Anomaly Detection and Moving Towards Real Time PV Disaggregation with μPMUs

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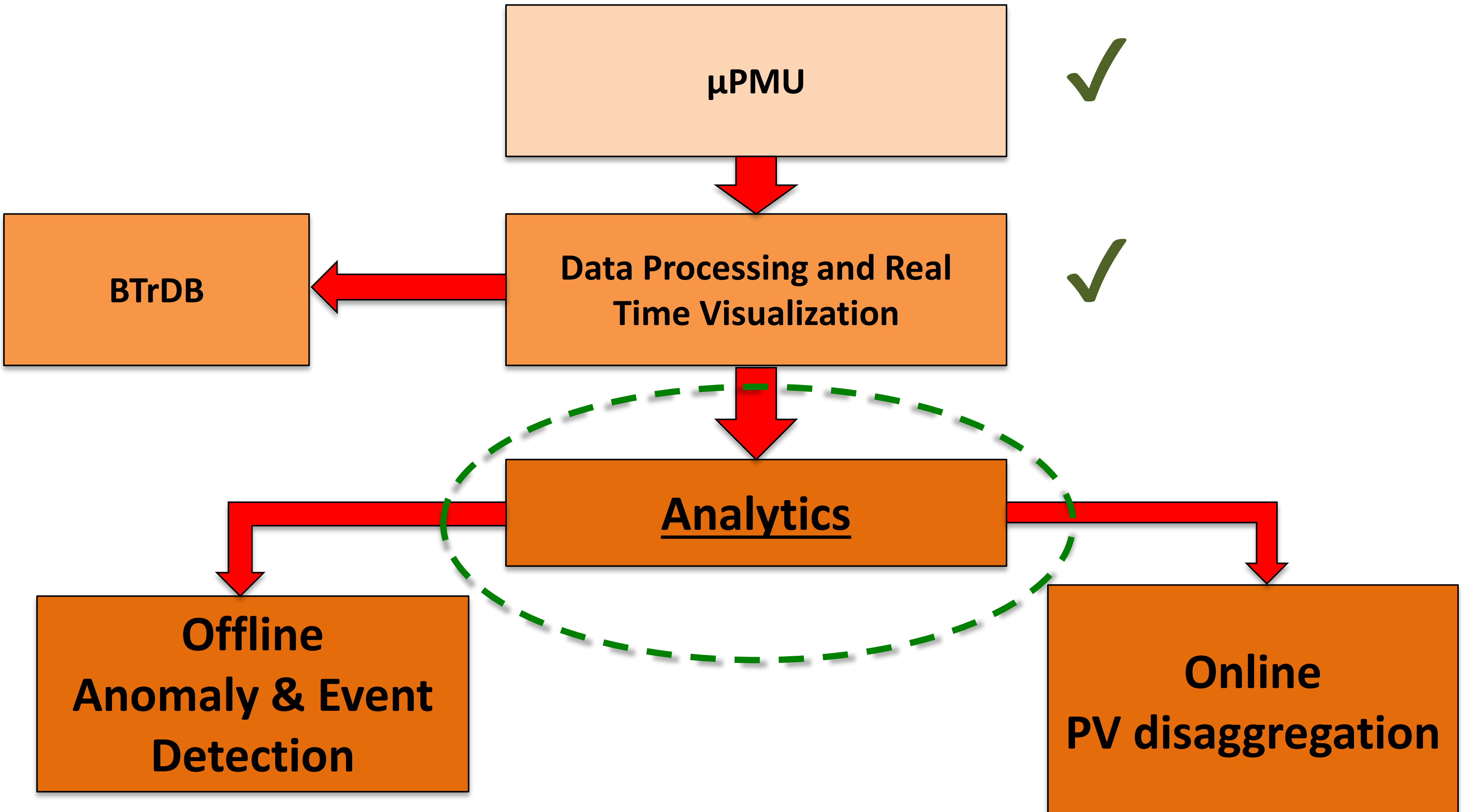
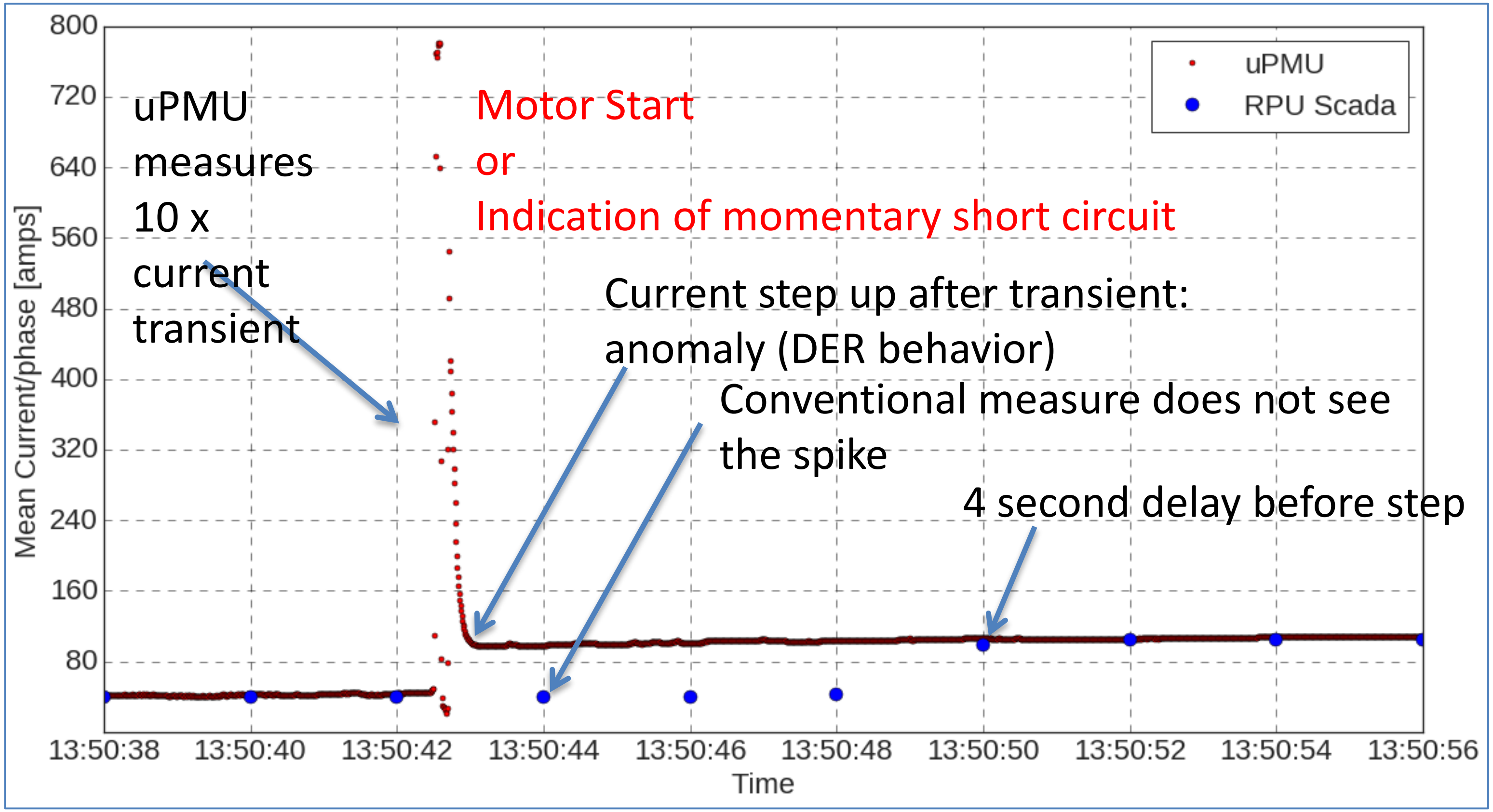
Overview


