

Successful Deployment and Application of Distribution PMU's

*Emma M Stewart
Deputy Associate Program Leader
Cyber and Infrastructure Resilience*

October 24 2018



Intro: Success Stories

- How did we get to here?
- Success During the ARPA-E RPU Project
 - The big wins – PV disaggregation, papers, demonstration, event detect
- Follow on projects – DOE integration, cyber, physical, CA EPIC
- Overall Deployment

Micro-synchrophasors (μ PMUs) for distribution systems



Three-year, \$4.4 M ARPA-E OPEN 2012 project (2013-2016)

Research partners CIEE, UC Berkeley, Lawrence Berkeley Lab, Power Standards Lab, Lawrence Livermore Labs

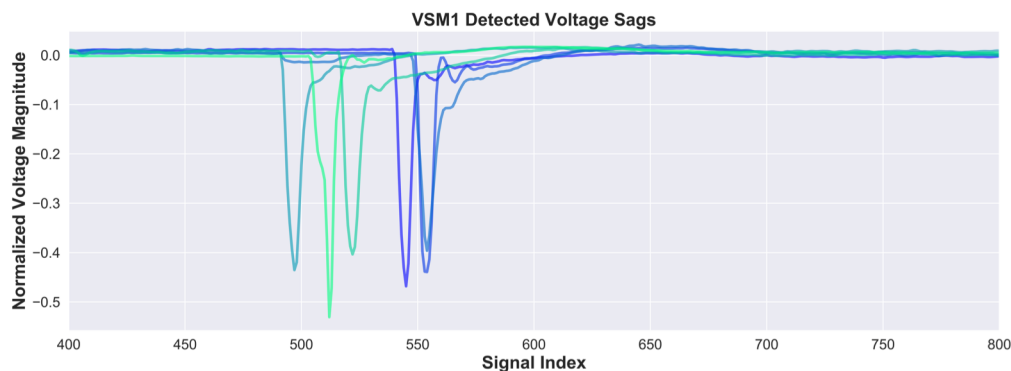
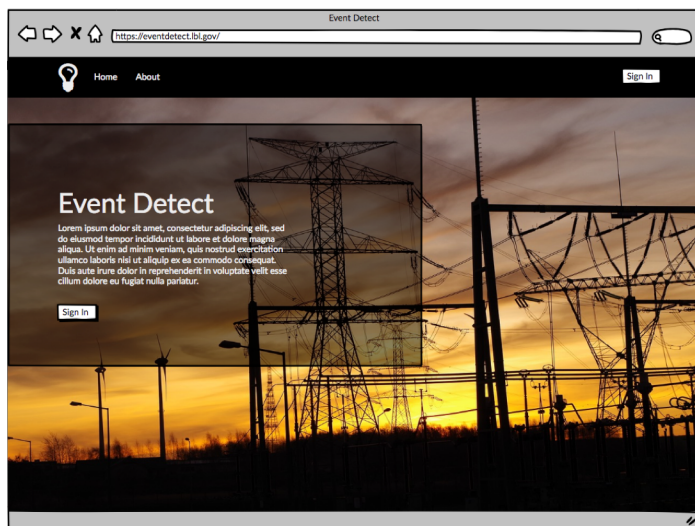
Field installations at Riverside Public Utilities, Southern California Edison, Pacific Gas & Electric, Alabama Power, Georgia Power, Tennessee Valley Authority



The Start...use cases and deployment

- Event Labeling – solving the labeled dataset issue
- Forensic investigation – event analysis
- Control and visualization – operational integration
- Research and development future

Development of a Supervised Training Dataset with expert user input (Success 1)



Answering a key “need” for application of supervised ML to grid data

“what are the events and how do we label them”

“we don’t know what we are looking at”

