First Solar®

Analysis of PV Power Plant Performance

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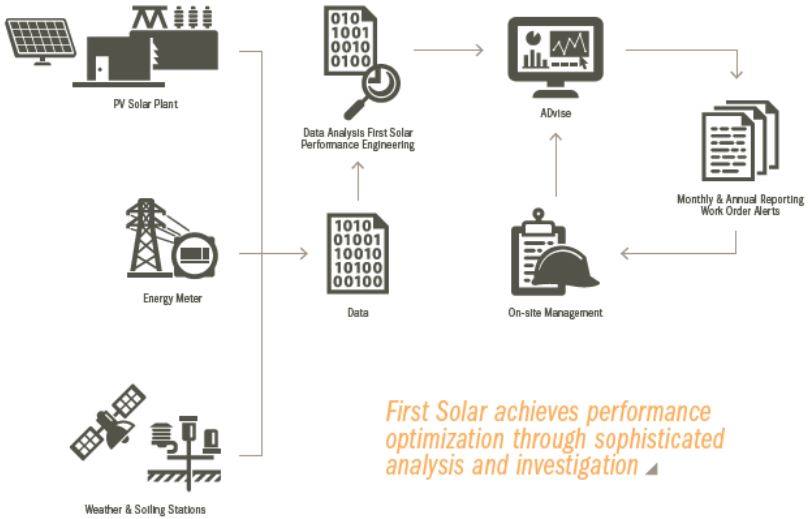
First Solar Performance Engineering

- First Solar provides Performance Engineering solutions for over 3.5 GW of PV power plants
- Fleet consists of plants from 2 MW to 550 MW
- Performance Engineering services are provided as a part of wider O&M solution and as a standalone ADvise service



First Solar

skytron® pioneers of energy
A First Solar Company

skytron® energy services

5.8 GW sold

in house developed and manufactured HW solution

4.8 GW in PVGuard service

real time remote & local supervision platform

Industry-Leading Multi-Site Plant Management

170 MW in O&M service

advanced operation center and power plant operation service

FULLY PRODUCTIZED SCADA SOLUTION & O&M

What is Performance Engineering?

Performance Engineering is…

Analytics

Reporting

Plant Health Assurance

Real world complications make it challenging

1. Energy production influenced by external drivers: ***clouds, dust, temperature, humidity, soiling, outages, shading***
2. Finding needles in a **very big** haystack
3. Plant data is imperfect: ***communications failures, sensor failures, miscalibrations***

Data Monitoring and Quality

Assessing plant performance requires reliable data

Key Performance Engineering Data Points

- Power Monitoring Instrumentation: Harness CTs, Inverters, Power Meters
- Auxiliary Instrumentation: Transformers, MSTs, Matrix Temperature
- Onsite Conditions: Weather Stations, Soiling Stations, Reference Modules

Data Reliability: Automated Data Recovery and Weekly Validation Report

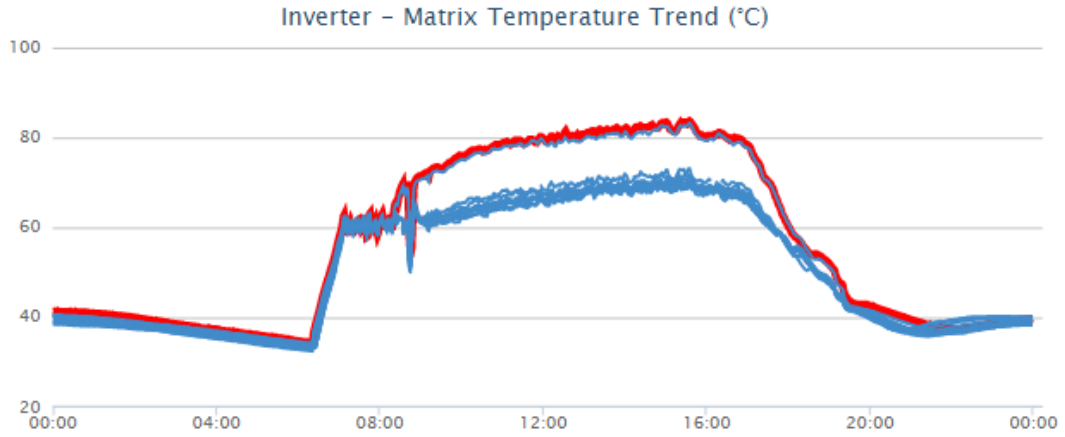
- Processes in place to automatically recover data from data loggers and onsite historian
- Weekly quality report and review meeting to assess gaps in data and quality issues

Field Weather Station

Identifying Sensor and Equipment Issues

Analytical tools assist with identifying sensor problems

- Daily Sensor Validation identifies when sensors or instrumentation indicate abnormalities
  - Algorithms search dataset and flag sensors outside of a user-specified threshold
  - Performance engineer reviews exceptions and adds a work order for the asset using integrated functionality
  - Example: Exception generated for daily average temperature of an inverter higher than its peers.



