Operational Performance on Plant and Inverter Level: Data Analytics for Optimizing Operations and Maintenance

Quality and Sustainability of PV Systems Conference
Brussels, 3 May 2018

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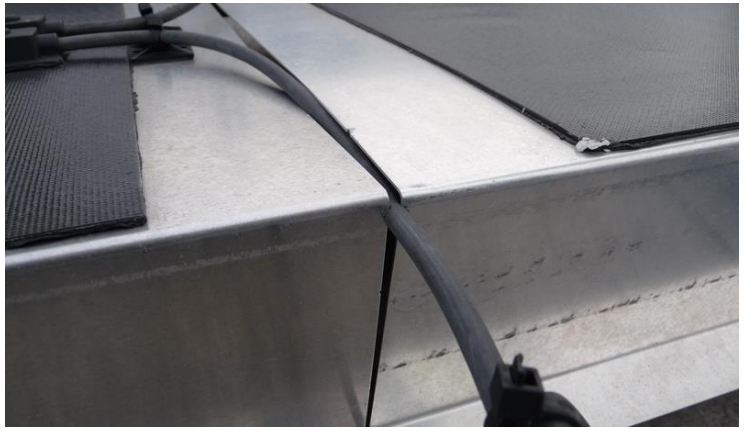
Accelerating the energy transition … since 1999

Outline

- PV plant performance in operation
- Catastrophic failure: inverter reliability in the field
- Non-catastrophic failure: hidden and creeping faults
- Beyond monitoring: data analytics in O&M
- Examples