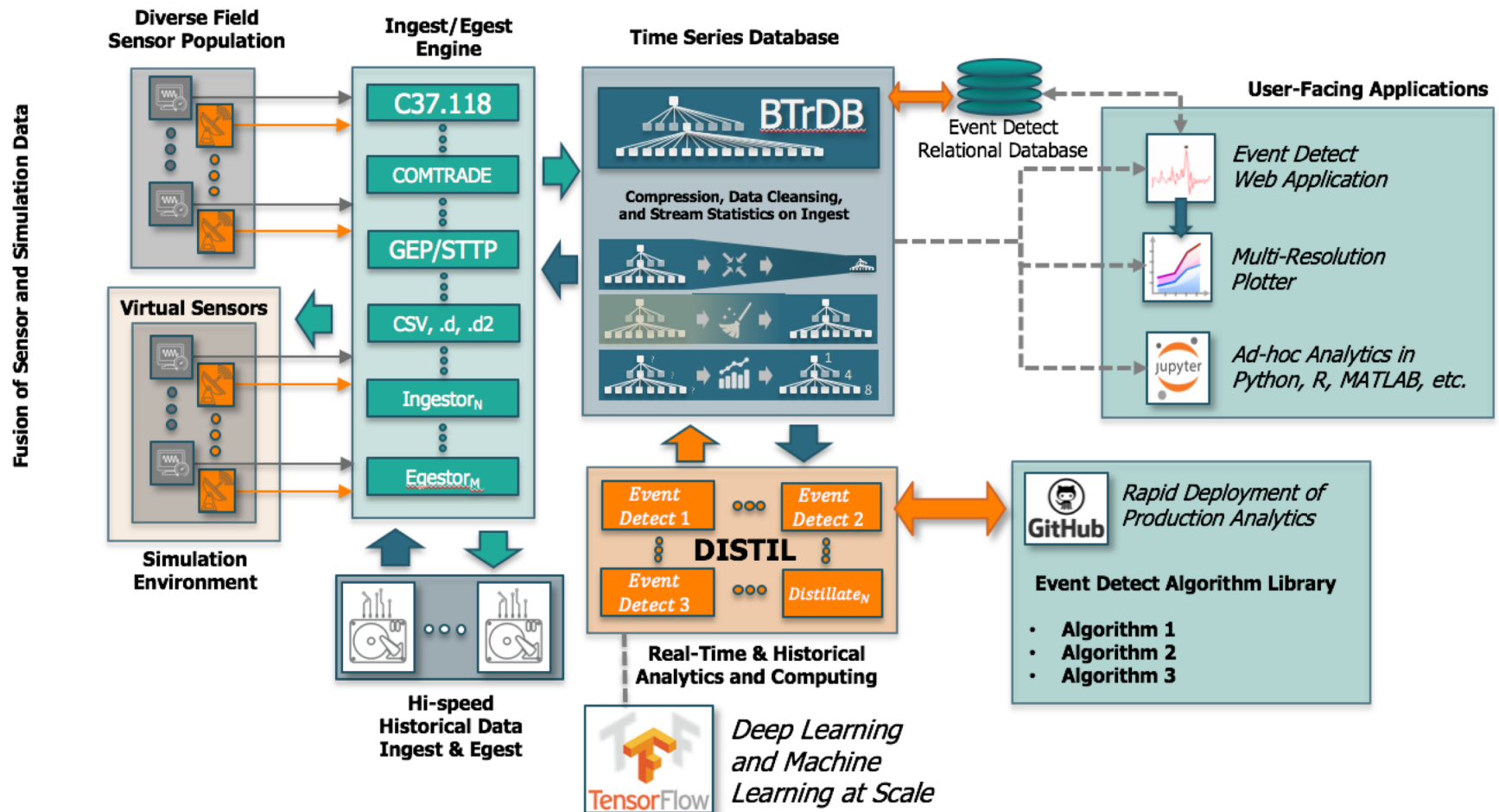
“I need a dataset labeled by knowledgeable power systems engineers”

Reduce need for large volumes of historical data and very complex unsupervised algorithms

No way for engineers to view “anomalous” events in a systematic manner for labeling – especially in new datasets

EventDetect Structure: Event Labeling

PingThings PredictiveGrid™ with Event Detect



User Profiles, Stats, and Dashboards, Event Searching

[Dashboard](#)
[Random Event](#)
[Search](#)
[Profile](#)

Logout

Profile

Profile

First Name
Last Name

Allen

Email

allen@pingthings.io

Timezone

Eastern Time Zone

Update

User Statistics

% of All Labels

Recent Activity

	Oct/ov	Dec	Jan
M			
W			
F			

Labels

65

Rank

9

Joined

24 Sep 2018

Event Detect

Dashboard

Random Event

Search

Profile

Logout

Dashboard

Statistics

Events
792

Labels
807

Users
11

Export Training Set

Download CSV

Top Users

All Time

Shawn Dunn

Gina Johnson

Jeffrey Lyons

David Riley

Last Week

Gina Johnson
Angel Anderson
David Riley

Recent Activity

Label Charts

Labels By Type

Labels Over Time

Events Labeled

Search

Any

Location

Any

Status

Open

Time Period to

☐ Only with Attachments
☐ Only with Comments

[Clear filters](#)

