Inverter Classifier: A Boosting Model for Detecting Inverter Underperformance



By Sandra Villamar

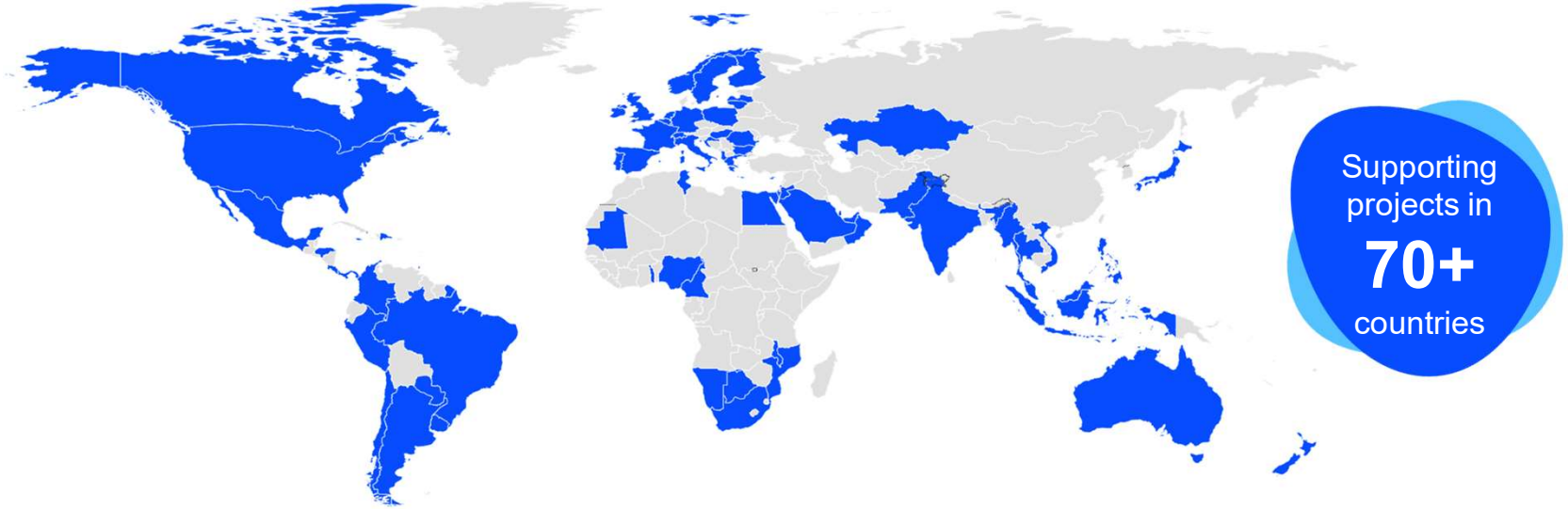
POWERFACTORS

We Empower the People that Power the World.

©2025 Power Factors | All Rights Reserved

Power Factors is the global leader in renewable energy management

POWERFACTORS



300+ GW
Managed assets

65+ GW
SCADA/EMS projects

18k+
Project sites in

70+
Countries

600+
Global customers

600+
Employees

© 2025 Power Factors, LLC. All rights reserved.

POWERFACTORS

Trusted partner to 600+ customers globally



"Power Factors delivers, ensuring that we can move confidently and quickly with the growth of our managed assets pipeline."

Origis Energy

"Power Factors enables us to dial into what's causing the portfolio issues and identify where we are losing money. The platform highlights everything you need to know."

Ventient Energy

"When we rolled out Power Factors, I spent less time on software admin and more time improving plant performance."