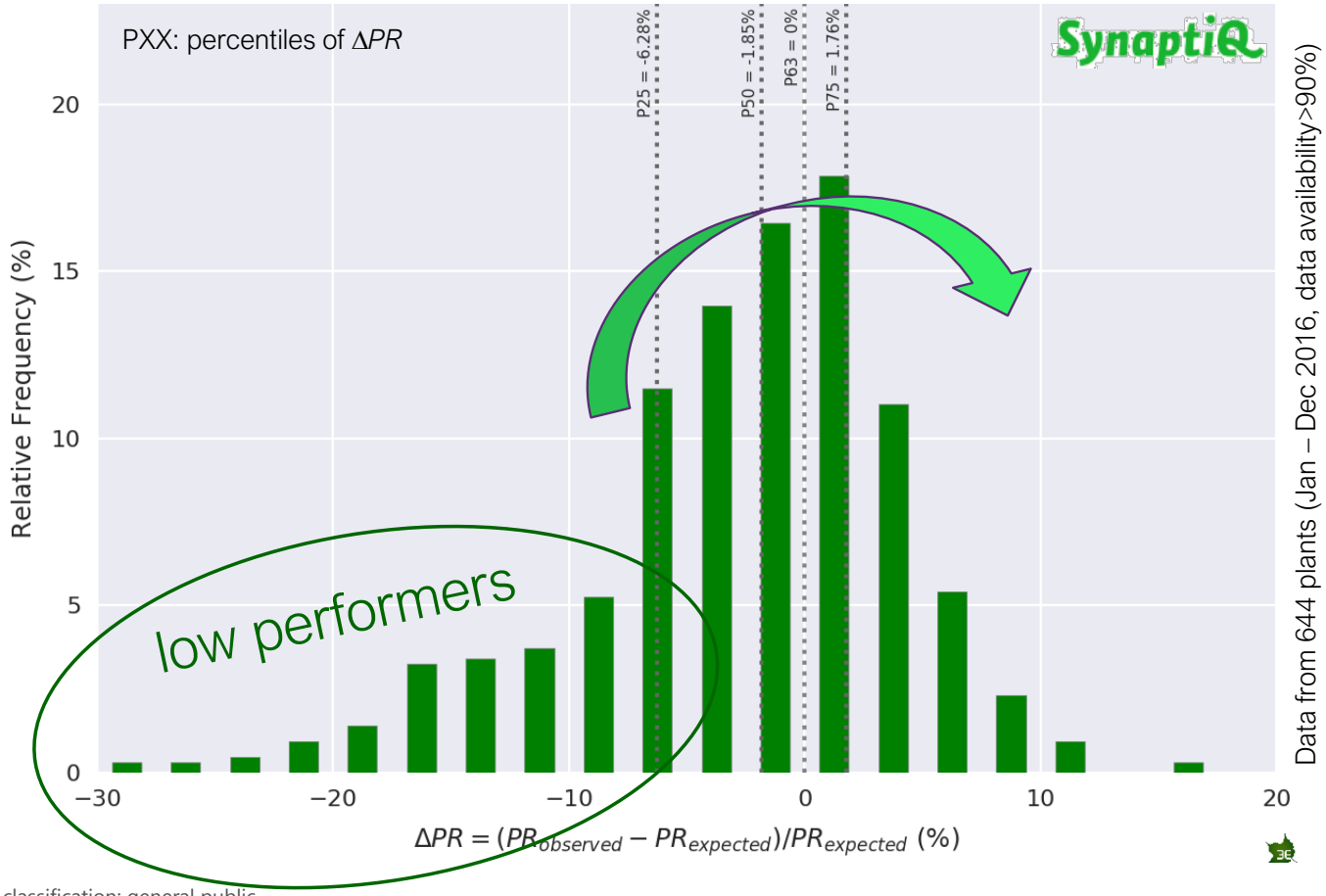
Experience from the field



The photos are anecdotal and show some examples of what can happen in the field

PV Plant Performance in Operation: Quality in Operation Matters

Statistics of 644 plants monitored by 3E

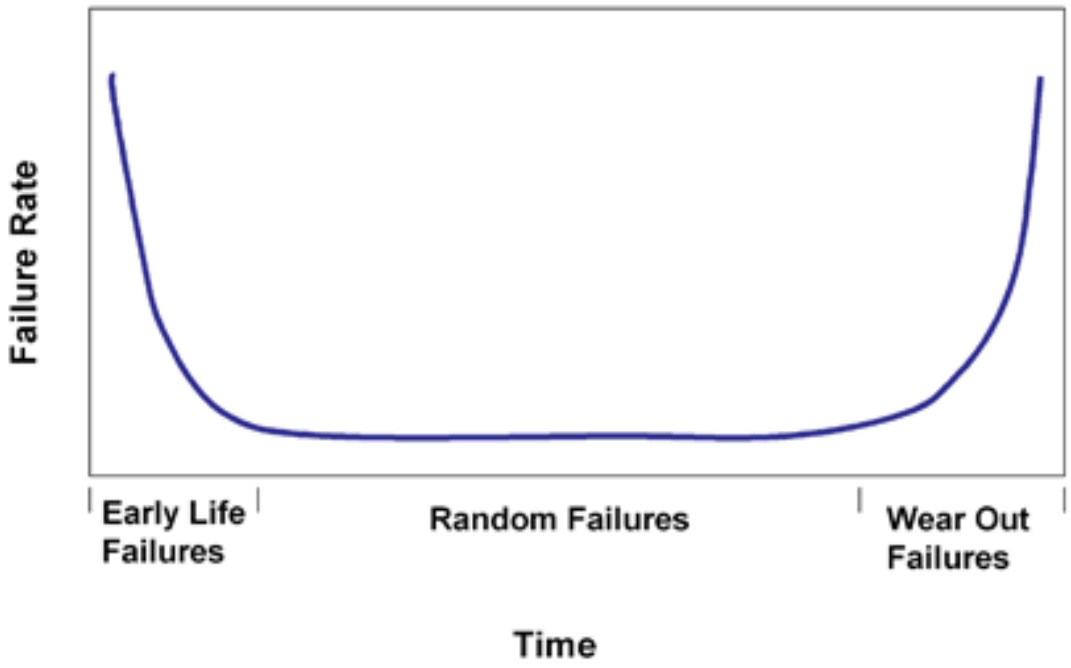


Catastrophic vs Non-Catastrophic Failures

- **Catastrophic failure**
  - Device ceases to operate entirely

- **Non catastrophic failures**
  - Device operates but at lower efficiency which can lead to larger losses