µPMU
BTrDB
Data Processing and Real Time Visualization
Analytics
Offline Anomaly & Event Detection
Online PV disaggregation

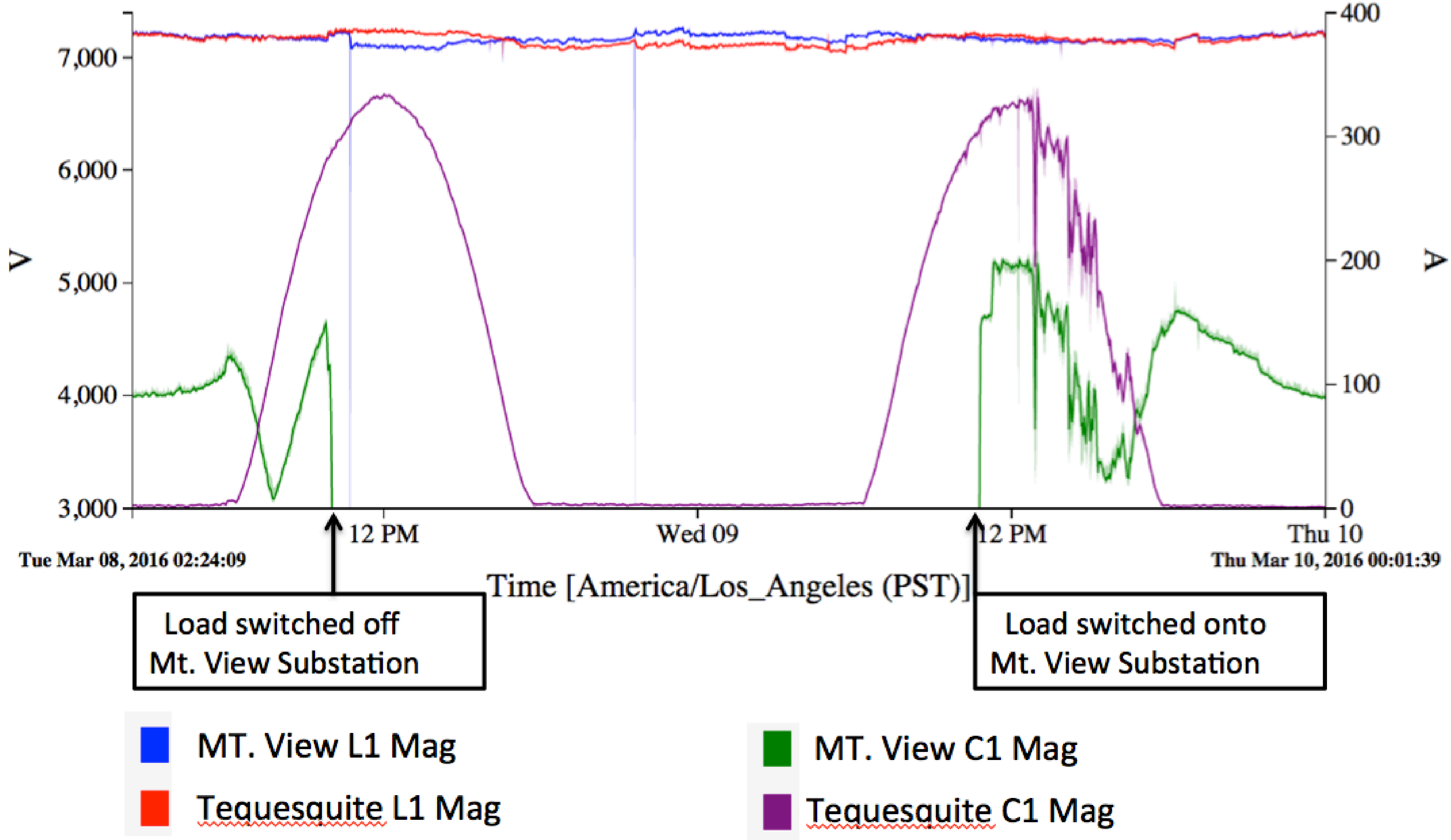
Anomaly/Event Detection

- Aim is to create training datasets for future machine learning applications
- As we view the µPMU data, we have determine there is a lot we don't know about the true time series behavioral characteristics of the distribution grid
  - To some expert users, they can see an event and say exactly what it is
  - But how do we create transferrable, useful actionable knowledge from that dataset?
- EventDetect – creating a training dataset, with expert user input, from our existing database

