GENERAL YIELD MONITORING AND PERFORMANCE EVALUATION

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

Version: Proceedings

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Seminar "Quality of PV-Systems"
Munich, 6th June 2011
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Agenda

- Monitoring approaches and system components
- Quality aspects
- Selection criteria
- Methodology for the PR evaluation
- Benchmarking of PRs
- Examples for results from independent monitoring

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Monitoring Approaches

- General considerations / Rationale
- Applications
- Software
- Measured values
- Inverter based monitoring
- Manufacturer independent monitoring

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Monitoring Approaches – General Considerations

- Identify appropriate budget for the potential economic yield on stake
- What are the risks to be controlled?

- Which services are required?
  - Daily check
  - Analysis of operational behaviour
  - Support of maintenance activities
  - Web visualisation
  - Reporting
  - Benchmarking
  - Consulting to increase PR
  - Quality assurance
  - Bankability approval

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Monitoring Approaches – General Considerations

- Which information can be provided?
  - Energy yield
  - Energy resource
  - Performance Ratio
  - Failures (DC array, inverters, automatic switches)
  - Information about tracking
  - Assessment of generator and inverter efficiency
  - Software status / inverter operation information
  - Climatic boundary conditions
  - Availability of the public grid
  - Logging of power limitation or reactive power requests from utility
  - Long-term degradation

Monitoring Approaches - Applications

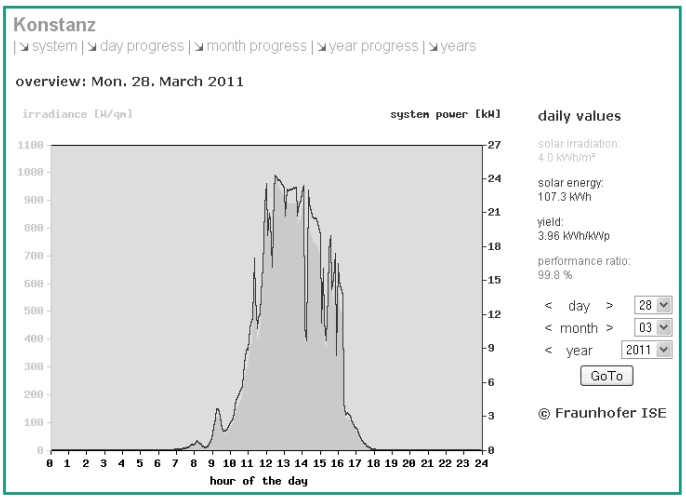
- Small and medium sized systems
- Large scale
- Reference systems
- Pilot systems (technology validation)
- Investigative performance evaluation

Monitoring Approaches – 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 Approaches – 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



Monitoring Approaches – Measured Values

- Minimal configuration
  - Total energy
  - Regional irradiation data
- Basic configuration
  - Total energy
  - Irradiation measured with a Si sensor

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Monitoring Approaches – Measured Values

- Standard configuration
  - Total energy
  - Energy of groups of inverters or of each individual
  - Irradiation measured with a Si sensor
  - Irradiation measured with a Pyranometer for P > 600 kWp or thin film
  - Module temperatures
  - Ambient temperature
  - DC currents and voltages (maybe only exemplarily)

