PERFORMANCE EVALUATION IN MULTI-MW PV PLANTS

Presentation at the OTTI seminar "Monitoring of PV-Systems", June 2011

Version: Proceedings

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Seminar "Monitoring of PV-Systems"
Munich, 7th June 2011
www.ise.fraunhofer.de

Agenda

- Monitoring concepts for Multi-MW PV Plants
- Quality aspects
- Methodology for the PR evaluation
- Cross-checking yield prognoses
- Aspects of independent monitoring
- Exemplary field experience

Monitoring Concepts for Multi-MW PV Plants

- General considerations
- Hardware concepts
- Software concepts (surveillance and evaluations)

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Monitoring Concepts – General Considerations

- Key measured variables are identical to those of small PV plants,

  BUT a higher yield is under risk

  -> available budget ought to be more appropriate for Risk Control

- Particular characteristics of Multi-MW PV Plants
  - Extent of the plant
  - High power ratings
  - MV grid connection
  - Regular maintenance available

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Monitoring Concepts – Hardware

- More accurate and sophisticated measurement equipment
- Additional, redundant equipment
- Additional measurements
  - irradiation with pyranometers
  - grid voltage
  - power limitation or reactive power request by utility
- Extent of the plant requires
  - additional meteorological sensors
  - appropriate communication technology

Monitoring Concepts – Hardware

- Increased effort for
  - dispersed energy metering at distributed inverters
  - DC current measurement at central inverters

- Breaking the system into many sub-systems for cross-monitoring

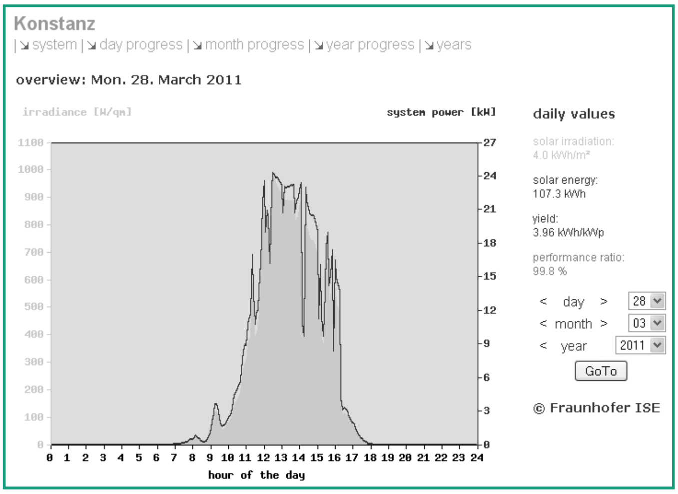
- May be considered:
  - Maintenance tracking
  - Maintenance support (cleaning, mowing)

Monitoring Concepts – Software

- Comparison of sub-systems (cross-monitoring)
- Expert based Operation Data Analysis System (ODAS)
  - Module failures
  - Inverter failures
  - Inefficient inverter operation
  - Shading effects
  - Snow coverage
  - Limitations induced by the grid

Monitoring Concepts – Software

- Tool for alert configuration and alert management
- Tool for incident management (supporting maintenance of PV plant and Monitoring System)
- Web portal for
  - Yield overview
  - Overview over potential revenue losses
  - Maintenance requirements



Quality Aspects

- General criteria and comments
- Irradiation measurement
  - Pyranometer
  - Si sensor
- Energy metering
- Temperature measurements

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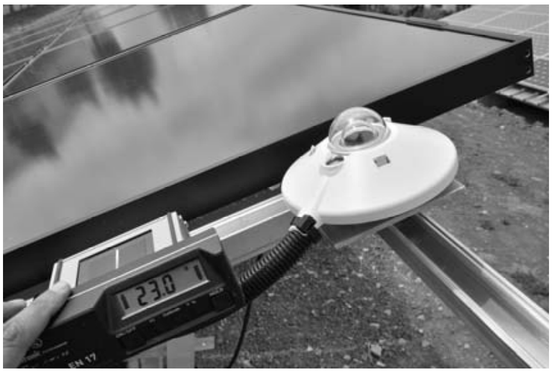
Quality Aspects

- Quality is crucial to ensure
  - Reliability
    - data availability
    - data accessibility
  - Accuracy of measurements
    - Calibration and inspection on-site?
    - Maintenance intervals?
- Measurement interval (shorter 15 minutes)
- Uninterruptible Power Supply (UPS)
- Data security / backup
- Controlled automatic restart after blackouts?
- Watch-dog functionality?