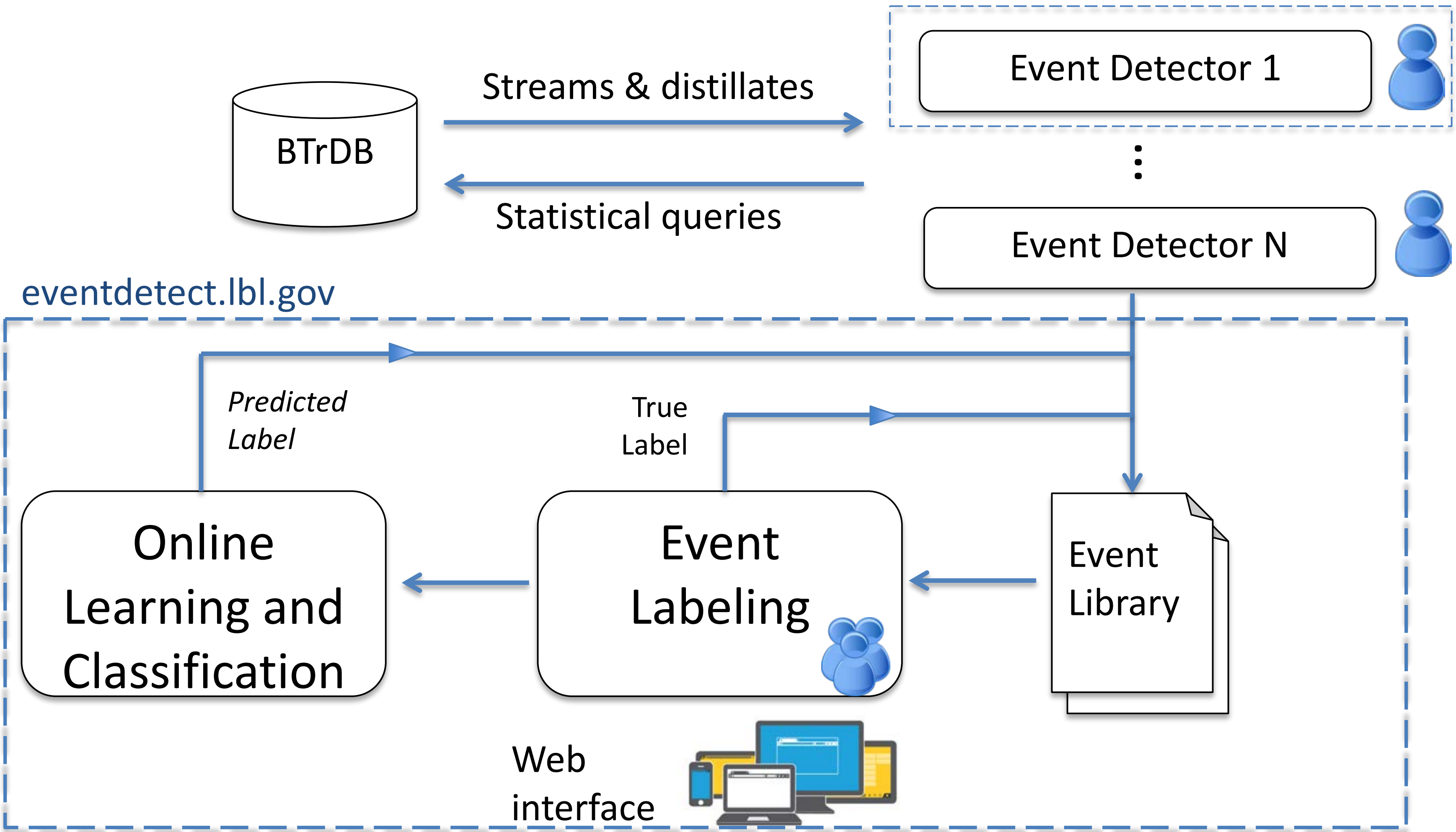
Anomaly – Current Transient



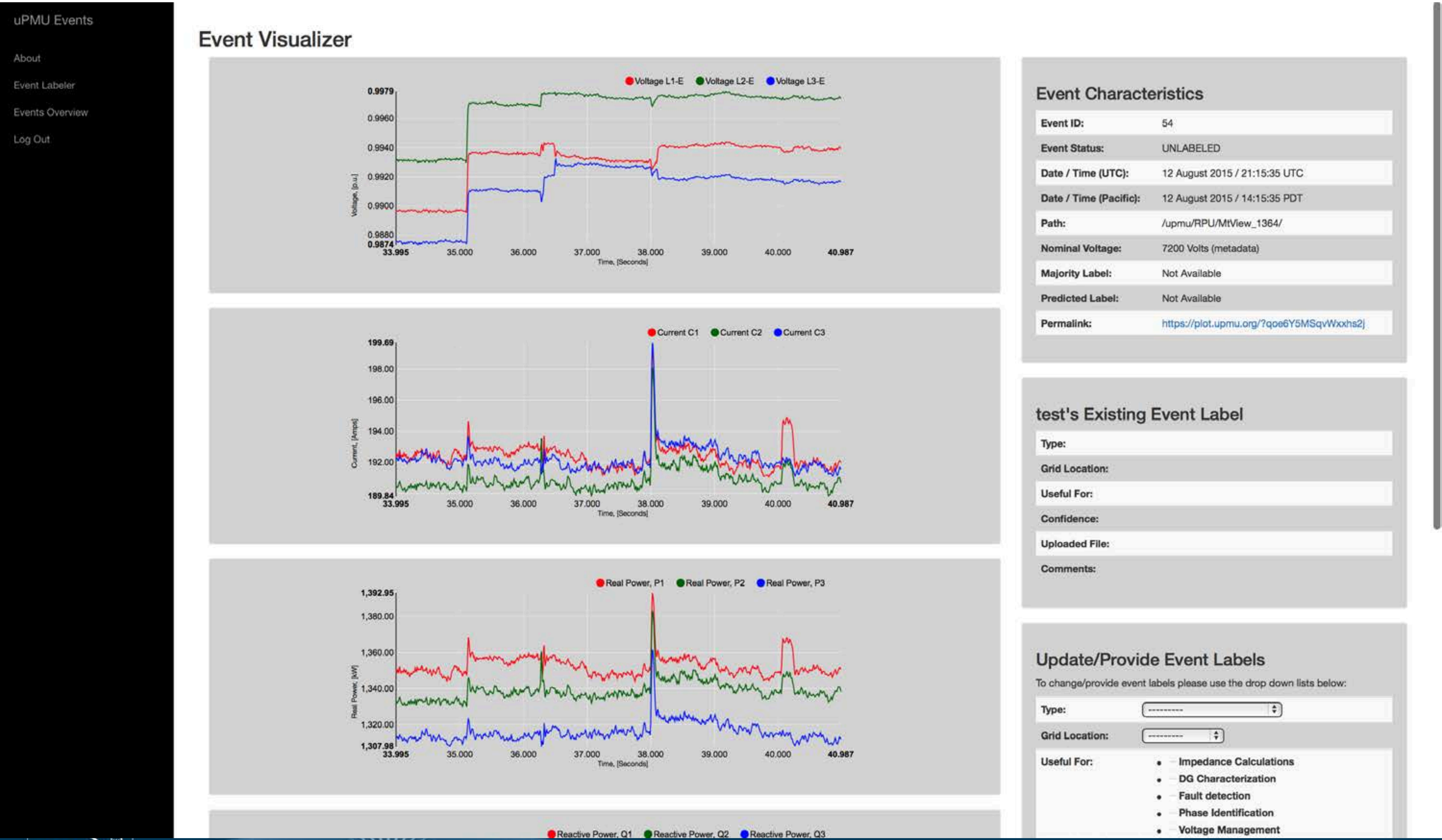
Feeder Reconfiguration



