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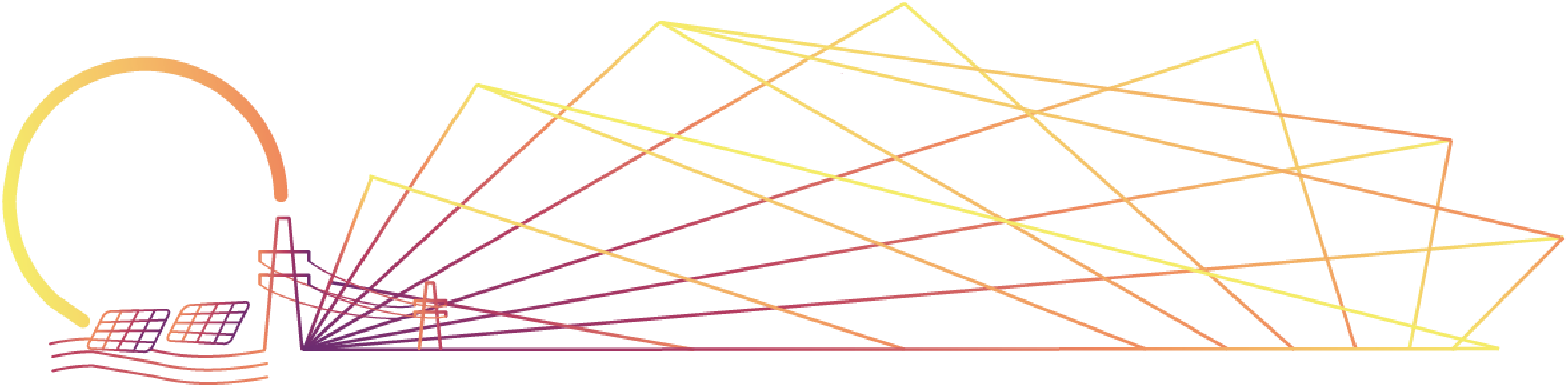
Monitoring and data analytics for fault diagnosis and O&M in large PV plants

Solar Quality Summit, 24th January 2023



Aiming LCOE Improvement

$$LCOE = \frac{CAPEX + OPEX\ (PV)}{EP\ (PV)}$$

CAPEX: Capital Expenditure
OPEX: Operational Expenditure
EP: Energy/Electricity Production
PV: Present value

- Better knowledge of new technologies performance reduces Weighted Averaged Cost of Capital (WACC)
- Automatic supervision tools and maintenance prescription reduces on-field inspection and unnecessary preventive labor costs
- Early fault detection and predictive maintenance increases main energy KPIs: Performance Ratio (PR) and Energy Availability (EA)

Failure Detection and Diagnostics (FDD) tool in Large PV Plants

PV plant configuration

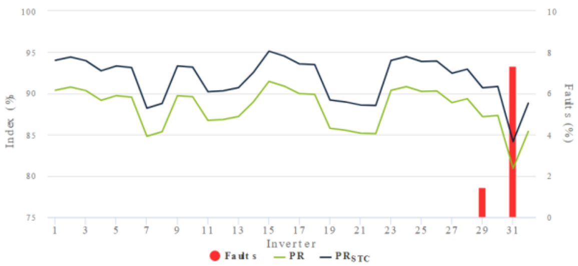
SCADA Monitoring Data

Data ETL and Quality Assessment

Models Development

Fault Detection and Diagnostics

Supervisor Dashboard



CMMS

Data Extraction, Transformation and Loading (ETL)

