Degradation of PV modules, inverters, components and systems

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Joint Research Centre

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European Commission

OUTLINE

- Purpose
- PV modules
  - ✓ BIPV as a special case
- Inverters
- PV systems
  - ✓ BIPV as a special case

}
- Baseline
- Definition
- Possible approach(es)

- PV systems
- Suggested inputs to the PV preparatory study

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PURPOSE

Transitional method for **definition and evaluation of degradation** of photovoltaic (PV) modules, inverters, other components and PV systems.

- ✓ To establish a definition of the degradation rate for solar PV modules, inverters and PV systems that will be included in the preparatory study on Ecodesign and Energy-labelling.
- ✓ To establish one (or more equivalent) method(s) to enable quantitative evaluation of the degradation of PV modules, inverters, components and PV systems.

Degradation versus failure

- Degradation — Decrease in the power or energy generation of a PV product compared to the initial value and under the same conditions (e.g. STC)
- Failure — Termination of the ability of the PV product to deliver electrical energy and/or event that creates safety issues

→ **Replacement is assumed to be due to a failure**

→ *Limiting event* — any event for which the PV product loses its ability to perform as required (e.g. in EN 4555x)

- Technical → *Failure*
- Owner decision → *Degradation without failure (e.g. discoloration)*
- …

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PV Modules

Available baseline (not exhaustive)

1. First-hand experience
    - Skoczek A, Sample T and Dunlop E. 2004 *The results of performance measurements of field-aged crystalline silicon photovoltaic modules*. Prog. Photovolt. Res. Appl. **17** 227-240
2. Scientific peer reviews on very differentiated world-wide installations
    - Jordan Dirk C et al. 2017 *Photovoltaic failure and degradation modes* Prog. Photovoltaics Res. Appl. **25** 318-26
    - Jordan Dirk C et al. 2016 *Compendium of photovoltaic degradation rates* Prog. Photovoltaics Res. Appl. **24** 978-89
    - Kurtz S et al. 2017 *Qualification Testing versus Quantitative Reliability Testing of PV – Gaining Confidence in a Rapidly Changing Technology*. In: 33rd European Photovoltaic Solar Energy Conference and Exhibition, (Amsterdam) pp 1302 - 11
3. IEA PVPS Task 12 and 13 reports
4. Product Environmental Footprint (PEF) document for PV products

Possible approaches: PV modules (1)

1. Prescribed values
   - c-Si: 0.5% - 0.6% per year (median value), 0.8% - 0.9% per year (mean value)
   - thin-film (including µc-Si) and HIT: 1 %/year
   - Failure rates: 0.1 %/year for c-Si, not available for thin-film PV (Jordan et al. 2017)
2. Measurements
   - Accelerated tests → not universally considered a good replica of actual behaviour under real conditions
   - Measurements from the field →
     - ✓ at least 5 years of measurements
     - ✓ several distinct geographic and climatic regions
     - ✓ independent assessment by ISO/IEC 17025 accredited laboratories
   - For completely new technologies this might be not enough

Quality and degradation: EN 61215

Standard	Subject covered
EN 61215-1	Design qualification and type approval - Part 1: Test requirements
EN 61215-2	Design qualification and type approval - Part 2: Test procedures
EN 61215-1-1 to -4	Specific requirement for each PV technology

Specific tests covered:

- *Thermal cycle test*, with temperature and electrical current as stressors;
- *Damp heat test*, combination of effects due to temperature and humidity;
- *Humidity freeze test*, on sealing materials and components;
- *UV test*, for polymeric components;
- *Static mechanical load test* simulates loads such as those by constant wind or homogeneous snow accumulation;
- *Hot spot test* linked to partial shading on modules;
- *Hail test*.

Quality and degradation: accelerated tests

Standard	Subject covered
EN 61701	Salt spray testing, mainly of connectors
EN 62716	Ammonia corrosion testing
EN 62782	Load variations on the PV module surface compared to EN 61215
IEC TS 62804-1	Detection of potential-induced degradation (PID)
IEC TS 62804-1-1 (draft)	Delamination due to PID
IEC TS 62804-2 (draft)	Detection of PID in thin-film PV modules
IEC 62852	Safety requirements and tests for connectors of PV
IEC 62916	Test of susceptibility of by-pass diodes to electrostatic discharges
IEC 62979	Thermal runaway test of by-pass diodes, component of the PV module for its own and eventually the user safety
IEC 62938 (draft)	Non-uniform snow load testing on inclined plane
IEC 63126 (early draft)	Guidelines for qualifying PV modules, components and materials for operation at higher temperatures
IEC TS 63140 (draft)	Advanced testing of protection and performance measurement of thin-film PV modules when exposed to partial-shading conditions

Possible approaches: PV modules (2)

3. Estimate method similar to what used in the building sector

- Not verified yet for PV
- Requires a collective reference database of verified field data under:
  - several climatic conditions
  - several in-use conditions
- Application of factor method based on estimated local conditions and their weight to influence degradation
  - Requires wide knowledge of the degradation paths of PV modules
  - Requires detailed knowledge of the local and in-use conditions under which the PV modules will be installed

Not suggested, unless significant active contribution from all stakeholders in the creation of the database

Inverters

Available baseline

1. IEA PVPS Task 12 and 13 reports
2. Product Environmental Footprint (PEF) document

Definition of degradation for inverters

NOT clearly available. They are considered either working or not.