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Quality Aspects

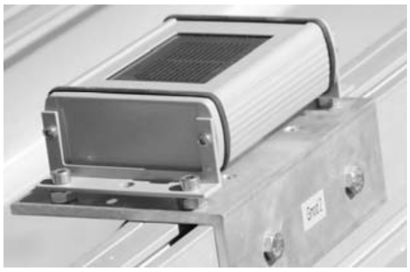
- Webcam?
- Precipitation sensor?
- Wind sensor?

Quality Aspects – Irradiation Measurement

- Pyranometer
  - Minimum two pyranometers in module plane
  - At least one of which has
    - Secondary Standard
    - daily uncertainty < 2%
  - Additional horizontal pyranometer may serve as validation of meteorological resource according to yield prognosis!

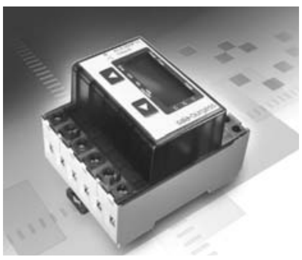
Quality Aspects – Irradiation Measurement

- Crystalline Si reference cell
  - Temperature compensation/correction
  - Stability of sensitivity
  - Uncertainty < 5%
  - Recommended:
    - Characterisation in certified laboratory (to reduce uncertainty)
    - Replacement after 2 years (stability check)
    - Cleaning weekly (or as required)
  - Attention!
    Annual totals can differ up to 5% compared to the pyranometer



Quality Aspects – Energy Metering

- Ensure operability at high currents over hours
- Direct measurement vs. transformers
- Uncertainty max. 1%
- Approved for PV inverter applications?
- High impulse rates (resolution) if applicable
- Reactive energy metering?



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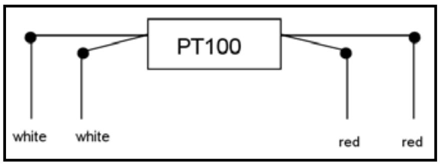
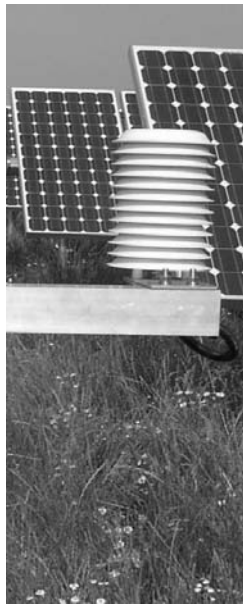
Quality Aspects – Temperature Measurements

- Temperature measurements (2-wire, 3-wire, 4-wire)



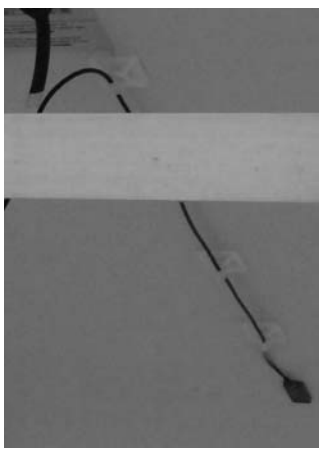
- Ambient temperature
  - Positioning
  - Passive ventilation
    vs.
  - Active ventilation
  - No ventilation