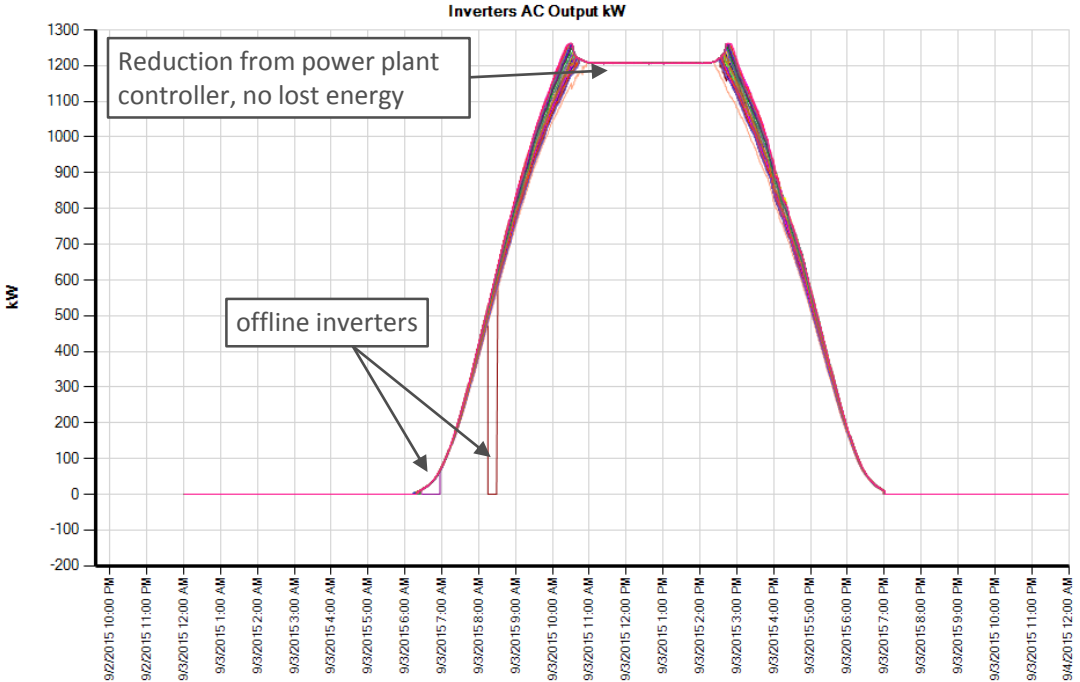
Next steps…

- Maintenance Recommendation submitted.
- Site Technician performed inverter cooling system maintenance
- Operating temperature returned to normal

Identifying and Calculating Lost Energy

Accurate representation of lost energy is important for assessing plant health

- Offline inverters: Calculate lost energy for each offline inverter separately using the measured output of peer inverters that remain online. Normalize for DC capacity.
- Derated inverters: Specify a threshold at which an inverter is considered “derated”. Lost energy is the difference between the output of healthy peer inverters and the de-rated inverter.
- Plant offline or curtailed: Estimate lost energy using a model of the PV plant, typically with measured weather and soiling conditions as inputs
- Clipping due to DC:AC ratio and lost output due to irradiance are not considered as outages as these impacts are included in the plant model.