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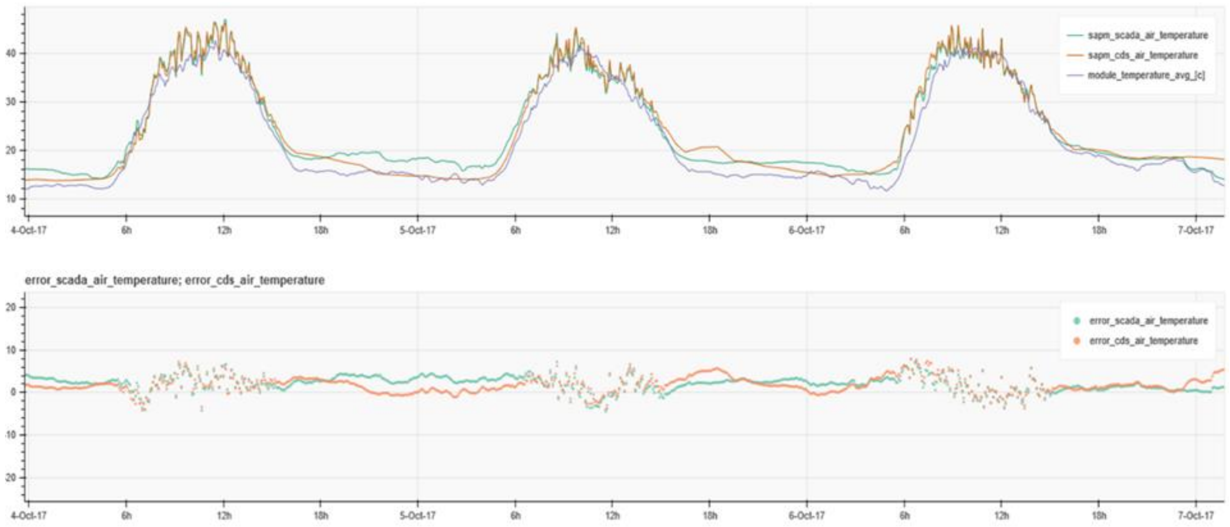
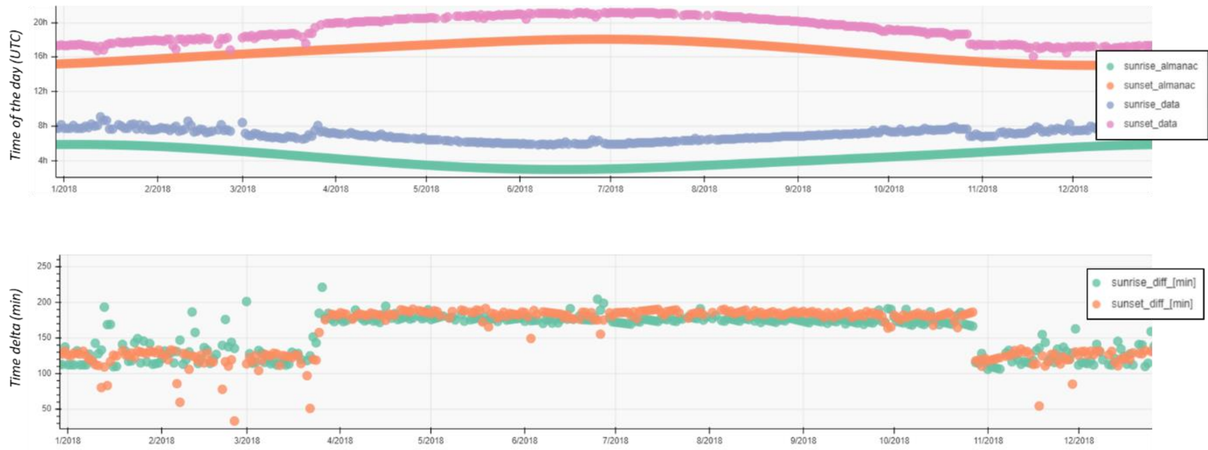
- A quite demanding stage **difficult to completely automate**
- **Data from very different sources** requiring:
  - Structure and naming translation for a common ontology
  - Magnitudes and scale unification
  - Time consistency, unification and synchronization
  - Availability analysis and potential recovery and complementation



