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PV Monitoring and Modeling

a machine learning perspective

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U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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Overview

What is Machine Learning?

What?

Machine Learning is the science of programming a computer so that they can learn from data

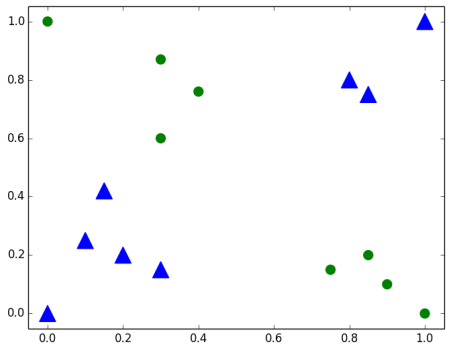
Two main types:

1. Supervised learning:
   Inputs w/ desired outputs
2. Unsupervised learning:
   Inputs w/out desired outputs

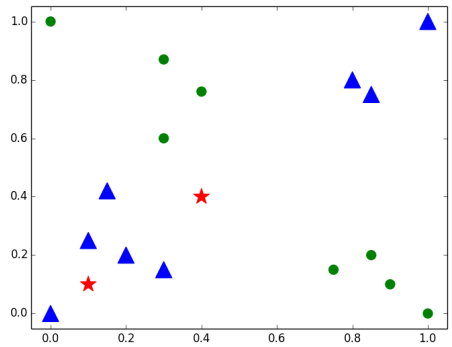
Supervised Learning Example

Classification using Support Vector Machine

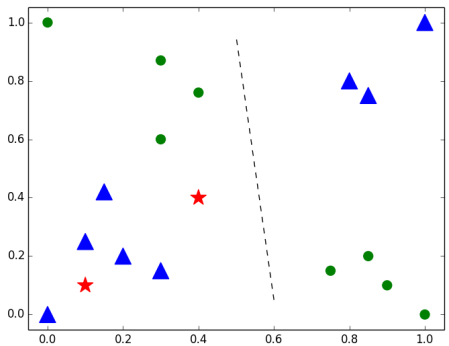
XOR data



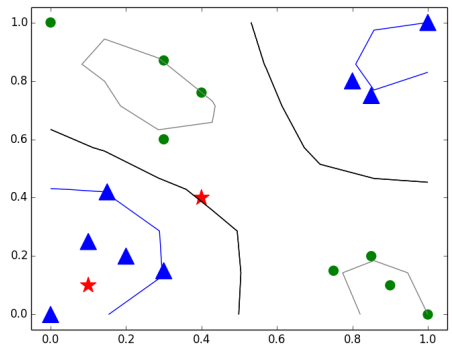
Classify new data



Not linearly seperable



Non-linear classification



Why use Machine Learning?

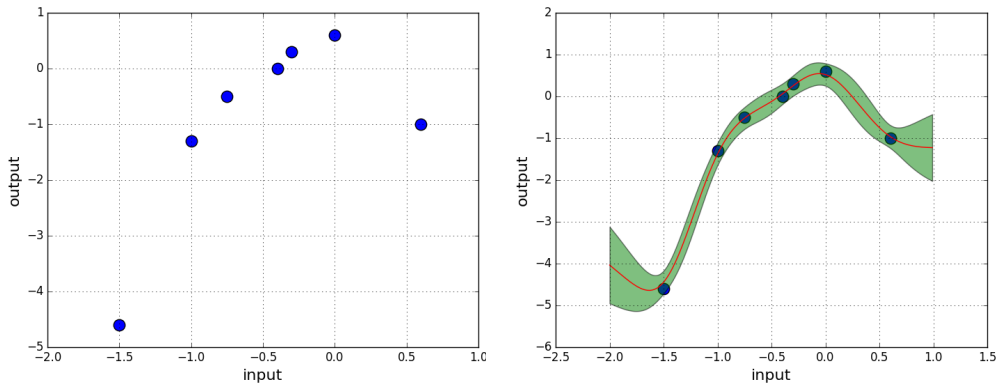
Why?