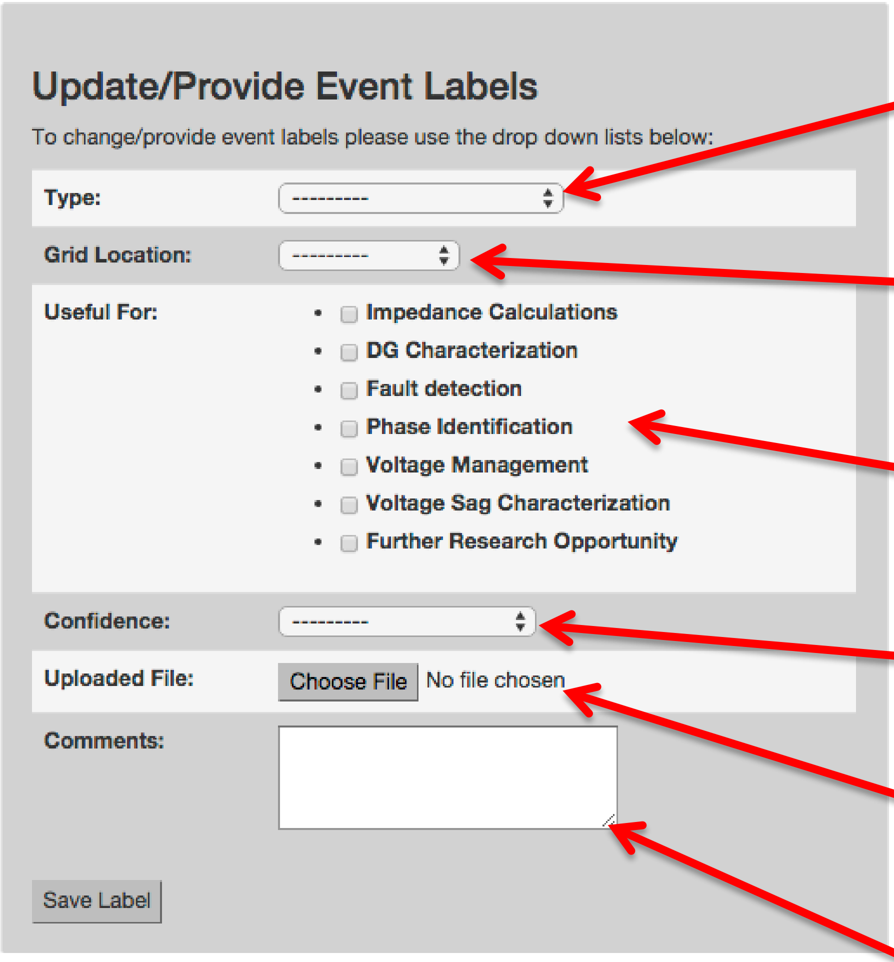
EventDetect



Interface Overview



User Input



Type of Event e.g. tap-change, cap bank switching, short circuit etc.

