Spatial & Temporal Analysis of Operational Solar Farms

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Introduction

Spatial analysis is underused in renewable energy. GIS applications are often used for visual elements in reports and not as much as an analytical tool. Spatial analysis has the capability to be used in the conceptual, design and operational phases of projects to better assess, optimize, and mitigate performance issues. This analysis examines more than four years of operational data from three solar farms to identify underperformance and apply spatial analysis to assess potential causes, whether from design or unidentified component failures. The methodology applied here can be used to inform potential operational adjustments, including backtracking or reconfiguration, and lessons learned can be used to apply in the development phases to mitigate potential underperformance prior to construction.

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Methodology

OPERATIONAL DATA ANALYSIS

Through a statistical analysis of more than four years of operational data for three solar farms, production, availability, and irradiance data area analyzed temporally. Irradiance data from nearby weather stations is used to filter and validate the irradiance data from the site pyranometers. Availability data is used to filter outages that were due to module, inverter, or other known failures. Correlations are conducted between the weather station, pyranometer, and production data for each project. A predictive random forest regression is created for the last two years for each project to create a baseline of expected production.

The predictive analysis is then used determine which inverter blocks are underperforming and when that underperformance happens, considering expected degradation of modules. The data is examined for repeated seasonal, unexpected, and consistent, and flags are applied for each within the time series.

SPATIAL ANALYSIS

As-built planes of array and graded surfaces were not provided. The existing terrain is analyzed to develop approximate planes of array based on the best-fit plane beneath each tracker row. A sensitivity analysis is performed by "pinning" the ends of the rows to the existing terrain as another approximation of the planes of array. The existing surface is analyzed directionally. North-south and east-west slopes are derived, and the variation of the terrain is derived within 1.5 times the center-to-center distance between each row from each row's north-south axis.

Two equations are developed: one predicts the losses or gains over expected normalized production based on the orientation of the plane of array with respect to north-south; the other predicts potential losses due to inter-row shading east west. An algorithm is developed by combining the equations and analyzing the project using the approximated planes of array (both methods). The algorithm analyzes each tracker row, first looking at the orientation of the plane of array north-south, then the three-dimensional orientation of the tracker with respect to adjacent trackers. Losses or gains from expected normalized production are calculated for each tracker row with respect to the north-south plane of array orientation, and losses are calculated for each row for the east-west variations in the planes of array with respect to adjacent rows. Overall losses or gains are calculated as a percentage, and then combined for each inverter block. Blocks are assigned a ranking of 1 to 5 based on their expected performance, with 5 being the lowest ranking.

SPATIAL/TEMPORAL ANALYSIS

Normalized production, availability, and irradiance data for each inverter block are input into ArcGIS Pro to create a spatial and temporal database on a monthly basis. The flags developed in the statistical analysis of the operational data are also included in the database. The flags are then compared to the rankings developed in the spatial analysis. Additional flags are applied for inverter blocks that are underperforming but are not ranked low in from the spatial analysis.

Results

The predictive spatial analysis correlates with the production data. Inverter blocks that ranked low in the spatial analysis are underperforming with respect to the baseline plant performance for all projects. Inverter blocks that show higher seasonal losses have higher predicted east-west losses. Blocks with higher predicted north-south losses consistently underperform on an annual basis.

The worst performing inverter blocks that could not be attributed to availability are examined for each project. Those blocks had rows that had higher predicted losses based on the analysis of the terrain. While some losses were shown in the north-south direction, most losses were due to the east-west variation in the terrain and the assumed plane of array. Individual rows, which are typically set within a small depression, had much higher predicted losses. For those with high east-west losses, losses in the winter/spring/fall are higher compared to the site average.

Next Steps

The spatial analysis algorithm can be used identify potential causes for underperformance and to inform backtracking settings to mitigate losses due to inter-row shading. If losses are extreme due to plane of array orientation, individual tracker rows could be reconfigured. The analysis can also be used to identify for site inspection inverter blocks that underperform for no obvious reason.