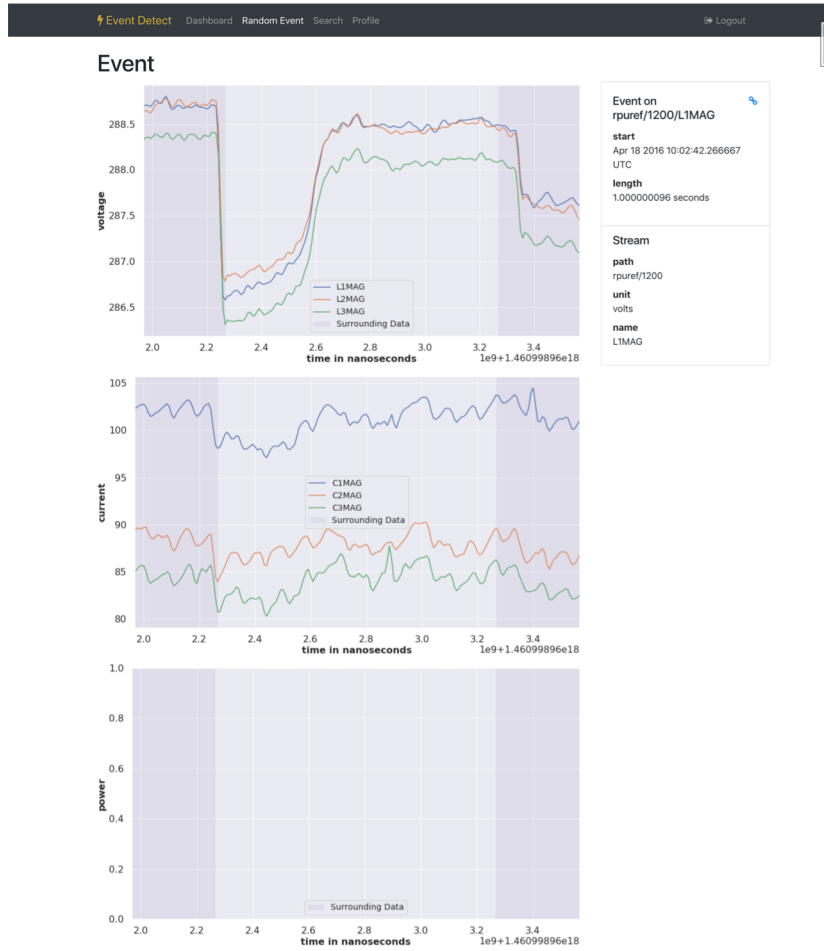
Matching Events

Previous [1](#) [2](#) [3](#) [4](#) [5](#) [6](#) [Next](#)
786 Items in 53 pages

rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:02:42 Z 20669 UTC LIAGG votes 🗳️ 2 ballots have been submitted You have submitted a ballot	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:05:44 Z 45169 UTC LIAGG votes 🗳️ 0 ballots have been submitted	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:10:45 Z 45169 UTC LIAGG votes 🗳️ 1 ballot has been submitted You have submitted a ballot	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:14:46 Z 45169 UTC LIAGG votes 🗳️ 2 ballots have been submitted	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:16:48 Z 45169 UTC LIAGG votes 🗳️ 0 ballots have been submitted	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:21:49 Z 45169 UTC LIAGG votes 🗳️ 2 ballots have been submitted	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:27:50 Z 45169 UTC LIAGG votes 🗳️ 0 ballots have been submitted	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:31:51 Z 45169 UTC LIAGG votes 🗳️ 0 ballots have been submitted	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:35:52 Z 45169 UTC LIAGG votes 🗳️ 0 ballots have been submitted	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:41:53 Z 45169 UTC LIAGG votes 🗳️ 0 ballots have been submitted	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:45:54 Z 45169 UTC LIAGG votes 🗳️ 0 ballots have been submitted	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:51:55 Z 45169 UTC LIAGG votes 🗳️ 0 ballots have been submitted	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 10:55:56 Z 45169 UTC LIAGG votes 🗳️ 0 ballots have been submitted	View
rune/1200 - Event on pure/1200/LIAG Apr 19 2016 11:01:57 Z 45169 UTC LIAGG votes 🗳️ 0 ballots have been submitted	View

