VDE SPEC

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Solar Module Quality Standard (SMQS)

Part 2: Measurements on PV Modules as Part of a Holistic Quality Assurance Concept

VDE SPEC 90038-2 V1.0 (en)

VDE

Foreword

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No draft has been published for the present VDE SPEC prior to publication.

This VDE SPEC resulted from the work of a project group between the authors as stated below.

This VDE SPEC was developed according to the VDE SPEC procedure. VDE SPEC 90038-1 (en) has been developed in a project group aiming for a Solar Module Quality Standard (SMQS) and it cannot be granted that all possibly interested parties could have been involved. However, a proposal for interaction for public interaction was made by means of according to the VDE procedure and all parties – possibly not involved at this point – were asked to participate in the process.

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Executive Summary

Photovoltaics is a rapidly growing source for renewable electricity production worldwide. Solar modules are the central component for the direct generation of electrical energy from natural sunlight through the photovoltaic (PV) effect and a central component of solar PV systems.

Solar modules are manufactured as a mass product and are typically purchased in large quantities. In module supply contracts, requirements for the solar modules' quality are usually agreed, which are summarized in this specification.

As a generic text, this SMQS (Solar Module Quality Standard) series of specifications represents a way of simplifying the purchasing process: Requirements are described in general terms and a selection option for specifying the technical conditions to be agreed upon in the purchasing contract is defined. During contract negotiations the customer and seller/manufacturer can easily define the intended level.

Although the authors have made every effort to ensure that this specification is free of errors and inconsistencies, no guarantee can be given that this guide is absolutely free of errors. The same applies to the completeness of the topics listed.

Part 1 of this series of specifications provides definitions and technical requirements for the documentation and the production site and certain further requirements.

Part 2 of this series provides details for measurement and testing procedures.

Part 3 of this series provides a framework for production monitoring requirements.

The three parts contain checklists that can be agreed upon during module supply/purchasing negotiations.

Contents

Introduction

Photovoltaic solar energy is a rapidly growing segment in electrical power supply worldwide. There are great opportunities for a further renewable expansion of this infrastructure in grid feed-in. In the segment of utility scale PV power plants addressed within this specification ground mounted PV systems have a major and rapid impact on further development.

Today, solar modules are sourced through a global supply chain. Therefore, this specification is published exclusively in English language.

The aim of this series of specifications is to standardize communication between manufacturers and customers to guarantee an elevated level of quality and at the same time speeding up the purchasing process.

After all, PV Modules are planned as the longest-lasting key components of a PV system.

1 Scope

This specification aims to describe the quality level and framework conditions for solar modules made of crystalline silicon using today's technology (i.e. in the year of publication of the specification). The focus is on solar modules that are usually used in so-called ground mount PV systems.

Other technologies, such as thin-film modules or modules based on tandem solar cells, are not within the scope of this document. For products based on these technologies, the text can nevertheless be used as a guide. However, the applicability and completeness must then be checked with particular care by the user.

Not in the scope of this text are evaluation catalogs regarding electroluminescence (EL) or visual criteria (VI). Such catalogs are typically either agreed upon based on manufacturer’s documentation or may be documented separately. Furthermore, this VDE SPEC does not specify any safety requirements. The corresponding safety standards for PV applications apply.

Although it is quite possible that different scenarios are conceivable, this specification uses the terminology „manufacturer” and „customer”. No distinction is made between „manufacturer” and „seller” and „supplier”. Moreover, the terms „customers” and „buyer” could also be used equivalent within this specification. Users of this specification are requested to adapt the terms to their corresponding actual situation if necessary.

Part 2 of this series of specifications provides quality requirements for the measurements applicable to solar modules purchased.

Different quality levels („basic”, „standard” and „advanced”) are defined, which can be selected by the manufacturer and the purchaser of solar modules. In some cases, such differentiation is not provided as suggested, and then the definitions shall be binding. Eventually, a checklist is provided to simplify the documentation of technical conditions during contract negotiations for the purchase of modules.

Part 2 of this series provides an overview of the measurement and testing methods that are widely used in quality assessment and quality assurance of PV modules on the market. Typical acceptance levels for the various tests are listed in the appendices. An average quality is highlighted in **bold** letters**.**

2 Normative References

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies).

2 PfG 2944 07.23*, (test basis TÜV Rheinland) Ultraviolet-Induced Degradation (UVID) testing for PV modules*

EN 50380:2017, *Marking and documentation requirements for Photovoltaic Modules*

IEC TS 60904-1-2, *Photovoltaic devices – Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices*

IEC 60904-9, *Photovoltaic devices – Part 9: Classification of solar simulator characteristics*

IEC TS 60904-13, *Photovoltaic devices – Part 13: Electroluminescence of photovoltaic modules*

IEC 61215 Series, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval*

IEC 61701 Ed.3.0, *Photovoltaic (PV) modules – Salt mist corrosion testing*

IEC 61730 Series, *Photovoltaic (PV) module safety qualification*

IEC 61853-1, *Photovoltaic (PV) module performance testing and energy rating – Part 1: Irradiance and temperature performance measurements and power rating*

IEC 61853-2*, Photovoltaic (PV) module performance testing and energy rating – Part 2: Spectral responsivity, incidence angle and module operating temperature measurements*

IEC 62716, *Photovoltaic (PV) modules – Ammonia corrosion testing*

IEC TS 62782, *Photovoltaic (PV) modules – Cyclic (dynamic) mechanical load testing*

IEC 62788-1-6 + Amd. 1, *Measurement procedures for materials used in photovoltaic modules – Part 1-6: Encapsulants – Test methods for determining the degree of cure in Ethylene-Vinyl Acetate*

IEC TS 62804-1, *Photovoltaic (PV) modules – Test methods for the detection of potential-induced degradation – Part 1: Crystalline silicon*

IEC 62938 Ed.1.0, *Photovoltaic (PV) modules – Non-uniform snow load testing*

IEC 62941 Ed.1.0, *Terrestrial photovoltaic (PV) modules – Quality system for PV module manufacturing*

