VADER: Visualization and Analytics for Distributed Energy Resources

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Current Goals:
[What Now] Situational Awareness – state estimation, device status …
[What If] Scenario Analysis - operations planning, impact of technology evaluation, resource placement …

Eventual Aim:
Closing the Loop - optimizing controls …

Research Output:
Develop algorithms, tools, methodologies for deployment
VADER Workflow

Raw Data → Access → Ingestion → Analytics → Applications

- **Raw Data**:
  - Utility
  - Public
  - 3rd Party

- **Access**:
  - Data Plug

- **Ingestion**:
  - Virtual SCADA

- **Analytics**:
  - What Now
  - What If

- **Applications**:
  - Services
    - Visualization
    - Reporting

- **Analytics Subcategories**:
  - Traditional: SE/PF
  - Direct: ML/Stat
Data Sources

Utility
- SCADA – substation measurements
- non-SCADA – Smart Metering, Line Sensing
- GIS – nominal device specifications

Public
- Weather, Solar Irradiance
- Google Street View/Satellite

3rd Party
- EV: mobility + charging
- PV: voltage + injection
- Energy Storage
Virtual SCADA

SCADA ~ real time access to all instrumentation
Practical Limitations ~ Delays, Missing Data, non-aligned

Data Analysis Tasks
- Imputation
- Re-alignment/resampling
- Other data cleaning tasks
Analytics Paradigms

Analytics Approaches

**Traditional Methods** - well defined input/output – Example: State Estimation, Load Flow

*System Primitives* - Network, Load, Supply, Device Parameters - System State

**Direct Methods** - Estimate desired quantities by empirical models
   Estimate system primitives from sensor data
DER Integration Use Cases
- Locational Net Benefit Analysis
- Flexibility Estimation/Planning
- Performance Evaluation of Distribution Systems
- Overgeneration/Undergeneration/Reverse PF detection
Projects Summary and Progress Report

Estimating (DSN) System Primitives

Supply and Demand Primitives
1 - AMI Based Load Forecasting
2 - Solar Disaggregation

Network Primitives
3 - Estimation of Line Impedances via AMI (voltage)
4 - Estimation of AMI connectivity

Estimating System State

Topological State (discrete device status)
4 - Detection of network configuration via AMI and Line Sensing
5 - Distribution Outage Detection

Direct Learning of Power Flow Model

6 - Machine Learning Based Based Power Flow

Choice of Projects:
Where is there a lack of knowledge from utility perspective?
Where can we leverage statistical models + physical intuition + sensor data?
Estimating Demand Primitives

**Aggregation Benchmarking**
[Sevlian2016]

- **Methods** – SARIMA, NN, SVR
- **Forecast Horizon** – $1/n$ hour ahead
- **Aggregations** – $1 - 100K$ user

Bias-Variance Decomposition
Quadratic growth of MSE

**Method Benchmarking**
[Yu2017]

- **Methods** – (many)
- **Forecast Horizon** – $1/n$ hour
- **Aggregations** – 1

Show SVR is reliable the best performing: 56% the best procedure

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Estimating Supply Primitives

Solar Disaggregation [Kara2016]

- **Net metering:** No knowledge of individual generation.
- **Side information:** solar irradiance, net load, line measurements,

**Contextually Supervised Source Separation**

- **Source Separation Method**
- **Convex Optimization**
- 5-15% error using AMI and Line Sensing alone
Estimating Network Primitives

Reconstruction of Device Connectivity [Weng2016]
Where are my AMI's connected?
Detect GIS Errors from sensor data
Voltage Mag (phase) known at each bus

Conditional Independence of AMI-voltage
Graphical Model formulation
\[ p(v) = \prod_{i=2}^{n} p(v_i|v_{pa(i)}) \]
GM network reconstruction: Chow-Lui Algorithm

Can be extended to Mesh Networks [Liao2016]
Assume joint-Gaussian model
Conditional independence model of v-observations
Group-Lasso Formulation
Estimating Network Primitives

Estimation of Line Impedances [Yu2017]
Assume only additive error \( \Rightarrow \) Least squares approach

\[
y = \begin{bmatrix} p \\ q \end{bmatrix} \quad X \text{ depends on voltage magnitude + phase}
\]

\[
(g^*_L, b^*_L) := (X^T X)^{-1} X^T y
\]

Error in power injection + voltage mag? Error in Variable (EIV) model.

Formulate Maximum Likelihood Estimation
Generalized Low Rank Approximation (solved via SVD)

\[
\min_{\hat{x}, \hat{y}} \left\| [X^T, y] - [\hat{X}^T, \hat{y}] \right\|_2^2,
\]

subject to \( \text{Rank}([\hat{X}^T, \hat{y}]) < 2m + 1 \).
Estimating the System State

**Network State:**
- Radial Topology
- Outage Condition

**Power System State:**
- Voltage Mag/Phase
- Power Injections
Estimating Network State [Sevlian2016]

AMI + Line Measurements Model
Detect Switch Status s.t. fully connected

Traditional Approach:
General State Estimation; Voltage, Current

Flow Based Detection
Simple assumptions, detection guarantees
Robust to noise, unknown impedance

Spanning Tree Detection
Nodal Injection
Edge Flows
Estimating Network State (Outage Topology)

AMI (kwh) + Line flows
[Sevlian2017]

Optimal Hypothesis Testing
Real Time Current Measurements
AMI Forecast of aggregates
Compare RT-line flows to AMI forecast

Optimal Sensor Placement
Greedy Algorithm
Minimize Maximum Missed Detection

AMI (V) [Liao2016]

Optimal Change Point Detection
Real time stream of voltage data
Data driven estimation of pre/post stats

Evaluated Scenarios
Islanded DERs
mesh network
Standard Radial

\[ \mathbf{v}^{1:N} = \{ \mathbf{v}[1], \mathbf{v}[2], \cdots, \mathbf{v}[N] \} \]
Estimating Power Flow Equations [Yu2016]

Traditional Approach:
Use methods so far to extract primitives
\((p, q, v)\) – observed \(\Rightarrow\) min MSE leads to estimate

Direct Approach: (machine learning for power flow)
Assume only noisy \(p, q\) are observations
Want to determine voltages
No reliance on topology/impedance/devices/active devices + dynamics

Use Kernel Mapping
Support Vector Regression w/ poly kernel

\[
y = f_y^*(x) = \sum_{t=1}^{T} \alpha_t^* K(x, x_t)
\]

Physical Domain
Line Params + topology

Observation Domain
Support Vectors + weights
References

[Sevlian2016]: R. Sevlian and R. Rajagopal. A Scaling Law for Short Term Load Forecasting on Varying Levels of Aggregation. (under review)