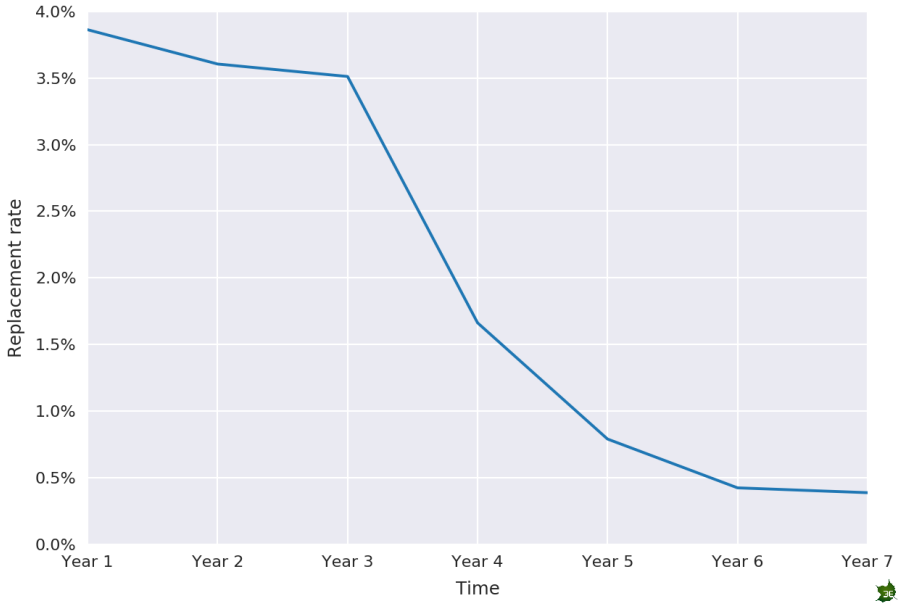
Bathtub Curve Showing Probability of Failures over the Lifetime of a Product



Inverter replacement rate as function of lifetime: 1st phase of bathtub curve?

In business plans, life of an inverter is typically assumed around 13 years (Baumgartner, EUPVSEC 2015)

- Assessment on 2000 commercial PV plants operating since 2010 and smaller than 100 kW (Solar Bankability)
- About 10% of inverters replaced after 6 years (majority within the first 3 years)
- First part of a bathtub curve:



Inverter replacement rate decreasing from ca. 4% in the 1st year to less than 1% in the 5th year

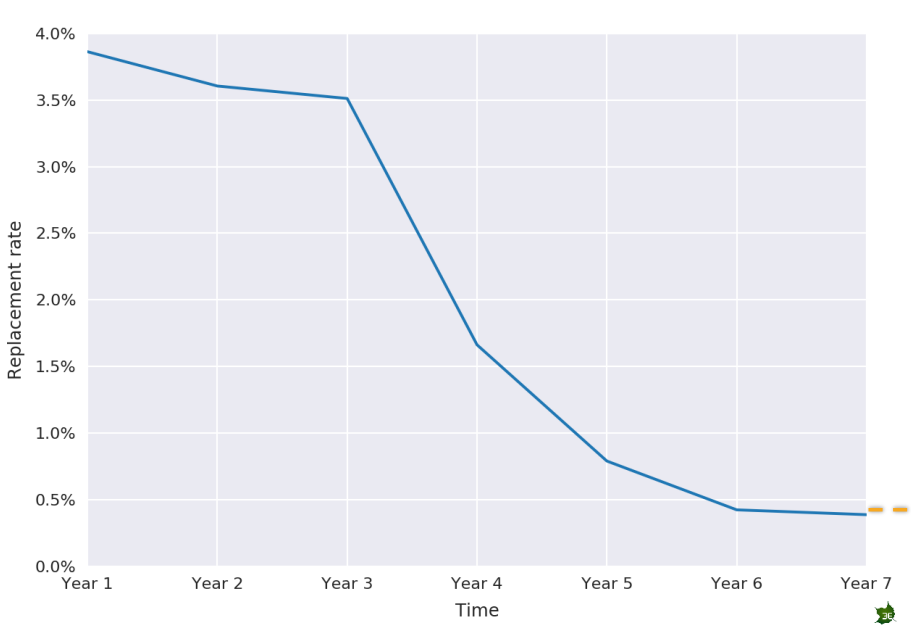
First Indications of Inverter Reliability in the Field