IEC TS 63126, *Guidelines for qualifying PV modules, components and materials for operation at high temperatures*

IEC TS 63209-1*, Photovoltaic modules – Extended-stress testing – Part 1: Modules*

IEC TS 63342 Ed.1.0, *C-Si photovoltaic (PV) modules – Light and elevated temperature induced degradation (LETID) test – Detection*

ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement GUM*

ISO 1101, *Geometrical product specifications (GPS)*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO 2859-1, *Sampling procedures for inspection by attributes – Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot* inspection

ISO 8510-2, *Adhesives – Peel test for a flexible-bonded-to-rigid test specimen assembly – Part 2: 180° peel*

GB/T 2790-1995, *Adhesives, 180-degree peel strength test method for a flexible-bonded-to-rigid test specimen assembly*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

3.1
Standard Test Conditions (STC)

Environmental standard test conditions for Solar PV Modules as defined in IEC 61215 series and IEC 60904 series.

3.2
Sun simulator

A sun simulator is used for indoor STC measurements of solar cells and PV modules. The main components of a solar simulator are the light source that illuminates the module and the current-voltage measuring device with which the characteristic curve of the DUT is determined.

3.3
Bill of Material (BOM)

The list of all primary products and auxiliary materials used in production.

3.4
Manufacturer

Any legal entity that manufactures a product or has developed or manufactured a product and places this product on the market under its name or trademark. A manufacturer may entertain several production sites.

3.5
Production site

Actual factory/workshop used for the production of PV modules under the module supply contract.

3.6
Degree of Cross linking

Value obtained by the „primary method" as described in IEC 62788-1-6 for EVA. In the sense of this document also applicable for POE or a mix of EVA and POE.

3.7
anti PID function

property of embedding material, glass, and/or solar cells, that makes sure that no significant loss is observed (5 % loss or less when specified in this specification) according endurance testing of per IEC TS 62804-1.

3.8
Critical Defect

A critical defect is a defect that judgement and experience indicate is likely to result in hazardous or unsafe conditions for individuals using, maintaining or depending upon the product; or a defect that judgment and experience indicate is likely to prevent performance of the function of a major end item.

3.9
Major Defect

A major defect is a defect, other than critical, that is likely to result in failure, or to reduce materially the usability of the unit of product for its intended purpose.

3.10
Minor defect

A minor defect is a defect that is not likely to materially reduce the usability of the unit of product for its intended purpose or is a deviation from established standards having little bearing on the effective use or operation of the unit.

3.11
Current sorting

The modules of a power class can be sorted according to current (I_{MPP} or I_{SC}) classes by agreement. There are usually a maximum of three current classes, which are often labelled I1, I2, I3 or L, M, H depending on the manufacturer.

3.12
Silver Module, Golden Module

The Golden Module is the central reference module for calibration of the sun simulators of a PV module manufacturer. Silver Modules secondary reference modules produced on a sun simulator calibrated with the Golden Module. Silver Modules are used in daily production to calibrate and monitor the sun simulators.

3.13
National Accreditation Body

In the context of this Specification a national Accreditation Body is a national organization which is underwriter to IAF and/or ILAC with the scope for Photovoltaic measurement or certification

3.14
Accreditation Body

authoritative body that performs accreditation

Note: The authority of an accreditation body is generally derived from government.

[SOURCE: ISO/IEC 17000:2004, 2.6, modified – The references to other terms within ISO/IEC 17000 have been replaced by hyperlinks to entries in the IEV.]

In the context of this Specification a national Accreditation Body is a national organization which is underwriter to IAF and/or ILAC with the scope for Photovoltaic measurement or certification.

4 Symbols and abbreviations

The following abbreviations are used in this text

AI	Artificial Intelligence
AIST	National Institute of Advanced Industrial Science and Technology (United States)
AM	Air Mass
BO	Boron-Oxigen
B/S	back sheet (rear side plastic foil of GBM, not applicable for GGM
CB	Certifying Body, issuing the product certificate and accredited by a member body of IAF
Ce	Cerium (chemical element)
CDF	Constructional Data Form for Photovoltaic Modules
CID	Current Induced Degradation
CO_2	Carbon dioxide
DH	Damp Heat
DL	Dynamic load
DUT	Device under Test
EL	Electroluminescence
EVA	Ethylene-vinyl acetate
GBM	Glass-backsheet module: PV module with glass at the front side and B/S at the rear side
GGM	Glass-glass modules: PV module with glass at the front side and rear side
GHG	Greenhouse gas
GPS	Geometrical Product Specification
HF	Humidity Freeze
IAF	International Accreditation Forum (www.iaf.nu)
IEC	International Electrotechnical Commission (www.iec.ch)
ISO	International Standardisation Organization (www.iso.org)
IQC	Incoming quality control
IV	Current-Voltage
LeTID	Light and elevated temperature induced degradation
LID	Light Induced Degradation
MPP	Maximum Power Point: operation condition providing peak output for a PV module
MQT	Module Quality Test
NREL	National Renewable Energy Laboratory
PA	Polyamide
PAN file	(from French. „panneau"): full dataset defining a specific PV module for PV Syst
PET	Polyethylene terephthalate
POE	Polyolefin Elastomer
PID	Potential Induced Degradation
PST	Pre-shipment test
PV	Photovoltaic
PVF	Polyvinyl fluoride
PVDF	Polyvinylidene fluoride

PV Syst	Software made by PVSYST SA (Satigny, Switzerland) for yield calculation
Sb	Antinomy (chemical element)
SI	International System of Units
SNR	Signal to Noise Ratio
SoP	Start of Production
SOP	Standard Operation Procedures (e.g. work instructions)
STC	Standard Testing Conditions
TPT	B/S consisting with a three-layer construction: PFV - PET - PVE
TS	Technical specification
γ_m	Safety factor
UL	Underwriter Laboratories
UVID	Ultra Violet (light) Induced Degradation: possible degradation mechanism for solar cells
QA	Quality assurance