Previous [1](#) [2](#) [3](#) [4](#) [5](#) [6](#) [Next](#)
786 Items in 53 pages

Event Labeling



time in nanoseconds

Your Label

Type
Voltage Sag

Location
Distribution

Useful For

- ☒ Impedance Calculations
- ☐ DG characterization
- ☐ Fault Detection
- ☐ Phase Identification
- ☐ Voltage Management
- ☐ Voltage Sag Characterization
- ☒ Further Research

Confidence
5

Comments
hi

Attach file
Choose file Browse

Save

Other Labels

by Kimberly Roy July 5, 2018, 8:18 p.m.

Type
Voltage Sag

Grid Location

Useful for
DG characterization, Phase Identification, Voltage Management

Confidence
2

Online for Utility x 2 October 2018

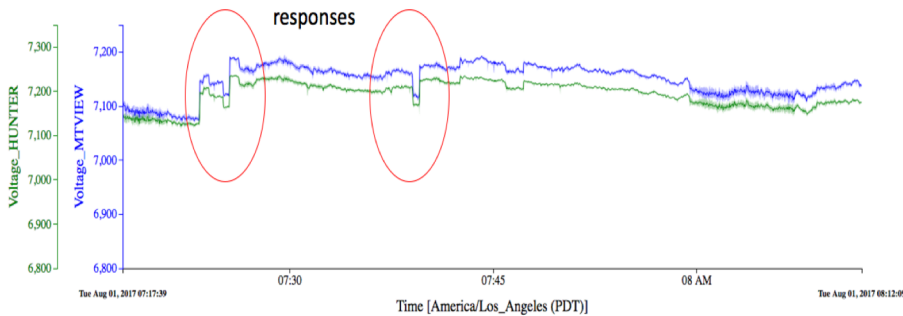
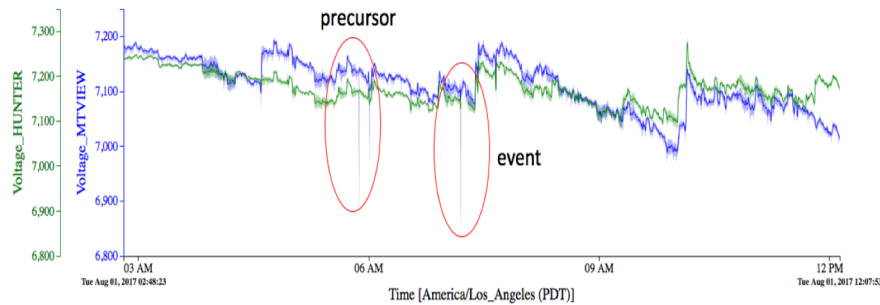
How to use this tool: click on the thing you want to label. Business: other word: good: improve: better: ever research somebody happy.

Incident Analysis for Utility Partners (Success 2)

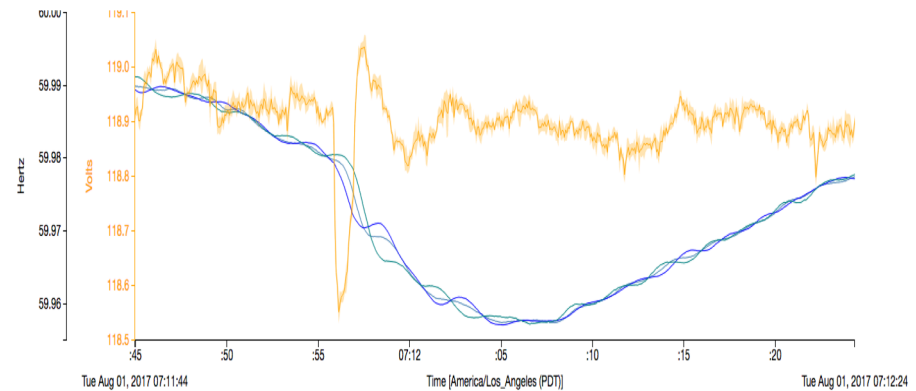
- Question from the utility partner: We had two outages today, storm or transmission system - SCADA doesn't show anything to help us with root cause, help?
- Anomaly Detection had pulled the two incidents into our "eventdetect" system
- Determined one system wide, one local... determined errors in control system response within utility
- Doing this requires data science and grid expertise... can't do one without the other

