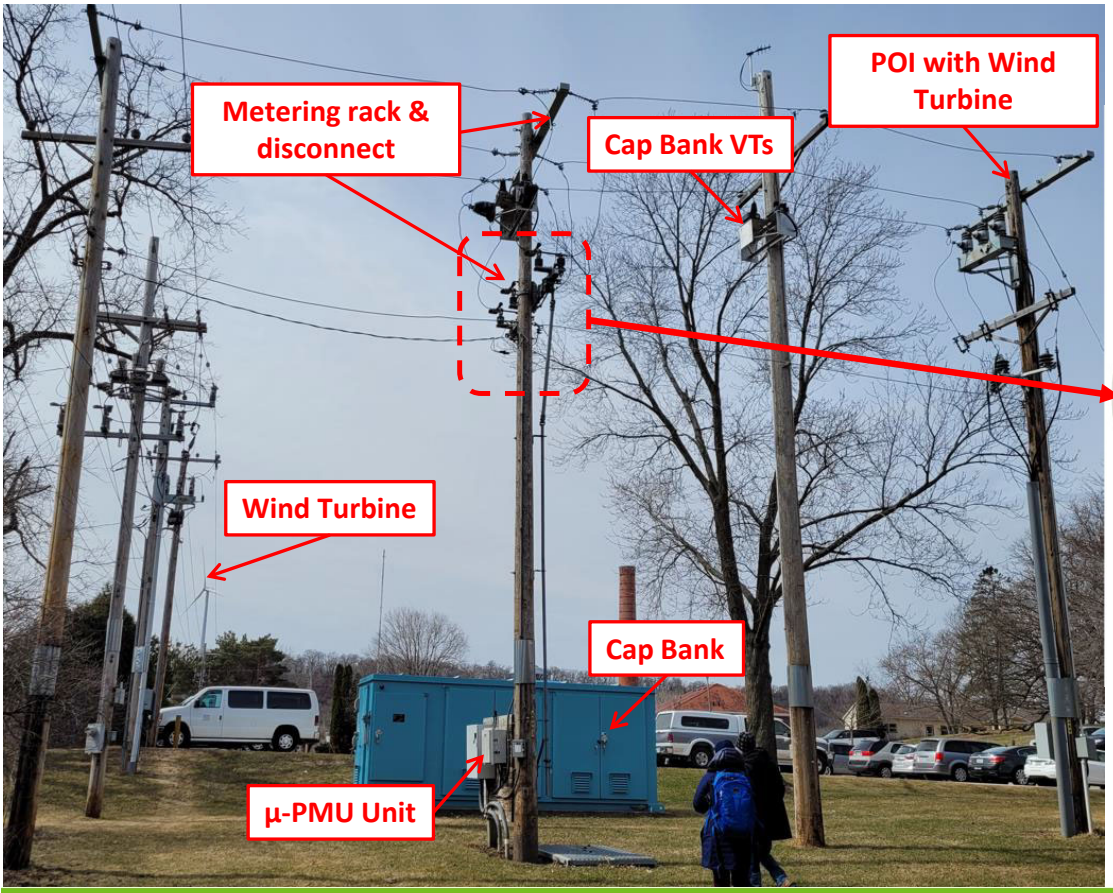
Cradlepoint 4G Cellular Modem

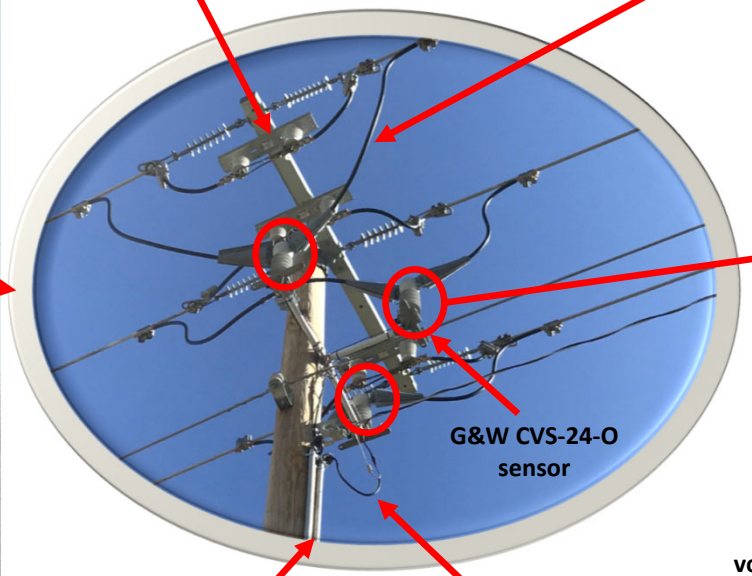
Digital Signal Processor

12 V Power Supply

G&W Processing Unit. Three inputs for three phases (Voltage/Current are combined)

