How ML Enhances Operational Monitoring Efficiency

Improving Theoretical Power Calculations Under Near-Shadowing Conditions

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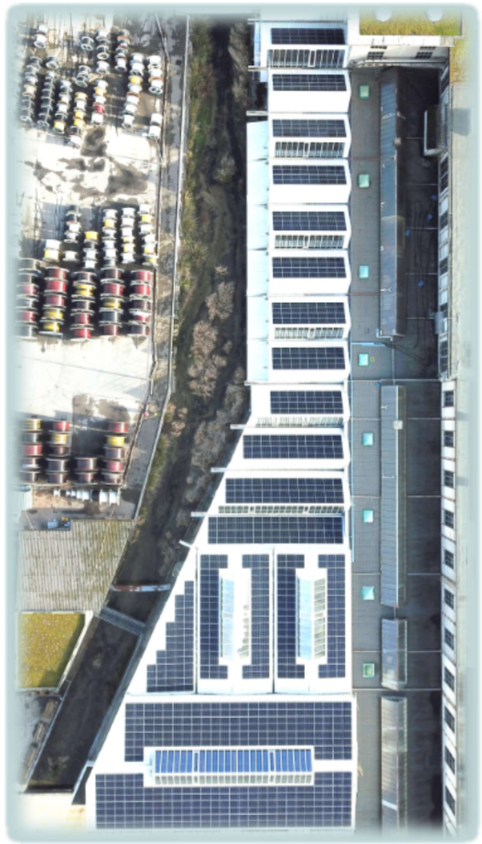
CONTEXT : THE HIDDEN INEFFICIENCY IN C&I SOLAR

Across Europe, up to 15% of C&I solar production is lost
- a silent drain on performance and profitability.



<u>Key pain points:</u>

- **Complex rooftops: multiple orientations, shading, snow, local conditions**
- **Fragmented ownership & self-consumption: data trapped in silos**
- **Thousands of relative small sites: O&M teams overwhelmed**
- **No tailored digital solution: fragmented tools, data overload**

→ Result: Lost yield • Higher OPEX • Limited scalability

OPERATIONAL CHALLENGES

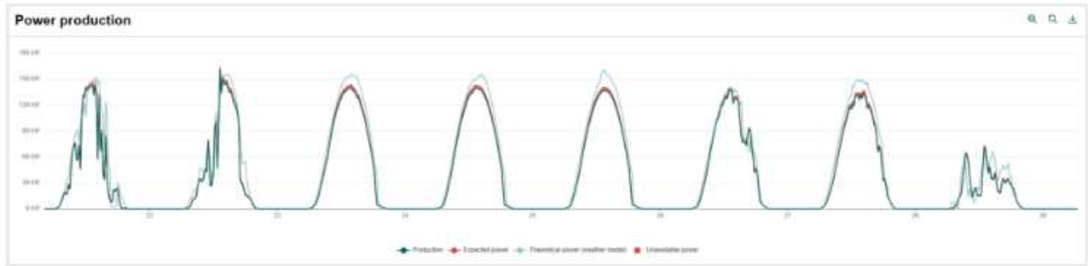
Accurate theoretical power is critical for solar asset monitoring

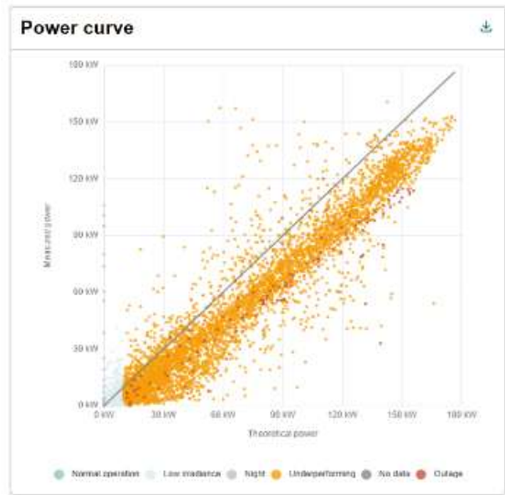
Compare expected vs. actual PV production in real time

