# Basic principles for designing PV plant monitoring systems

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01.10.2013

# Why is monitoring important?

1. Owner and Lender want to know whether plants operate according to expectations
2. Contractual restrictions
3. Immediate action on failures
4. Eases the planning of preventive maintenance

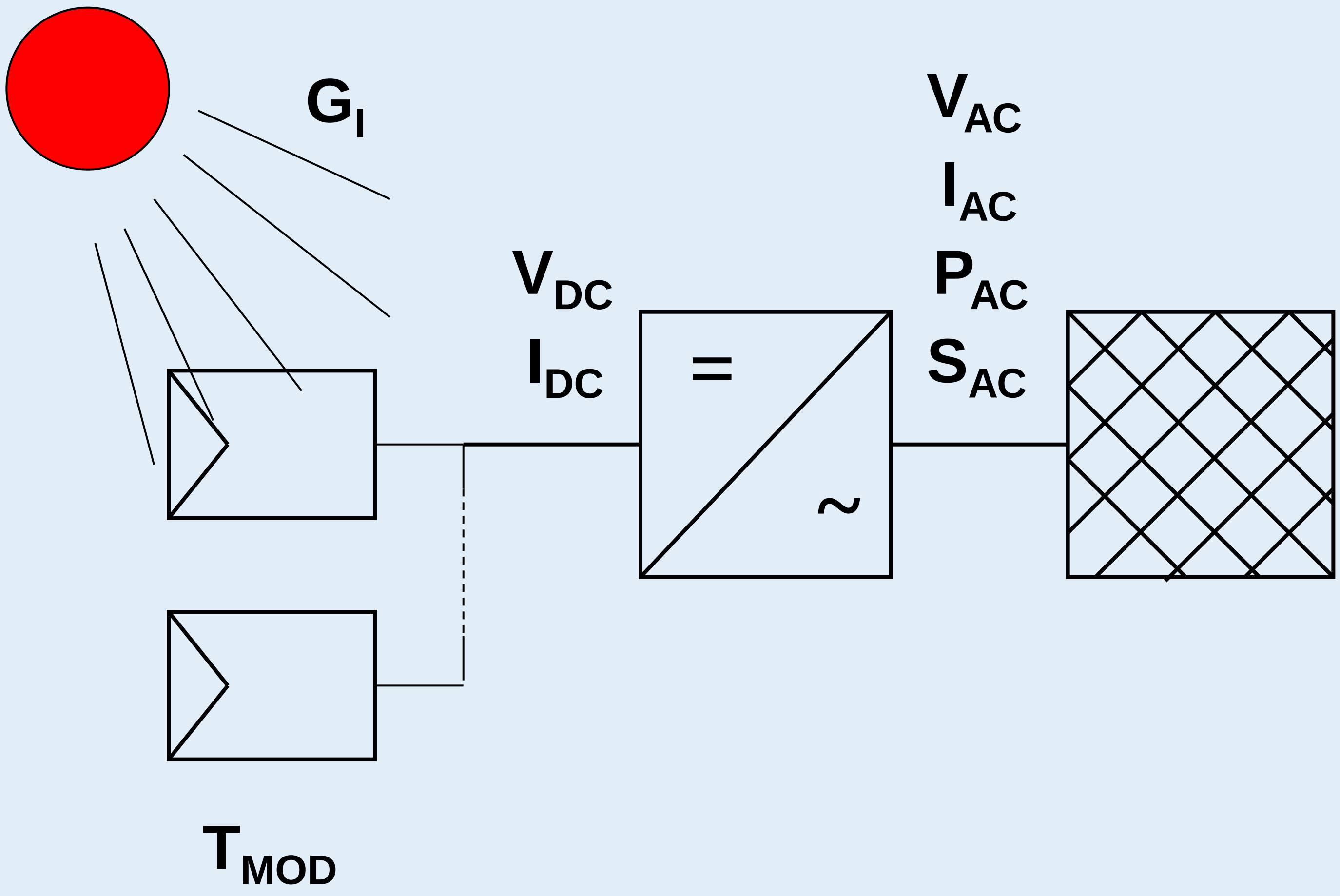
# Requirements of monitoring systems

1. Easy installation and commissioning
2. Reliable monitoring
3. Reliable fault detection and alarm notification
4. Quick and accurate localization of faulty components
5. Remote diagnostics

1) Specific requirements for monitoring systems in large-scale PV systems, M. Hamer