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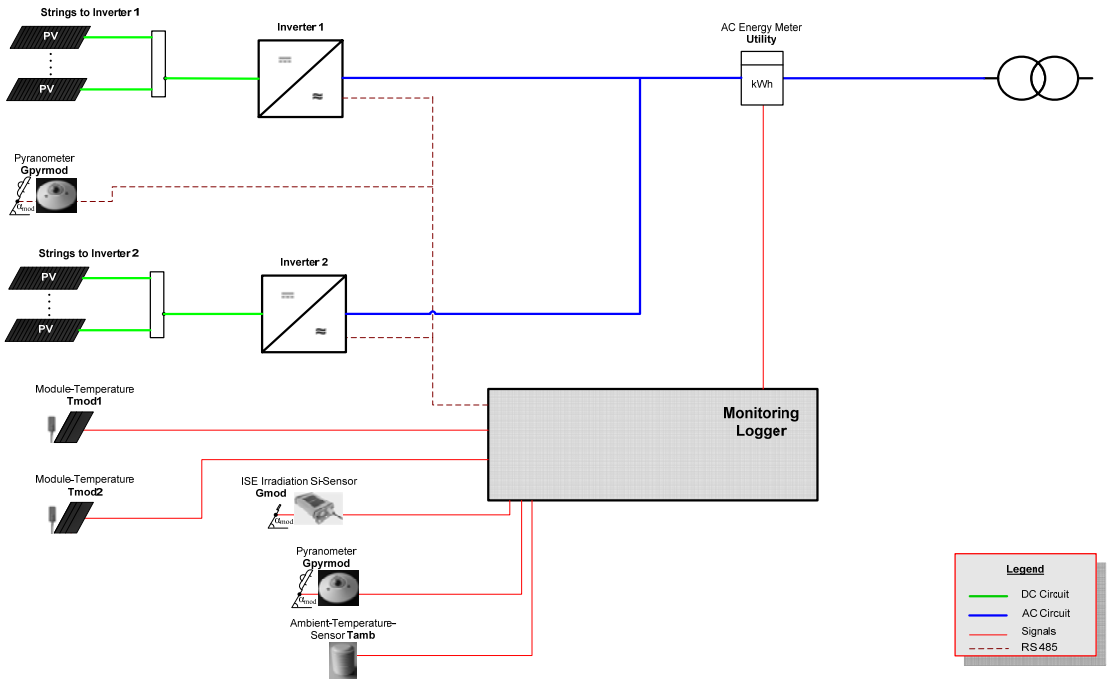
Monitoring Approaches – Inverter based

- 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)

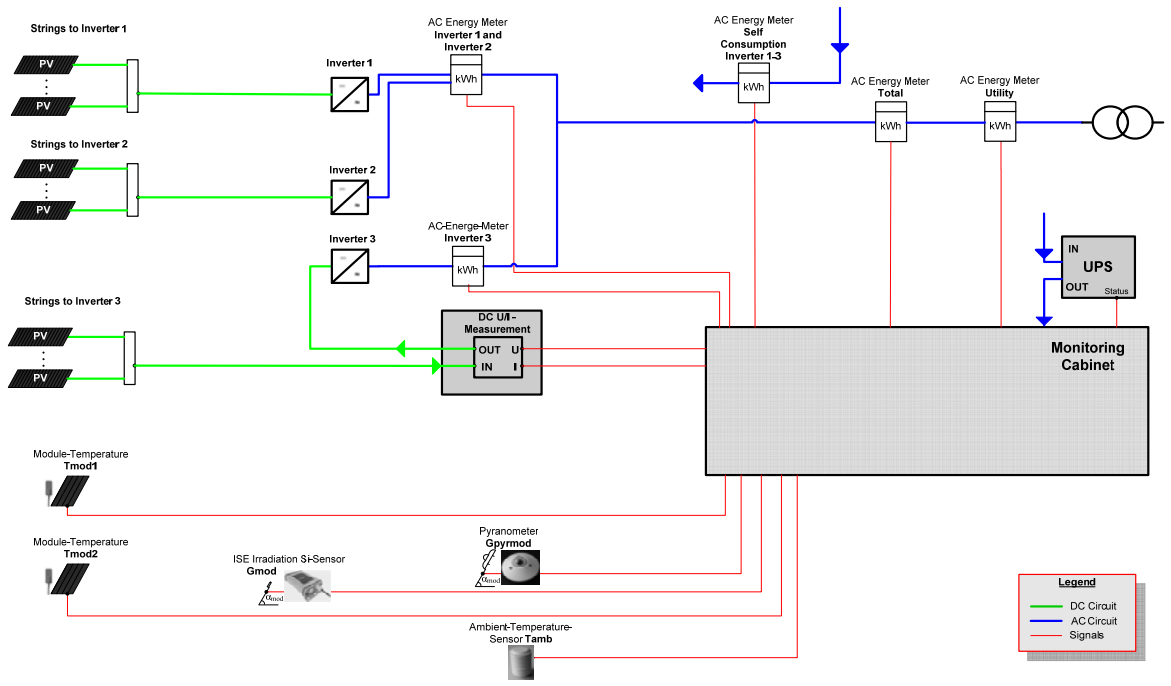
Inverter based Monitoring



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



Monitoring Approaches – Further Considerations

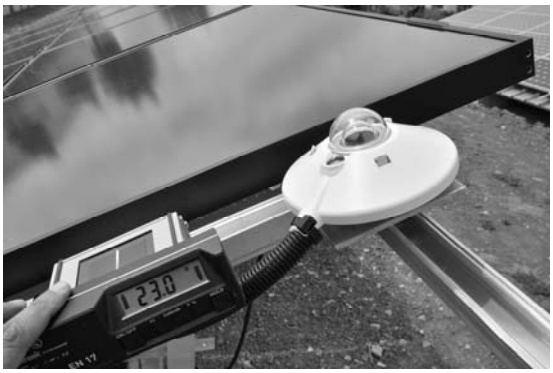
- These facultative requirements may indicate that independent monitoring is necessary
  - Independent of project developer?
  - Independent of O&M company?
  - Bankability issue?
  - Reporting to investors?