1. Regression
2. Classification
3. Density estimation
4. Others

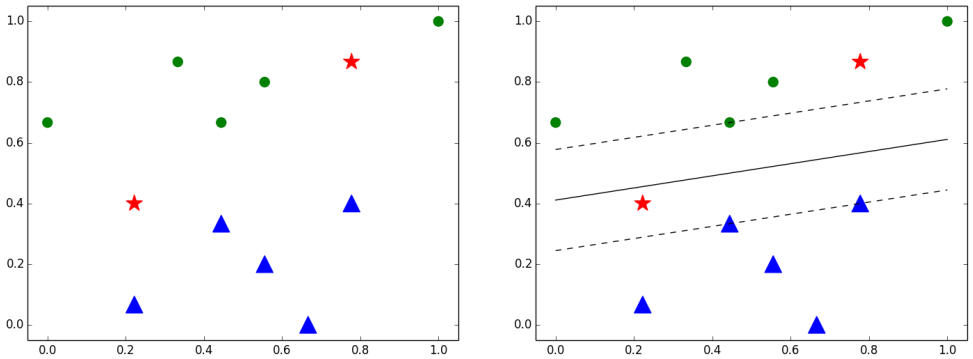
Approaches:

1. Artificial Neural Networks
2. Deep Learning
3. Support Vector Machines
4. Clustering
5. Many others

Regression (Gaussian Process)



Classification (Support Vector Machine)



How can Machine Learning Provide Value?

Design

1. Specify system
2. Estimate production
3. Confirm budget/financing

Model Types:

1. SAPM
2. Single Diode
3. Others

Build

1. System matches design
2. Correct Equipment/Connections
3. Reliable data monitoring

Model Types:

1. N/A

Operate

1. Monitor
2. Validate performance
3. Identify faults

Model Types:

1. Model-based
2. Model and ML
3. ML

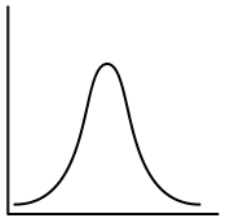
Machine Learning Applications?

Data Monitoring Quality:

Rule-based

```
if True then
    Report
else
    No Report
end if
```

Outlier Detection



Validate Performance:

Extensive Data

Inputs = {E,T_{module}}

Outputs = {Power}

Limited Data

InputsA = {P_{nearby} }

InputsB = {$E_{forecast}$}

Outputs = {Power}

Fault Analysis:

Fault Detection

Anomaly/Novelty

Detection

Fault Diagnostics

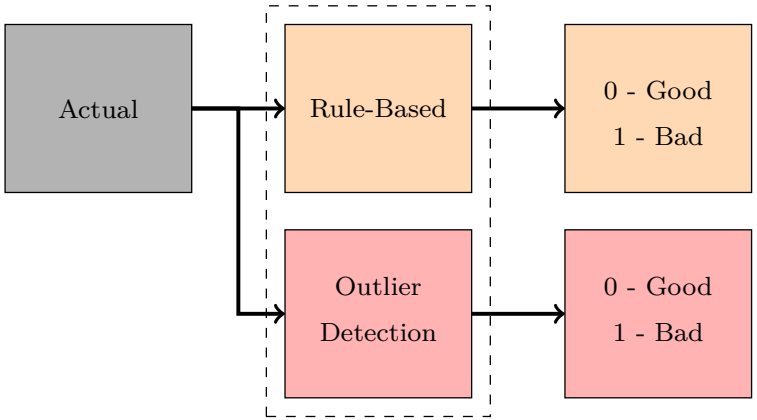
Multi-Class Classification

Data Monitoring: Rule-Based versus Outlier Detection

Problem Statement

Machine learning can use polluted data that contains incorrect or corrupt data records to identify outliers by assuming a distribution.