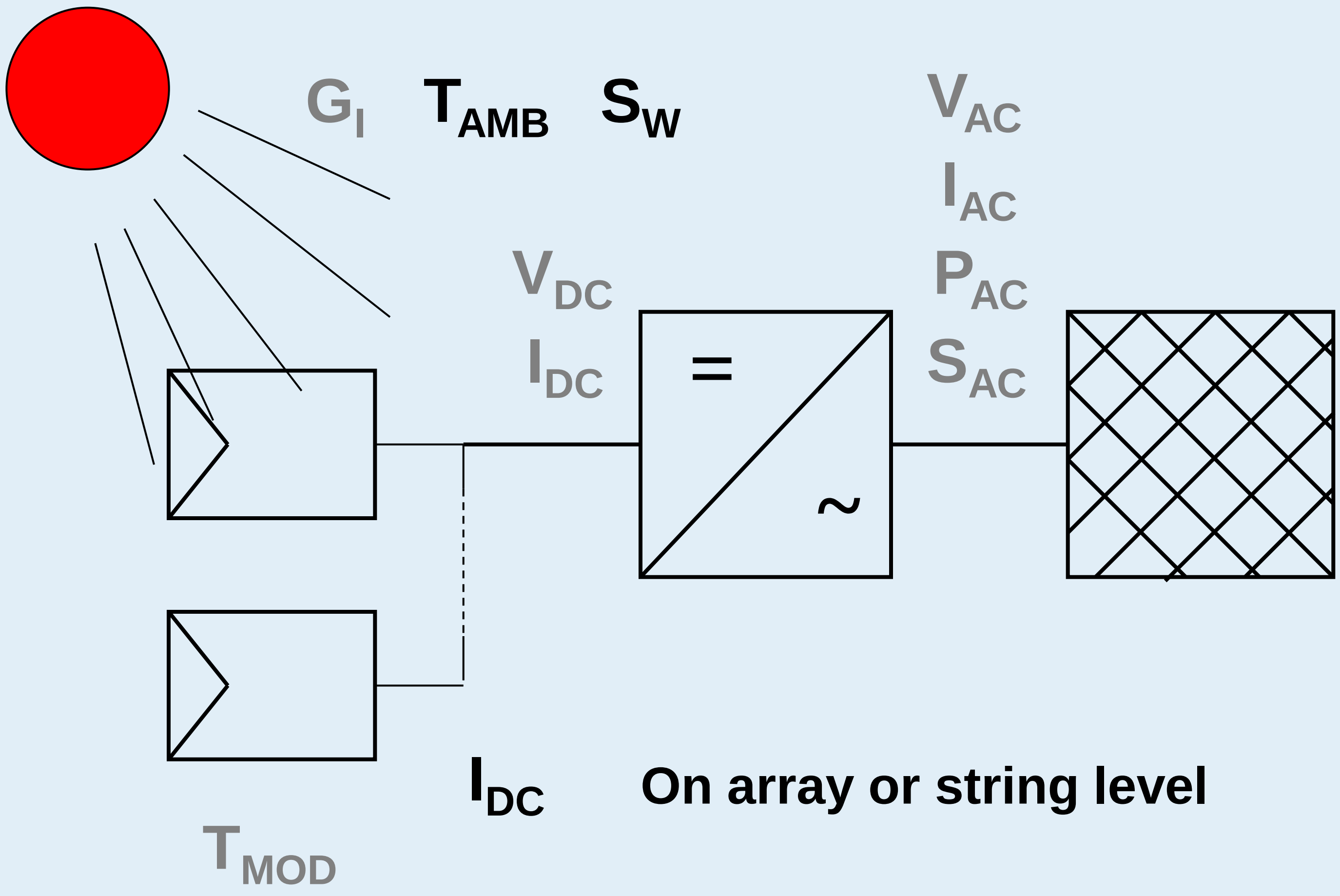
# Measured parameter

## Minimum standard for utility scale plants



# Measured parameter

## Very helpful in case of failure detection




$I_{DC}$ **On array or string level**

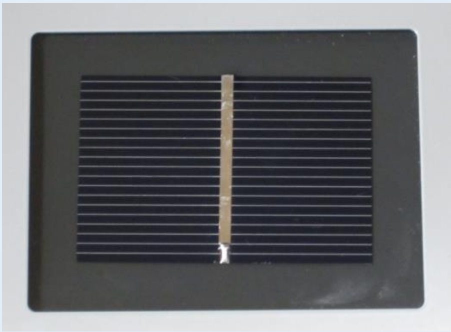
# Solar radiation sensors

## Selection of sensor depends on scope of monitoring!

- Yield and PR assessment (of utility scale plants)
- Contractual issues
- Irradiance data based on termophile sensors