Quality Aspects

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

Quality Aspects

- Quality is crucial to ensure
  - Reliability
    - data availability
    - data accessibility
  - Accuracy of measurements
    - Absolute and repeatability
    - Calibration and inspection on-site?
    - Maintenance intervals?
    - Distinguish from resolution!



- Measurement interval (shorter 15 minutes)
- Consideration if samples, averages or integrals are required

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Quality Aspects (2)

- Uninterruptible Power Supply (UPS)
- Data reduction for transfer?
- Data security / backup
- Controlled automatic restart after blackouts?
- Watch-dog functionality?
- Webcam?
- Advanced meteorological monitoring includes
  - Precipitation sensor
  - Wind sensor
  - Relative humidity

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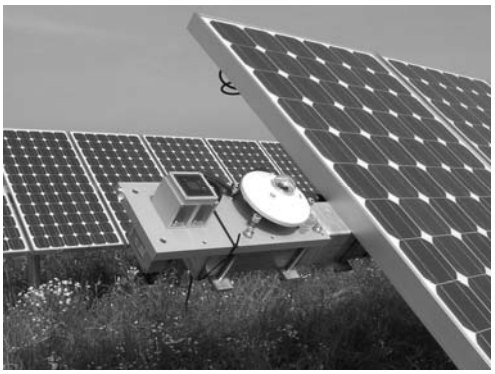
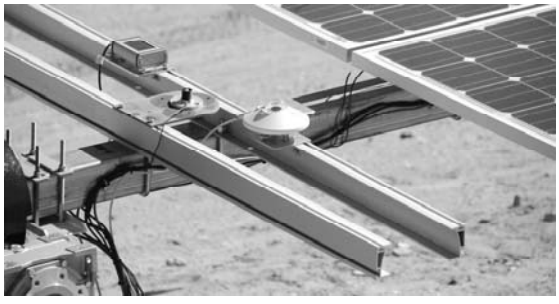
Quality Aspects – Further Selection Criteria

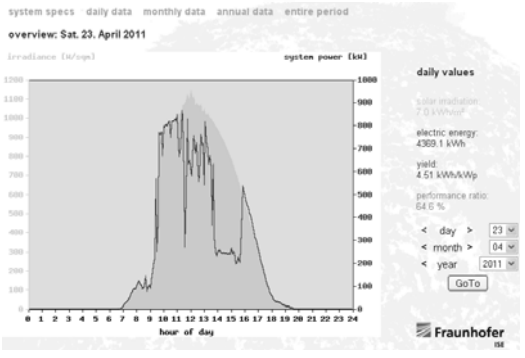
- Who will…
  - design the monitoring system?
  - maintain the monitoring system?
  - provide comprehensive services?
  - analyse the monitoring data?
  - draw conclusions from results?
  - prepare relevant reports?



Quality Aspects – Irradiation Measurement

- Pyranometer in module plane
  - Recommended:
    - Secondary Standard
    - daily uncertainty < 2%
- Additional horizontal pyranometer may serve as validation of meteorological resource assessment in yield prognosis!