Process



Results

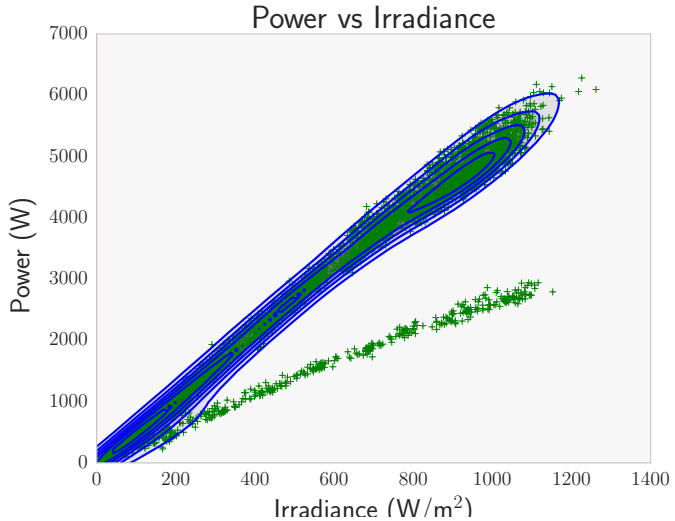
Rule-Based

Rules were not violated

if Power $>$ P_{mpp} x $Number_{mod.}$ x 1.2 $=$ 7776
then
    Alarm
else if Power $<$ 0 then
    Alarm
end if

Kernel Density Function

Outliers were detected

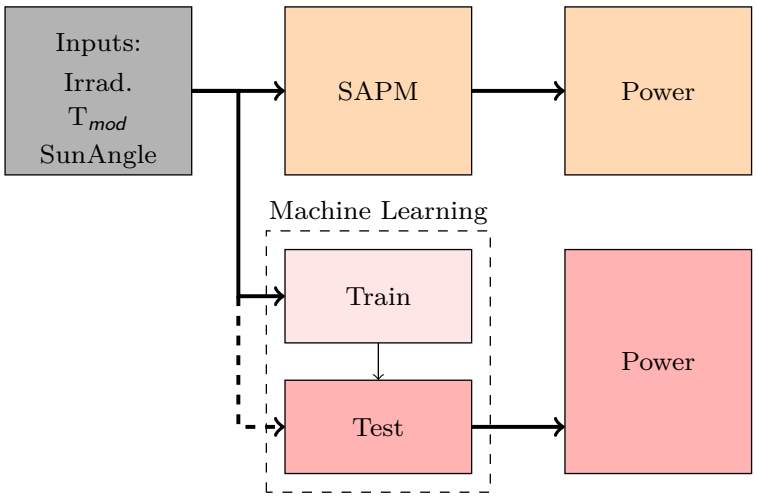


Validate Performance: Extensive Data

Problem Statement

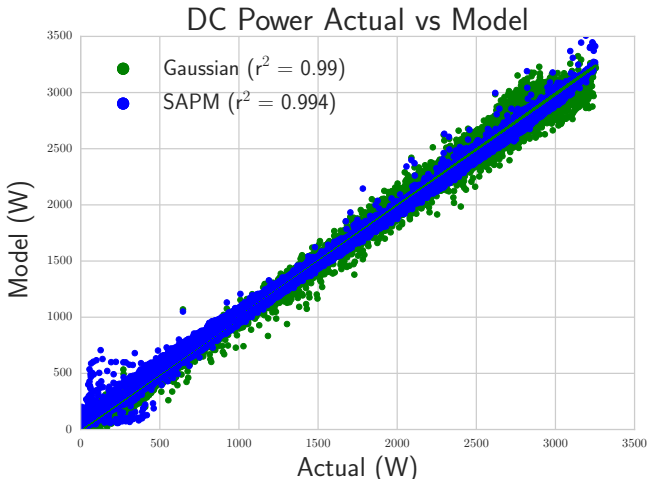
Machine learning can model existing PV systems using collected weather and performance data.