Error detection and recovery in temperature measurement

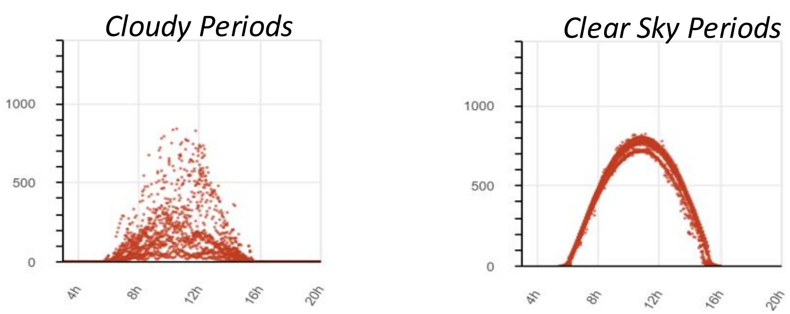


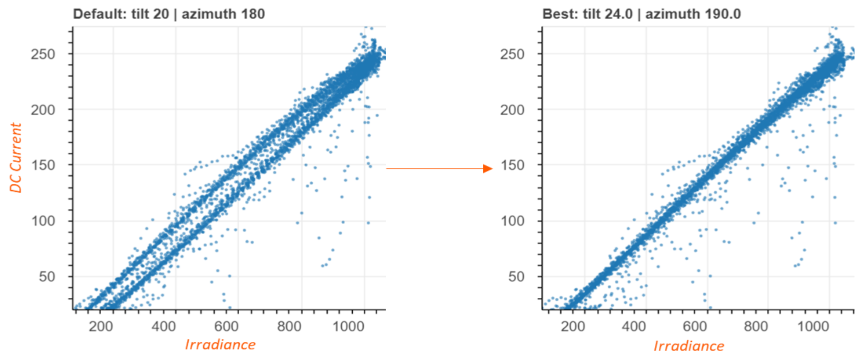
Detection of time shift from UTC

Data Quality Assessment

- A key-point **to reduce uncertainty and dispersion** of developed models.
- **Basic filtering** based on IEC-61724:
  - Range: maximum and minimum value differentiated by seasons
  - Dead value: constant value during a time period
  - Abrupt value: high difference between two time steps
- **Advance filtering** based on solar expertise:
  - Check if data are real, physically possible
  - Multivariable analysis
  - Multidevice analysis
  - PV inverter operating range and mode filter
  - Clear-Sky condition filter
  - Pyranometer misalignment detection and correction