Analysis Event 1 (System Wide Event)

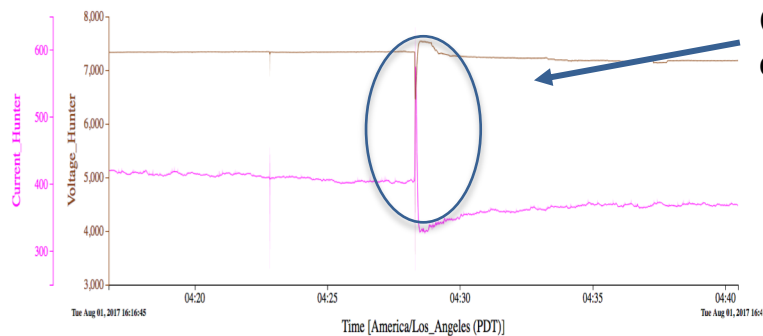
Early Morning Event & Response (System Wide Voltage Deviation plot of **Voltage** & **Current** measured in Riverside, CA)



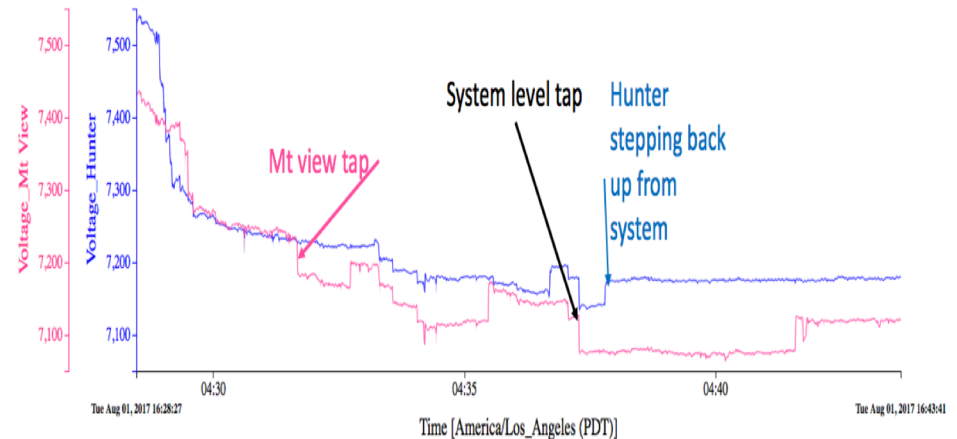
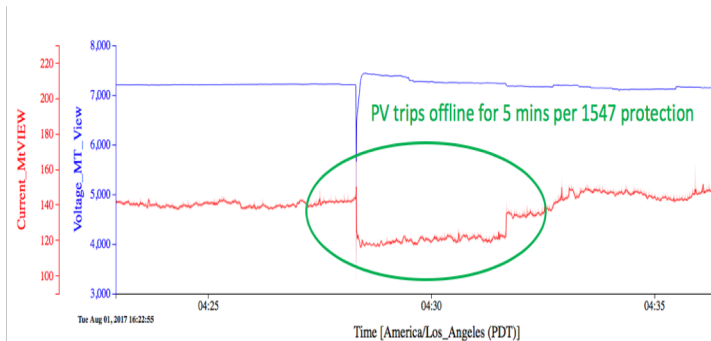
frequency across N & S CA, 10 sec oscillation in response to **Voltage** event



Analysis Event 2 (local event)



Current Response & Energy of event locally indicated lightning



PV Systems all tripped – Current measured at Hunter & Mt View

Voltage sag measured at Hunter and Mt View (Blue & Brown)

Voltage control response error

DER Control Demonstration at RPU (Success 3)



- Demonstrate how μ PMU data can be used to improve network planning, operational monitoring, and control
- Validate the results of the power system analysis study performed last summer against a live deployment at the Hunter circuit at UCR
 - Integrate μ PMUs with SGS Active Network Management (ANM) platform
 - Integrate SGS ANM with the PV Inverters
 - Perform Voltage Angle Constraint Management test cases