Detect under-performance early

Identify inverter and string anomalies

Improve performance loss analysis





Summary

Mean Bias: -7%

MAE (Mean Absolute Error): 12 kW

Correlation (R) : 0.95%

Samples: 5 Months , 15 min

Traditional solar performance models often struggle to bring a reliable and cost effective power reference

LIMITATIONS OF CONVENTIONAL APPROACHES

Standard PV theoretical power models have limitations

Typical solar models rely on

Irradiance-based physical equations
Static shading assumptions
Generic module and inverter performance curves

⚠ Why this becomes problematic for near-shadowing

Highly localized effects at string or inverter level
Strongly time dependent
Seasonal and sun-angle sensitive

Consequences

Increased false alarms
Misinterpretation of production losses
Additional manual analysis for monitoring teams
Reduced confidence in PR and performance KPIs

ML-BASED ENHANCEMENT APPROACH

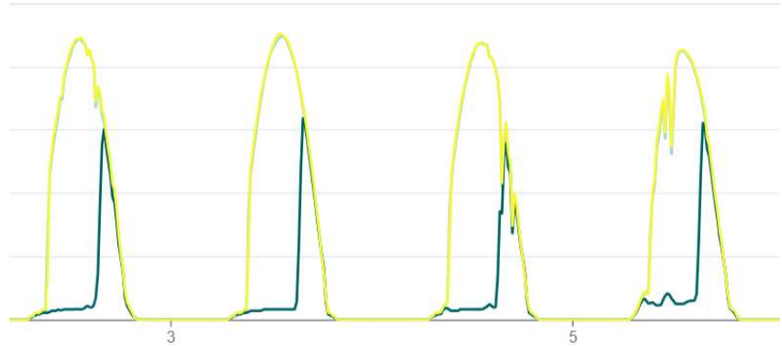
Using ML to improve PV theoretical power estimation

Data sources used by the ML models:

- → Historical plant production
- → Weather forecasts and satellite data
- → Module temperature coefficients
- → Historical shadowing behavior by time and season

Machine Learning enables:

- → Learning complex shading patterns automatically
- → Capturing non-linear impacts of partial shading
- → Adapting dynamically to changing environmental conditions
- → Improving expected power estimation at high granularity



Goal : Generate a realistic PV theoretical power curve under actual operating conditions.