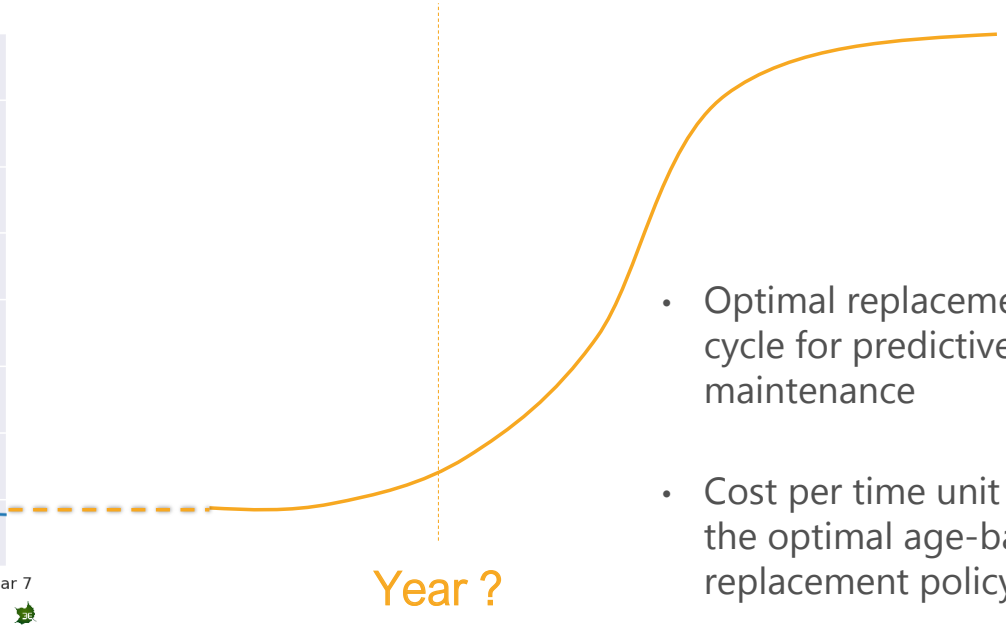
More than 30 brands and multiple models within one brand

- Despite differences in service policy, number of replaced inverters gives a first indication of reliability in the field
- New inverter models typically suffer the most from early failures
- Inverter failure rates are rarely disclosed by manufacturers
- Higher rates found may be due to early failures which are typically not accounted for in claims made by manufacturers

When Would the Wear-out Failures Start?

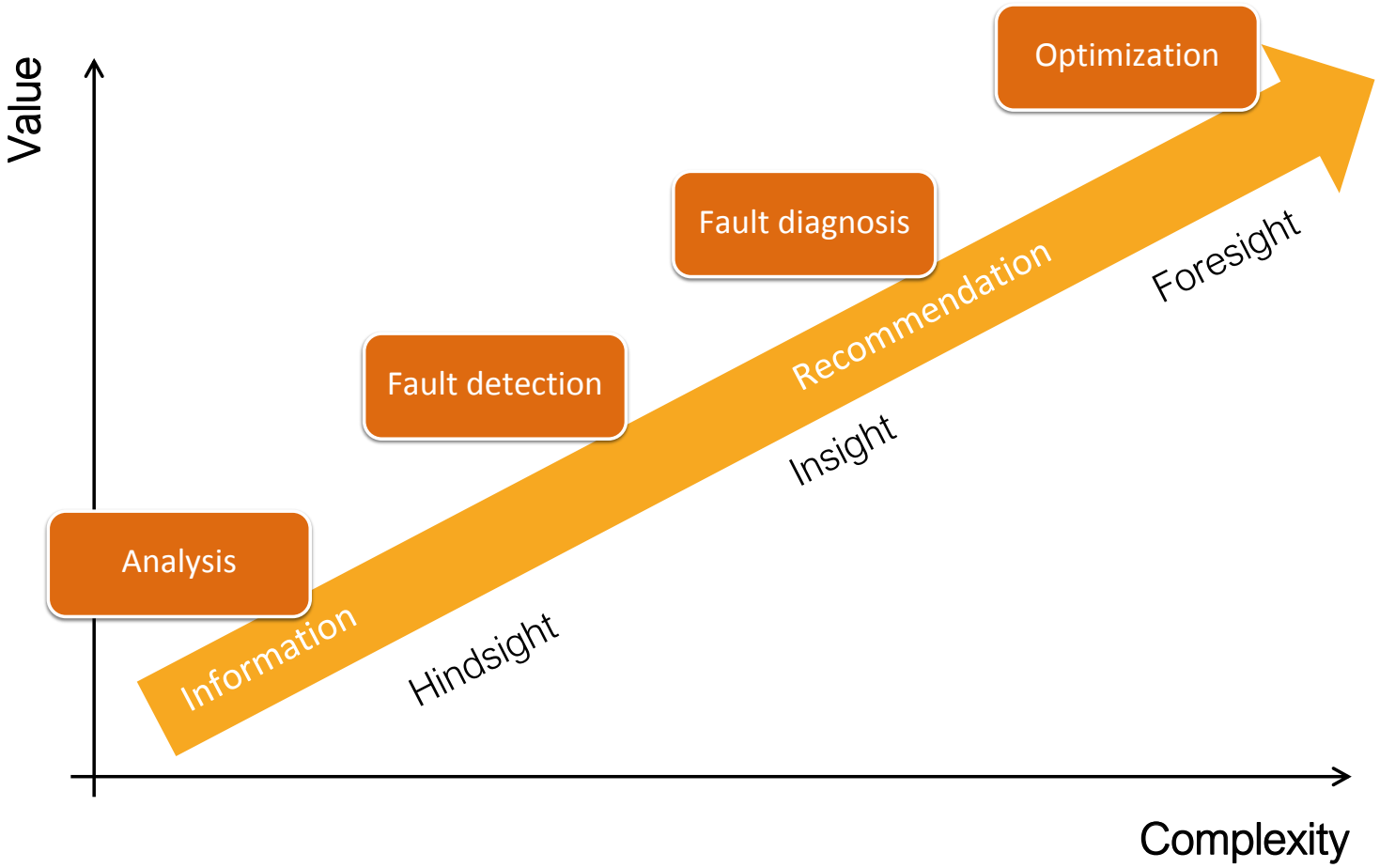
When is the right time to replace an inverter?