Clear-Sky condition filter

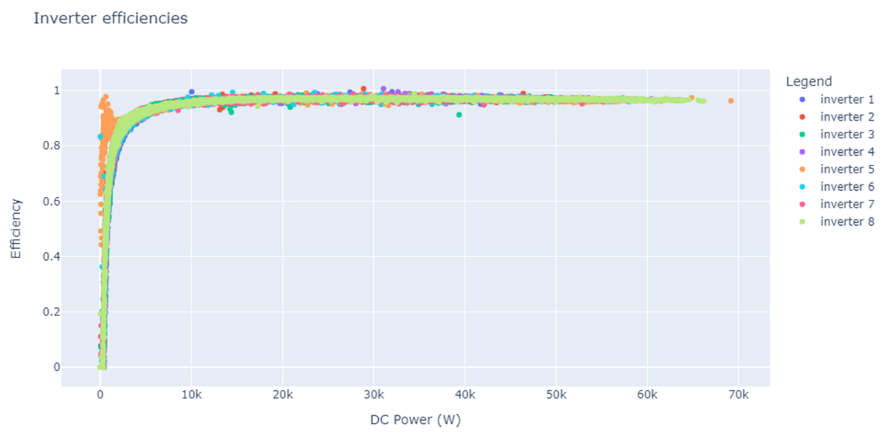




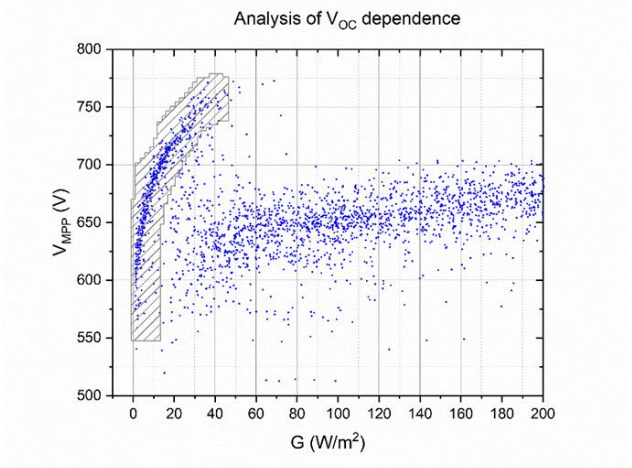
Pyranometer misalignment detection and correction

Models Development

- **Physical model** at component or system level (bifacial, floating, etc.)
  - Providing and explaining the expected performance of the asset
  - Able to roughly detect and quantify unexpected faults but requiring expert diagnostics
- **Data driven model** also known as statistical model or black box
  - Providing the real performance of the asset
  - Able to detect unexpected faults but requiring training datasets and expert diagnostics
- **Hybrid model** of State of Health (SoH) parameters and **digital twin**
  - Providing and explaining the real performance of the asset
  - Able to provide precise fault quantification and diagnostics but unable to detect unexpected faults



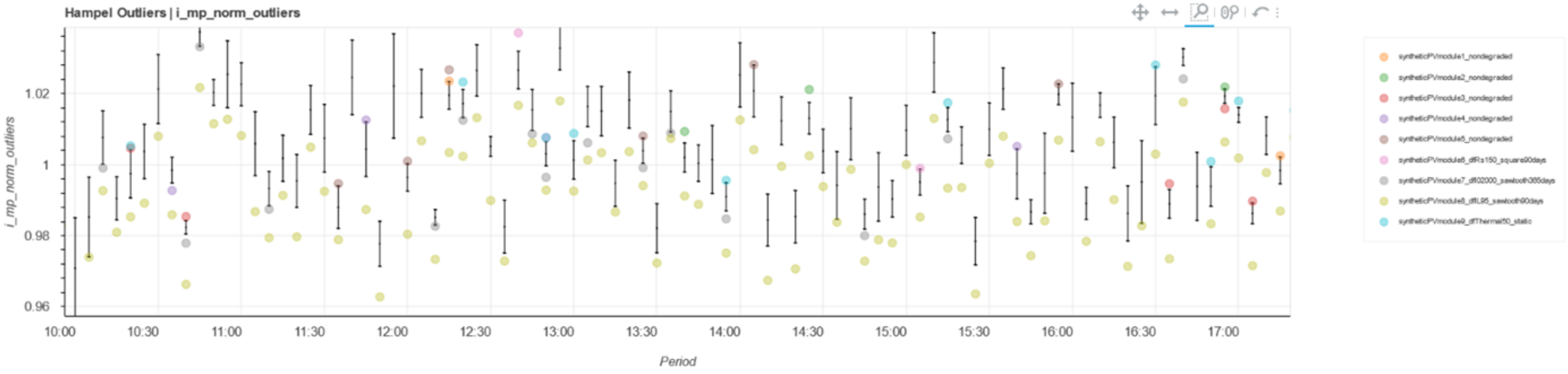
Data driven model of PV inverter efficiency