Whether Event was Transmission or Distribution or Unknown

Allows for Easy Grouping of Event for Future Applications

Confidence in Assigned Type

Upload File e.g. SCADA for comparison or images

Additional User Comments

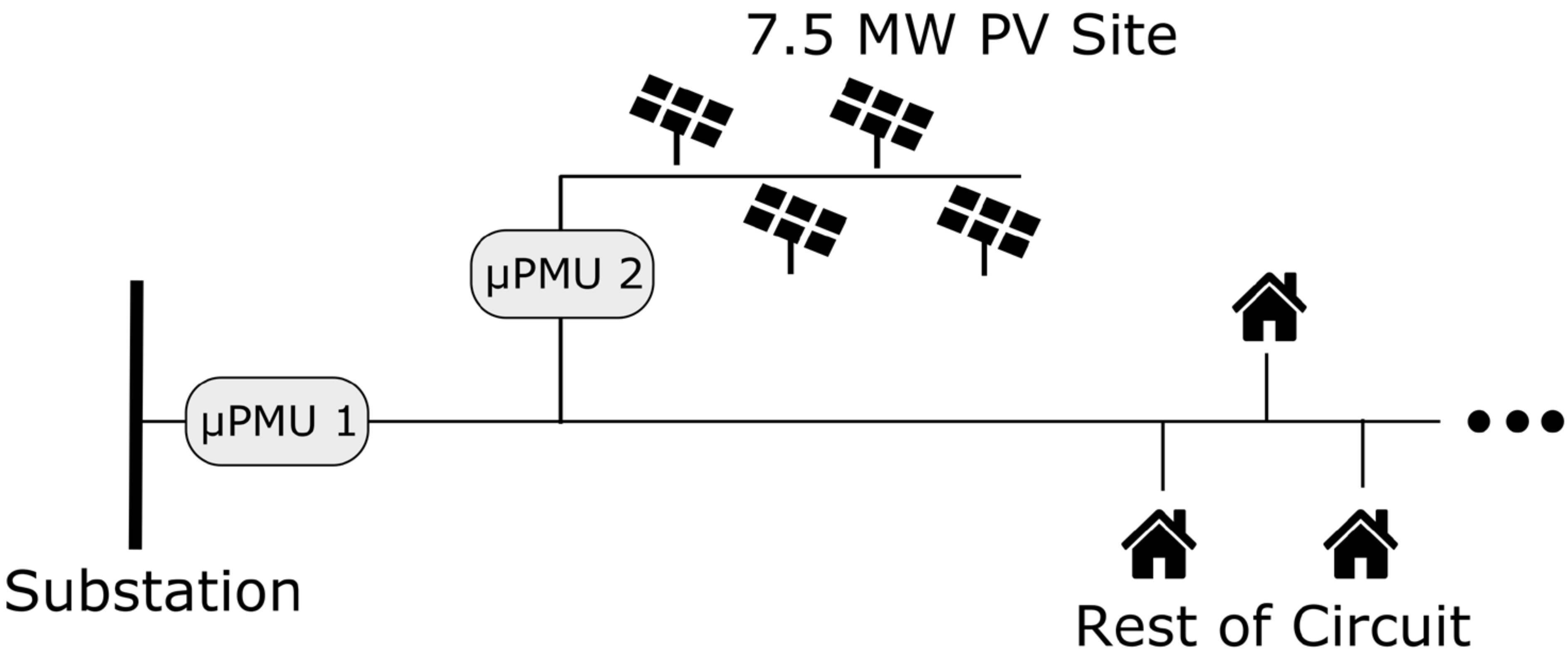
Utility and Research Progress

- Events being pushed from BTrDB utilizing event detection algorithms
- 10 users, 3 utilities, 1 university, 6 labs
  - 100+ events tagged
  - Feedback forms sent out
  - Adding basic topology of feeder
- Future work
  - Apply data gathered to other similar locations and determine if correct events
- If interested in becoming a user email Emma estewart@lbl.gov

Online PV Disaggregation

Given a μPMU at the substation/feeder head; can we estimate the real-time PV production downstream from that device

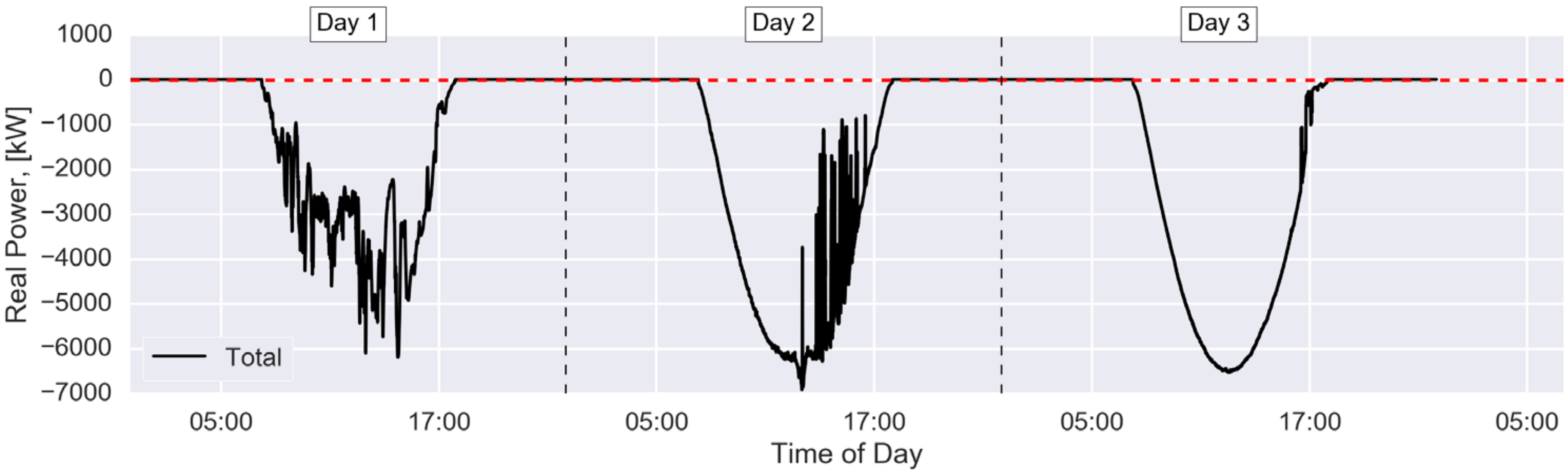
Riverside Public Utility µPMUs



Motivation

- Highly distributed behind the meter PV is often invisible to operators
  - Estimated as a function of generation capacity and irradiance measurement
  - Individual communication from behind the meter inverters would be a solution – but reliant on customer communication networks
  - Disaggregation of PV and Load gives visibility, on both the short term performance, and correlation of feeder conditions such as voltage profile
- Disaggregation allows resource to be used in operations, with greater confidence
- Poor estimation of resource gives sub-optimal grid planning and operational conditions

PV Profiles – Selecting types of generation days



A bad day | A good but variable day | A good day

Existing State of the Art

- Normally a Model Based Approach, rather than purely data driven
- Real time visualization of PV is 15 mins to 4 hrs ahead, with 15% RMSE
- Communication from large PV networks is instantaneous, but utilizing 1 minute data
- Aggregate information from inverters is available, but without knowledge of electrical topology for feeder impact
- Operational integration is achieved in forward thinking utilities such as HECO and SMUD, substation level and often irradiance based

Limitations in Model Based Approach

- Given Site Specific Global Horizontal Irradiance
  - Direct Normal Irradiance RMSE ≈ 15% across all-sky conditions[1]
  - No Model Performs Consistently over all-sky conditions[1]
  - Recent models ≈ 30 Year Old Models[2]
- Irregular PV Soiling Rates
- Variable Degradation Rates
- Disconnects/tripping not accounted for

New approaches using µPMU networks

- We considered 3 analytics methods using the data
  1. Time Invariant Power Factor Based Method
  2. Linear regression
  3. Contextually Supervised Generation Estimation
- Also considered addition of other data – distant irradiance - to improve estimation, and allow correction over time