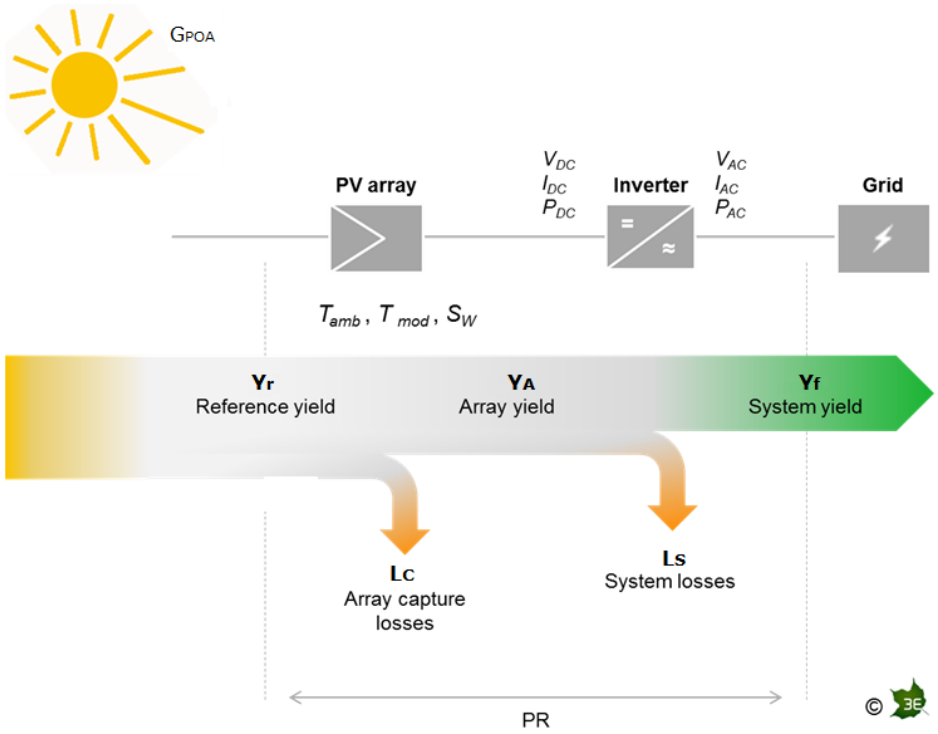
- Optimal replacement cycle for predictive maintenance
- Cost per time unit under the optimal age-based replacement policy