- Plant STC power
- Issues in the plant
- Plant response in second range

Pyranomter



c-Si reference cell

# Solar radiation sensors

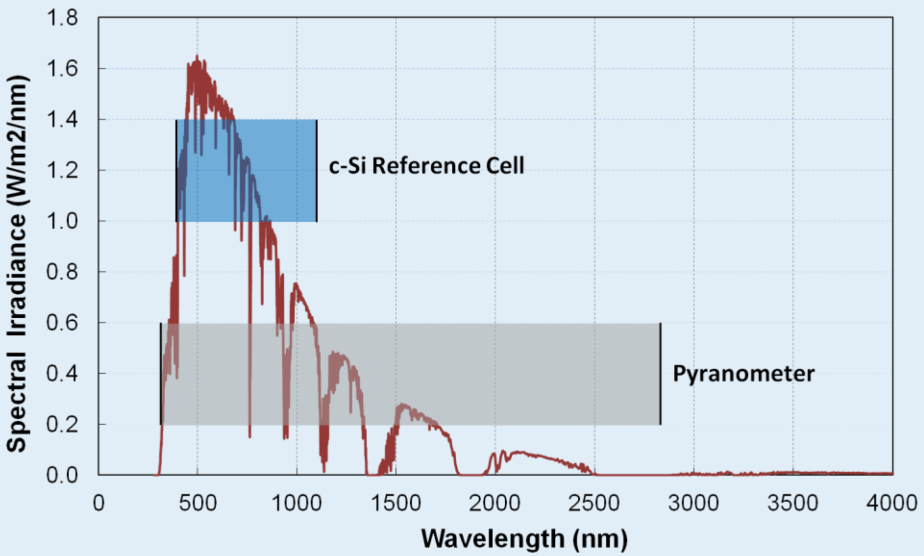
## Spectral response

### Pyranometer

- Thermoelectric effect
- Black body
- Uniform spectral response

### Reference Cell

- Silicon based photodiode
- Photoelectric effect
- Selective spectral response



# Solar radiation sensors

## Technical specification: Pyranometer vs. reference cell

| Specification | Secondary standard [1)] | First Class [1)] | Second Class [1)] | c-Si Reference cell |
|---|---|---|---|---|
| Response time | < 15 s | < 30 s | < 60 s | << 1s |
| Non-stability | ±0.8% | ±1.5% | ± 3% | ± 0.2% [2)] |
| Non-linearity | ± 0.5% | ± 1% | ± 3% | ± 0.5% [3)] |
| Spectral selectivity | ± 3% | ± 5% | ± 10% | c-Si:± 0.5% [4)]<br>high η: SMM=1.7% [5)]<br>a-Si: SMM=2.1% [6)] |
| Tilt response | ± 0.5% | ± 2% | ± 5% | up to 90% |

1) ISO 9060_1990
2) Uncertainty in PV module measurement - part 1 Calibration of crystalline and thin-film .., D. Dirnberger
3) PTB, S. Winter
4) Uncertainty of field IV curve measurements in large scale PV systems, Daniela Dirnberger
5) Comparison of indoor and outdoor performance measurements of recent commercially available .., A. Virtuani
6) Results of the European Performance project on the development of measurement .. , Werner Herrmann
7) A degradation analysis of PV power plants, K. Kiefer