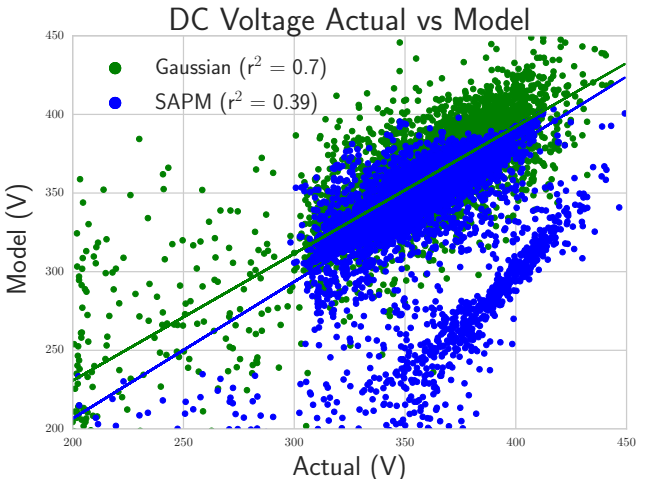
Process



Train: 01/16 to 12/16 -> Test: 01/17 to 04/17

Results



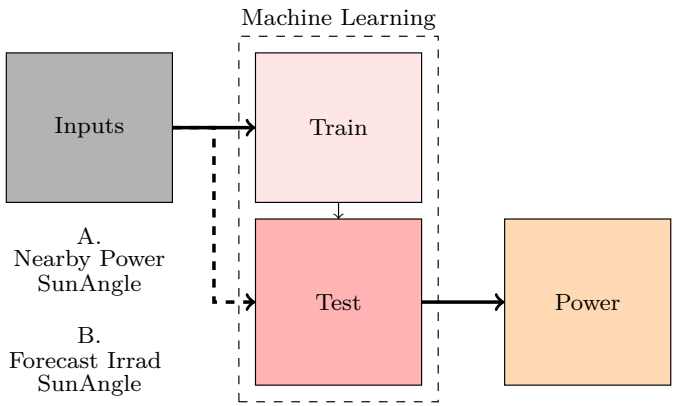


Validate Performance: Limited Data

Problem Statement

Machine learning can model existing PV systems where power is the only monitored value. The algorithm can associate PV power with nearby system outputs and forecasted irradiance.

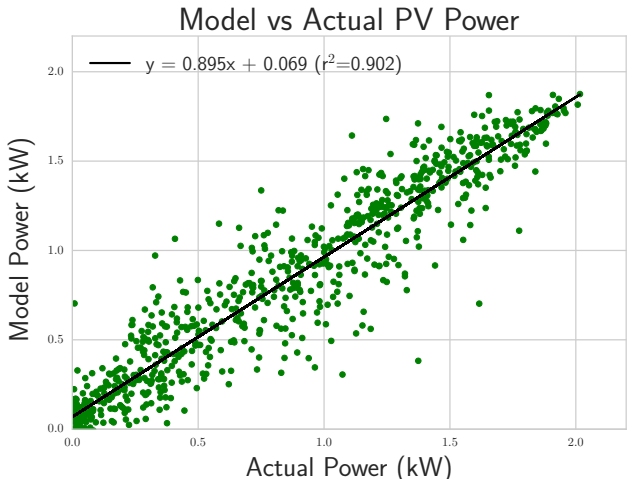
Process



Results

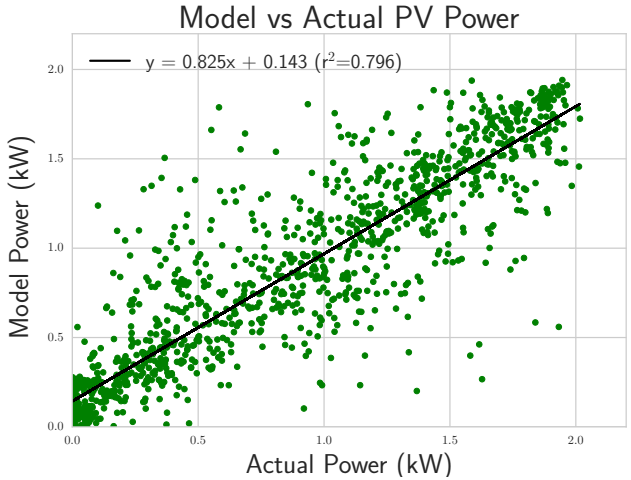
Inputs A:

1. Nearby Power (17km)
2. Sun Angle



Inputs B:

1. Forecast Irrad. (NOAA)
2. Sun Angle



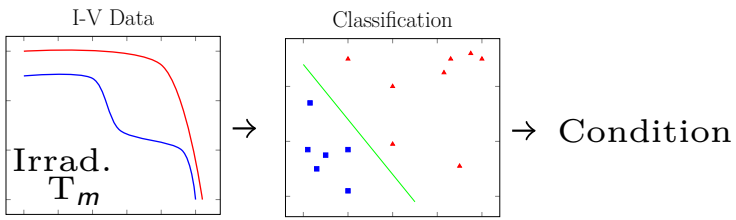
FDD: Novelty Detection (I-V Data)

Problem Statement

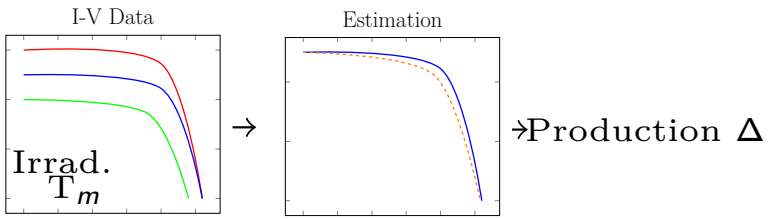
Machine learning can be used to perform binary classification of I-V curve data.