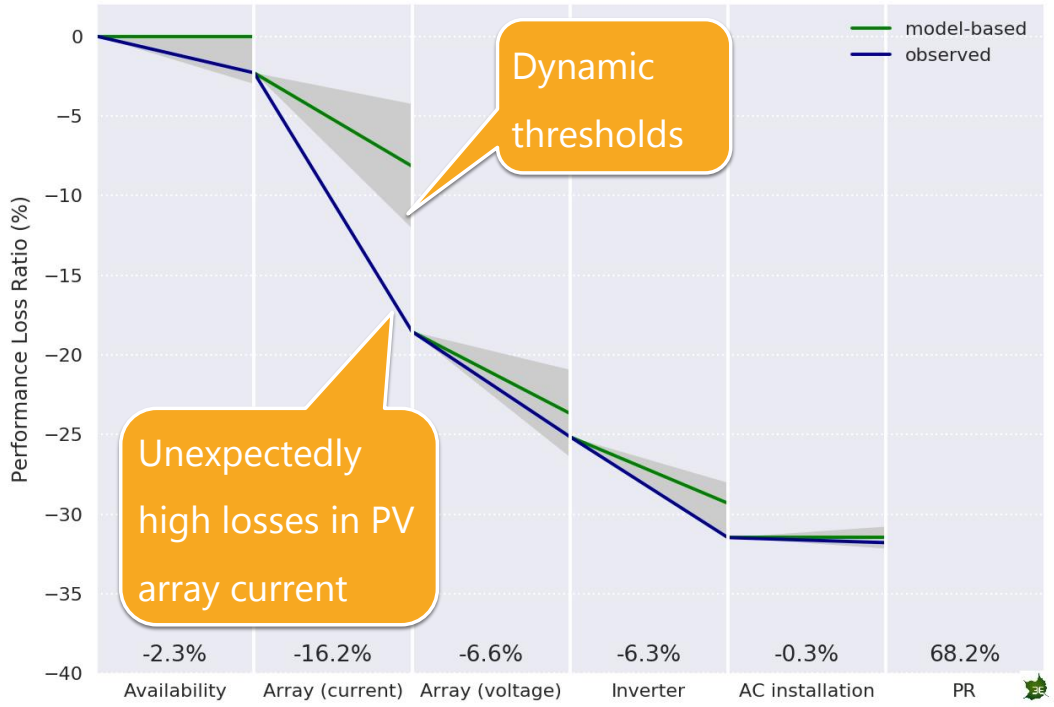
Big Data Analytics: Value and Complexity for Different O&M Objectives



3E's PV Health Scan: Data Analytics for Fault Detection

Data mining with artificial intelligence: example for limit checking (2 MW rooftop in Belgium)



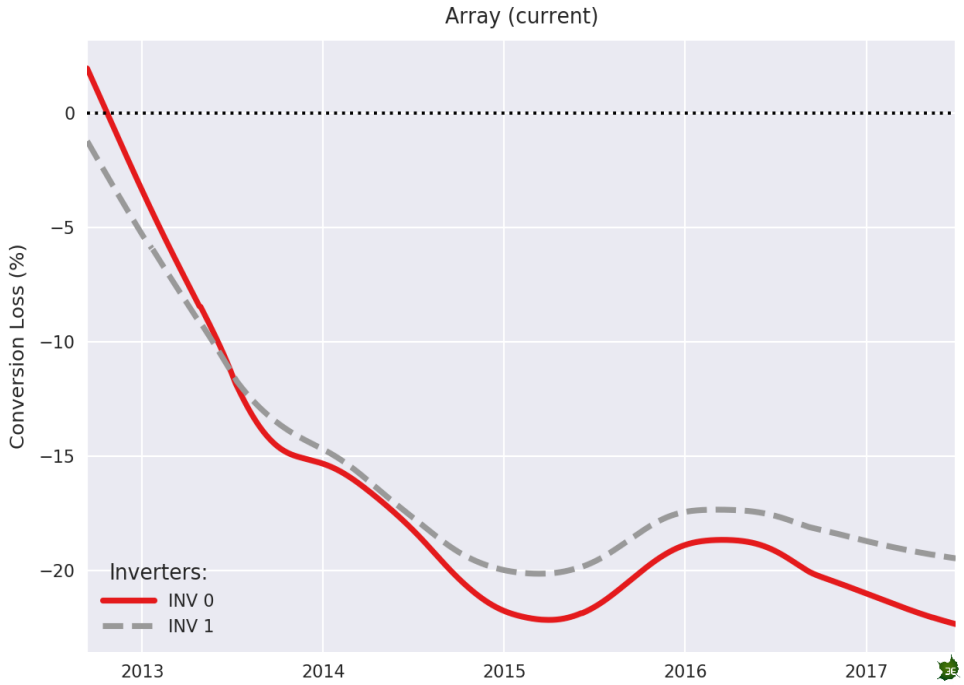


- Fault detection: what's wrong?
- Applicable to all inverter inputs or strings if monitored: where is it wrong?
- Automatic diagnosis through machine learning: why is it wrong?