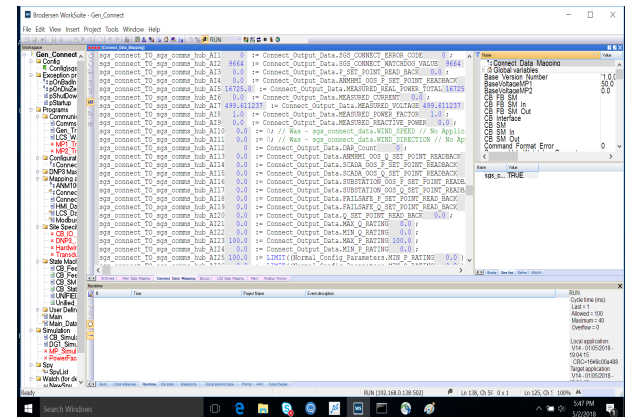
Phase Angle from multiple μ PMU as a control signal demonstration (Success 3)

- Validated assumptions that we could minimize down time for RPU's customers during maintenance by monitoring voltage angle constraints and controlling PV inverters to address any breach.
- Demonstrated that by manipulating the set-point of PV inverters, voltage angle at a NOP can be adjusted.
- Further analyzed historical data and observed that the voltage angle do get breached at least once a day.
- sgs connect controller was setup as a Modbus Client
- sgs connect successfully read values (real power, reactive power, voltages, etc.)