Table 1 – Symbols used

Symbol	Quantity referenced	SI Unit (if applicable)
Voc	Open Circuit Voltage (of a PV Module)	[V]
Isc	Short Circuit Current (of a PV Module)	[A]
k	Coverage factor of the expanded measurement uncertainty	-
m	Expanded measurement uncertainty	%
P	Power	[W] (often noted as [Wp]) [MW] (often noted as [MWp])
P_{max} , P_{min}, $P_{average}$	Power at MPP , maximum/minimum/average value	[W] (often noted as [Wp]) [MW] (often noted as [MWp])
RH	Relative humidity	[%] (not a SI Unit)
t	Tolerance	%
T	Temperature	K, °C
η	Efficiency	(%)
η_{rel200}	Relative low-light efficiency at 200 W/m²	(%)

5 Tests and Measurements

5.1 Power Measurement at STC

5.1.1 Basics

The performance under Standard Test Conditions (STC) is typically determined using sun simulators. The STC conditions are defined as irradiation of 1000 W/m², as an AM 1.5 spectrum and in the form of a cell temperature of 25°C.

The measurement procedure is specified in IEC 61215-2. The cell temperature for the measurement must be 25 ± 2°C and the irradiation must be in the range 1,000 ± 100 W/m².

There are also measurements in the sun. As a rule, these are measurements with portable IV-curve measuring devices, which have a too high measurement uncertainty to be used as a basis for billing large systems.

For a power measurement of PV modules, a large number of parameters must be defined. This results in an unmanageable number of possible combinations. This specification presents the usual variants with regard to the location, the devices used and the calibration standards used. Tolerances and measurement uncertainty are also discussed.

The final chapter presents common combinations that can be used.

5.1.1.1 Apparatus

The essential properties of sun simulators, the spectrum achieved, the spatial uniformity and the temporal stability are defined in IEC 60904-9. There are four characteristics for each property, which are labelled A+, A, B or C in descending order of quality. The devices labelled A+A+A+ are those that come closest to the standard spectrum and show the least deviation in terms of spatial and temporal uniformity.

A distinction can be made between three major types of construction and operation:

Production sun simulators, laboratory sun simulators and mobile sun simulators.

In terms of the light source, all three types can achieve the highest class A+A+A+ as per IEC 60904-9. The biggest differences are in the temperature control of the PV modules.

Stationary laboratory set-ups have devices to homogenize the temperature of the solar modules to 25 ± 2°C before measurement.

In production, the entire workshop (or at least the relevant area) is temperature controlled. However, the deviation from the value 25°C may be higher than in the laboratory.

In most cases, no temperature control of the modules is provided for mobile devices. In case temperature control is a precondition for mobile devices, such preconditioning will limit the throughput capacity of the mobile device set-up. IEC 61215-2 specifies a temperature of 25 ± 2°C for the test specimens. Therefore, power measurements according to IEC 61215-2 can only be carried out in small quantities with most mobile devices.

5.1.1.2 Tolerance

The tolerance t_1 (to be specified in [%]) is specified by the module manufacturer and defines the maximum permissible deviation between the actual power and the rated power. The tolerance must be specified on the rating plate (label) and in the data sheet in accordance with the applicable requirements of IEC 61215-1. The tolerance may be symmetrical or asymmetrical with respect to the rated power and may be specified by the manufacturer in relative or absolute units. If the tolerance is specified asymmetrically, t_1 is the value corresponding to the (relative) distance of the lower power value of the specified interval compared to P_{max} (NP).

<u>Example:</u> The nominal power P_{max} (NP) is specified as 500 W_p

Case 1: The symmetrical tolerance t_1 is ± 3 %:

In this case, the manufacturer declares that the actual output of a compliant module must be in the range between 485 W_p and 515 W_p (since 3% of 500 W_p is 15 W_p).

Case 2: asymmetrical tolerance -0%, +5%

In this case, the manufacturer declares that the actual output of a compliant module must be in the range between 500 W_p and 525 W_p.

In this case, t_1 = 0 (as the lower limit of the specified tolerance is P_{max} (NP))

The tolerance t_1 can alternatively be specified by the manufacturer in [W_p]; in this case it should be recalculated in units of % (rule: two valid decimal places) in relation to P_{max} (NP).

<u>Example:</u> P_{max} (NP) is 560 W_p

Informative note: The manufacturer's „tolerance“ is often referred to as „binning“ or „sorting“. The so-called „positive sorting“ provides t_1 = 0. For reasons of clarity, only the term „tolerance“ should be used. This corresponds to IEC 61215-1

5.1.1.3 Uncertainty of measurement

Every power measurement is subject to a measurement uncertainty. The measurement uncertainty m_1 depends on the selected measurement procedure and the measuring devices used and is determined by the test laboratory. In accordance with IEC 61215-1-1, the maximum permissible value of the expanded measurement uncertainty m_1≤ 3.0 % for the power measurement (P_$_{max}$ (Lab)) for c-Si modules.

An expanded measurement uncertainty (k=2) is the measurement uncertainty that has a confidence interval of 95%. The basic definitions are taken from ISO/IEC Guide 98-3, Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement GUM:1995.

For c-Si modules, the range of measurement uncertainties with k=2 in laboratories and production facilities is currently between 1.0% and 3.0%.

When evaluating tests in the course of quality assurance, it must be agreed on a case-by-case basis whether and in what form the measurement uncertainty is taken into account.

As long as no other precise information on the measurement uncertainty is available, it can be assumed that the deviations from the true value due to measurement uncertainties behave symmetrically. If the average of a number of measurements is considered, then the various contributions to measurement uncertainty cancel each other out in a symmetrical distribution and it is legitimate to use the average measured value without taking the measurement uncertainty into account.