Process

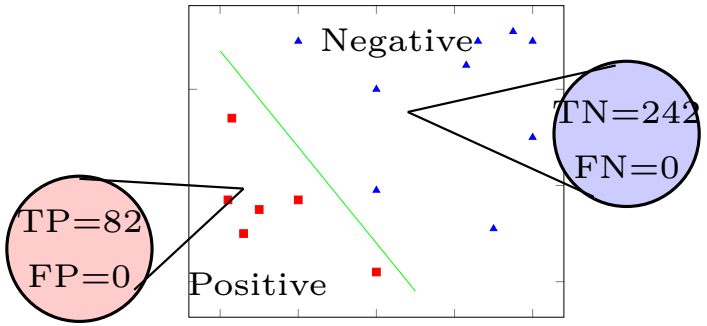
Classification



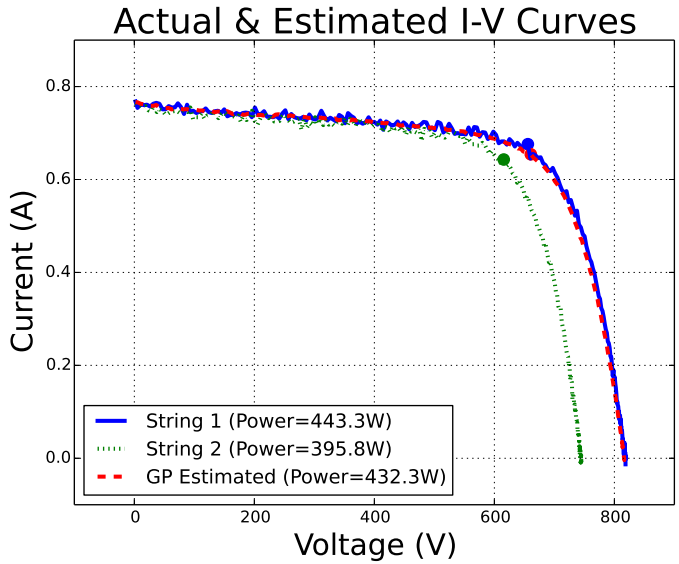
Estimation



Classification



Estimate Loss

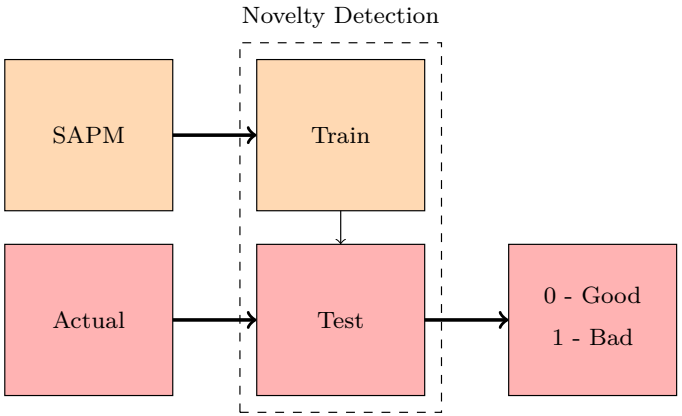


FDD: Novelty Detection (Max Power Point Data)

Problem Statement

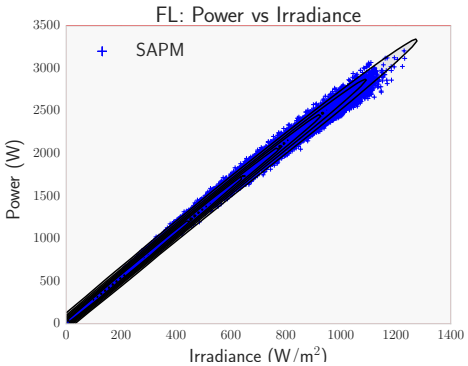
Machine learning can be used to identify anomalies automatically by training on "clean" data and testing on new, possibly polluted, observations.

Process

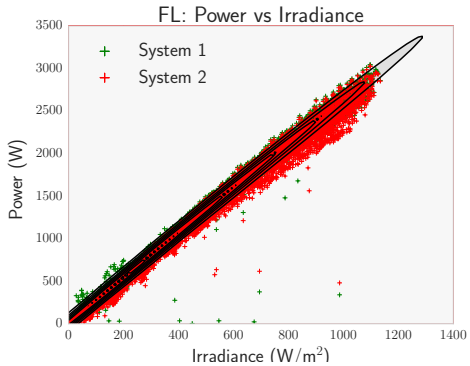


Train & Test Results

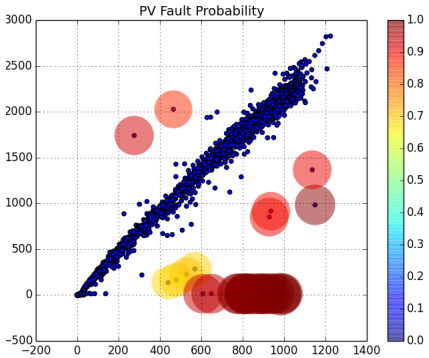
Train



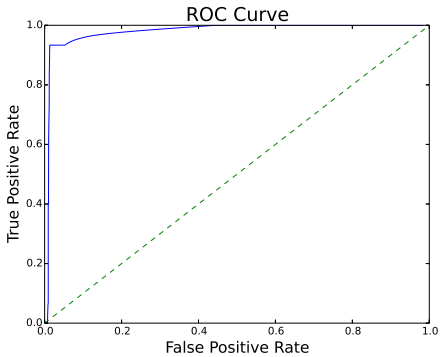
Test



Estimate Probabilities



Evaluate Accuracy

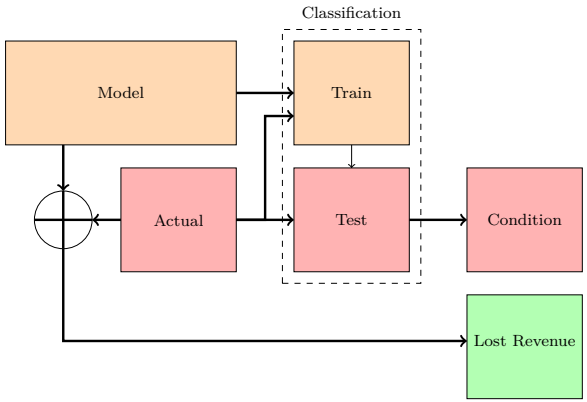


FDD: Classification (Max Power Point Data)