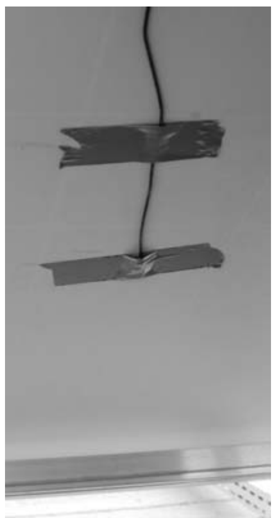


Quality Aspects – Temperature Measurements

- Mounting of sensors for module backside temperature

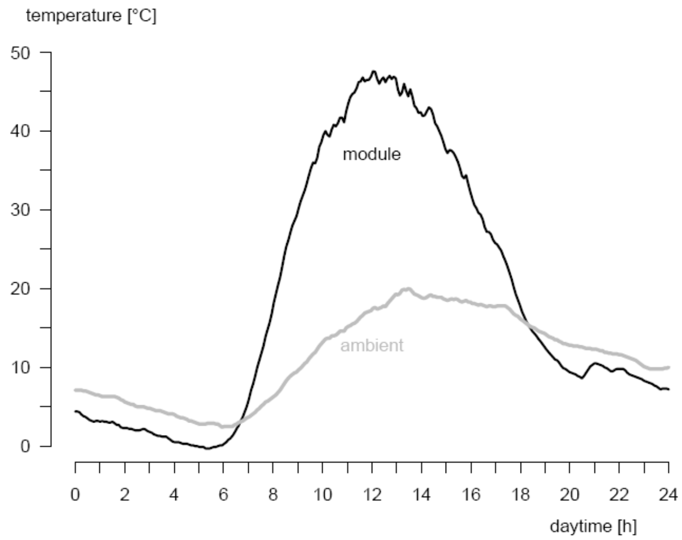
  Ensure thermally good, long-term contact!





Quality Aspects – Temperature Measurements

- Exemplary measurements for ambient and module backside temperature

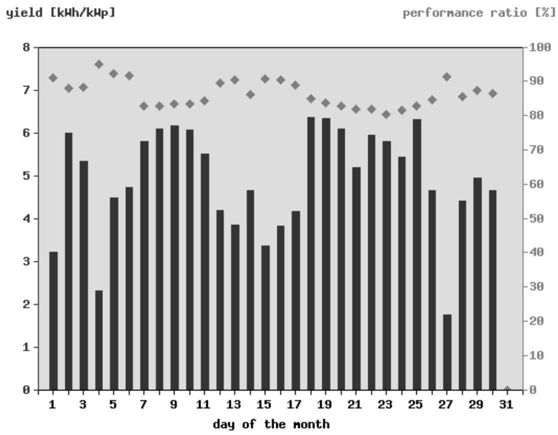


Methodology for the PR Evaluation

- Prerequisites and expectations
- Data validity check
- Calculating the Performance Ratio
- Considerations for comparison campaigns

Methodology for Evaluating the Performance Ratio

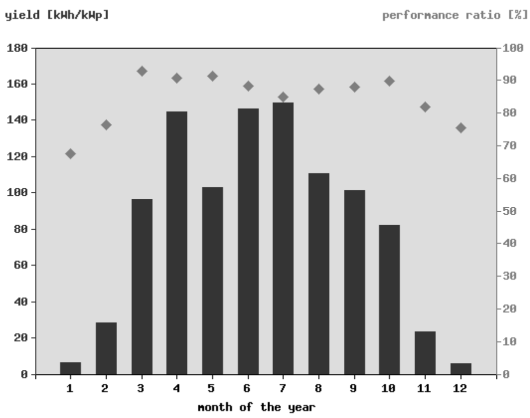
- Prerequisite
  - Data availability >99%
  - Data comprising at least a year
  - Data reliability and quality as listed in previous slides



- Results will include
  - Maintenance interruptions
  - Failures (also unidentified)
  - Interruptions or limitations deriving from the grid

Methodology for evaluating the Performance Ratio

- Data validity check
  - Values within permissible range?
  - Values reasonable?
    - e.g. temperature difference not too high
    - e.g. irradiation corresponds to power output
    - etc.
  - Derived values are valid only if all source values are OK