5.1.1.4 Traceability and calibration standards

Traceability means that a measured value can be traced back to a recognized standard through an unbroken chain of comparative measurements. In the end, these are usually so-called standards of SI units, which are provided by the respective National Metrological Institute.

In photovoltaics, there is the World Photovoltaic Scheme (WPVS). This is the highest authority for PV power measurements. The WPVS members (e.g. Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany, National Institute of Advanced Industrial Science and Technology (AIST), Fukushima, Japan, National Renewable Energy Laboratory (NREL), Golden, Colorado, USA) compare their measurements by means of continuous round robin comparisons. A round-robin comparison is the exchange of test specimens in order to compare measurements between different laboratories.

WPVS laboratories usually calibrate so-called WPVS cells. These cells are 2x2 cm in size and have a special encapsulation. The accredited calibration and testing laboratories have their WPVS cells calibrated by the WPVS member laboratories and use these cells to calibrate the sun simulators. Only in the next step the first solar modules can be measured.

The WPVS cells can be measured by WPVS members with a measurement uncertainty of 0.3-0.5%.

The measurement uncertainty increases with every step along the calibration chain away from the WPVS standard or another first level standard that is directly traceable to SI units. Commercial calibration and testing laboratories have a measurement uncertainty of between 1.3 and 3.0% when measuring a PV module, depending on the effort involved.

With mobile sun simulators measurement uncertainties of 5-6% are not uncommon during operation on the construction site.

The WPVS laboratories are currently working on providing reference modules. A measurement uncertainty of 1.0% is currently available (2024).

In addition to the traceability of a calibration standard (WPVS cell or a reference module), stability is also important. WPVS cells are made of semiconductors with very long-term stability. If normal solar modules are used as a reference module, it is important to stabilize them beforehand. The stabilization should also be documented.

The lower the measurement uncertainty of the reference module, the lower the measurement uncertainty of the measured power in production.

The following specifications can be made for the references:

- Top level institution of the calibration chain
- Test laboratory vs. calibration laboratory as accepted origin of the reference module
- List of qualified laboratories
- Acceptance criteria for reference cells or reference modules as Golden Modules
- Specification of the handling of bifaciality of the modules
- List of data which shall provided to the customer

5.1.1.5 Bifacial PV modules

For bifacial modules, it must be defined how the power of the reference modules is measured and transferred to the modules in production. The simplest way is to exclude the contribution of the rear side as far as this is technically possible.

This is practically impossible when measuring in production. The resulting systematic error can be estimated by determining the STC power on modules from production in the laboratory using the same method with which the reference modules are measured.

5.1.2 Location of the measurement

5.1.2.1 Production

Two types of sun simulators and two types of reference modules are generally available from the manufacturer.

There are sun simulators in production that are integrated into the production automation and optimized for high throughput. These sun simulators are usually calibrated with a so-called Silver Module. This is a reference module that is generated in the in-house laboratory with the help of the so-called Golden Module.

Most manufacturers have one or more in-house (owned by the manufacturer, often in the vicinity of the workshop) accredited (by a National Accreditation Body for the applicable scope per ISO IEC 17025) test laboratories. The sun simulators in these laboratories are usually more precisely air-conditioned and can achieve a lower measurement uncertainty than the sun simulators in production. As a rule, the Golden Module is stored within this laboratory and the Silver Modules are produced in these in-house laboratories.

Two quality assurance measures are widely used:

- Witness Calibration: the entire calibration chain and the equipment used are checked by an authorized representative of the customer.
- Witness measurement: A sample is taken and measured again using the manufacturer's equipment.

The following points shall be specified:

- Selection of the type of sun simulators used
- Definition of the reference
- Definition of how the bifaciality of the DUT is taken into account

5.1.2.2 Laboratory prior to transport (PST pre shipment test)

After packaging, a random sample is taken and a performance measurement is usually carried out in an external laboratory. The following specifications are recommended:

- Requirement for accreditation
- Requirements for the measurement uncertainty
- Traceability/reference requirement
- Requirements for the data to be collected
- Sampling strategy

- List of possible laboratories
- Client, cost allocation

5.1.2.3 Harbour (after delivery to region of destination)

In Rotterdam, and possibly also in other harbors, it is possible to carry out performance measurements.

There are providers who work with stationary equipment and those who offer spatially flexible measurements with a lorry or trailer, even in the port.

In some cases, these measurements are not offered by ISO 17025 accredited service providers. In some cases, these are not STC performance measurements in accordance with IEC 61215, which is why the performance of non-accredited providers is often referred to as a flash test. A flash test is not necessarily a standardized measurement.

A random sample is taken from the delivery lot and the service provider usually carries out a performance measurement in the warehouse. The following specifications are recommended:

- Requirement for accreditation
- Measurement requirements
- Requirements for the measurement uncertainty
- Traceability/reference requirement
- List of possible providers
- Client, cost allocation

5.1.2.4 Laboratory after transport

A random sample is taken at some point between arrival at the port of destination and arrival at the construction site. An ISO 17025 accredited laboratory carries out an STC performance measurement on the selected test specimens. The following specifications are recommended:

- Requirement for accreditation
- Requirements for the measurement uncertainty
- Traceability/reference requirement
- Requirements for the data to be collected
- Sampling strategy
- List of possible laboratories
- Client, cost allocation.

5.1.2.5 Construction site

A performance measurement can be carried out on the construction site as part of an incoming goods inspection.

This service is offered by both ISO 17025 and non-accredited service providers.

Non-accredited service providers often refer to the service as a flash test. A flash test is not necessarily a standardized measurement.

A random sample is taken from the delivery batch and a performance measurement is carried out by the service provider on the construction site or in the immediate vicinity. The following specifications are recommended:

- Requirement for accreditation
- Sampling strategy
- Measurement requirements
- Requirements for the temperature control of the test specimens
- Requirements for the measurement uncertainty
- Traceability/reference requirement

- List of possible providers
- Client, cost allocation

5.1.3 Acceptance criteria

5.1.3.1 Individual measurement

An individual measurement is particularly relevant in the context of the performance guarantee of PV module manufacturers.