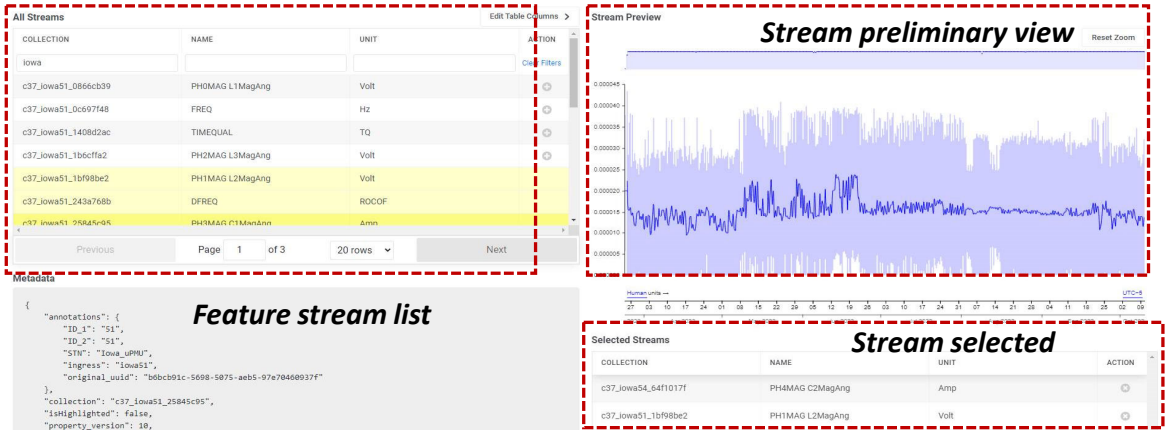
μ-PMU Field Deployment - Grid Connection



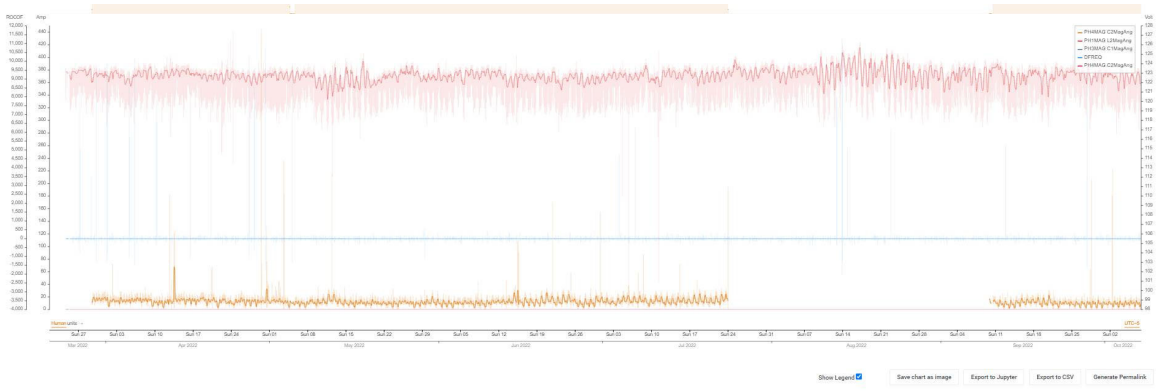


µ-PMU Data Collection and Visualization

- Cellular modem and GPS directly transmit the livestream data to data collection server.
- Data Resolution: 120 points/second
- Third-party platform provides µ-PMU data management and visualization.
- Features including three-phase voltage, current, voltage and current angles , frequency, and differential frequency are recorded.