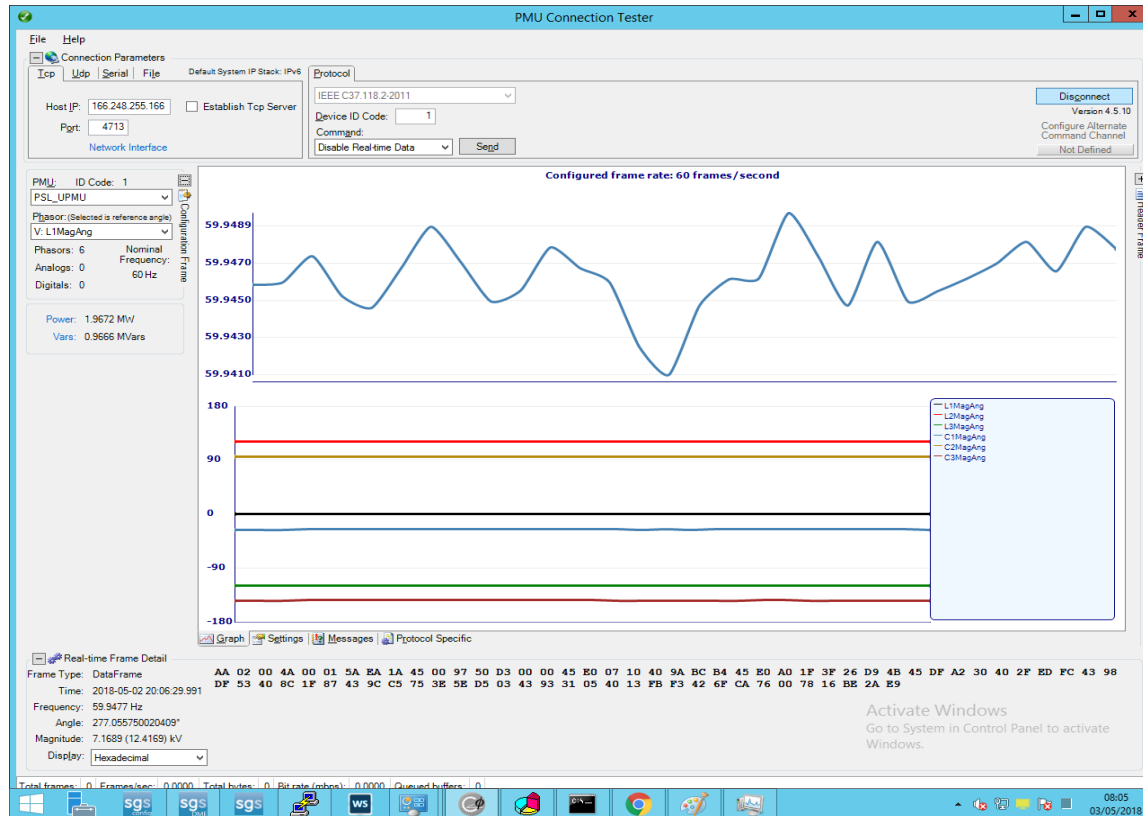
PV Inverter Modbus Communication Module



sgs connect reading values from PV inverter



μPMU Communication Test

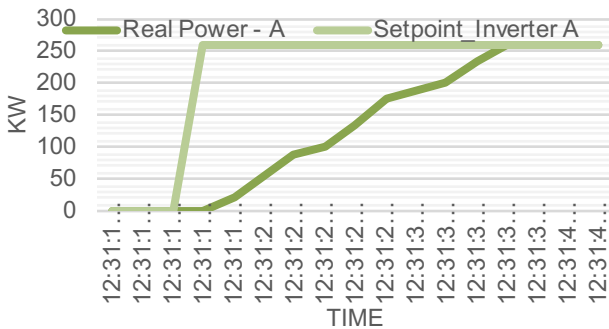


- Successfully established communication with the μPMU for feeder 1225. All voltage magnitude and angle data were successfully polled to the SGS Strata and recorded by the SGS Data Historian service.

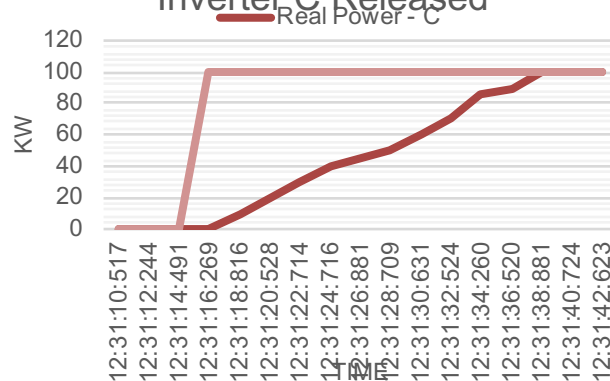
Upper DeadBand Breach Use Case

The three PV controllers react to the breach in 5 second issuing new setpoints **fully releasing Inverters A and C to 100 kW and 260 kW**, respectively; and **curtailing Inverter B to 0 kW**.

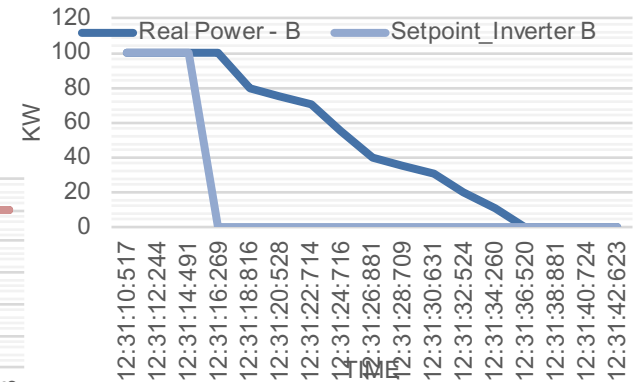
Upper DeadBand Breach Inverter A Released



Upper DeadBand Breach Inverter C Released



Upper DeadBand Breach Inverter B Curtailed



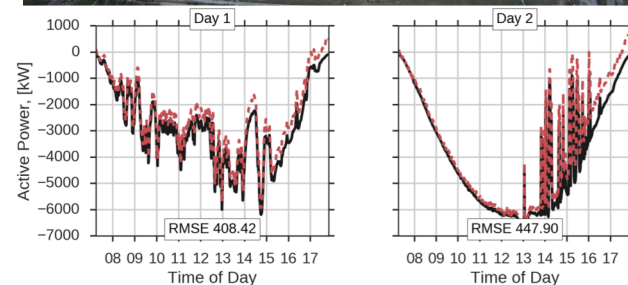
PV Disaggregation Integration with μ PMU data to SGS ANM Platform (Success 4)

■ Motivation:

- Most existing forecast and real time disaggregation algorithms rely on:
 - Irradiance measurements
 - All inverters communication (similar to smart meter readings)

■ Why is this an improvement?

- Actual performance based analysis – if PV is disconnected can be accounted for
- Feeder performance is synchronized and correlated with PV behavior for analysis of root cause for power quality or voltage control issues
- Full visibility with small number of sensors