As a rule, the technical requirements are specified in the performance guarantee certificate. Deviations may be agreed in individual cases.

The normative definition of the STC performance measure form the basic set of requirements.

Moreover, the following specifications for STC performance measurements are recommended:

- For the technical realization of the measurement:
  - Requirement for accreditation
  - Requirements for the measurement uncertainty
  - Traceability/reference requirement
  - Requirements for the data to be collected
  - Sampling strategy
  - List of possible laboratories
  - Client, cost allocation
- Acceptance limits:
  - Guaranteed minimum performance
  - Assured degradation per year
- Treatment of the measurement uncertainty when determining the real STC power
  - Average of measurements

The average of a larger number of STC performance measurements is particularly relevant in the context of the acceptance of a delivery lot.

The normative definition of the STC performance measure form the basic set of requirements.

Moreover, the following specifications for STC performance measurements are recommended:

- For the technical realization of the measurement:
  - Requirement for accreditation
  - Requirements for the measurement uncertainty
  - Traceability/reference requirement
  - Requirements for the data to be collected
  - Sampling strategy
  - List of possible laboratories
  - Client, cost allocation
- Treatment of the measurement uncertainty when determining the real STC power
- Mathematical treatment of the result:
  - Guaranteed average minimum performance
  - Treatment of the measurement uncertainty when determining the average real STC power (if not defined elsewhere)
  - Formula for determining the average real STC power

5.2 Electroluminescence (EL)

5.2.1 Fundamentals

Electroluminescence (EL) is an imaging technique that visualizes a series of defects in solar cells. In EL, direct current flows through the solar module in the forward direction, which excites radiation in the 1,150 nm wavelength range. This radiation is recorded with a camera that is sensitive in this wavelength range.

The procedure is described in IEC TS 60904-13:2018. Some EL images of cells with selected fault patterns are shown in the annex to the TS. However, due to the rapid technical development, the fault patterns shown there are no longer relevant today. They mostly show multicrystalline cells with two or three busbars.

As a rule, EL fault catalogues developed by the manufacturers of solar modules are used. Different defect catalogues are usually used for the evaluation of EL images at the end of production and on arrival from the construction site.

The defect catalogues are generally defect-centered and do not evaluate the entire production batch. This means that the defect catalogue alone describes for each individual defect the maximum extent to which it may occur, without asking whether the module already has other defects or which defects other modules have.

The starting point for this standard is to first define how many of the modules must be completely free of anomalies. Modules that show anomalies are evaluated in the second step using the error catalogue.

5.2.1.1 Apparatus

The two relevant devices for an EL image are the camera including lens and filter and the DC power supply. The specifications required for the camera/recording quality differ depending on the location and are listed there.

For the DC power supply, a distinction must be made between single modules and the energization of entire strings.

Depending on the objective, IEC TS 60904-13:2018 sets the current carrying capacity to I_{SC} or 0.1 I_{SC}. This can be implemented in production and in the laboratory.

For EL images of entire strings, a current rating of I_{SC} can often not be achieved because no suitable current sources are available. In this case, different amperages can be agreed.

5.2.1.2 Interpretation of EL images

EL images are usually interpreted based on error catalogues that classify anomalies and define PASS/FAIL criteria for each of the anomalies.

Most manufacturers provide defect catalogues for end-of-line (EOL) EL images and for EL images made during the incoming goods inspection.

IEC TS 60904-13:2018 contains a few sample images that show anomalies. The images in IEC TS 60904-13:2018 are outdated. A manufacturer-independent standard that refers to the current module technology is not available.

Error catalogues should:

- The images contain examples of the abnormalities that were recorded on actual test specimens
- Be structured so simply that a manual evaluation can be carried out in less than 60 seconds

AI-supported evaluation software is used in production and by testing service providers. After defining an error catalogue, the manufacturer should provide 20 EL images for each listed anomaly, which were taken on identical modules and show the FAIL or PASS anomaly, in order to check the evaluation software.

5.2.2 Location of the measurement

5.2.2.1 Production

An end-of-line (EOL) EL image is made in production. The parameters of the available system are to be defined.

- Test current

- Camera resolution
- Temperature of the test specimens
- Pass/fail criteria
- Sharpness class according to IEC TS 60904-13:2018, clause 4.2.1.2
- Signal to noise ratio (SNR), IEC TS 60904-13:2018, clause 4.3

5.2.2.2 Laboratory prior to transport

It only makes sense to send PV modules from production to an external laboratory if they have been checked for perfect condition before dispatch. Therefore, EL images in a test laboratory only serve to check whether the modules have been damaged during transport from production to the laboratory.

This check is absolutely essential in order to rule out the possibility that the results of the tests in the laboratory provide a result that is overlaid by transport damage.

The assessment of whether the test specimens are suitable for the planned test can be left to the accredited test laboratory.

Exceptions to this rule are possible. These cases are so specific that they must be defined on a case-by-case basis.

5.2.2.3 Harbour

There are stationary and mobile devices in the harbor for taking EL images of PV modules.

Minimum specifications:

- Test current
- Camera resolution
- Temperature of the test specimens
- Pass/fail criteria

Optional specifications:

- Sharpness class according to IEC TS 60904-13:2018, clause 4.2.1.2
- Signal to noise ratio (SNR), IEC TS 60904-13:2018, clause 4.3

5.2.2.4 Laboratory after transport

If PV modules are sent to an external laboratory after transport from the warehouse or from the construction site, it is generally not practical to check them for perfect condition using EL before dispatch. Therefore, EL images in a test laboratory are primarily used to check whether the modules have been damaged during transport.

This check is absolutely essential in order to rule out the possibility that the results of the tests in the laboratory provide a result that is overlaid by transport damage.

The assessment of whether the test specimens are suitable for the planned test can be left to the accredited test laboratory.