Approach 1:Time Invariant Power Factor Based

- Simple approach for disaggregation

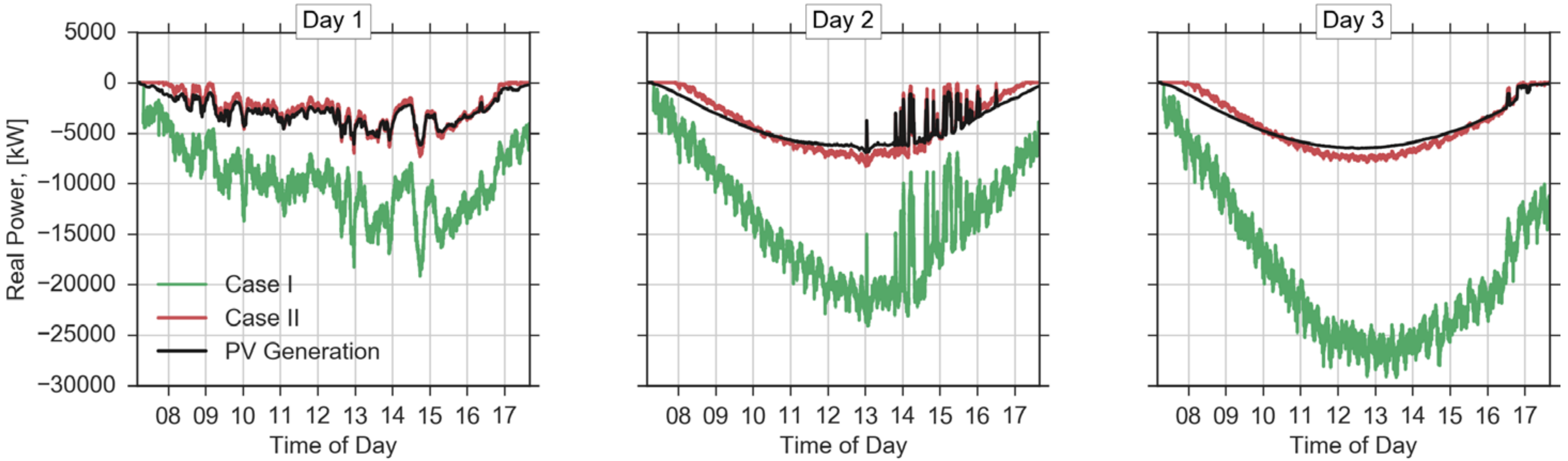
$$\begin{bmatrix} \boxed{\begin{matrix} cos\Phi_{Load,t} & cos\Phi_{PV,t} \\ sin\Phi_{Load,t} & sin\Phi_{PV,t} \end{matrix}} \end{bmatrix} \times \begin{bmatrix} \boxed{\begin{matrix} |S_{Load,t}| \\ |S_{PV,t}| \end{matrix}} \end{bmatrix} = \begin{bmatrix} \boxed{\begin{matrix} |S_{PMU,t}|cos\Phi_{PMU,t} \\ |S_{PMU,t}|sin\Phi_{PMU,t} \end{matrix}} \end{bmatrix}$$

Assumed Time Invariant | Unknown | Known

- Learn power factor of load from measurements obtained from μPMU
  - during night time, or
  - before PV installation
- Assume solar power factor ~ -1
- Both are time invariant

Initial Results Approach I

- Case 1: PF for Each Phase Learned During Prior Night
- Case 2: Sample PF = 0.97



- Reactive power consumption of PV non-negligible wrt to load ⟶ Model suffers heavily
- RMSE > State of the Art

Approach 2: Linear regression

- Use Irradiance Proxy: PV power output ~ 4 miles away on different circuit
- Regress over Active power

$$P_{PMU}^{T} = \overbrace{R + kQ_{PMU}^{T}}^{\text{Load Active Power}} + \overbrace{C_{eff}\,\phi^{T}}^{\text{PV Active Power}} + \varepsilon$$