Cypress Creek Renewables

POWERFACTORS

©2025 Power Factors | All Rights Reserved

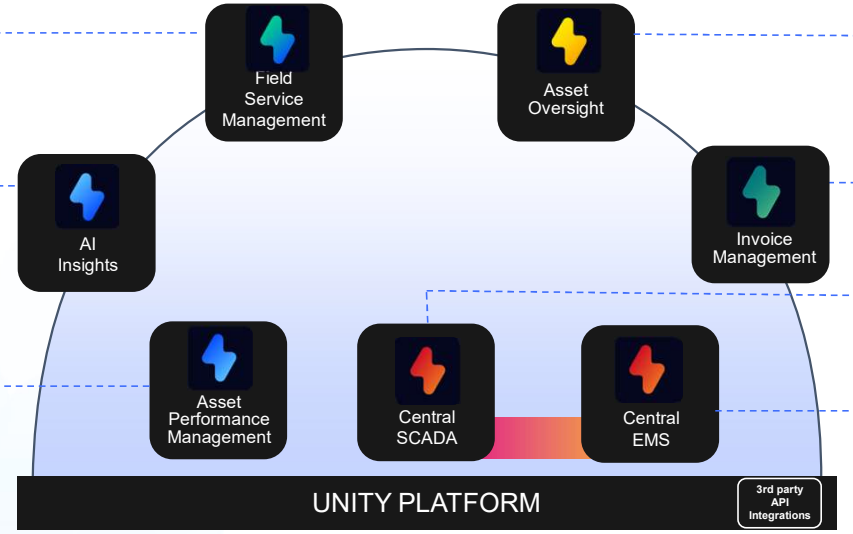
Unity REMS Core Products

POWERFACTORS

Optimize field service through work order management, personnel scheduling, inventory management and maintenance KPIs.

Leverage AI-powered analysis and recommendations for solar, wind, storage, and hybrid assets.

Optimize asset availability and yield at scale with sophisticated monitoring, analysis, and intuitive workflows.



Portfolio-level view of assets to provide a comprehensive system of record and enable oversight of operations and service providers.

Centralized and automated management of invoices to enable cashflow management, streamlined reporting, and accurate financial & revenue management.

Scale operations through centralized real-time monitoring and bulk controls across your portfolio.

Centrally optimized controls across multiple BESS and/or hybrid assets to achieve value stacking and minimize risk of revenue loss.



Securely monitor your renewable assets on-site for reliable and efficient performance.

Locally monitor, control, and optimize BESS or hybrid plants to ensure compliance with market and grid demands.

Locally control and optimize solar assets to ensure compliance with market and grid demands.

UNITY

© 2025 Power Factors, LLC. All rights reserved

©2025 Power Factors | All Rights Reserved | Company Confidential

Agenda

POWERFACTORS

Problem

- Problem
- Goal

Solution + Explanation

- Solution: Inverter Classifier
- Why ML

Development of Inverter Classifier

- Data Collection
- Feature Engineering & Selection
- Model Training & Selection

Performance of Inverter Classifier

- Current State
- Challenges
- What's Next

©2025 Power Factors | All Rights Reserved

Agenda

POWERFACTORS

Problem

- Problem
- Goal

Solution + Explanation

- Solution: Inverter Classifier
- Why ML

Development of Inverter Classifier

- Data Collection
- Feature Engineering & Selection
- Model Training & Selection

Performance of Inverter Classifier

- Current State
- Challenges
- What's Next

©2025 Power Factors | All Rights Reserved

What's the Problem?

- Sites have problems.
  - inverter module outages
  - soiling
  - tracker stalls
  - and much more…





- These problems lead to **incorrect** or **unclear loss allocation**.
- Additionally, if any of these problems are **recoverable energy losses**, this means that the **site is not producing as much as it could**.



POWERFACTORS

©2025 Power Factors | All Rights Reserved

Source: https://solarbuildermag.com, https://www.solarunsoiled.com, https://www.renogy.com

Goal

We want to…

- **Find** underperforming inverters
- **Understand why** they are underperforming
- With **minimal data capability** requirements



So that…

- We have a **clear loss allocation** on a given site.
- We can **minimize any recoverable losses**.
- We can **reinforce** conclusions from other analyses.

POWERFACTORS

©2025 Power Factors | All Rights Reserved

Source: https://www.nlc.org

Agenda

POWERFACTORS

Problem

- Problem
- Goal

Solution + Explanation

- Solution: Inverter Classifier
- Why ML

Development of Inverter Classifier

- Data Collection
- Feature Engineering & Selection
- Model Training & Selection

Performance of Inverter Classifier

- Current State
- Challenges
- What's Next

©2025 Power Factors | All Rights Reserved

Solution



LightGBM model

inputs data → outputs a classification + probability for each class

for a single inverter on a single day.