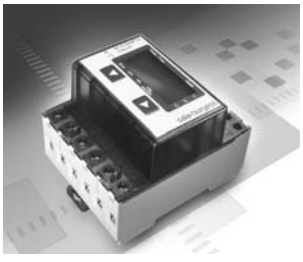


Quality Aspects – Irradiation Measurement

- 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

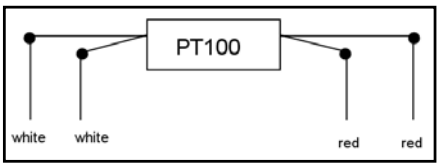
Quality Aspects – Energy Metering

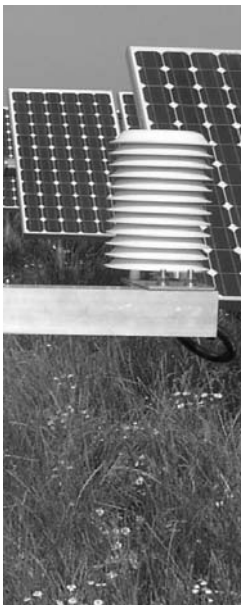
- Ensure operability at high currents over hours
- Direct measurement vs. transformers
- Uncertainty max. 1%
- Meters approved for PV inverter applications?
- High impulse rates (resolution) if applicable
- Reactive energy metering?



Quality Aspects – Temperature Measurements

- Temperature measurements (2-wire, 3-wire, 4-wire)
- Ambient temperature
  - Positioning
  - Passive ventilation
    vs.
  - Active ventilation
  - No ventilation





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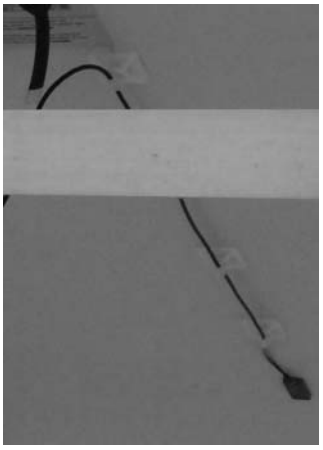
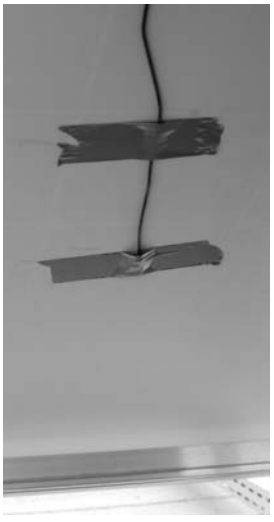
Quality Aspects – Temperature Measurements

- Mounting of sensors for module backside temperature

  Ensure thermally good, long-term contact!





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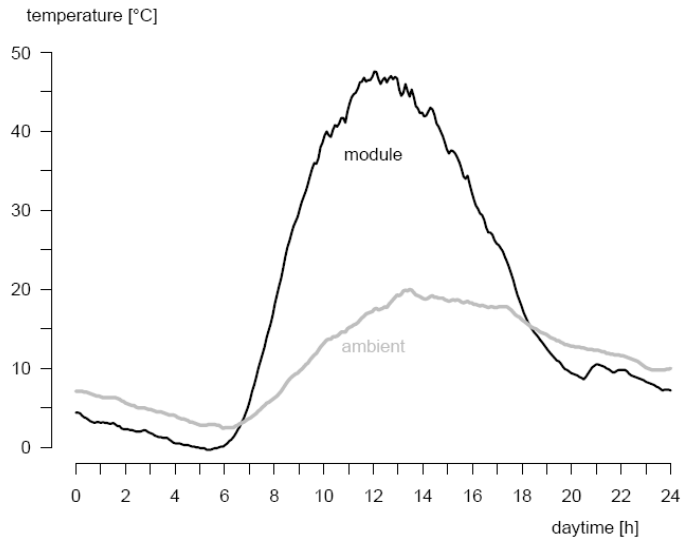
Quality Aspects – Temperature Measurements

- Exemplary measurements for ambient and module backside temperature



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Methodology for the PR Evaluation

- Prerequisites and expectations
- Data validity check
- Calculating the Performance Ratio

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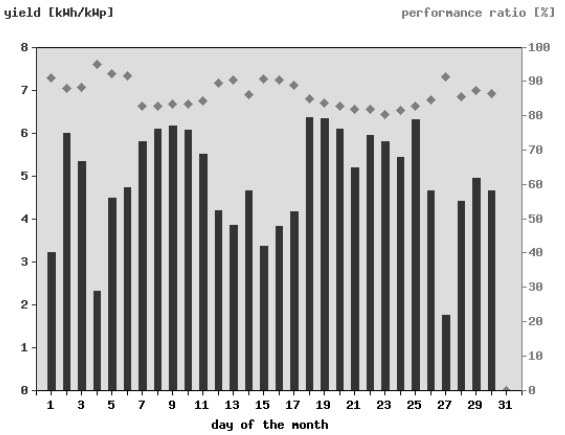
Methodology for Evaluating the Performance Ratio