EXAMPLE OF WORKFLOW

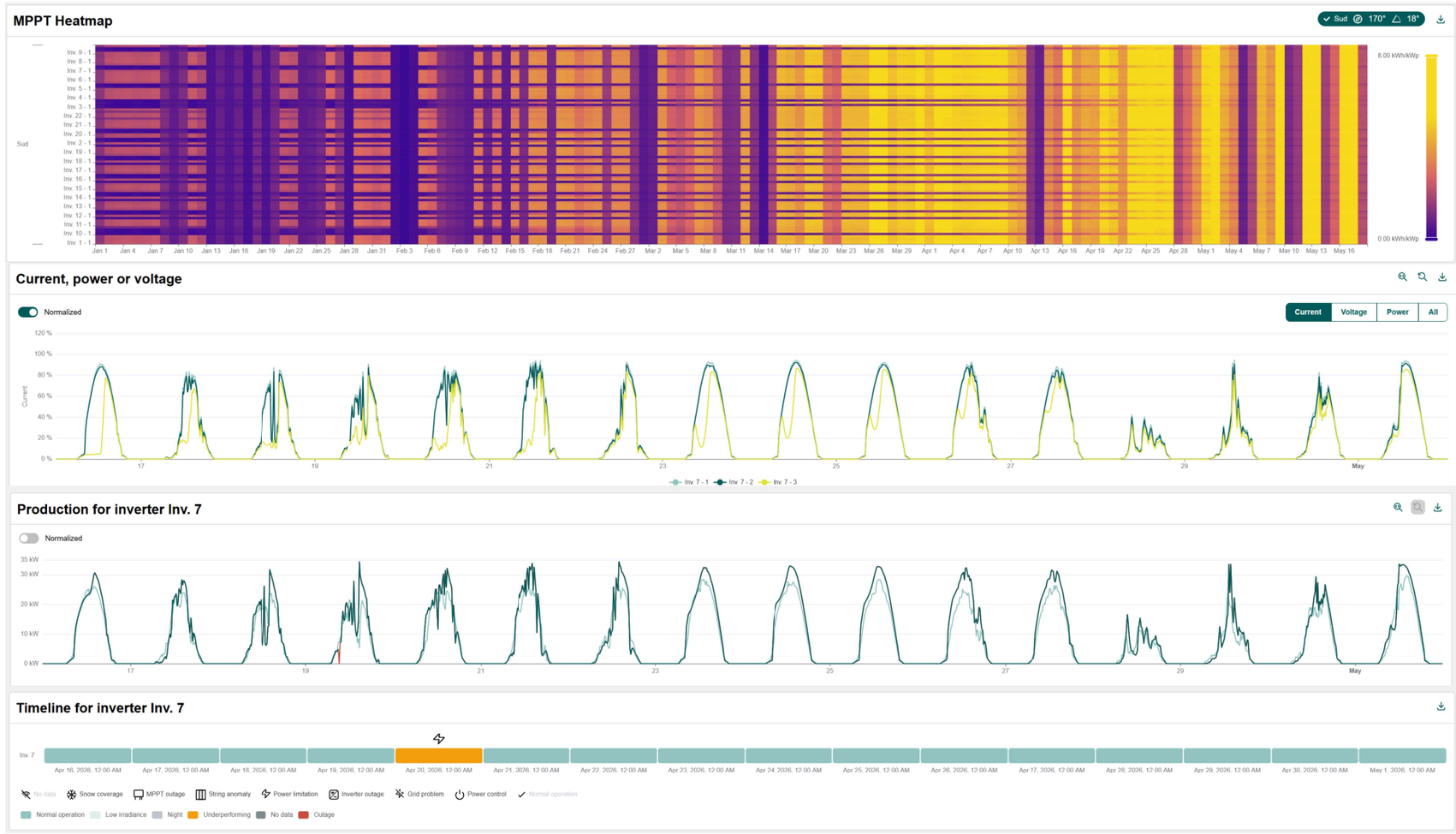
1) Collect operational and meteorological data

2) Train ML model using historical production behavior

3) Predict expected PV production considering shading effects

4) Compare with measured production

5) Trigger alerts only for meaningful deviations



OPERATIONAL BENEFITS

Tangible improvements for solar asset monitoring

Monitoring efficiency gains

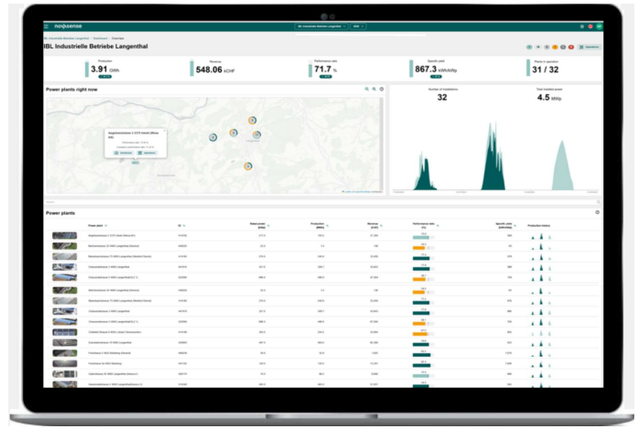
- ✔ Significant reduction in false positives
- ✔ Faster detection of underperforming strings or inverters
- ✔ Better prioritization of operational incidents
- ✔ Reduced manual validation workload