Classifications:

- Normal Operations
- Reduced AC Capacity
- Reduced DC Capacity
- Shading or Tracker Outage
- Snow
- Soiling

©2025 Power Factors | All Rights Reserved

Gather data from given inverter and day



Inverter on
May 14, 2025

Create features

avg ambient temp	20.8
.	
.	
.	
std AC power	6.52

Run LGBM Classifier



Get output

Classification: Normal Operations

Probability Vector:

Normal Operations	92
Export Limit	0
Reduced AC Capacity	2
Reduced DC Capacity	4
Shading	1
Snow	0
Soiling	0
Tracker Outage	1

Explanation: Why was ML chosen?

- Data analysts look at a variety of data sources and analyze trends.
- **This is exactly what an ML model does.**

☑ An ML model does the job of a data analyst **in an instant**.

☑ ML can help provide insights with **minimal data capability**.

✗ **Physics-based models need explicit information** to make a concrete conclusion.

POWERFACTORS

©2025 Power Factors | All Rights Reserved

Agenda

POWERFACTORS

Problem

- Problem
- Goal

Solution + Explanation

- Solution: Inverter Classifier
- Why ML

Development of Inverter Classifier

- Data Collection
- Feature Engineering & Selection
- Model Training & Selection

Performance of Inverter Classifier

- Current State
- Challenges
- What's Next

©2025 Power Factors | All Rights Reserved

Development: Data Collection

Manually labeled data until we met the following requirements:

- Minimum amount of observations per class
- Minimum amount of unique inverters per class
- Minimum amount of site observations per class
- Maximum amount of site observations in dataset
- Examples of inverters cycling through multiple underperformance issues

Created a representative test set:

- Met the above requirements.
- Ensured **test set only includes unseen inverters**.

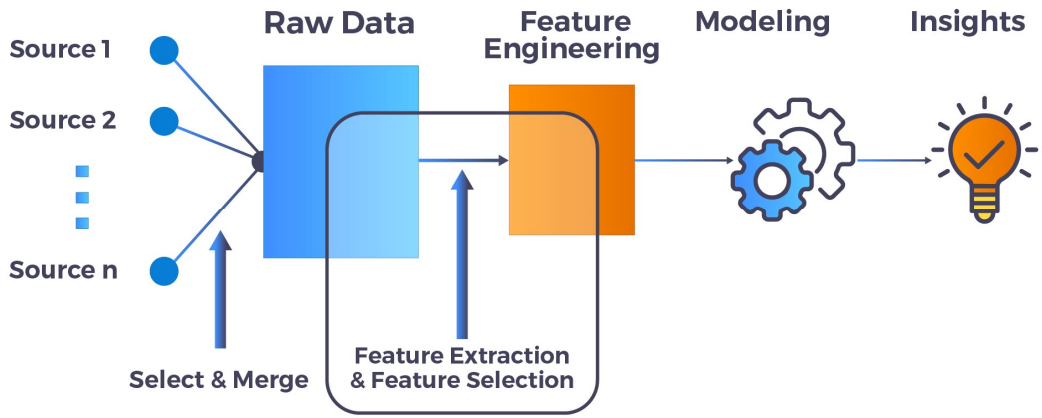
Label	Training	Test	Total
Export Limit	850	150	1000
Reduced AC Capacity	1100	200	1300
Reduced DC Capacity	1400	250	1650
Shading	1500	300	1800
Snow	600	150	750
Soiling	1500	250	1750
Tracker Outage	750	150	900
Normal Operations	5250	1550	6800

~ 16K labeled inverter-days

POWERFACTORS

©2025 Power Factors | All Rights Reserved

Development: Features



Feature Engineering

- Selecting, extracting, and transforming relevant attributes from the available data.
- Translated **human diagnosis into machine diagnosis**.

Feature Selection

- The process of **selecting a subset of relevant features** for use in model construction.
- **Metrics**: SHAP + Split Feature Importance + Gain Feature Importance

POWERFACTORS

©2025 Power Factors | All Rights Reserved

Source: https://k21academy.com/datascience-blog/hands-on-data-science-and-machine-learning-labs-with-python/