- 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

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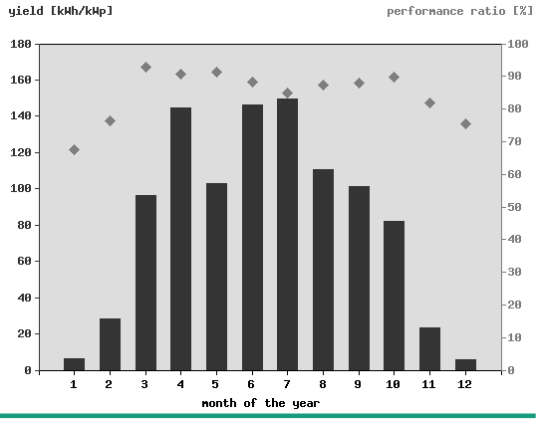
Methodology for Evaluating the Performance Ratio

- 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



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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

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

$$PR = \frac{\text{Spec. Yield [kWh/kWp]}}{\text{Irradiance [kWh/m²]}}$$

Benchmarking of Performance Ratios

- General remarks
- Examples

Benchmarking of PRs – General Remarks

- Important note: Distinguish between PR_{Pyr} and PR_{Si} !

- Differences between system design in prognosis and actual design?
- Does the actual power meet the nameplate power?

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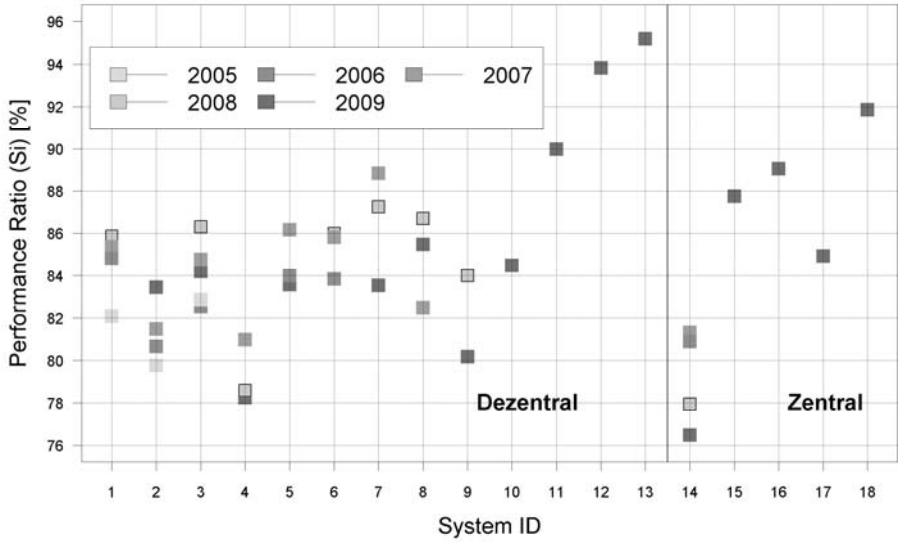
Benchmarking of PRs – Example 1

- Comparison of systems with distributed and central inverter layouts



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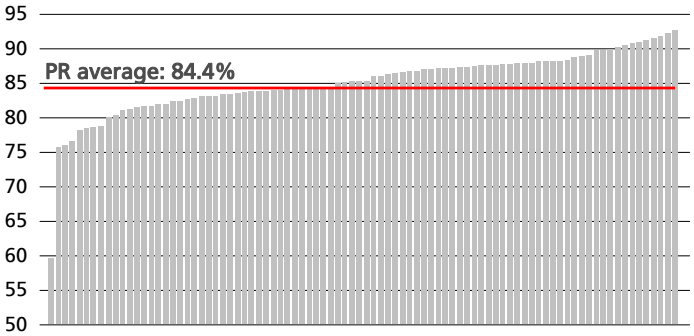
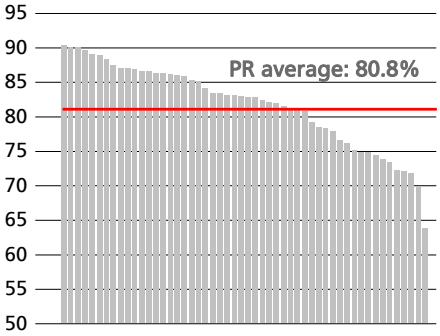
Benchmarking of PRs – Example 2