Methodology for evaluating the Performance Ratio

- Normalisation of energy output onto module power
  - Nameplate module power
  - Actual module power for scientific purposes only
- Calculating the Performance Ratio

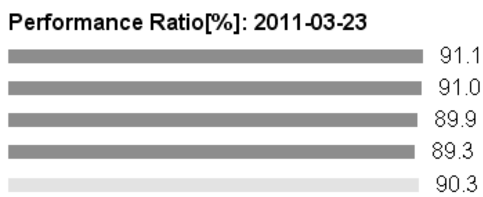
$$PR = \frac{\text{Yield}}{\text{Irradiance} * \text{Area} * \text{Efficiency}}$$

$$PR = \frac{\text{Spec. Yield [kWh/kWp]}}{\text{Irradiance [kWh/m}^2\text{]}}$$

Methodology for evaluating the PR - Comparisons

Are there any differences in

- module power?
- dimensioning / system design? (PV array-wiring-inverter-transformer)
- metering on LV or MV side?
- shading situation?
- Module orientation?
  It is largely considered by aligned irradiation sensors, but azimuth orientation slightly influences
  - spectrum of irradiation
  - average operating temperature of PV generator



Methodology for evaluating the PR – Advanced Comparisons

Impact of differences in ambient temperature and module ventilation can be reduced by normalising the PR onto a weighted module temperature

- Determining the weighted module temperature

$$T_{\mathrm{mod},weighted} = \frac{\sum T_{\mathrm{mod},i} \bullet G_i}{\sum_{year} G_i}$$

$T_{\mathrm{mod,i}}$ = Module temperature in interval i

G_{i} = Irradiation in interval i

- Normalisation of the PR must consider the temperature coefficient, if various module technologies are part of the comparison

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Cross-checking Yield Prognoses

- General remarks
- Examples

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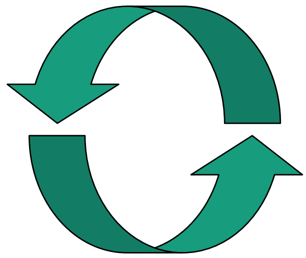
Cross-checking Yield Prognoses – General Remarks



- Investor and other parties will compare
  - Yield prognosis
  - Actual yield according to monitoring
- Is irradiation resource as expected?
- Component specific monitoring evaluations may validate the yield assessment study
- Yield prognosis may be tuned to operational behaviour
- Important note: Distinguish between PR_{Pyr} and PR_{Si} !
- Differences between system design in prognosis and actual design?

