Anomaly Detection and Moving Towards Real Time PV Disaggregation with μPMUs

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Overview

μPMU

Data Processing and Real Time Visualization

BTrDB

Offline Anomaly & Event Detection

Analytics

Online PV disaggregation

PV disaggregation

Anomaly & Event Detection
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

- uPMU measures 10x current transient
- Motor Start
- Indication of momentary short circuit
- Current step up after transient: anomaly (DER behavior)
- Conventional measure does not see the spike
- 4 second delay before step
Feeder Reconfiguration

- Load switched off Mt. View Substation
- Load switched onto Mt. View Substation

- MT. View L1 Mag
- Tequesquite L1 Mag
- MT. View C1 Mag
- Tequesquite C1 Mag
EventDetect

BTrDB

Streams & distillates

Statistical queries

Event Detector 1

Event Detector N

eventdetect.lbl.gov

Online Learning and Classification

Event Labeling

Event Library

Web interface

Predicted Label

True Label
User Input

Update/Provide Event Labels
To change/provide event labels please use the drop down lists below:

Type:

Grid Location:

Useful For:
- Impedance Calculations
- DG Characterization
- Fault detection
- Phase Identification
- Voltage Management
- Voltage Sag Characterization
- Further Research Opportunity

Confidence:

Uploaded File: Choose File No file chosen

Comments:

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

7.5 MW PV Site

Substation

μPMU 1

μPMU 2

Rest of Circuit
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

\[
\begin{bmatrix}
\cos \Phi_{Load,t} & \cos \Phi_{PV,t} \\
\sin \Phi_{Load,t} & \sin \Phi_{PV,t}
\end{bmatrix}
\times
\begin{bmatrix}
|S_{Load,t}| \\
|S_{PV,t}|
\end{bmatrix}
= \begin{bmatrix}
|S_{PMU,t}| \cos \Phi_{PMU,t} \\
|S_{PMU,t}| \sin \Phi_{PMU,t}
\end{bmatrix}
\]

- 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 $\sim -1$

- Both are time invariant
Initial Results Approach 1

- 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

\[
P_{PMU}^T = R + kQ_{PMU}^T + C_{eff}^T \phi + \varepsilon
\]

Total Error Assumed
\[
\varepsilon_{PV} \approx \varepsilon_{Total}
\]

\[
P_{Load}^T = KQ_{PMU}^T + R
\]

\[
P_{PV}^T = P_{PMU}^T - P_{Load}^T
\]
Initial Regression Results Approach

- 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”

\[ P_{PMU}^T = P_{Load}^T + P_{PV}^T \]

- 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 $\alpha$, load weighting, and $\beta$, 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