- Benchmarking with grouping of PV systems under quality assurance consultancy contracts

89 PV plants with continuous quality assurance



…and 43 with monitoring only



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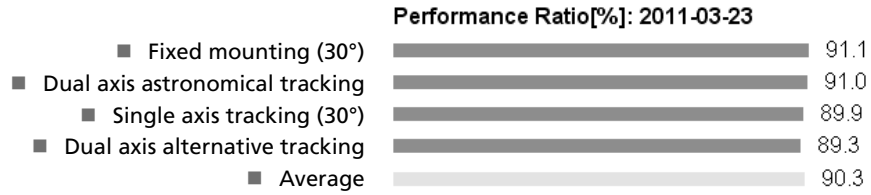
Benchmarking of PRs – Example 3

- Benchmarking different tracking options



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Exemplary Field Experience

- Single axis tracking
- Daily power curves of tracking options
- Long-term Monitoring
- Inverter power limitation
- Erroneous inverter control
- Progress through monitoring

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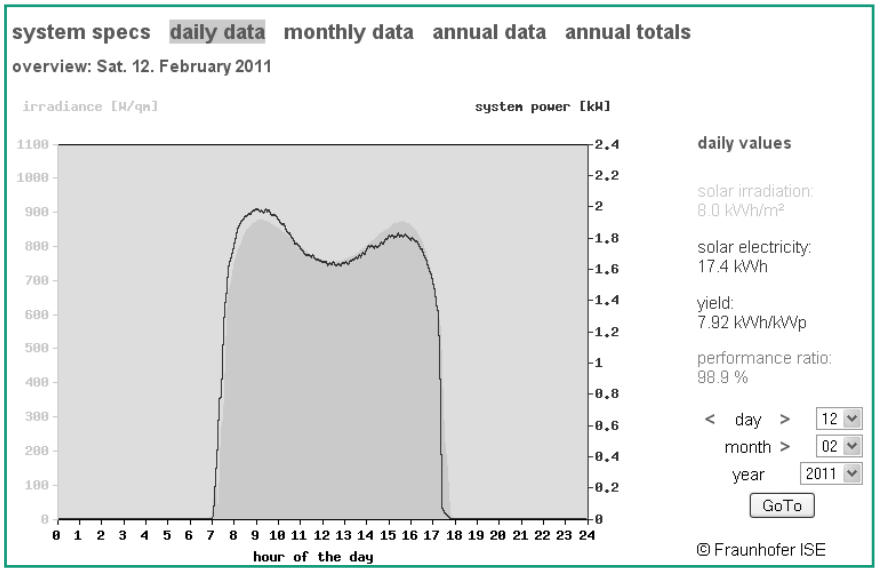
Examples – Single axis super power

- Single string with underrated power (tracking east/west)



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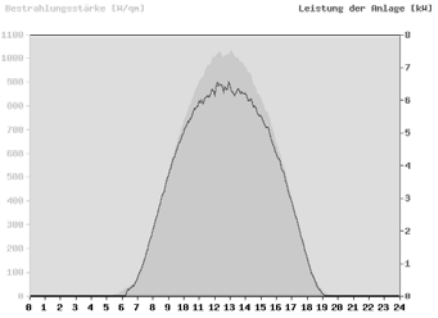
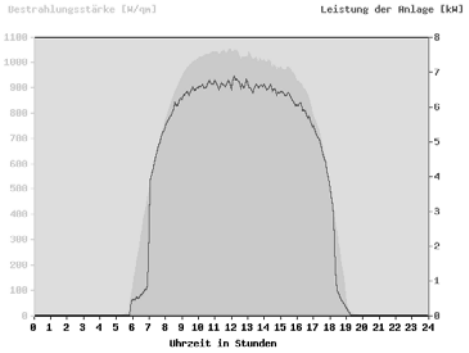
Examples – Daily curves of tracking options (19th April 2011)

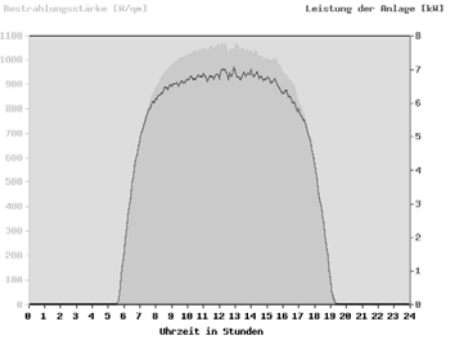
Fixed mounting (30°)



