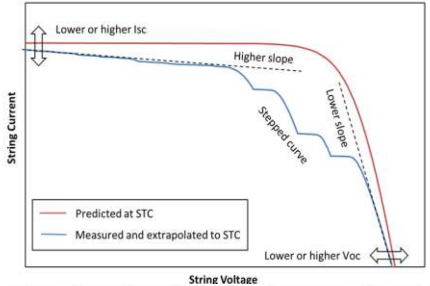
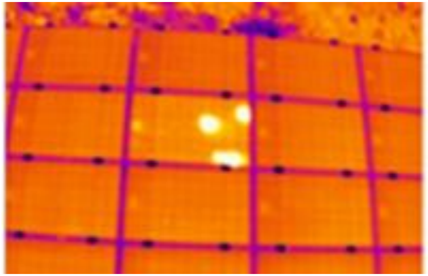
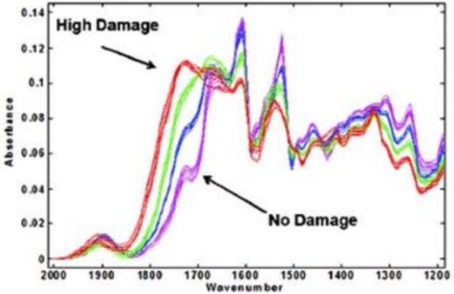
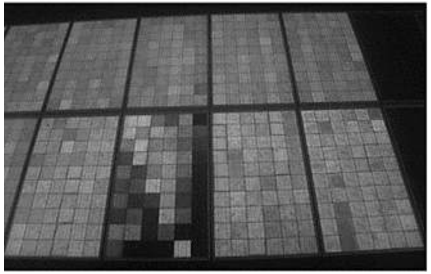








IEA PVPS

Qualification of PV Power Plants using Mobile Test Equipment

Dr Werner Herrmann, TÜV Rheinland Group

Task 13 Focus Workshop on Operation & Maintenance, 30 September 2021

Introduction

Field inspection of PV systems shall give plant operators or asset managers confidence that the PV power plant performs at current standards and provides the projected yield.

On-site inspection with mobile test equipment is aiming to identify the drivers for underperforming PV power plants or identify defective PV modules. Methods can be applied at different phases of PV projects:

a) **Quality assurance:** a) Sampling inspection of PV module shipments (Production site, warehouse, PV power plant); b) Acceptance testing of PV array prior to commissioning; c) Periodical Q&M measures

b) **Failure analysis of underperforming PV power plants:** Fault detection and identification of defective or degraded PV modules in operating PV arrays;

c) **Monitoring of degradation processes:** Periodical inspection of the same fielded PV modules or PV strings.

Introduction

Range of detectable failures with mobile test equipment:

PV string level

- Performance variation (shading, soiling, misalignment)
- Cabling or combiner box issues (open circuit failure, resistive losses)
- Insulation failures (ground faults)
- Induced degradation (PID, LeTID)

PV module level

- Performance variation (electrical mismatch)
- Underperforming electrical output power
- Cell cracks
- Interruptions in the cell interconnection circuit
- Bypass diode failure
- Localized heating (i.e. hot-spot, solder joint issues, cell cracks)
- Degradation monitoring (crack propagation, polymer ageing)
- BOM issues (polymeric footprint)