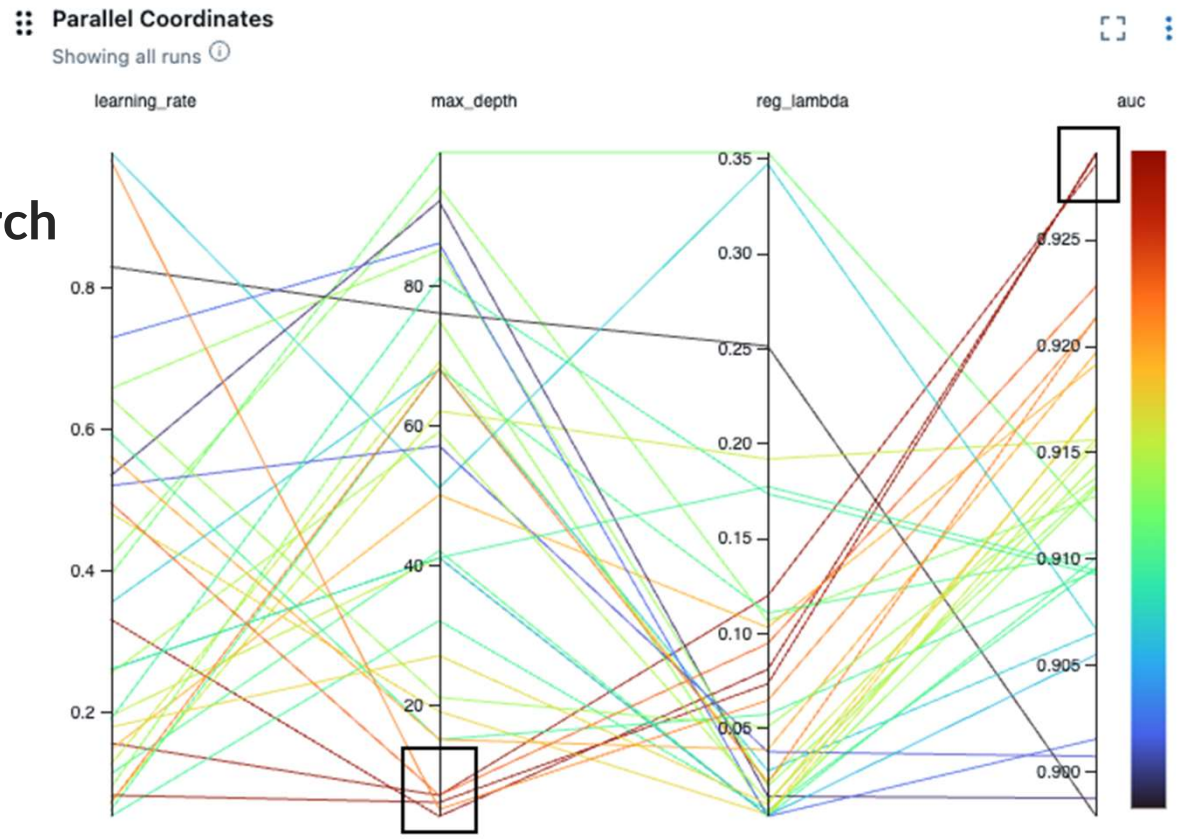
Development: Model Training & Selection

Training

- Custom **train-test split**
- **Sample weights by class**
- Custom **hyperparameter search space**
  - Lower and log uniform *learning_rate*
  - Smaller *colsample_bytree*
  - Larger *reg_alpha*
  - Smaller *max_depth*