3E's PV Health Scan: Data Analytics for Fault Detection

Data mining with artificial intelligence: example for limit checking

- **Figure of current-related array losses: deseasonalized trend**
- **Both arrays/inverters degrade systematically**
- **Long-term degradation rates: ~2.4% per year**
- **Probable root cause:**
  - Hot spots from shadow or soiling
  - Degradation of PV laminates



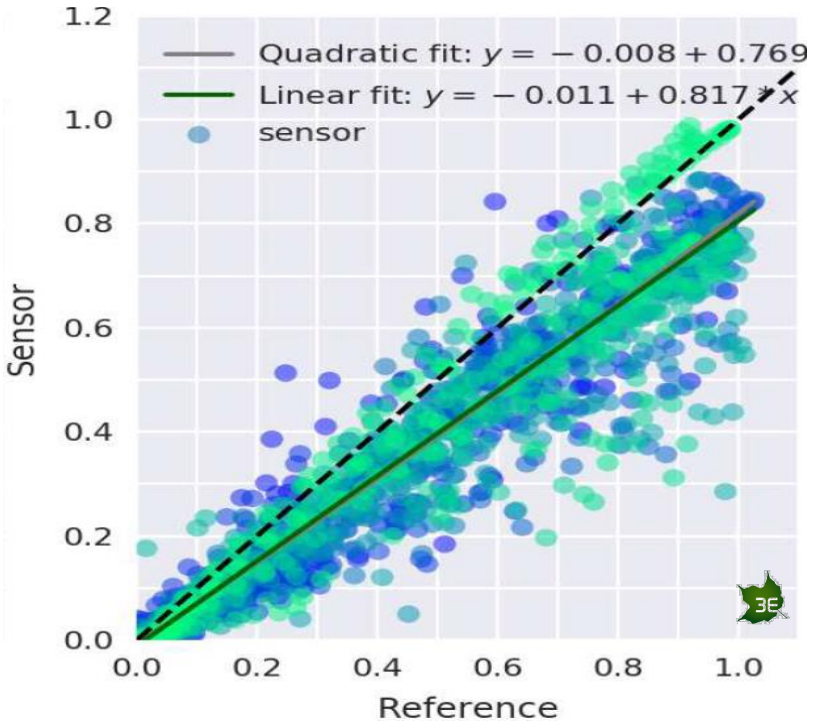
Time for a site visit, thermography and possibly a warranty claim.

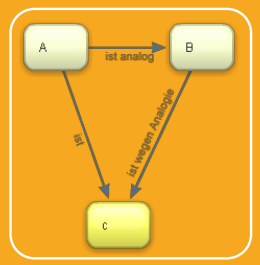
From Fault Detection to Automated Diagnosis

Example: 3E's automated Solar Sensor Check

This sensor:

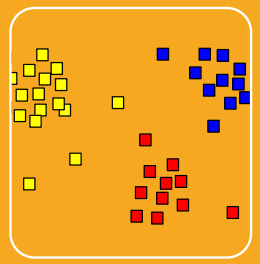
a) **needs cleaning**
b) **needs calibration**
c) **is ready for the trash**
d) **no idea**





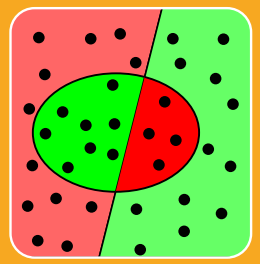
Classical AI

- Knowledge-based, phenomenological
- Inference-based
- Possibly fuzzy or Bayes logics



Unsupervised Learning

- Clustering methods
- Descriptive, not explanatory



Supervised Learning

- Classification methods
- Training data set required (*Ground Truth*)

Operation Risk Mitigation: Commercial Rooftops and Utility Scale Plants

Advanced Monitoring: Can these people see what's wrong with the inverter?

- **Easy processes for larger plants and portfolios**
  - Hardware independent and versatile
  - Monitoring, alerting, analysis, reporting and document management, ideally linked with ticketing
  - Actionable insights through data analytics
- **Higher energy yield through early fault detection**
  - Portfolios with 10 000s of devices generating GB of data each day
  - Operators lack time and tools for detailed analysis of several GB of new data each day
  - Hidden or creeping faults can take months to years to be detected and finally solved

Conclusions

- **LCOE is more than CAPEX**
  - quality in operation matters
- **Life expectancy of inverters:**
  - burn can be covered by 5 year warranty
  - end of life has never been systematically documented
  - an opportunity for manufacturers to make a difference
- **Data analytics for increasing O&M efficiency just started to be explored for PV**
  - fault detection
  - fault diagnosis
  - maintenance optimization

Thank you!