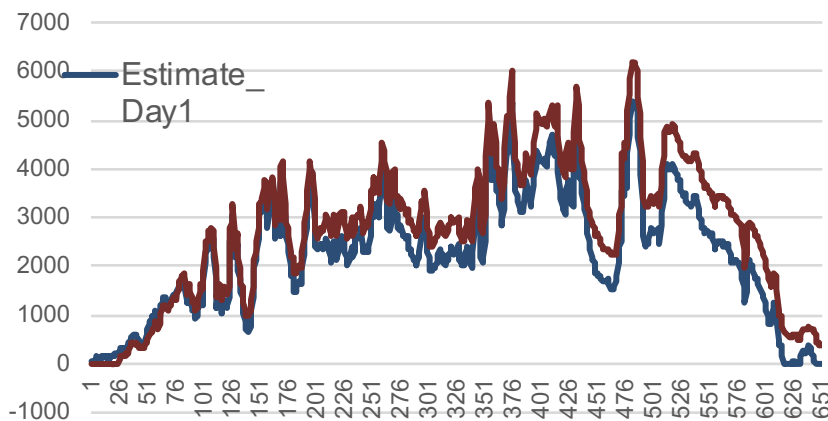
Integration to an operational environment of contextually supervised generation

uPMU Driven Algorithm Implementation in SGS ANM Platform

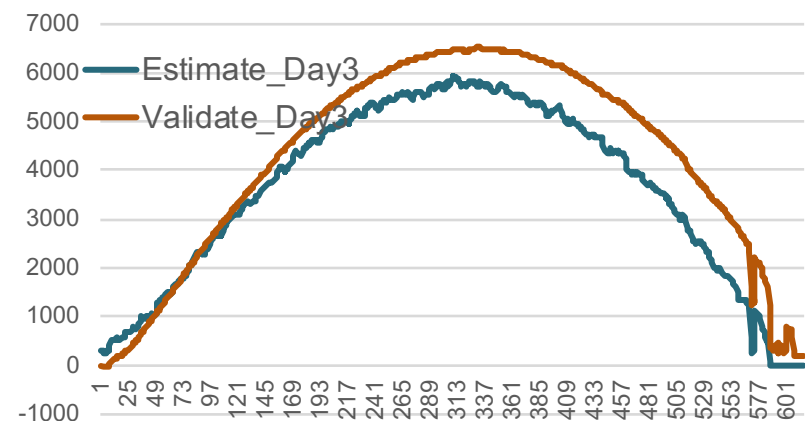
LBNL CSGE Algorithm had <6% RMSE on 1 minute data
R + D 100 Award 2017
Patent awarded

- Goal of follow on activity:
 - *Implemented the LBNL PV disaggregation algorithm in ANM pre-processor*
 - *Tested/validated with live utility data over 3 days*

Comparison of PV_{val} with PV_{est} (Day 1)



Comparison of PV_{val} with PV_{est} (Day 3)

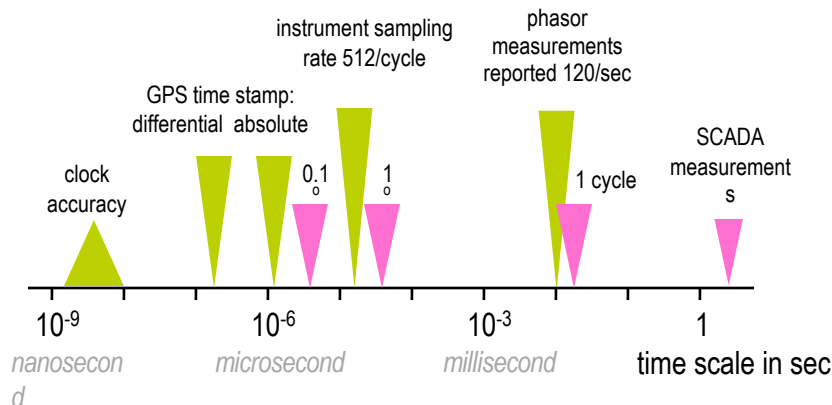


Future of Deployments, Implementation and Research

- Success: transition to the R + D and commercial community
- Integration into DOD and DOE Projects:
 - DOE GMLC: CleanStart DERMS – intentional islanding and
 - DOE CEDS: cyber intrusion detection, gps spoofing
 - DARPA RADICS
 - DOE OE Sensors FOA
 - DOE SETO Projects: ENERGISE analytics integration
 - CA EPIC: demonstration of DER and protection/line drop detection

Power Standards Lab μ PMU

- built on PQube3 power quality recorder
- capable of power quality mode with 512 samples per cycle
- time stamping to ns precision, μ s accuracy with GPS
- measures voltage & current, magnitude & angle (12 channels)
- 100V ~ 690V input
- 120 samples per second in PMU mode (each channel)
- local data buffering + batching (2 min), backup storage
- connectivity via Ethernet, 4G wireless



PSL

www.powerstandards.com