Selection

- Highest **F1-Score**
- **Confusion matrix**



POWERFACTORS

©2025 Power Factors | All Rights Reserved

Source: https://docs.databricks.com/aws/en/mlflow/visualize-runs

Agenda

POWERFACTORS

Problem

- Problem
- Goal

Solution + Explanation

- Solution: Inverter Classifier
- Why ML

Development of Inverter Classifier

- Data Collection
- Feature Engineering & Selection
- Model Training & Selection

Performance of Inverter Classifier

- Current State
- Challenges
- What's Next

©2025 Power Factors | All Rights Reserved

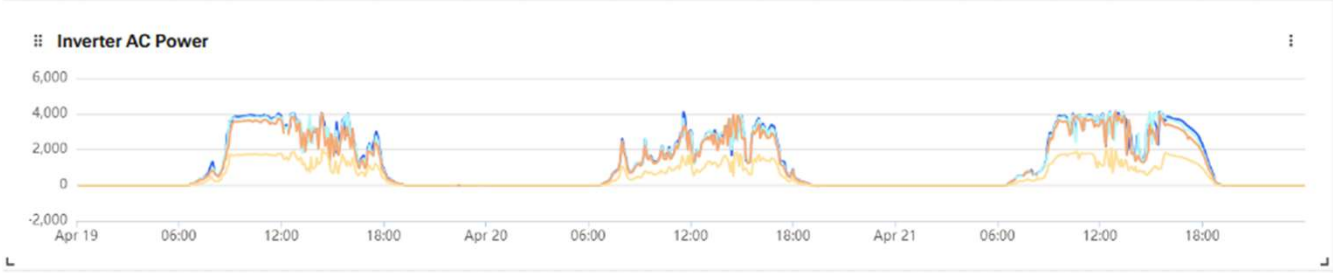
Performance

Reduced DC Capacity

Normal Operations

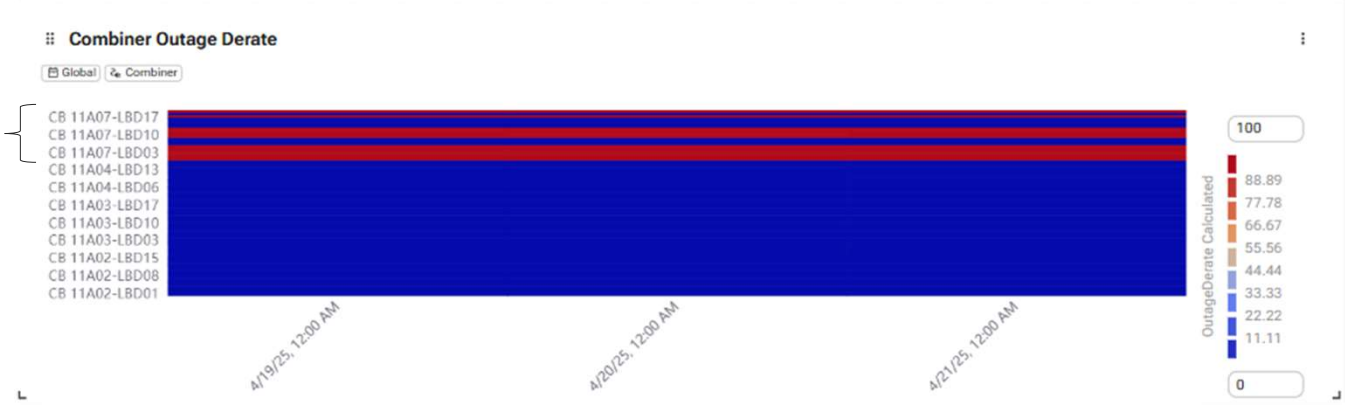


INV 7 has **similar trend but scaled down →** indicator of a Reduced DC Capacity issue