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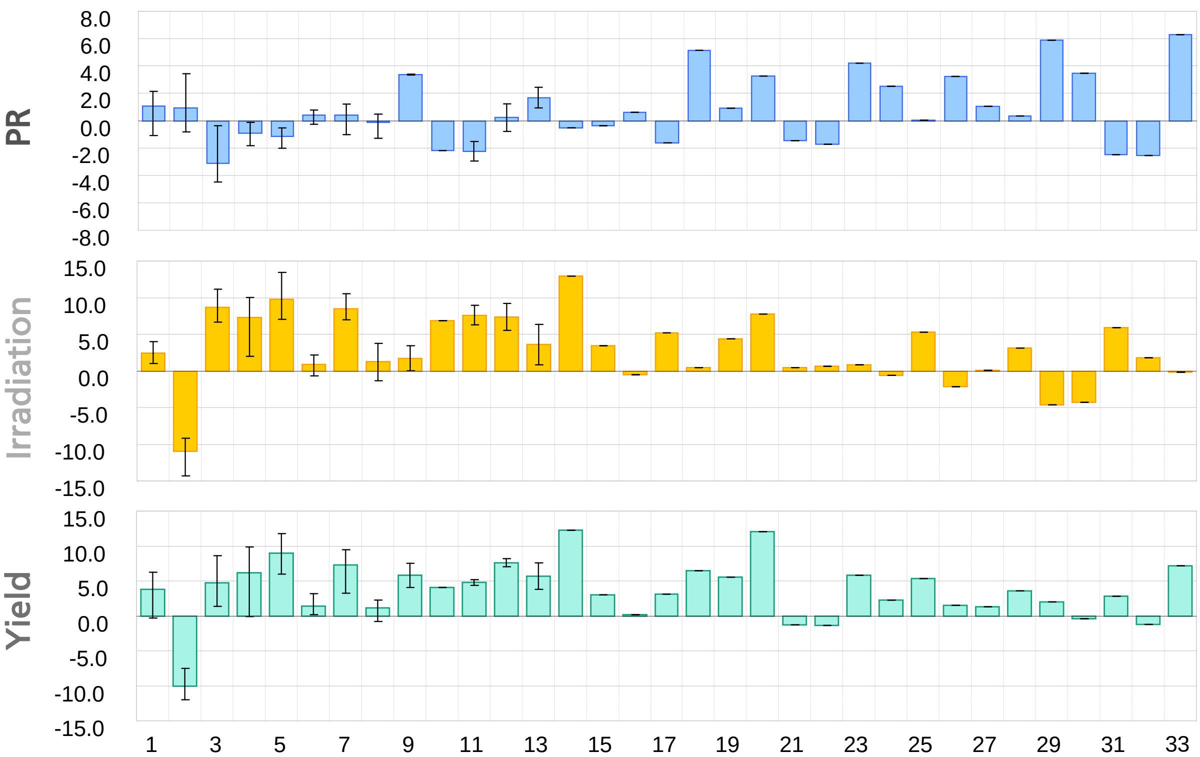
Cross-checking Yield Prognoses – Examples



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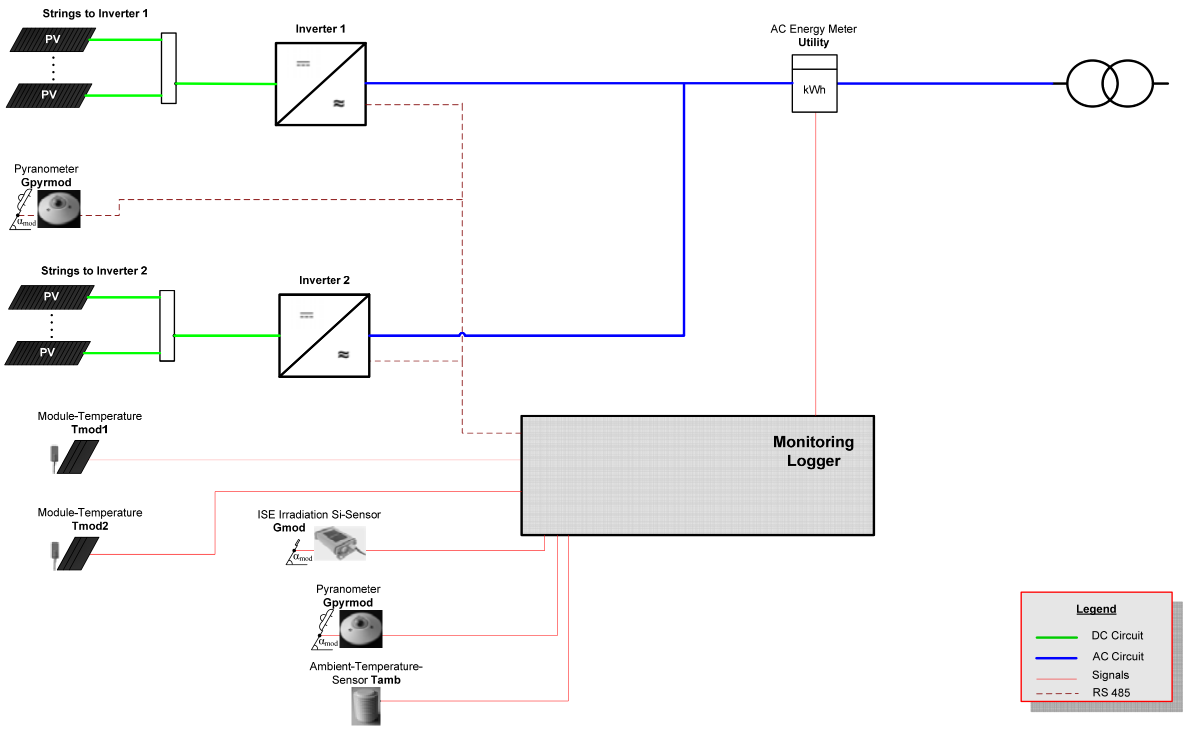
Aspects of Independent Monitoring