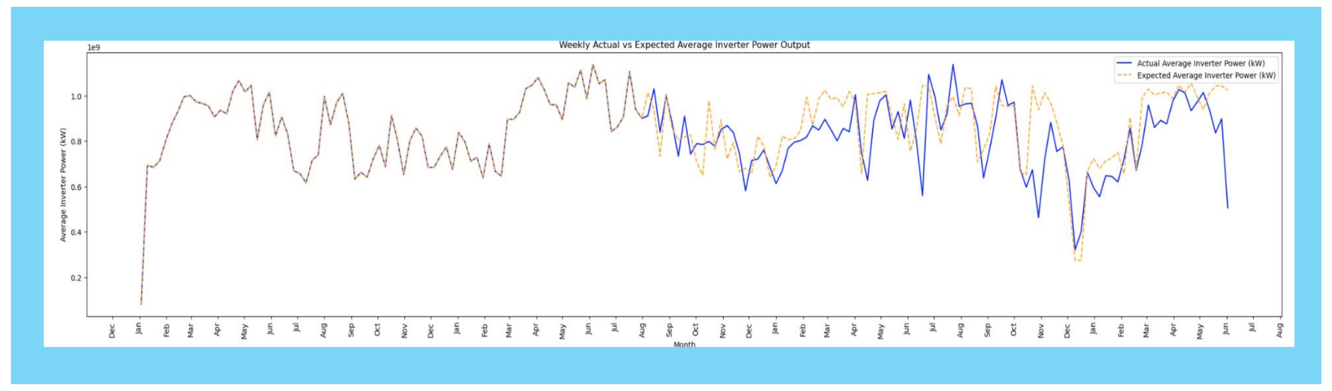
The spatial analysis algorithm will be augmented in future iterations to assess predicted plant performance temporally to better assess plant performance.

The relationship of the algorithm to backtracking settings for different tracker types and technologies will be developed.

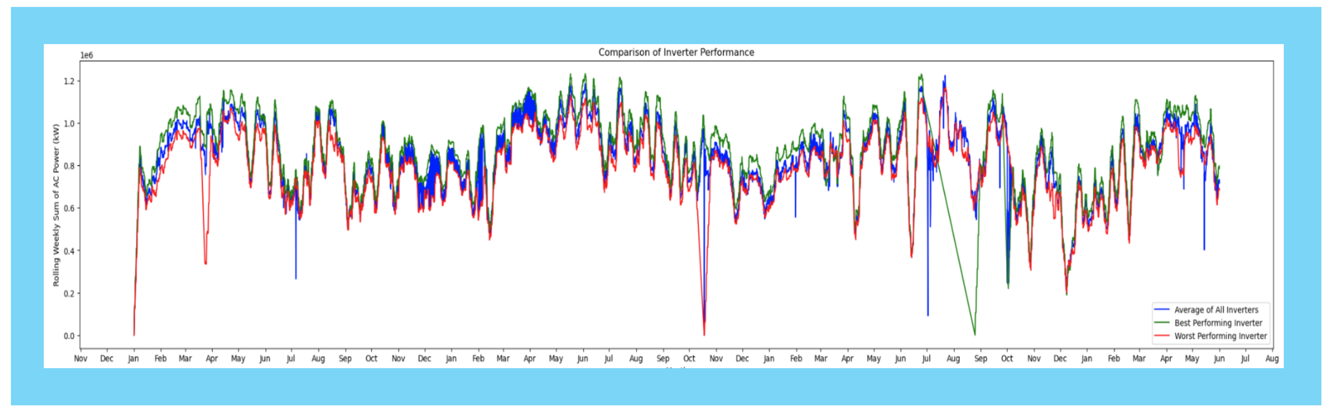
The results also show a need for a higher level of design in project development to mitigate losses due to plane of array orientation.

The spatial analysis algorithm can also be used in the design phase of a solar tracker project to optimize planes of array and mitigating production underperformance prior to construction.

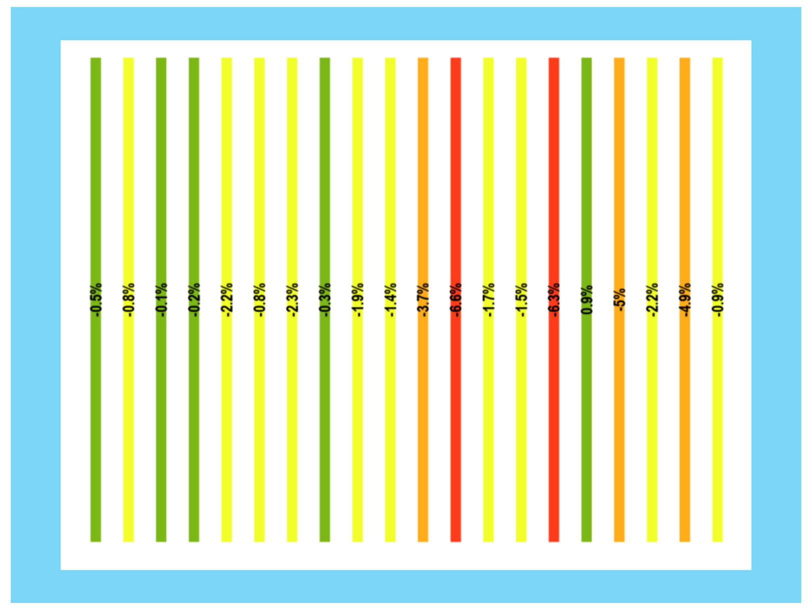
The analysis should also be applied to "terrain following" trackers, which have multiple plane-of-array orientations within a single row, to assess potential performance issues in those configurations.