If the modules do not show any abnormalities during the EL test, it can be concluded that the container from which the test specimens originate is highly unlikely to have suffered any systematic transport damage.

The reverse conclusion is not possible. If the modules show abnormalities, these should be investigated to determine their cause.

5.2.2.5 Construction site

5.2.2.5.1 Incoming goods inspection

There are permanently installed and mobile devices on the construction site for taking EL images of PV modules.

Minimum specifications:

- Test current
- Camera resolution

- Temperature of the test specimens
- Pass/fail criteria

Optional specifications:

- Sharpness class according to IEC TS 60904-13:2018, clause 4.2.1.2
- Signal to noise ratio (SNR), IEC TS 60904-13:2018, clause 4.3

5.2.2.5.2 Mounted modules

EL images of assembled modules are not generally the subject of a quality specification for PV modules. As they are part of the contract in individual cases, they are also listed here.

With regard to the test current and the temperature of the test specimens, the specifications of IEC TS 60904-13:2018 cannot be implemented in practice and must be adapted.

Recommended specifications:

- Test current
- Camera resolution
- Temperature of the specimens
- Pass/fail criteria

A determination of the

- Sharpness class according to IEC TS 60904-13:2018, clause 4.2.1.2 and the
- Signal to noise ratio (SNR), IEC TS 60904-13:2018, clause 4.3

should only be used for outdoor shots in justified individual cases.

5.3 Performance at low irradiance

5.3.1 Fundamentals

IEC 61215-2, MQT 07 describes the measurement of performance at low irradiance, specifically the power at an irradiance of 200 W/m².

MQT 07 describes the technical procedure of the measurement and the requirements for the measuring device. The performance is measured. The data is neither evaluated nor subjected to further processing.

5.3.2 Implementation

It is common practice in the industry to specify a relative low-light efficiency at an irradiance of 200 W/m² in relation to the STC output.

η_{rel200} = P_{200}/P_{STC} *1000/200

η_{rel200} = Relative low-light efficiency at 200 W/m²

P_{200} = Power in [W] at 200 W/m²

P_{STC} = Power in [W] at STC conditions

Specifications:

- Minimum value of the low-light efficiency
- Discount in percentage points to allow for measurement uncertainties

5.4 PID

5.4.1 Fundamentals

The testing of PV modules for susceptibility to Potential Induced Degradation (PID) is described in IEC TS 62804-1 Ed. 1.0.

The result of the test only describes the susceptibility of the module. The numerical value of the power loss in the course of the test is not related to the actual power loss that a susceptible module may exhibit during operation.

A distinction is made between PID-s triggered by shunts and PID-p of so-called polarisation.

The main mechanism of PID-s has been known for a good ten years and is caused by the migration of sodium ions from the glass to the cell surface.

PID-s is mostly found in n-type cells.

In addition to the degradation stress methods, IEC TS 62804-1 also describes recovery methods. As a loss of power could also have other causes, only successful recovery is considered proof that PID is present.

5.4.2 Implementation

5.4.2.1 PID-s

IEC TS 62804-1 provides two methods for PID-s:

Method A is carried out for 96 hours in a climate chamber at 60°C and 85% relative humidity. The circuit in the module is short-circuited and subjected to the maximum system voltage. The frame is earthed.

Method B is carried out for 168 hours at 25°C and below 60% relative humidity. The glass is covered with an aluminum foil, which is grounded together with the frame.

Both methods reliably detect susceptibility to PID. With method A, the earth potential is not as uniform across the entire glass as with method B.

Method A tends to be recommended for locations with low precipitation, where the earth potential is primarily applied to the frame. Method B is more suitable for locations with frequent precipitation, which distributes the earth potential over the entire surface via the water film.

For certificates and material qualifications, the procedure according to IEC TS 62804-1, is the standard approach. The latest version of IEC 61215-2 requires Method A from IEC TS 62804-1 and with a pass/fail criterion of 5% max. deviation. It is not recommended to use this criterion as the 5% threshold appears too large for a failure mode which is typically not demonstrating a stabilized minimum at the end of the test time.

If large volumes have to be tested for quality assurance, simplifications can be agreed compared to the IEC TS, which allow testing to be carried out much more cost-effectively and in larger volumes with only a slight reduction in informative value.

Simplifications Method A:

60°C +- 3 °C or 85°C +- 3 °C
85 +- 5% rel. humidity
Only one representative temperature sensor required
96h +- 4h

Simplifications Method B:

25°C +- 3 °C
Only one representative temperature sensor required
168h +- 8h

5.4.2.2 PID-p

Testing for PID-p sensitivity is much more complex than testing for PID-s and is aimed more at research and development tasks and is not used in the quality assurance of PV modules.

5.4.3 Required specifications for PID-s

- Method A/B
- Simplification Y/N
- Different degrees of sharpness
- Permissible power loss

5.5 LeTID

5.5.1 Fundamentals

Light and enhanced temperature induced degradation (LeTID) has come into focus with the introduction of the PERC cell architecture. In principle, the effect also exists in older cell concepts, but it occurs there to a much lesser extent. The latest generation of cells, n-type TOPCon cells, on the other hand, are significantly less sensitive to LeTID.

The IEC TS 63342:2022 test method addresses LeTID. The two-stage test method initially provides for a 24-hour current-induced degradation (CID) at low temperature. This essentially corresponds to LID stabilization. The CID is preceded by the actual LeTID test in order to be able to separate the two degradation effects. The test specimens are then energized at 75°C to trigger the LeTID effect.

The LeTID test procedure is very complex. A simplified procedure can be used for sensitivity screening on a larger number of items as part of quality assurance.