Hybrid model of open-circuit voltage

Fault Detection

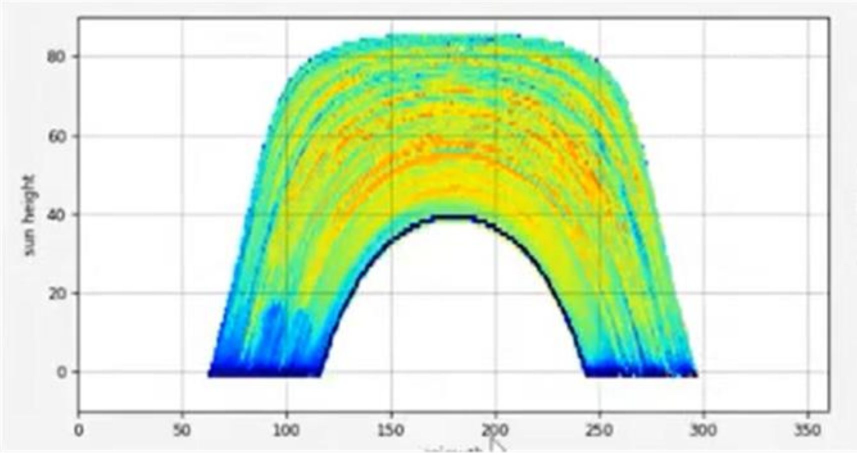
- Detection of **potential deviations** between:
  - Expected and real performance through physical and hybrid models
  - Real performance between different normalized instances through data driven and hybrid models
  - Real performance along the time through data driven and hybrid models
- Different **detection time windows** to notice:
  - Simple and direct faults in real-time
  - General faults daily
  - Long-term degradation issues periodically



Detection of potential deviations between different PV arrays

Fault Diagnostics

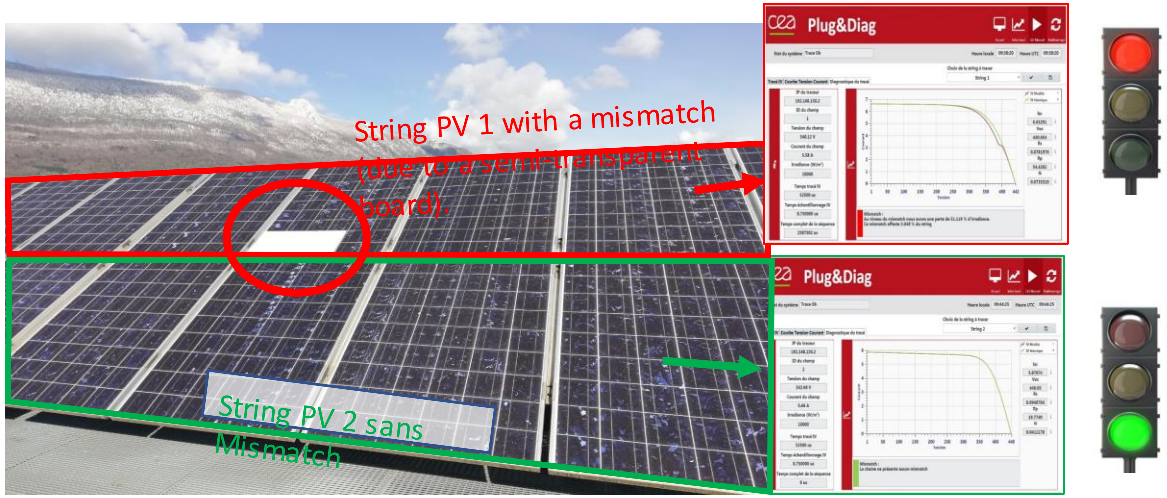
- The best approach is a **cross-check of all the existing techniques** for diagnostics:
  - Fitted hybrid models are self-explanatory, but only if existing faults are considered in the model
  - Both physical and hybrid models can also estimate energy loss corresponding to detected faults helping to quantitative evaluation and alarm filtering
  - Data driven models required labelled datasets, but they can also identify unexpected faults through pattern recognition (like those only related to data quality issues) when other models fail
- **Time evolution** of detected deviations **is also considered for diagnostics** of some particular faults (shadowing, soiling, etc.)