Total Error Assumed

$\varepsilon_{PV} \approx \varepsilon_{Total}$

Purely Resistive Portion Of Load

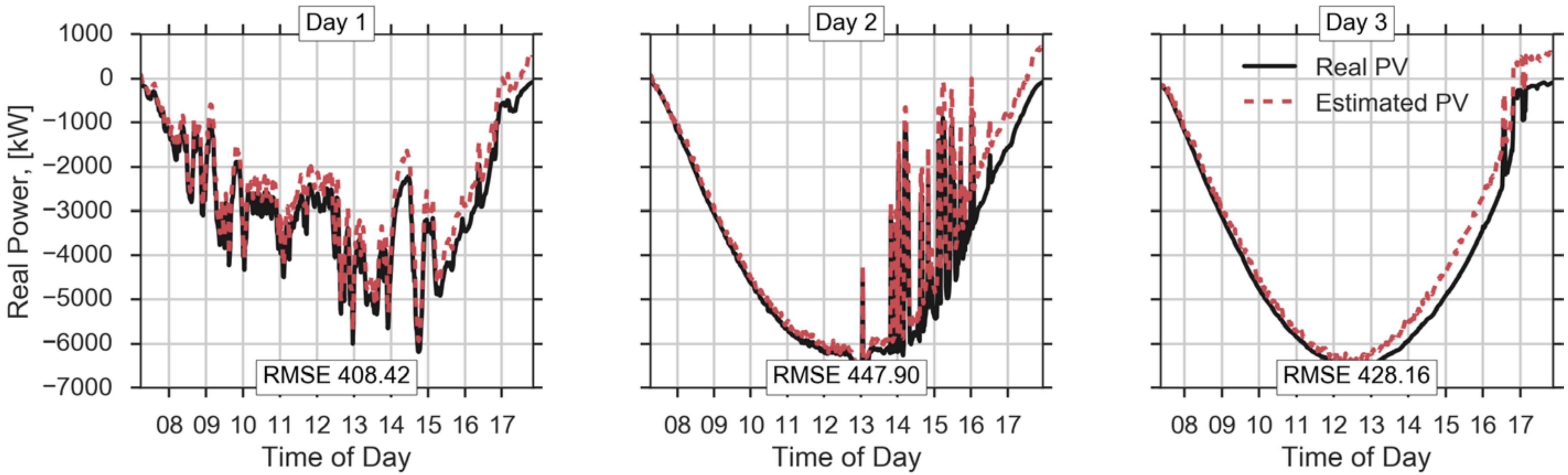
Effective Capacity

Irradiance Proxy

$$\boxed{P_{Load}^{T} = KQ_{PMU}^{T} + R}$$

$$\boxed{P_{PV}^{T} = P_{PMU}^{T} - P_{Load}^{T}}$$

Initial Regression Results Approach 2



- RMSE ~6%
- Good – but can we do better?

Approach 3: Contextually Supervised PV Separation

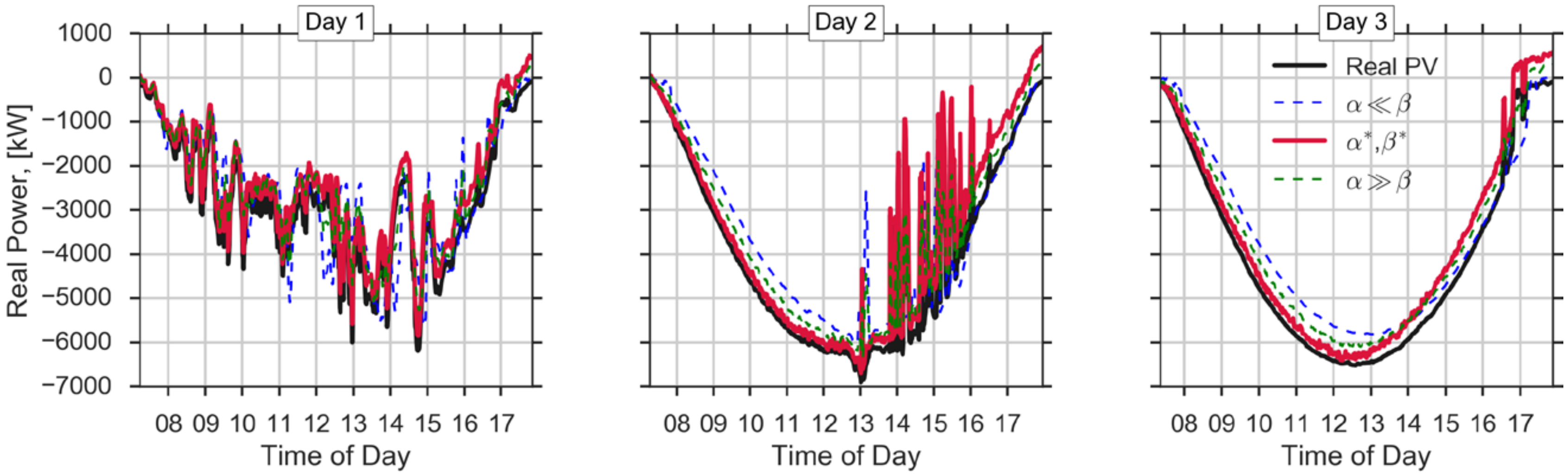
“Attempt to separate a single aggregate signal into a mixture of unobserved component signals”

$$\underbrace{P^{T}_{PMU}}_{\text{Aggregate Signal}} = \underbrace{P^{T}_{Load} + P^{T}_{PV}}_{\text{Unobserved Component Signals}}$$

- Allows for the model errors to be methodically attributed to the individual load and PV models as a function of their observed variance

Preliminary Results Approach 3: Contextually Supervised

- Effects of α, load weighting, and β, PV weighting



- RMSE initially <6%
- Benefit of approach is it learns behavior over time with supervisory approach – RMSE will improve
- More data added, better the RMSE

Future Work

- Eventdetect.com
  - Get more users!
  - Use training data set in algorithms for predictive analytics with utility partners
- PV disaggregation
  - Explore added benefit of additional irradiance proxies
  - Extend work to more geographically dispersed residential PV
  - Explore impact of inverters participating in voltage control utilizing real time simulation environment

Questions?

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References

1. Gueymard, Christian A. “Direct and indirect uncertainties in the prediction of tilted irradiance for solar engineering applications” Solar Energy 83.3 (2009): 432-444
2. Gueymard, Christian A. “Progress in direct irradiance modeling and validation.” Solar 2010 Conf., Phoenix, AZ, American Solar Energy Soc. 2010