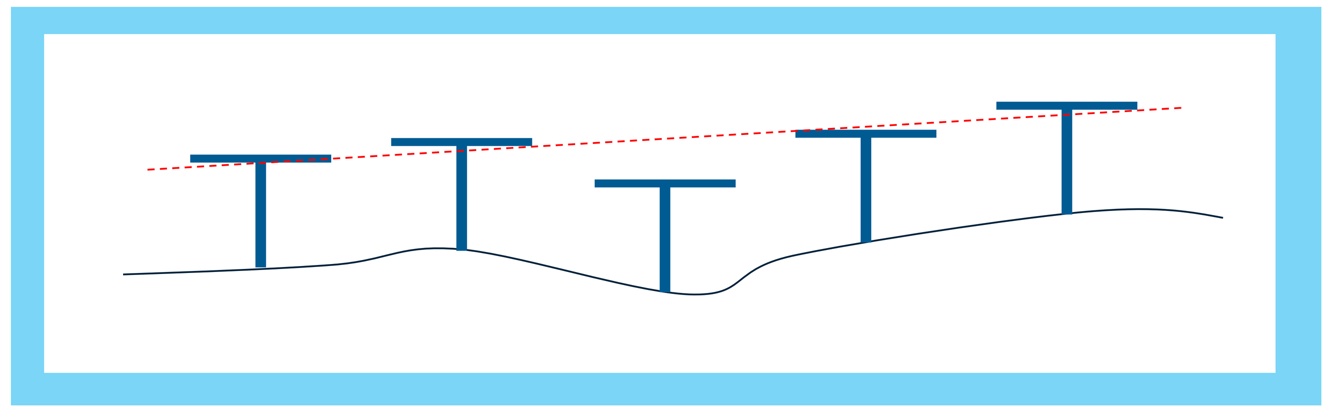
The results of the random forest predictive analysis for one of the projects examined. The blue line shows the actual production with the yellow line showing the predicted production for the project.



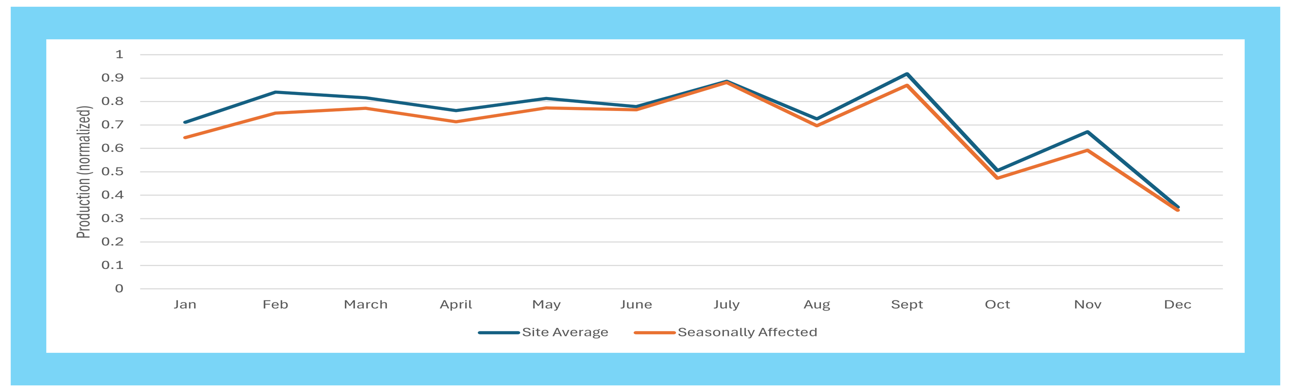
The average production and the predictive analysis is used to find inverter blocks that are underperforming.



A sample set of tracker rows showing the east-west predicted losses. While the terrain is not complex, the variation east-west is enough to cause higher losses compared to the overall project.



The change in terrain east-west (looking from the south), the trend line of the planes of array, with the center tracker row within a small depression. The orientation of the center tracker row here leads to higher losses within the inverter block.



The site average production over one year and an inverter block that shows seasonal underproduction and has high east-west losses.