Single axis tracking (East/West axis)



Dual axis tracking



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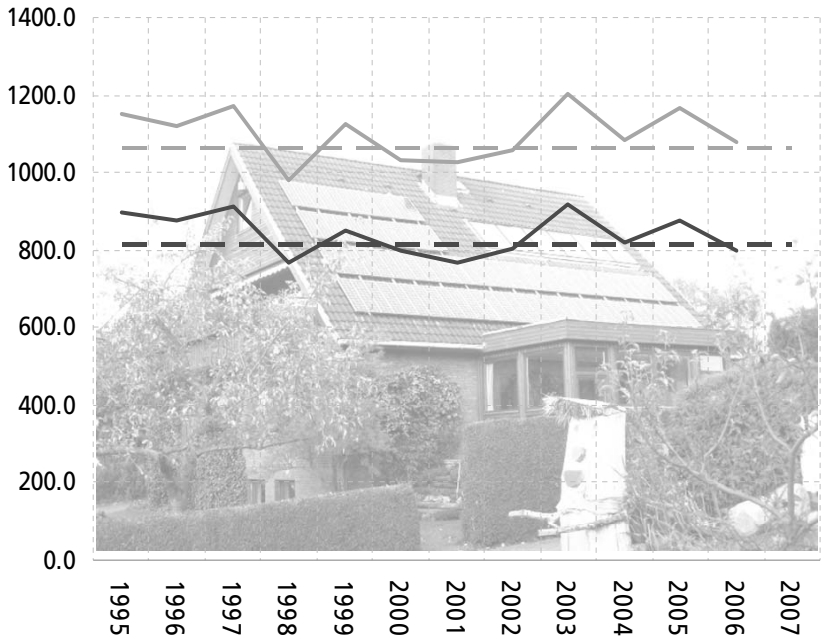
Examples – Long-term Monitoring



Yield [kWh/kWp]
Irradiation [kWh/m²]

dashed lines = averages

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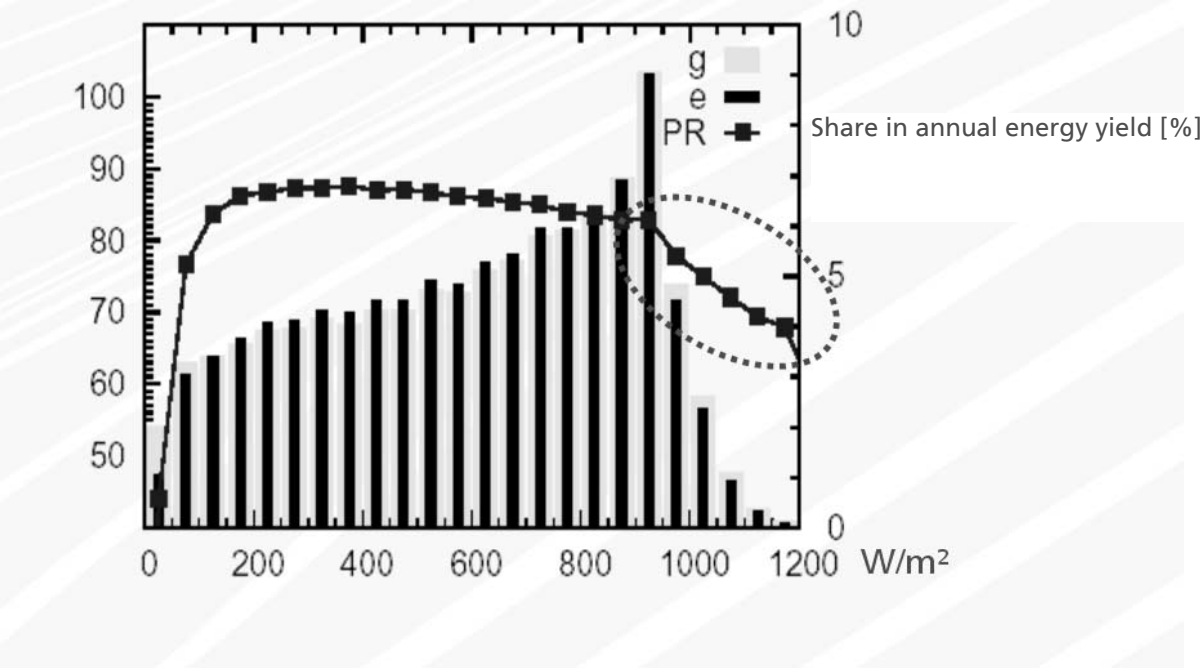
Examples – Inverter Power Limitation