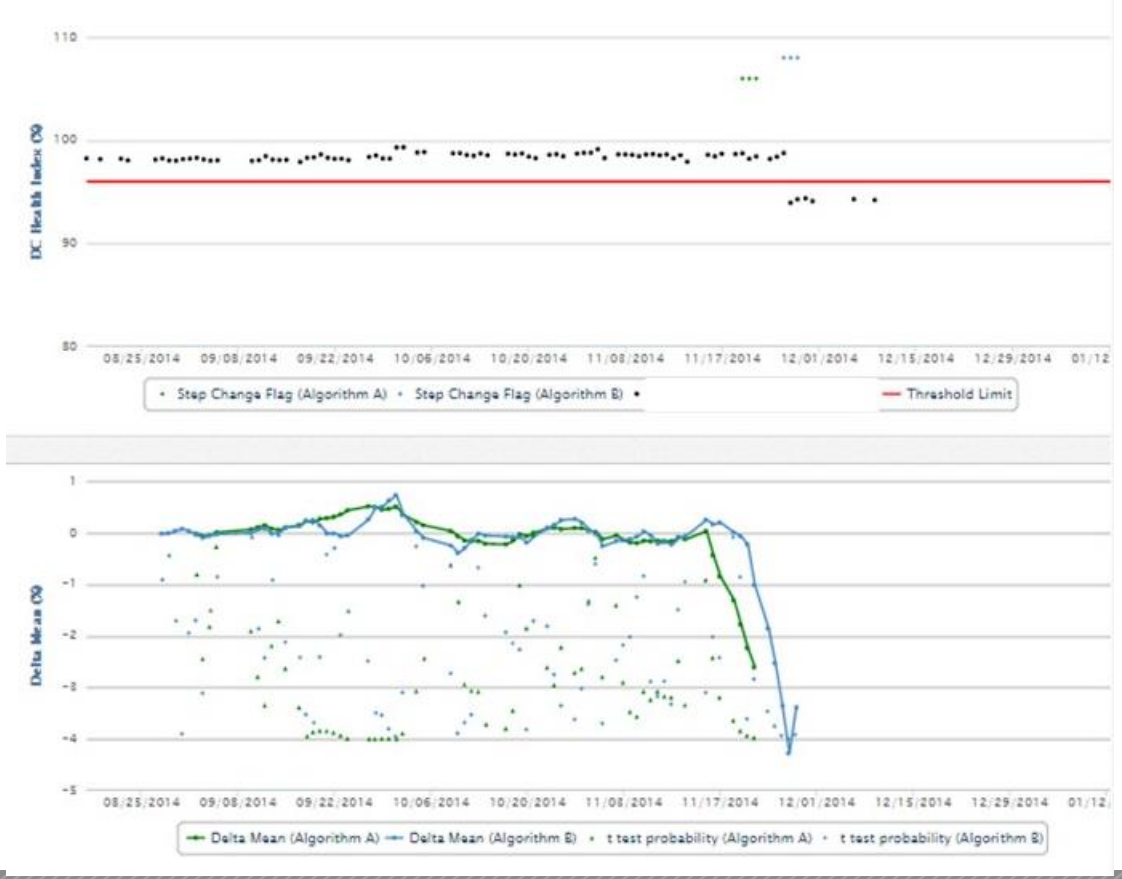
Monitoring DC Health

Analytical tools assist with identifying low performance

- DC Health Analysis identifies generation issues at the string level in the field (without string-level monitoring)
  - Calculates a DC Health Index for each inverter feeder and identifies a drop that indicate a string offline
  - Performance engineer reviews exceptions and adds a work order for the asset

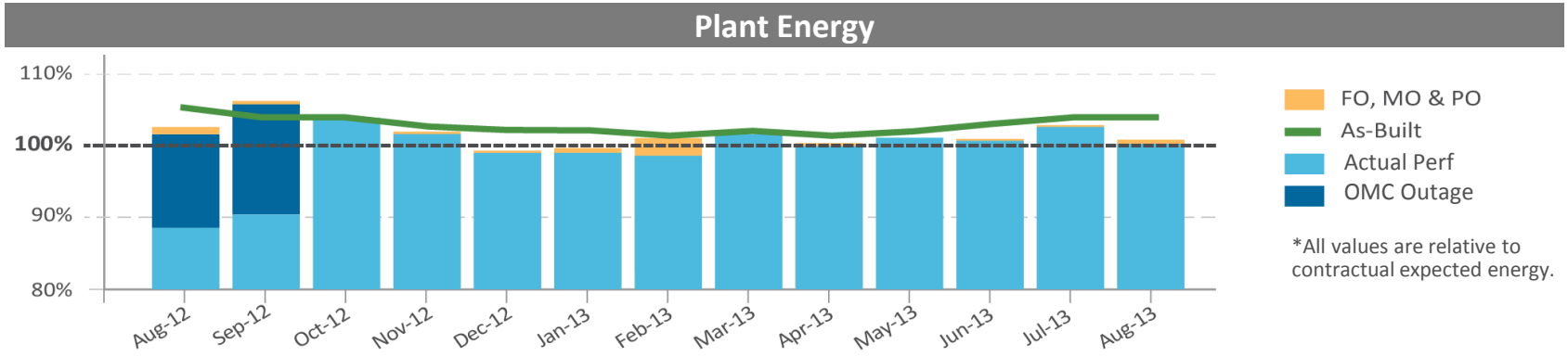
Next steps…

- Maintenance Recommendation submitted.
- Site Technician checked string-level measurements and identified an open harness fuse.
- Restored lost DC capacity.