- Monitoring approaches
  - Inverter based Monitoring
  - Manufacturer independent Monitoring
- Considerations

Monitoring Approaches – Inverter based

- Inverter based Monitoring
  - Additional effort minimised
    - Usage of integrated measurement equipment (operation control)
    - Single communication bus
  - Accuracy limited (mainly designed for operation control!)
  - Measurement problems affect operation and monitoring
  - No redundant data access
  - Limited options for extensions (e.g. by additional sensors)

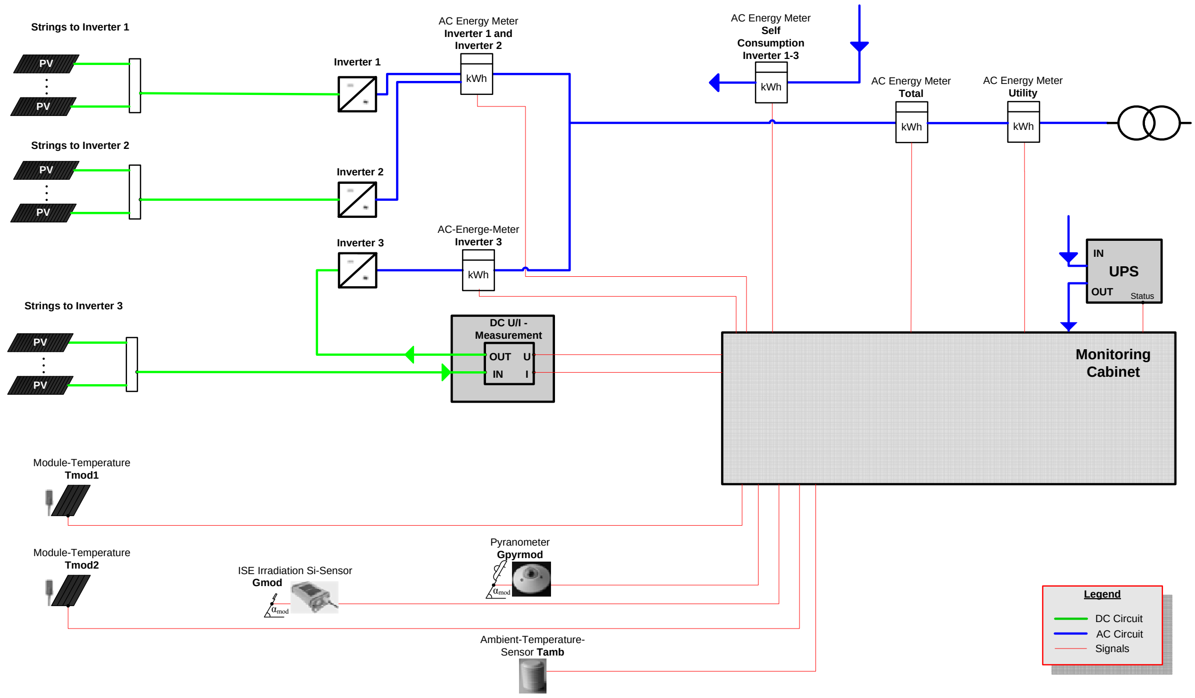
Inverter based Monitoring



Monitoring Approaches - Manufacturer independent

- Manufacturer independent Monitoring
  - Additional effort
    - Through external energy meters and DC measurements
    - Through extra wiring or limited accessibility of DC bars
    - Redundant measurements and infrastructure (e.g. communication)
    - Access to inverter based measurements maybe limited
  - Accuracy appropriate for purpose
  - Measurement is independent of
    - component manufacturer
    - component operation errors
  - Design might be plant specific (unlimited options)