(a) Feature stream selection function

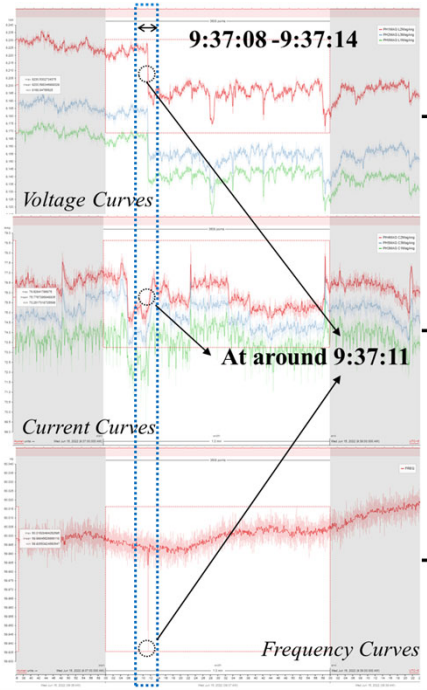


(b) Feature stream visualization

µ-PMU Data Collection and Visualization

- µ-PMU event detection can be also visualized on the Powerside platform with detailed description.

Micro-PMU measurement during an event



→ **Voltage sag observed**

→ **Current swell observed**

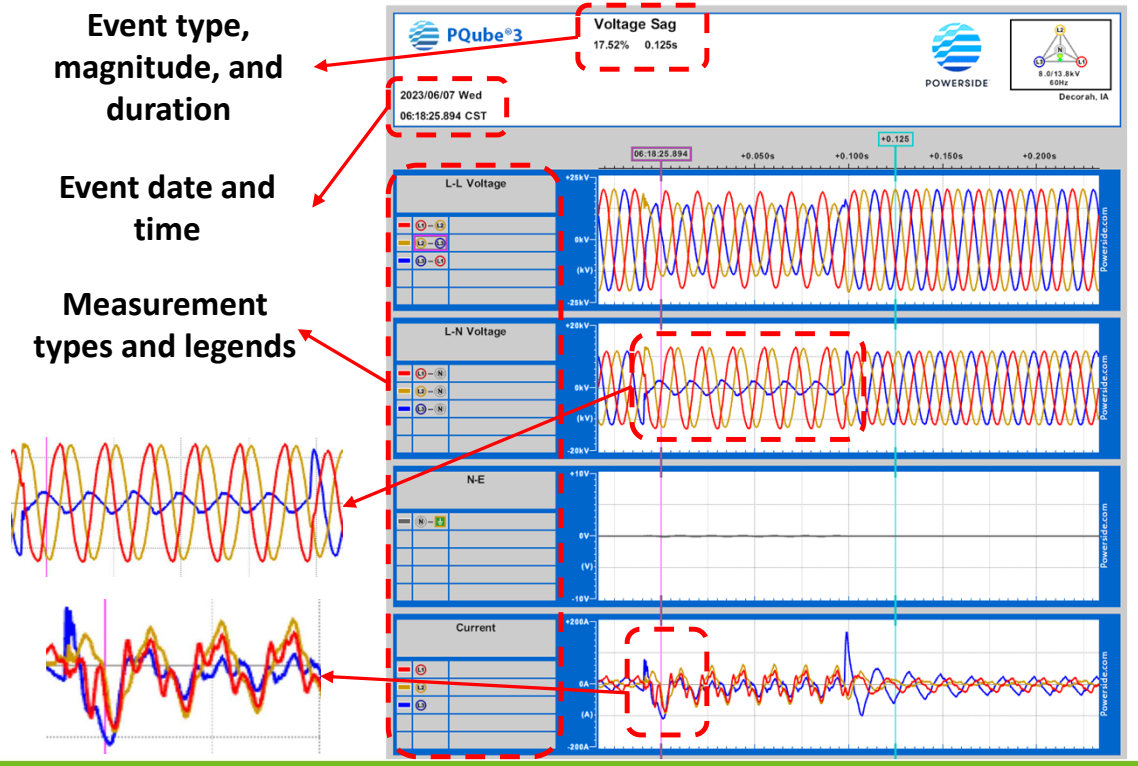
→ **Frequency sag observed**

Voltage sag event recording by PQube3 sensor

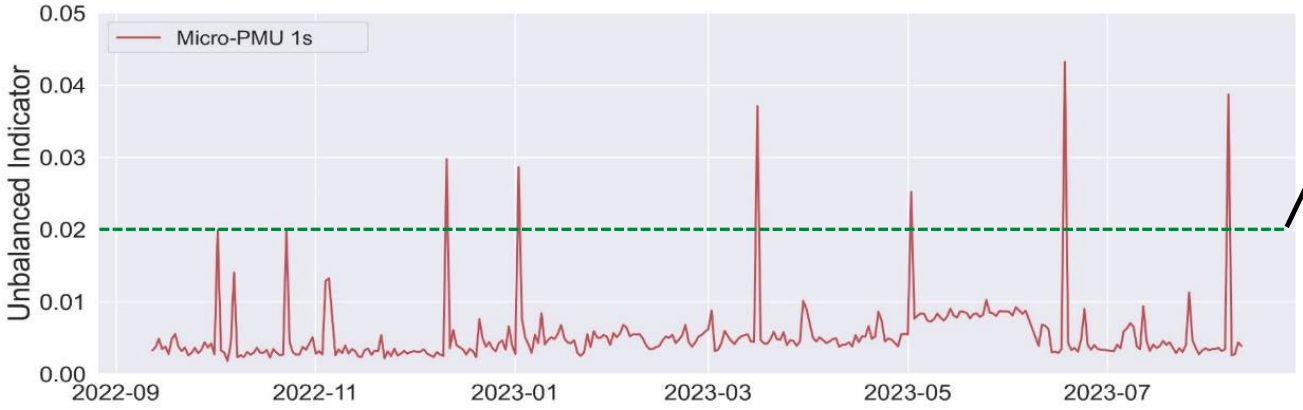