Assessing Plant Performance

- Monitor year-over-year trends against contractual and as-built plant models
  - Adjust for actual weather conditions (e.g., run PVSyst or irradiance scaling)
  - Perform root cause analyses of performance lower than expected
  - Work with the site to mitigate performance issues



Plant revenue is maximized by ensuring plant health

Assessing Plant Performance

One Year Energy Guarantee and Performance Index

— Compares measured plant performance against the contractual PVSyst model adjusted for actual conditions (weather, soiling, availability).

Effective Availability

$$EA = \frac{E}{E + E_{Lost}}$$

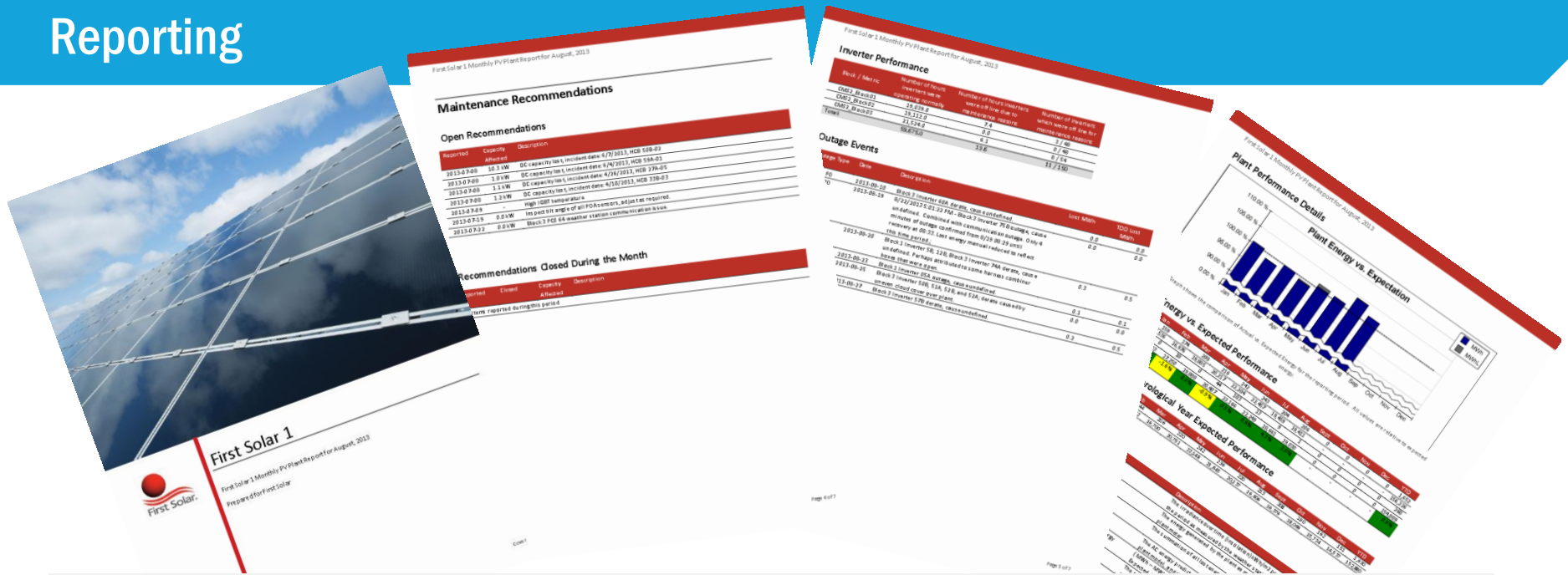
E is the energy generated by the PV plant measured at the revenue meter.
E_{Lost} is the energy lost due to plant availability events.

First Solar PlantPredict

— Cloud-based web application that allows the user to set up and execute individual energy simulations

— Allows sub-hourly weather measurement input from on-site meteorological stations to model expected plant output with greater resolution

Reporting



- Comprehensive and detailed reporting informs the customer of performance, lost energy, etc.
  - Standard monthly and annual reports. Automated reporting tools adds efficiency and consistency
  - Performance Engineers can run ad hoc analyses to accommodate additional requests
    - SQL, JMP, MatLab

More Resources

- Hunt, K. & Blekicki, A. & Callery, R. 2015, “Availability of Utility-scale Photovoltaic Power Plants”, *Proc. 42nd IEEE PVSC*, New Orleans, Louisiana, USA.
- Littman, B. & Panchula, A. 2015, “PlantPredict: Utility-scale PV modelling software for solar project life-cycle assessment”, www.pv-tech.org, May 2015 pp. 41-46.