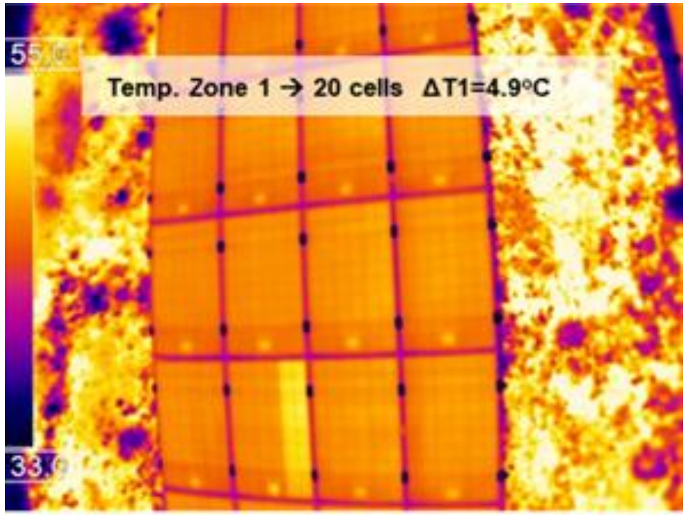
Analysis of generated current as a function of sun position

Fault Diagnostics Complemented by On-Field Inspection

- FDD tools can be complemented by on-field inspection techniques:
  - **IV-curve tracer measurements** able to distinguish mismatching effects and precise diagnostics under homogeneous operating conditions.
  - **Infrared thermography (IRT)** able to provide diagnostics with high spatial resolution.



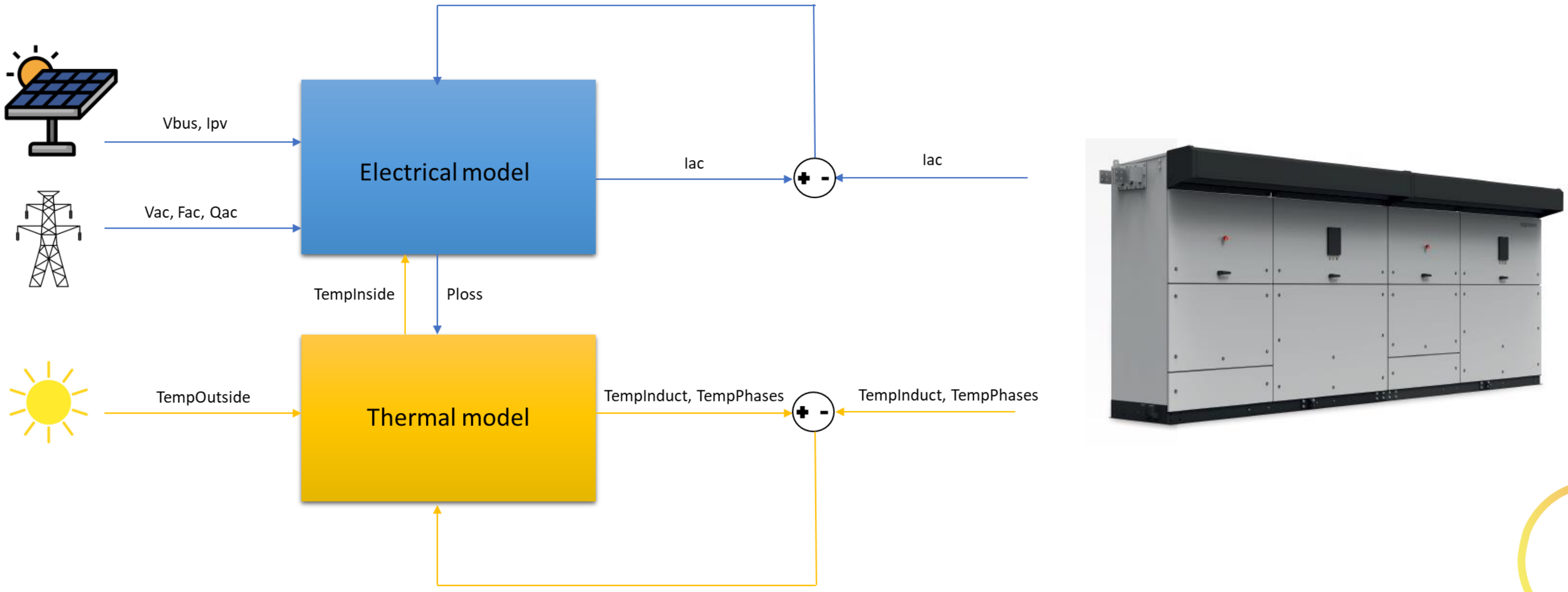
Diagnostics based on IV-curve measurement