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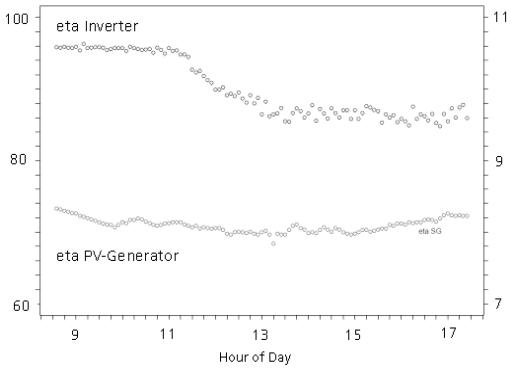
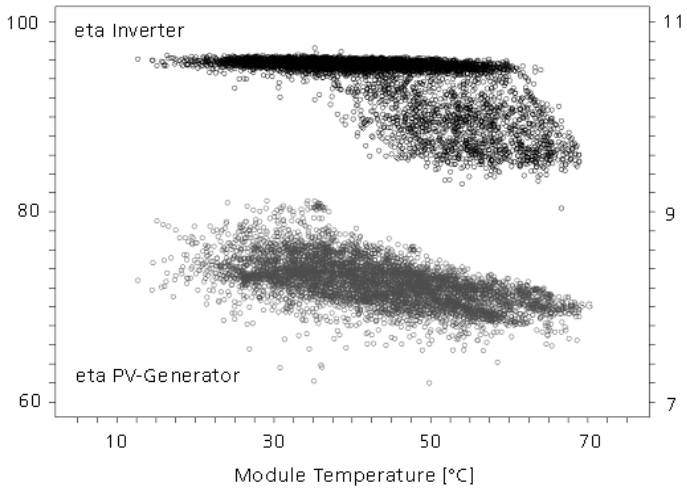
Examples – Erroneous Inverter Control

- Inverter with faulty control algorithm





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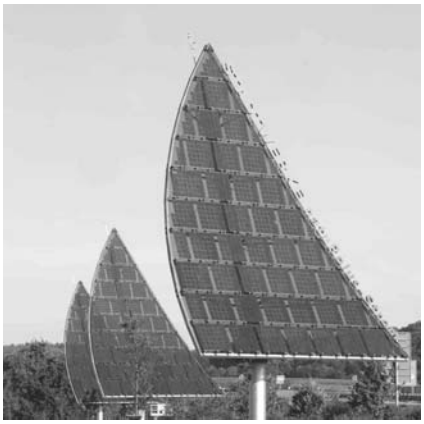
Examples – Progress through Monitoring

- PV performance increased through analysis of monitoring data
  - Optimisation of reflectivity of roof sheet
  - Correction of inverter firmware
  - Detection of faulty power limitation of inverter (fuses tripped)
  - Detection of faulty utility meters
  - Detection of grid interference
  - Optimisation of row distances
  - Optimisation of generator dimensioning



- Professional monitoring is cost efficient!

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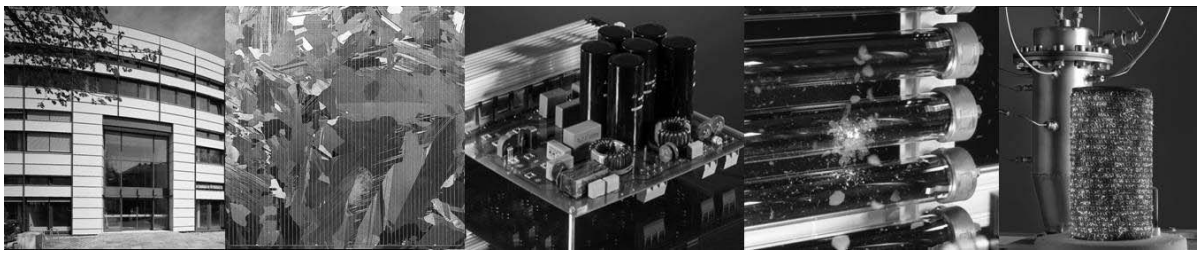
Thank you for your attention!



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