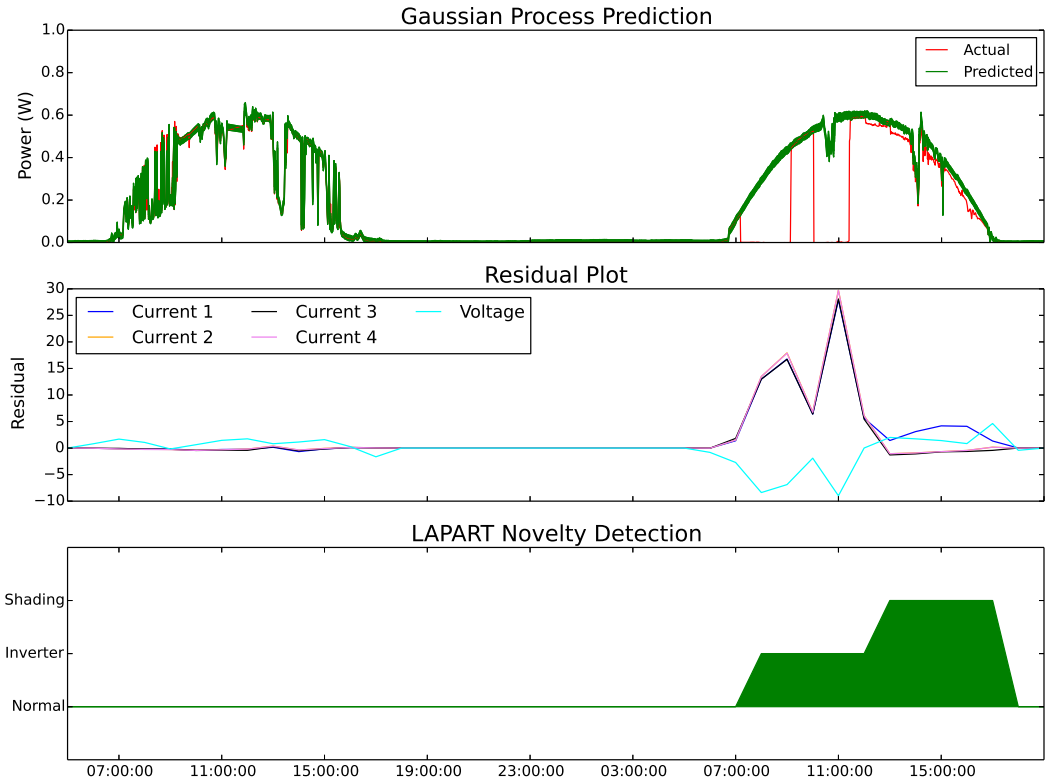
Problem Statement

Machine learning can be used to classify fault conditions and estimate lost revenue.

Process



Results



Summary

Machine Learning

1. What?
   - 1.1 machines can learn
   - 1.2 two main types of learning
2. Why?
   - 2.1 Regression
   - 2.2 Classification
3. How?
   - 3.1 Monitor
   - 3.2 Validation
   - 3.3 Faults

Examples

1. Data Quality
   - 1.1 Outlier Detection provides detailed review of collected data sets
2. Performance Validation
   - 2.1 ML can model PV power, current, and voltage given various inputs
3. Fault Detection
   - 3.1 Classify I-V curve and MPP data

Questions

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