Simplifications:

- Temperature measurement only on a representative test specimen at B-O CID
- Extended temperature range ±10°C, max. 35°C for B-O CID
- Temperature measurement only on a representative test specimen at LeTID
- Only one LeTID cycle with 162h + 8h with STC power measurement before/after stress
- Pass criterion for power loss, $\Delta P_{zul} > (P_{max} – P_{min})/P_{average}$
- Consideration of the measurement uncertainty

5.5.2 Implementation

Specifications:

- IEC TS or simplified procedure
- Three STC measurements before and after CID as well as the final measurement
- Permissible maximum power loss for CID and LeTID
- Measurement uncertainty to be taken into account for the repeatability measurement

5.6 LID

5.6.1 Fundamentals

Light induced degradation (LID) refers to initial degradation in the first few hours of operation caused by boron-oxygen complexes in the wafer.

Boron is only present as a dopant in the wafer of p-type cells. Monocrystalline p-type cells are particularly sensitive.

The scope of the LID can be determined by stabilization in accordance with IEC 61215-2 MQT 19.

The solar module is exposed to radiation of 5 kWh/m² at least twice in a solar simulator or in the sun. The STC power is measured before and after each radiation dose.

Stabilization according to MQT 19 is carried out until the stability criterion of

$(P_{max}–P_{min})/P_{average} < 0,01$

is reached.

LID testing is known to be important for p-type material, whereas under certain conditions (e.g. Ga doping for p-type or the use of n-type) a BO related degradation, which is the classical reason for the occurrence of LID is not expected.

According to IEC 61215, LID stabilization can be replaced by another validated method at the laboratory's discretion. This is usually Current Induced Degradation (CID). The module is connected to a current source in the dark and I_{sc} flows through it. The details of the procedure are up to the laboratory, as long as validation is successful.

5.6.2 Implementation

Specifications:

- LID/CID procedure
- Pass criterion for power loss, $\Delta P_{zul} > (P_{max} – P_{min})/P_{average}$
- Consideration of the measurement uncertainty

5.7 Crosslinking

5.7.1 Fundamentals

The determination of the degree of cross-linking of EVA is defined in IEC 62788-1-6:2017/AMD1:2020. There are various methods for determining the degree of crosslinking. Soxhlet extraction is the primary method.

In large parts of the industry, methods have become established in which the samples are not extracted in a Soxhlet extractor but in a round bottom flask in boiling xylene. Simplified procedures can be used in quality assurance as long as they are described.

While EVA was practically the only embedding material used for decades, the number of alternative materials, some of which are only specified in very general terms, has been increasing in recent years.

Polyolefins (POE) are widely used, although this is only a generic term, and EPE/EP, coextruded films made of EVA and POE.

Meaningful PASS/fail criteria can only be established with precise knowledge of the embedding materials used.

5.7.2 Implementation

Specifications:

- Simplified procedures
- Drying time after chemical extraction and prior to mass determination
- Minimum degree of crosslinking
- Measurement uncertainty

5.8 Peel Test

5.8.1 Fundamentals

The peel test is used in the solar industry both as a 90° peel test in accordance with IEC 61730-2:2023, MST 35, and as a 180° peel test for quality assurance.

MST 35 is expressly not required for certification if the modules are glass-glass modules or if the modules fulfil the requirements of Table 3 of IEC 61730-1:2023.

The peel test can only be carried out on finished products on glass-foil modules. Test specimens must be produced separately for glass-glass modules.

The test specimen on which the pull-off force for glass-glass modules is measured as a simulation should be as close as possible to the real product in terms of its properties during lamination and should be clearly defined in terms of its dimensions and composition.

In peel tests, the embedding material is usually pulled off the glass or the backing film is pulled off the embedding material and the force required for this is measured.

It is often not possible to determine the pull-off force between the backing film and the embedding material because another surface interface fails first.

There is no photovoltaic-specific standard for determining the pull-off forces on a solar module. ISO 8510-2:2006-12 or the Chinese standard GB/T 2790-1995 can be used, which in turn is an adaptation of the preliminary version of the above-mentioned ISO standard. Adjustments must be made in detail as, for example, the take-off speeds specified in the standard are too high in many cases. As a rule, an industry-specific adaptation of the standard will be used.

The peel test can be carried out by hand or by machine. Most hand-held devices are drag indicator instruments that display the maximum value, whereas in a machine peel test, the force is recorded along the path. The measurement produces a peak load just before peeling begins, which is well above the force required for subsequent continuous peeling.

5.8.2 Implementation

Specifications:

- Definition of the test specimen with all materials, dimensions and structure
- Definition of the procedure for laminating the test specimen

- Intended measuring device
- Determination of which measured value is evaluated as peel force
- Determination of the minimum value for the peeling force

5.9 Insulation Test

5.9.1 Fundamentals

The dry insulation test is defined as insulation test IEC 61215 MQT 03. In production, each module is usually subjected to an insulation test that generally deviates from MQT 03.

The MQT 03 provides for a two-stage voltage load on the test specimen. The electrical resistance is measured during the second load.

The PASS/FAIL criterion is 40 MΩ·m², the product of the module area in m² with the measured resistance.

5.9.2 Implementation

Required specifications:

- Maximum system voltage
- Test according to IEC 61215 MQT03 or simplified test
- If a simplified test is agreed, the SOP must be agreed

5.10 Wet leakage current test

5.10.1 Fundamentals

The wet leakage current test (WL) is defined as IEC 61215 MQT 15. The test specimen, including the connectors, is subjected to a test voltage equal to the maximum system voltage in a water bath for 120 seconds. The electrical resistance is determined from the measured leakage current. The PASS/FAIL criterion is 40 MΩ·m², the product of the module area in m² and the measured resistance. In fact, brand-new modules usually measure values in the range of several GΩ.

The wet leakage current test can also be carried out on site. In this case, the specifications for the temperature of the test fluid are difficult to fulfil. We recommend the following deviations from the IEC standard for measurements outside the laboratory:

- Liquid temperature 22°C ± 10°C
- PASS/FAIL Criterion 40 MΩ m² – 1.000 MΩ
- Option: Testing without connector

5.10.2 Implementation

Required specifications:

- Maximum system voltage
- Deviations from the standard for external measurement
- Submerged connector and J/box

5.11 Connector Wet Leakage Current Test

5.11.1 Fundamentals

The laminates are usually inconspicuous in the wet leakage current test. The few cases in which the test is not passed are in most cases caused by the connectors.