Benefits of on-site inspection

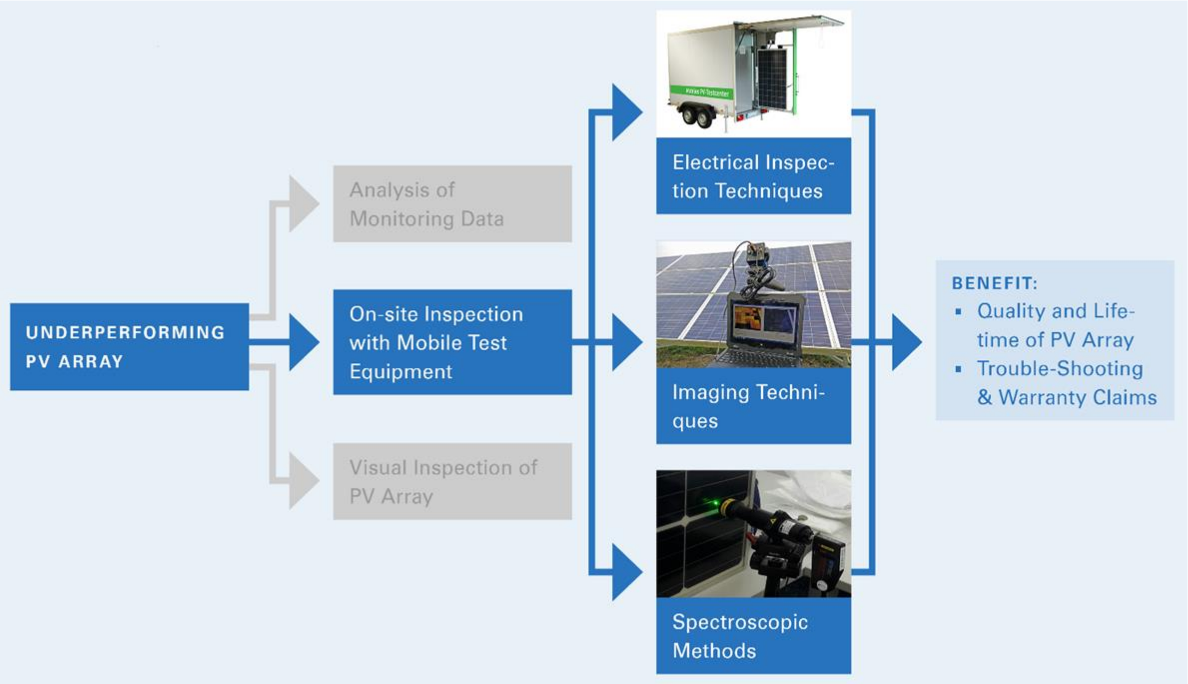
Particular strengths:

- Inspection is performed without dismounting and shipping the PV modules to a test laboratory

  ⇩

  Avoid transport risks and a long down time of the PV system

- Results are available immediately



- Targeted failure analysis ⇨ Choose combination of suitable inspection methods

On-site inspection methods

Type	Inspection method
Electrical inspection techniques	Daylight I-V measurement of PV strings and PV modules
	PV Module characterization with mobile test centre
	Dark I-V measurement of PV strings and PV modules
	PV plant testing vehicle
Imaging techniques	Drone-mounted electroluminescence (EL) & Infrared (IR) inspections of PV array
	UV fluorescence imaging
	Daylight electroluminescence imaging
	Outdoor photoluminescence imaging
Spectroscopic methods	Spectroscopic methods for polymeric materials
	Electrical impedance spectroscopy

Drone-mounted EL & IR inspection

- Inspection is performed on the operating PV power plant
- Wide application range of Remotely Piloted Aircraft Systems (RPAS) for field inspection of PV power plants:
  - Daytime visual inspection
  - Daytime IR inspection
  - Nighttime EL inspection
  - Nighttime UV-F inspection

⇒ Rapid detection and localization of defective PV module and interconnection issues

Detectable failures:
- Cabling issues
- Combiner box issues
- Cell cracks
- Bypass diode failures
- Interruptions in the cell interconnection circuit
- Induced degradation (PID, LeTID)

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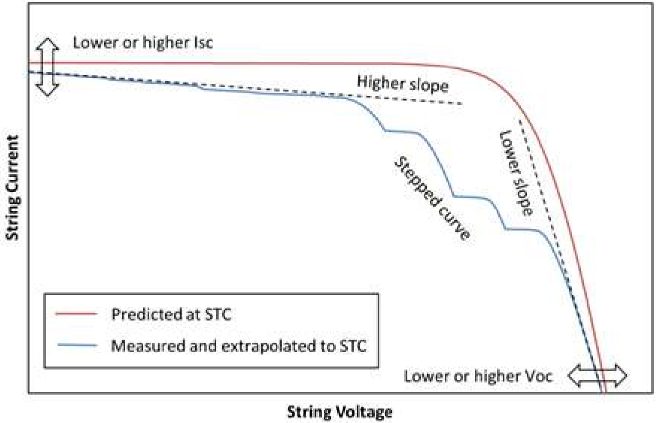
I-V measurement of PV strings

- PV string is disconnected from the PV array or inverter and connected to an I-V curve analyzer;
- I-V curve is measured in conjunction with solar irradiance (>600 W/m²) and module temperature
- Failure analysis ⇨ deviation between:
  a) "Measured and STC corrected" I-V curve;
  b) "Predicted" I-V curve ⇨ calculated by the software based on the PV module STC data and serial/parallel connection of modules.