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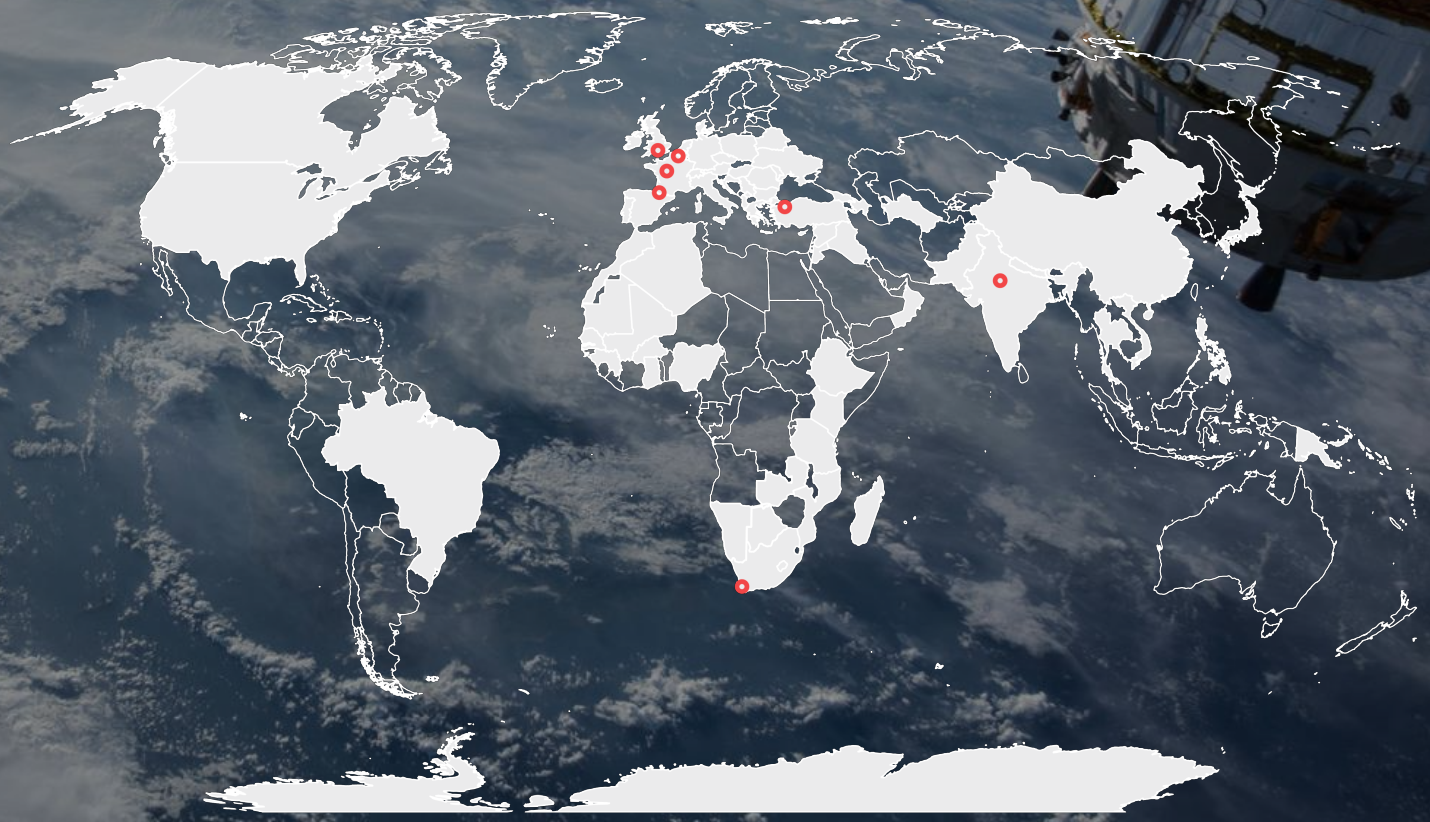

This work has received funding from the European Union under the Horizon 2020 programme, contract 662189 – MANTIS – ECSEL-2014-1.

Het Mantis project werd ook gesubsidieerd door het Brussels Hoofdstedelijk Gewest – Innoviris.