Manufacturer independent Monitoring



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Monitoring Approaches - Considerations

- Requirements
  - Independent of project developer?
  - Independent of O&M company?
  - Bankability issue?
  - Reporting to investors?
- Boundary conditions
  - Budget

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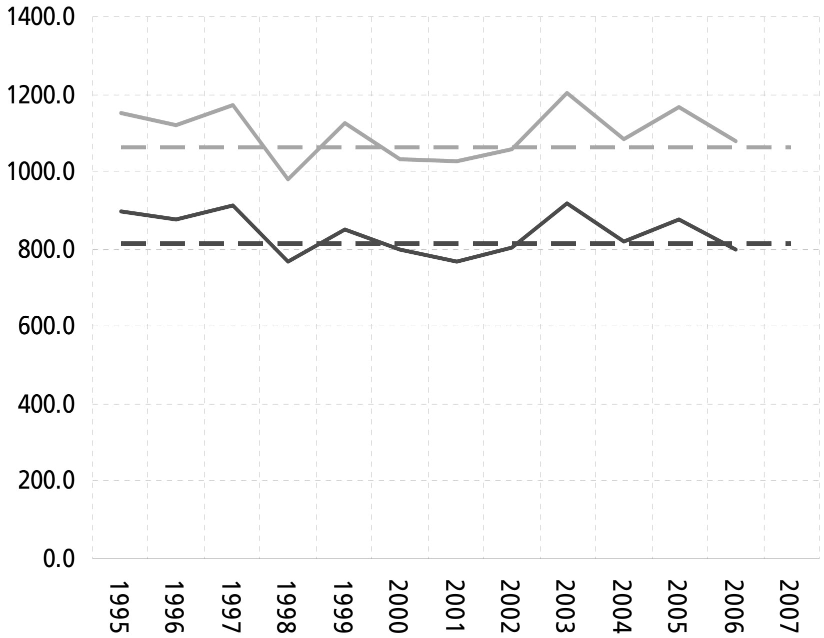
Exemplary Field Experience