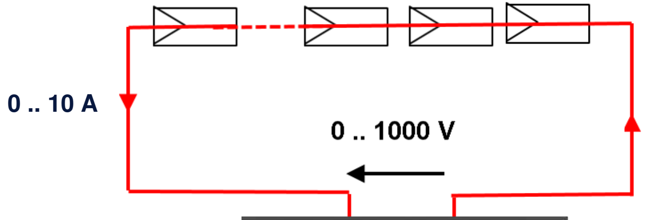


Detectable failures:

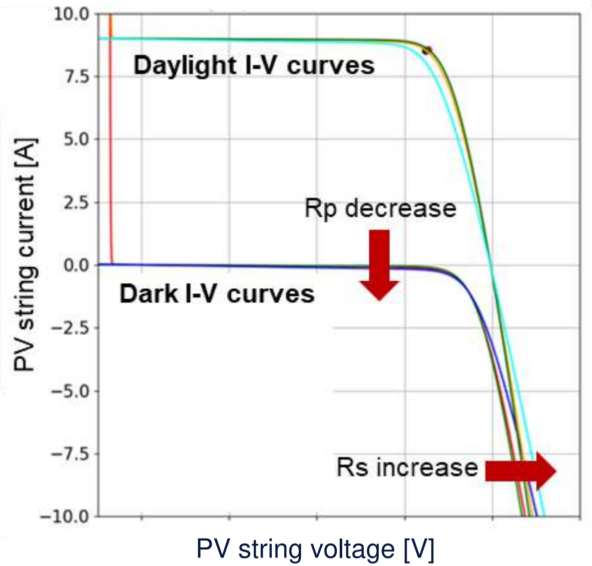
- Output power issues
- Cabling issues
- DC wiring losses
- Shading and soiling effects
- Electrical mismatch of PV modules and PV strings
- Bypass diode failures
- PID / LeTID on string level

Dark I-V measurement of PV strings

- I-V measurement is conducted during nighttime ⇨ PV strings are measured at almost the same test conditions (no impact of soiling, misalignment, etc.);
- PV string to be measured is disconnected from the PV array and connected to a programmable high voltage power supply;
- Variable reverse current is injected and I-V curve recorded.



Programmable high voltage power supply



Detectable failures:
- Bypass diode failures
- PID on PV string level
- Series resistance losses
- Electrical mismatch of strings

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PV module characterization with mobile test centre

- Batch measurement prior to installation
- Failure analysis: PV modules to be dismounted, but still short downtime of the PV system

Inspection range:

- Solar simulator:
  - Output power characterization @STC
  - Bypass diode functionality
- EL inspection
- IR inspection
- Dry/wet insulation test

Detectable failures:

- Output power issues (i.e. PID, LeTID)
- EL imaging: Cell cracks, interruptions in the cell interconnection circuit
- IR imaging: Heat generation due to high contact resistance
- Bypass diode failure
- Insulation resistance failure

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PV plant testing vehicle

- Test equipment for energy loss analysis is installed inside a truck
- Synchronized DC and AC monitoring in combination with meteorological measurements (pyranometers, ambient temperature, wind speed, humidity)
- DC monitoring of up to 16 PV strings under MPP tracking

Detectable failures:
- Performance ratio (PR) issues
- DC wiring losses
- Inverter efficiency loss
- Shading effects during the day
- Soiling & snow coverage effects
- Electrical mismatch of PV strings

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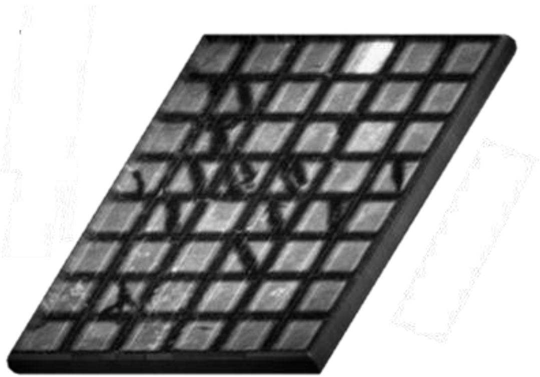
UV fluorescence (UVF) imaging