Event type, magnitude, and duration

Event date and time

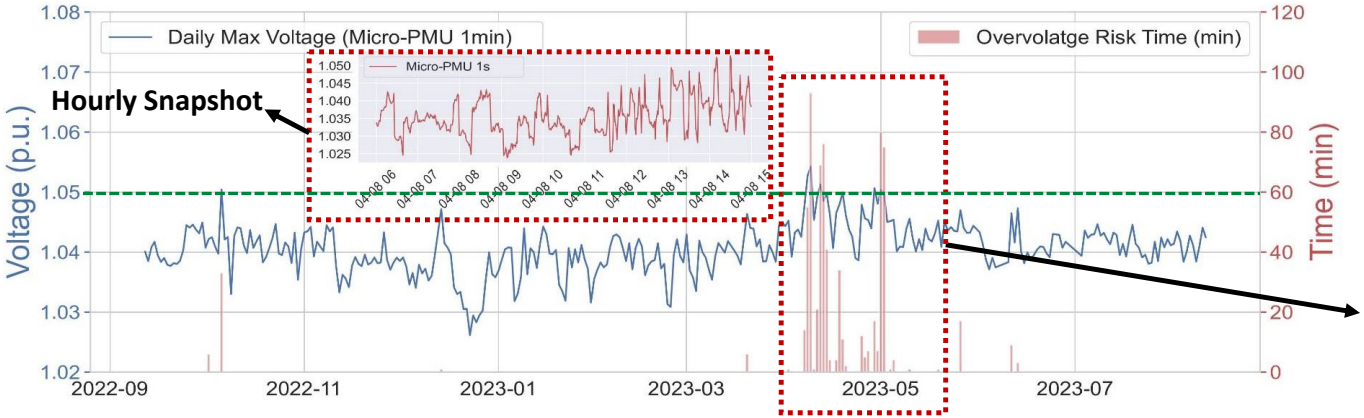
Measurement types and legends



μ-PMU Data Analytics - Voltage Issues



Profile of voltage phase unbalance



Profile of daily peak voltage (blue line) and overvoltage risk (red bar)

The voltage unbalance factor (VUF) obtained from micro-PMU data exceeds the IEEE standard (2%) for some periods.

VUF, which is the ratio of the negative sequence voltage component to the positive sequence voltage component:

$$R_{VU} = \frac{V_{negative}}{V_{positive}} \times 100\%$$

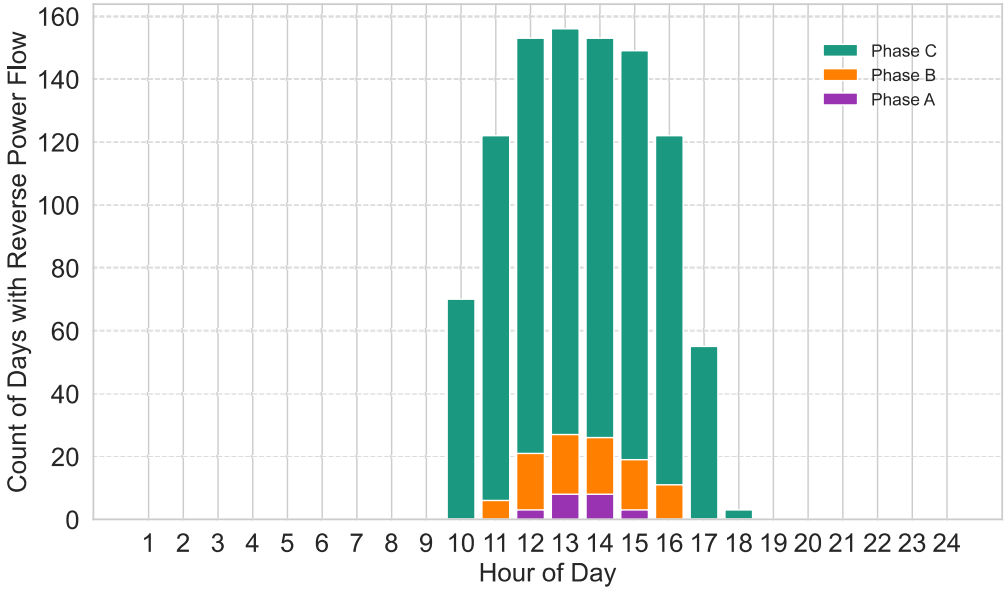
$V_{negative}$ and $V_{positive}$ can be calculated using three-phase voltage magnitude and angle.

Daily maximum voltage magnitude and overvoltage duration.

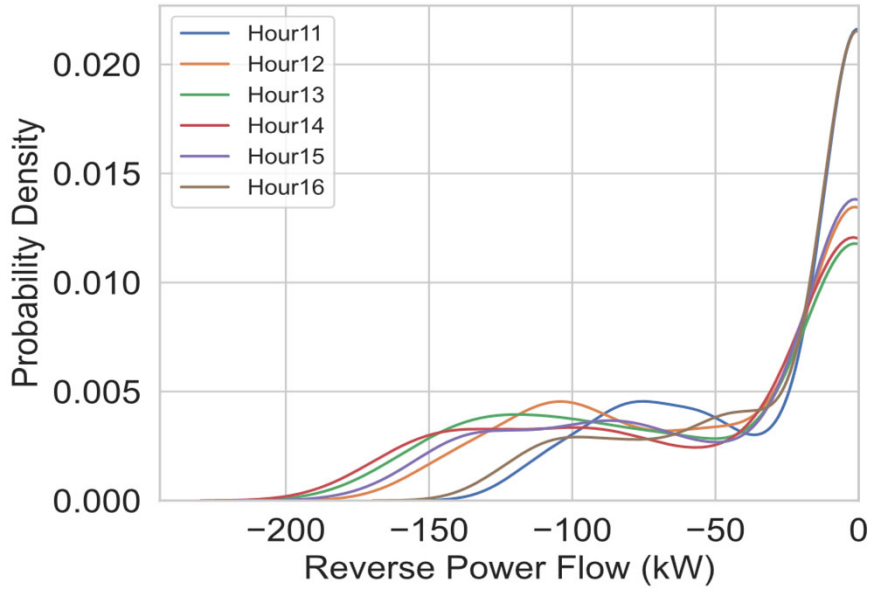
Significant overvoltage risks exist in April and May, with Voltage violating the ANSI standard (0.95 p.u. - 1.05 p.u.)

μ-PMU Data Analytics - Reverse Power Flow

- Monitoring reverse power flow helped us to recommend optimized energy storage strategies, such as energy storage scheduling, to our utility partners.



Frequency of reverse power flow in a year



Probability density of reverse power flow

- The reverse power flow in the three phases is unbalanced.
- Reverse power flow generally occurs from 10 a.m. to 5 p.m.
- The probability density of reverse power flow in high occurrence hours represents the distribution of the reverse power flow intensity.

Conclusions

- Demonstrated micro-PMU field deployment with grid model, location and connection, and device specifications.
- Introduced micro-PMU data collection/maintenance platform and event detection tools.
- Illustrated micro-PMU data analytics with voltage and current virtualization, voltage issues, and reverse power flow.
- Plan to install 4 more micro-PMUs to validate smart inverter settings.

Thank you!
Q&A

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