- Long-term Monitoring
- Inverter power limitation
- Erroneous inverter control

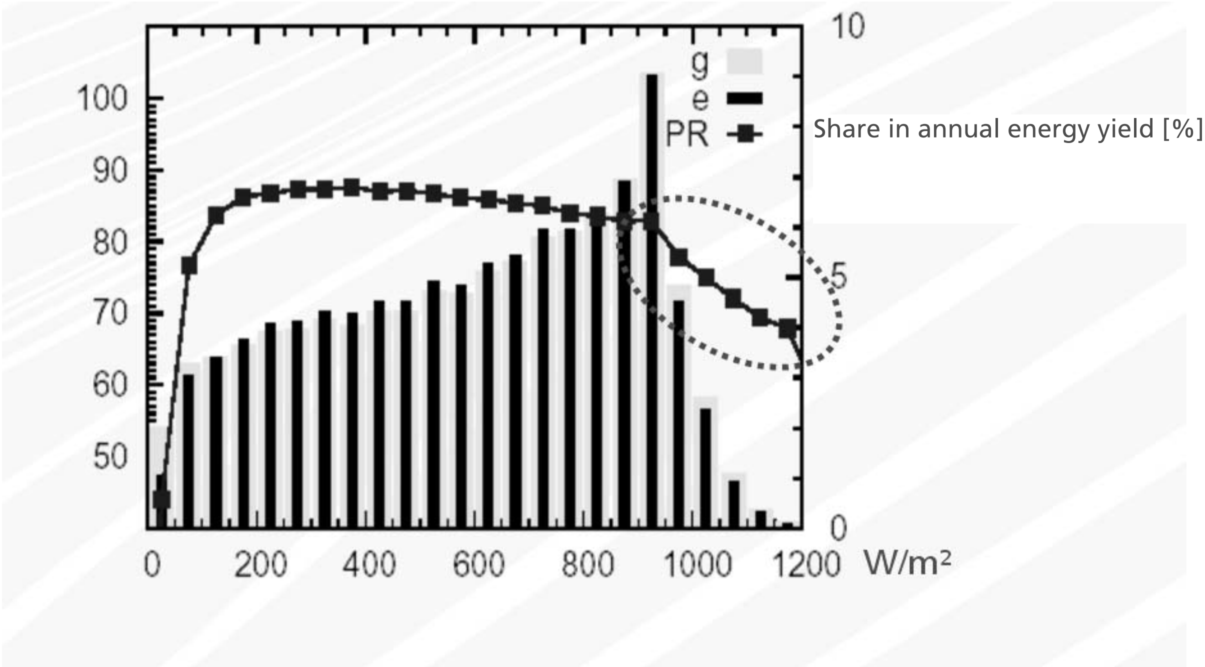
Examples – Long-term Monitoring



Yield [kWh/kWp]
Irradiation [kWh/m²]

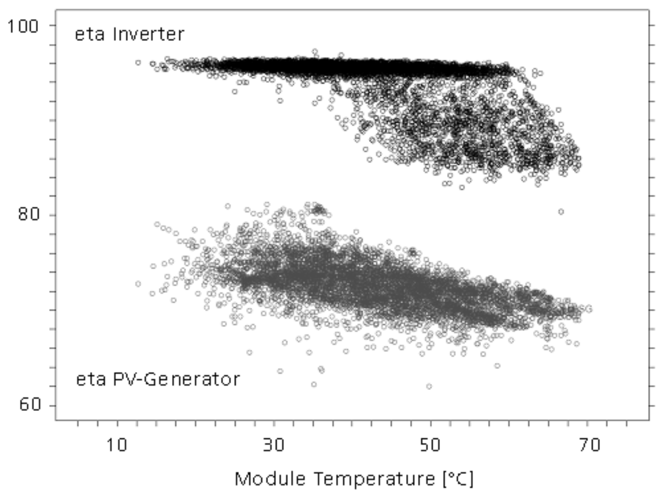
dashed lines = averages

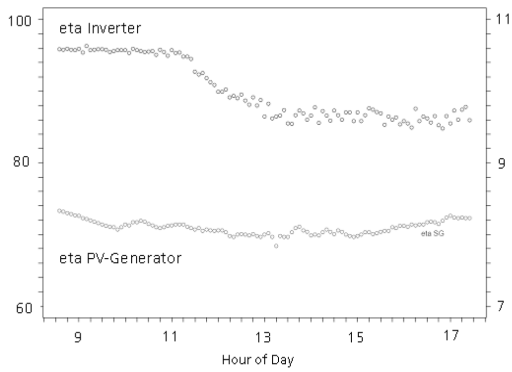
Examples – Inverter Power Limitation



Examples – Erroneous Inverter Control

- Inverter with faulty control algorithm





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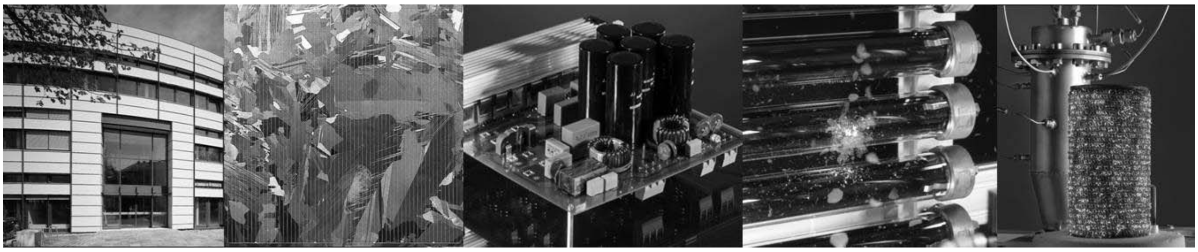

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