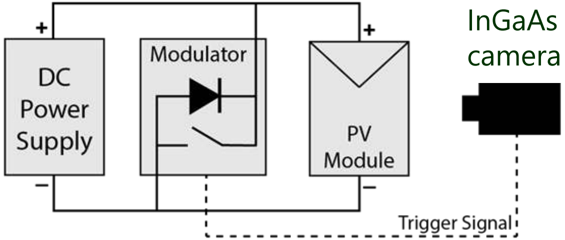
- Inspection is performed on the operating PV power plant, no disconnection of PV module required, measurements to be performed in dark environment
- UV light excitation ⇨ Fluorescence light is emitted from polymeric materials (Encapsulant, backsheet)
- Oxygen concentration in polymeric material reduces the fluorescence signal and makes cell cracks visible



Detectable failures:
- Cell cracks
- Distinction between older (wider dark area) and younger cell cracks
- Differentiation of used encapsulation and backsheet materials

Daylight electroluminescence (EL) imaging

- PV string is connected to a high voltage power source ⇨ Forward bias current is forced to flow through cells and EL radiation is emitted
- Near infrared (NIR) emission from the sunlight is much higher than the EL emission from the solar cell
- Application of lock-in measurement technique: EL images are acquired twice: a) with injected forward bias current, b) zero current (unbiased background)



- Software calculates the difference EL image and integrates the running average

Detectable failures:
- Cell cracks
- Interruptions in the cell interconnection circuit
- Induced degradation (PID, LeTID)
- Bypass diode failures

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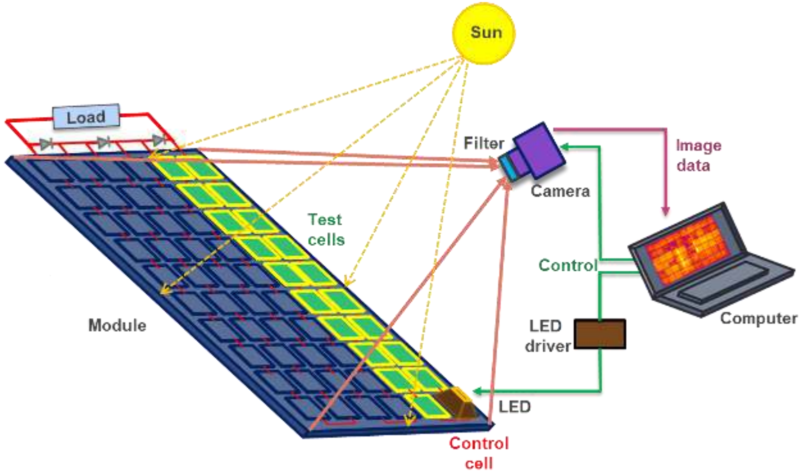
Outdoor photoluminescence (PL) imaging

- Contactless PV module inspection without electrical changes to the PV system;
- Photoluminescence: Stable sunlight is used as excitation source for emitting luminescence radiation of cells;
- Extraction of the weak PL signal with optical modulation test method: Variable irradiance level at “Control cells” (high power LED light source);
- PL signal of cell string is captured with an InGaAs CCD camera and processed by software.

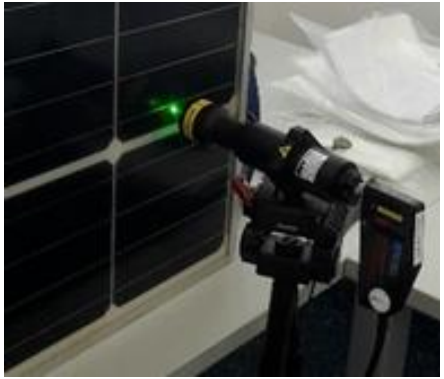


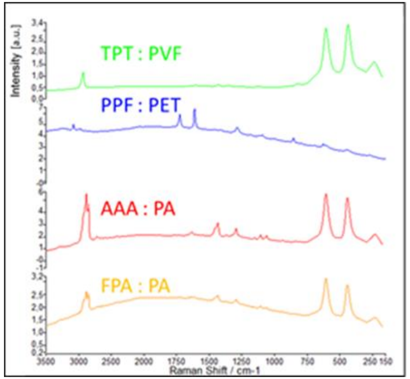
Detectable failures:
- Cell cracks
- Interruptions in the cell interconnection circuit
- Induced degradation (PID, LeTID)
- Bypass diode failures