Diagnostics based on IRT

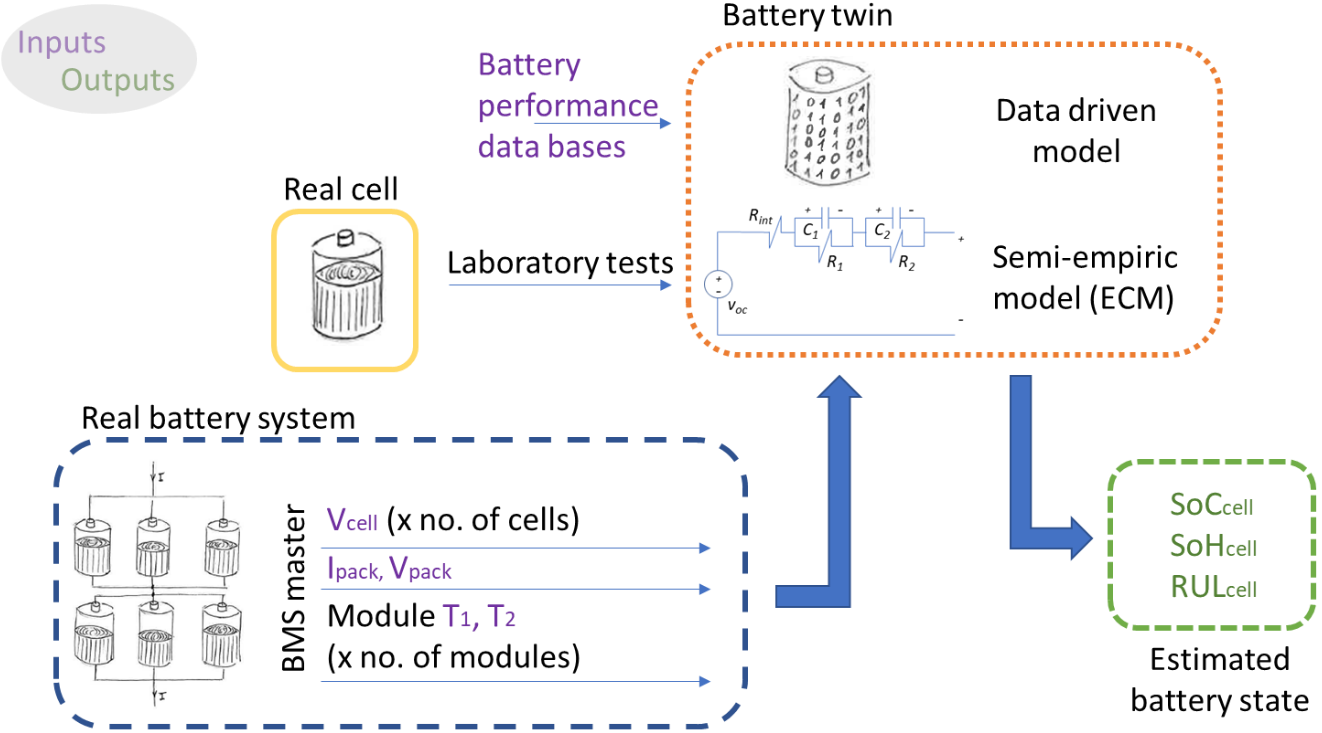
PV Inverter Digital Twin

- PV inverter digital twin consisting of **electrical and thermal models** fitted by monitoring data and providing:
  - Better performance characterization and fault detection and diagnostics of PV inverter
  - Anticipating potential faults improving Energy Availability



Battery Digital Twin

- Battery digital twin consisting of:
  - Data driven model for **Remaining Useful Life (RUL)** estimation from battery performance databases
  - Semi-empiric model for **State of Charge (SoC) and State of Health (SoH)** estimation from laboratory characterization of battery cell and monitoring data provided by Battery Management System (BMS)



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