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# Solar radiation sensors

## Differences in the measured annual irradiation

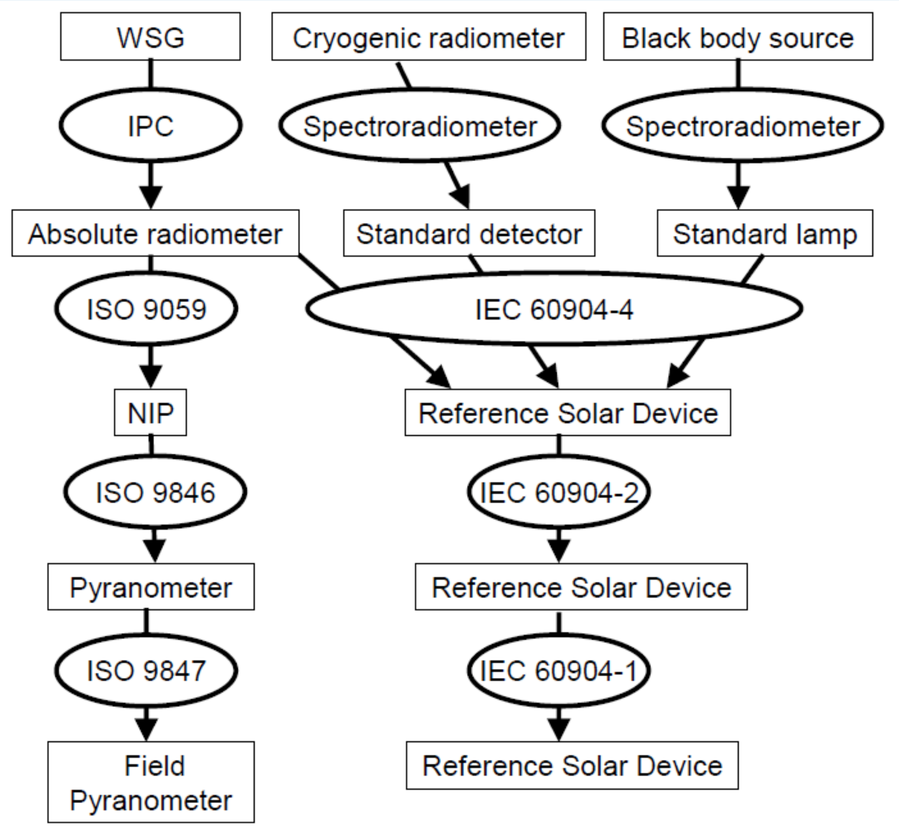
- On an annual basis reference cells measure 2-4% less global irradiation than pyranometers in Germany – resulting in 2-4% higher PR
- Depending on the location and sensor the scattering is large
- Different tilt and spectral response are dominating
- Correction procedures for converting “broadband” into “useful PV “ energy are proposed based on solar zenith angle and clearness index – no global validation so far

1) One year round robin testing of irradiance sensors measurement results and analysis, Mike Zehner
2) Are Yield certificates reliable? A comparison to monitored real world results, Björn Müller
3) Comparison of pyranometers vs PV reference cells for evaluating of PV array Performance, L. Dunn
4) Performance Ratio Revisited: Are PR>90% realistic?, Niels Reich

# Solar radiation sensors

## Traceability

- WSG
  - World Standard Group of absolute cavity radiometers
- IPC
  - International Pyrheliometer Comparision
- NIP
  - Normal Incidence Pyrheliometer
- Pyranometer
  - ISO 9846, 9847
  - First Class Pyranometer
- Reference cell
  - IEC 60904-2/ -4
  - Secondary Reference Device




1) D1.4.1 Actual practise and deficiencies of PV calibration traceability, JRC

# Location of temperature sensors

- Backside of representative modules
- Fix sensor in the center of the module behind one solar cell
- Use little or no conductive adhesive
- Alternative: - laminated sensor
  - Voc measurement of calibrated reference module

# Data sampling and storage

- Hourly values are not adequate, higher resolution eases detection of issues
- Typical 5 – 15 min
- 1 min reveals inverter shut down or irradiance enhancement
- 1 sec reveals MPP tracking issues
- No change from summer to winter time
- Irradiance and production must be synchronized

# Data visualization and treatment

- Clear visualization of main parameter like production, Yield and PR
- Comparison of Yield on the inverter, combiner box or string level
- Comparison of daily inverter with utility meter measurement
- Comparison of irradiance values from multiple sensors
- Comparison under stable weather conditions increases reliability
- Automatic fault detection eases interpretation
  - Degradation, soiling, module/string defect or snow cover [1)]

1) Failure detection routine for grid connected PV systems as part of the PVSAT-2 project, S. Stettler

# Recommendations

## Solar radiation sensors

- Use pryanometers if performance is compared with Energy Yield Prediction - **First Class or higher**
- Use reference cells for issues related to plant STC power and to inverter – **Discussion required about minimum standard!**
- Use multiple sensors to reduce uncertainty
- Use long-term stable sensors (only pyranometer or c-Si)
- Use sensors with traceable calibration and recalibration
  - Provider should supply information about quality standard
- Use representative location for the sensors
- Clean the sensors

# Recommendations

## General

- Data sampling: 1 sec
- Data averaging: 15 min or less
  - Store 6 month of high resolution data
- Use calibrated sensors
- Use monitoring to support O&M activities
- High quality monitoring together with O&M reports is advantageous if plant is sold
- Use monitoring to increase PV plants performance
- Use monitoring to control contractual warranties

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## Thank you…

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