Possible approach

Collection of field data is considered relevant, with inclusion of environmental conditions met by the inverter

PV Systems

Available baseline (not exhaustive)

1. First-hand experience
    - Skoczek A, Sample T and Dunlop E. 2004 *The results of performance measurements of field-aged crystalline silicon photovoltaic modules*. Prog. Photovolt. Res. Appl. **17** 227-240
2. Scientific peer reviews on very differentiated world-wide installations
    - Jordan Dirk C et al. 2017 *Photovoltaic failure and degradation modes* Prog. Photovoltaics Res. Appl. **25** 318-26
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3. IEA PVPS Task 12 and 13 reports
4. Product Environmental Footprint (PEF) document for PV products

Possible approaches: PV systems (1)

1. Prescribed values
   - c-Si: 0.5% - 0.6% per year (median value), 0.8% - 0.9% per year (mean value)
   - thin-film (including μc-Si) and HIT: 1 %/year
   - Failure rates: 0.1 %/year for c-Si, not available for thin-film PV (*Jordan et al. 2017*)
2. Measurements
   - Not feasible a priori, i.e. for prediction (EN 61829 and IEC 61724-1 are only for monitoring of already existing systems)
   - The period of monitoring must provide sufficient resolution to establish the linearity of the degradation
   - For completely new technologies the suggested 3-year period might be not enough

Possible approaches: PV systems (2)

3. Estimate method similar to what used in the building sector

- Not verified yet for PV
- Requires a collective reference database of verified field data under:
  - several climatic conditions
  - several in-use conditions
- Application of factor method based on estimated local conditions and their weight to influence degradation
  - Requires wide knowledge of the degradation paths of PV modules
  - Requires detailed knowledge of the local and in-use conditions under which the PV modules will be installed

Not suggested, unless significant active contribution from all stakeholders in the creation of the database

BIPV
Modules and Systems

Building Integrated PV Systems (BIPV)

Standard	Notes
EN 50583-1	PV modules used as construction products
EN 50583-2	PV systems integrated into buildings (structural aspects)
IEC 63092-1 (draft)	Based on EN 50583-1
IEC 63092-2 (draft)	Based on EN 50583-2
ISO 52000-1 and other parts	Energy Performance of Buildings
EN 15316-4-3	Method for calculation of system energy requirements and system efficiencies
prEN 50331-1 (draft)	Safety requirements for PV in buildings

Possible approaches: BIPV (1)

1. Prescribed values
    - Higher degradation rate than ground and open-rack mounted modules, still to be defined
    - Failure rates: about 10 times the ground and open-rack mounted modules (Jordan et al. 2017)

2. Measurements
    - Accelerated tests
        - → not universally considered a good replica of actual behaviour under real conditions
        - → Draft IEC TS 63126 *Guidelines for qualifying PV modules, components and materials for operation at higher temperatures*
    - Measurements from the field →
        - ✓ at least 5 years of measurements
        - ✓ several distinct geographic and climatic regions
        - ✓ independent assessment by ISO/IEC 17025 accredited laboratories

Possible approaches: BIPV (2)

3. Estimate method similar to what used in the building sector

- Not verified yet for PV
- Requires a collective reference database of verified field data under:
  - several climatic conditions
  - several in-use conditions
- Application of factor method based on estimated local conditions and their weight to influence degradation
  - Requires wide knowledge of the degradation paths of PV modules
  - Requires detailed knowledge of the local and in-use conditions under which the PV modules will be installed

Not suggested, unless significant active contribution from all stakeholders in the creation of the database

Suggestions to the PV preparatory study

Prescribed values approach:

- PV modules:
  - c-Si: between 0.5% and 0.6% per year (if median value), between 0.8% and 0.9% per year (if mean value) in a linear degradation assumption
  - Thin-film (including μc-Si) and HIT: 1 %/year in a linear degradation assumption
- Inverters: no degradation, only a failure rate corresponding to 1 - 2 replacements in the expected overall life span of the PV system
- PV systems:
  - c-Si: between 0.5% and 0.6% per year (if median value), between 0.8% and 0.9% per year (if mean value) in a linear degradation assumption
  - Thin-film (including μc-Si) and HIT: 1 %/year in a linear degradation assumption

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PV Modules

Functional parameter	Standards
Module Energy Yield DC	EN 61853-1, EN 61853-2, IEC 61853-3, IEC 61853-4
Module Performance Ratio (MPR)	EN 61853-1, EN 61853-2, IEC 61853-3, IEC 61853-4
Maximum power at STC	EN 60904-1
Module Energy Conversion Efficiency	Possible next edition of IEC 60904-1 (under revision)
Module Degradation Rates	*Not defined by standards*
Module Operational Life	*Not defined by standards*

Proposal from preparatory study for Ecodesign:

1 kWh of DC power output under predefined climatic and installation conditions for 1 year and assuming an intended service life of 25 years.

PV technologies

COMMERCIAL

Crystalline Silicon

Thin-film

EMERGING

Organic PV

NOVEL

Organic PV
Perovskite PV

Power conversion equipments (PCEs)

Functional parameter	Standards
Input range voltage, Grid range voltage, Start-up voltage, MPP voltage	IEC 62894 EN 50524 (withdrawn at present)
Inverter efficiency	IEC 61683
Inverter "European efficiency"	EN 50530 (withdrawn at present, new work item considered at CENELEC)

Proposal from preparatory study for Ecodesign:

1 kWh of AC power output from a specified inverter installed as part of a reference photovoltaic system under predefined climatic and installation conditions for 1 year and assuming a service life of 10 years.

PV Systems

Functional parameter	Standards
System Maximum power at STC	*Not existing, but it can be based on EN 60904-1, EN 61829*
System Energy output	*Not existing*
System Energy Yield	*Not existing*
System Performance Ratio (PR)	EN 61724-1 (generic definition, not sufficient as it needs final Energy Yield as input)
System Efficiency	*Not existing*

Proposal from preparatory study for Ecodesign:

1 kWh of AC power output supplied under fixed climatic conditions for 1 year (with reference to IEC 61853-4) and assuming a service life of 25 years.

Transitional methods

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