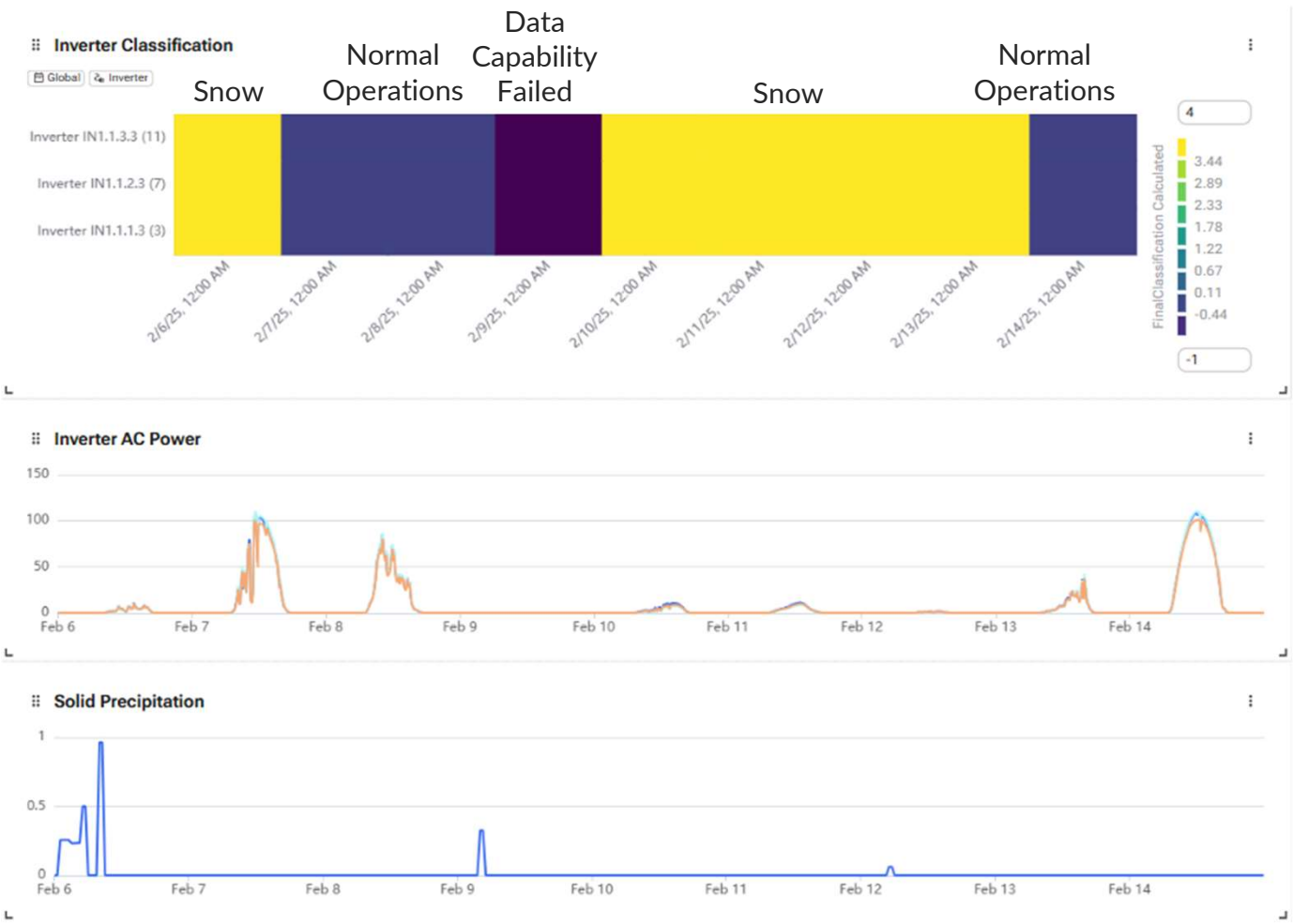
Supplemental information validates that there are indeed **combiner outages**

INV 7



POWERFACTORS

Performance



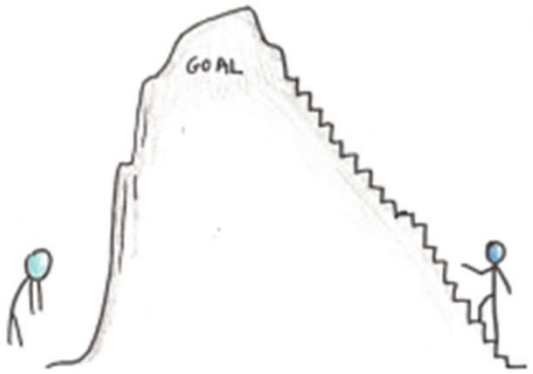
AC Power completely drops → there may be snow on the panels

Precipitation data validates that it snowed on the corresponding days we see underperformance.

POWERFACTORS

©2025 Power Factors | All Rights Reserved

Challenges



- Labeling data for training
  - Takes time, prone to human error
  - Looking into creating synthetic data
- Overfitting
  - Created rules for training data to enforce diversity
  - Tuned hyperparameters to limit model from relying too much on training data
- Finding the balance between
  - (1) giving the Inverter Classifier more information to perform better
  - (2) selecting inputs that are widely available on sites so that we don't limit the number of sites we can run the model on

POWERFACTORS

©2025 Power Factors | All Rights Reserved

Source: https://www.scotthyoung.com

What's Next?



- Label more data
  - Capture more inverters, more times of the year, more examples of each classification
  - Integrate data labeling in our Unity platform
  - Experiment with synthetic data
- Add more features
  - Now that the model is running and producing results, we have had a couple more ideas of features that would help identify classes without requiring extra data sources.
- Create Smart Events
  - Combine Inverter Classifier results with our other calculations and any other supplemental information to produce accurate and organized events.

POWERFACTORS

©2025 Power Factors | All Rights Reserved

Source: https://cdn.vectorstock.com



Thank You!

Sandra Villamar
sandra.villamar@powerfactors.com

POWERFACTORS