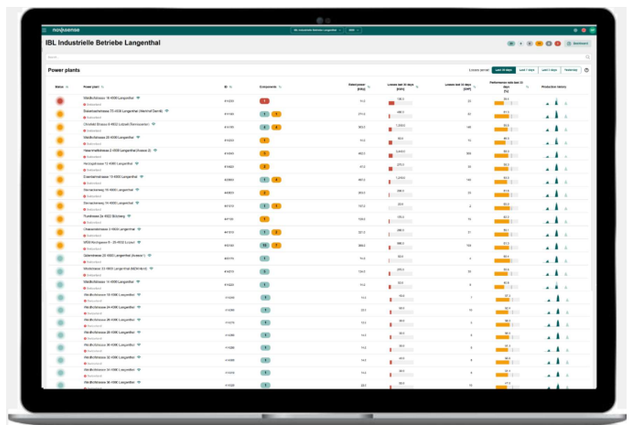
Improved solar performance analytics

- ✔ More accurate PR calculations
- ✔ Better identification of shading-related losses
- ✔ Improved availability and performance reporting
- ✔ Enhanced benchmarking across PV plants

Business value

- ✔ Increased operational reliability
- ✔ Reduced O&M analysis time
- ✔ Improved asset performance visibility
- ✔ Better decision-making for operators and asset managers





CONCLUSION

ML significantly enhances solar operational monitoring

Key takeaway

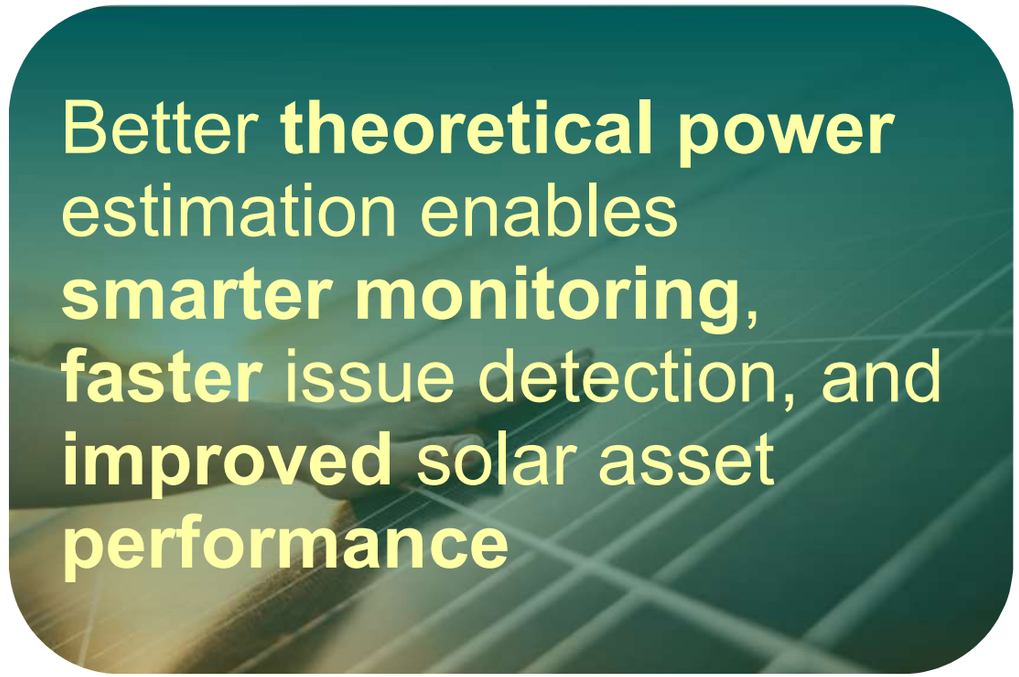
By integrating ML into PV theoretical power calculations:

- ✔ Near-shadowing effects are better represented
- ✔ Expected production becomes more realistic
- ✔ Monitoring teams focus on true operational issues
- ✔ Solar asset monitoring becomes more efficient and scalable

Strategic perspective

ML-enhanced monitoring supports:

- ✔ Advanced digital asset management
- ✔ Improved solar performance optimization
- ✔ Predictive maintenance strategies
- ✔ Continuous model improvement over time



The difference between a solar power plant and an asset is the intelligence behind it.

Thank you

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