Spectroscopic methods for polymeric materials

- Non-destructive material analysis without dismounting PV modules
- Identify the polymeric compounds of PV modules (encapsulants, backsheets)
- **NIR and Raman spectroscopy:** Identify the encapsulant in the PV module
- **FTIR spectroscopy:** Identify the polymeric backsheet, detect surface degradation effects (e.g. oxidation, hydrolysis)
- **NIR spectroscopy:** Determine the entire composition of the multilayer backsheet composite

Raman spectroscopy





Detectable failures:
- Polymer degradation
- Differentiation between different types of encapsulation and backsheet materials

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Electrical impedance spectroscopy of PV strings

- A sinusoidal harmonic signal is applied to the terminals of the PV string and the linear response is measured
- Electrical impedance: Ratio of the voltage response to an input current
- By analysing the response within different frequency ranges, information on specific features of the PV string are extracted

Detectable failures:

- Non-operative PV modules
- Insulation/ground failures
- Bypass diode failures
- Induced degradation (PID)

Summary 1

Inspection method or combination of inspection methods should be carefully selected according to various aspects:

a) **Inspection focus:** PV string or PV module

b) **Test requirements:** Daytime, nighttime, weather conditions, etc.

c) **Intervention in the PV system:** Disconnection of PV strings or PV modules, dismounting PV modules, high voltage issue

d) **Infrastructure requirements:** Paved roads for moving test equipment, power supply, etc.

e) **Throughput:** i.e. time required to inspect a certain number of PV modules or PV strings

Summary 2

Primary inspection method	Application					
	Inspection focus		Ambient requirement		Electrical disconnection of PV string or PV module	
	PV string	PV module	Day-time	Night-time	YES	NO
Daylight I-V measurement	X	X	X		X	
Dark I-V measurement	X			X	X	
PV plant testing vehicle	X		X		X	
Electrical impedance spectroscopy	X		X		X	
Thermal infrared imaging[1]	X	X	X			X
Nighttime electroluminescence imaging[1]	X	X		X	X	
Daylight electroluminescence imaging	X	X	X	X	X	
UV Fluorescence imaging		X	X	X		X
Outdoor photoluminescence imaging		X	X			X
Spectroscopic methods for polymeric materials		X	X	X		X

1) Partially covered in this report in chapter "Drone-mounted EL & IR inspection". For more details see: U. Jahn, M. Herz, M. Köntges, D. Parlevliet, M. Paggi, I. Tsanakas, J. S. Stein, K. A. Berger, S. Ranti, R. H. French, M. Richter and T. Tanahashi, "Review on Infrared and Electroluminescence Imaging for PV Field Applications: Report IEA-PVPS T13-10:2018", ISBN 978-3-906042-53-4, 2018

Publication

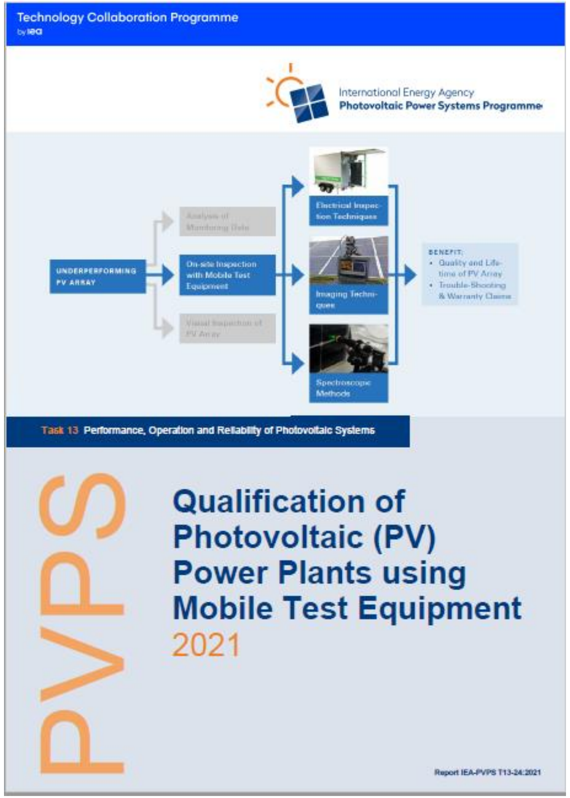
Results have been published in an IEA report:

IEA-PVPS T13-24:2021

Technical description, existing knowledge, best practice recommendations and economic considerations for different field inspection methods

Free download:

https://iea-pvps.org/key-topics/qualification-of-pv-power-plants-using-mobile-test-equipment/



Acknowledgements 1

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