It may therefore make sense in individual cases to agree to test only the connectors.

Such a test can be carried out by immersing only the connectors in a container with the test fluid. Otherwise, all specifications of the IEC 61215 series can be adopted.

If the test is carried out on site, the permissible temperature range of the test fluid should be extended to 15°C – 30°C.

5.11.2 Implementation

Required specifications:

- Maximum system voltage
- Minimum Riso

5.12 Static mechanical load test

5.12.1 Fundamentals

The static mechanical load test (ML) is described in IEC 61215-2 MQT 16.

A distinction is made between positive (push) and negative (pull) loads.

In addition, between the design load and the test load, which is normally 1.5 times the design load. The minimum design load according to IEC 61215 is 1,600 Pa, which results in a minimum test load of 2,400 Pa.

In general: Test load = $\gamma_m \times$ design load

The standard is open regarding both the design load and the definition of the safety factor γ_m. Express reference is made to the responsibility for assessing the required design load. Important parameters are the type of installation, local regulations or the climatic ambient conditions, all parameters that may require a different, higher design load and/or a higher γ_m.

According to IEC 61215-2, the ML does not provide a pass-fail criterion with regard to STC power or EL imaging.

5.12.2 Implementation

Required specifications:

- Definition of the assembly situation
- Expected design load, pressure
- Expected design load, pull
- Safety factor γ_m
- PASS/FAIL criterion STC performance
- PASS/FAIL criterion EL images

5.13 Cyclic dynamic load test

5.13.1 Fundamentals

IEC TS 62782:2016 describes a cyclic load test (DL) with 1,000 cycles of positive and negative pressure of 1,000 Pa on the module surface.

The scope indicates that this test alone is very unlikely to lead to a loss of performance. It is recommended to combine the test with other tests.

One example is Test Sequence 2, Mechanical Stress from IEC TS 63209-1:2021.

According to IEC TS 62782, the DL does not provide a pass-fail criterion with regard to STC power or EL images.

5.13.2 Implementation

Required specifications:

- Definition of the assembly situation
- PASS/FAIL criterion STC performance
- PASS/FAIL criterion EL images

5.14 Damp heat test

5.14.1 Fundamentals

The Damp Heat Test according to IEC 61215 MQT 13 lasts 1,000 hours and is often referred to by the abbreviation DH1000. Solar modules are stored in a climate chamber at 85°C and 85% relative humidity for 1,000 hours, which corresponds to approx. six weeks.

The main failure mechanism addressed by the DH test is the hydrolysis of polymer materials.

It is common practice in the R&D sector to carry out the DH test in an extended form for material qualification. DH1500, DH2000 are common, but sometimes even longer test sequences are used. It is controversial whether an extension beyond a certain level provides meaningful results.

The extended DH tests are also used to carry out quality benchmarking.

If the DH test is carried out with an extended number of hours, it is recommended to use the test sequences of IEC TS 63209-1:2021 in order to obtain comparable results.

5.14.2 Implementation

Specifications:

- BOM to be checked
- Duration
- Intermediate measurements
- Pass/fail criterion

5.15 Temperature cycling test

5.15.1 Fundamentals

The temperature cycling test (TC) in accordance with IEC 61215 MQT 11 comprises 200 temperature cycles between -40°C and +85°C and is often referred to by the abbreviation TC200.

Depending on the speed at which the climate chamber can realize the temperature ramps, the TC200 takes about a month to complete.

The main failure mechanism addressed by the TC test is material fatigue due to different expansion coefficients of the components used in the solar module.

It is common practice in the R&D sector to carry out TC tests with an increased number of cycles. The TC400 and TC600 requirement levels are widespread

The extended TC tests are also used to carry out quality benchmarking.

If the TC test is performed with an increased number of cycles, it is recommended to use the test sequences of IEC TS 63209-1:2021 in order to obtain comparable results.

5.15.2 Implementation

Specifications:

- BOM to be checked
- Number of cycles
- Intermediate measurements
- Pass/fail criterion

5.16 Humidity freeze test

5.16.1 Fundamentals

The humidity freeze test in accordance with IEC 61215 MQT 12 comprises 10 temperature cycles between -40°C and +85°C and is often referred to by the abbreviation HF10. It differs from the TC test in that one cycle lasts 24 hours and the modules are exposed to a high humidity of 85% relative humidity during the 20-hour heat phases.

The HF10 takes ten days to complete.

It is common practice in the R&D sector to carry out HF tests with an increased number of cycles. The requirement levels HF20 and HF30 are widespread.

The extended HF tests are also used to carry out quality benchmarking.

If the HF test is performed with an increased number of cycles, it is recommended to use the test sequences of IEC TS 63209-1:2021 in order to obtain comparable results.

5.16.2 Implementation

Specifications:

- BOM to be checked
- Number of cycles
- Intermediate measurements
- Pass/fail criterion

5.17 UV test

5.17.1 Fundamentals

Ultraviolet (UV) light can affect and damage both the cell and the materials of the modules.

In the area of IEC standards and specifications, the UV tests are designed for material degradation of the polymer materials.

In the de facto standards for market access for a product, IEC 61215 and IEC 61730 provide for MQT 10 with a total dose of 15 kWh/m², which generally does not lead to material defects.

IEC 61730 provides for an extended UV test in Sequence B with the MQT 54. The test specimens are exposed to UV radiation of 60 kWh/m² on both the front and back using the same method as defined in IEC 61215-2 MQT 10. However, IEC 61730 does not provide a pass-fail criterion for the final STC performance measurement.

The IEC TS 63209 specification defines a test branch in which UV irradiation of the rear side is provided. The dose is 180 kWh/m². This test sequence originally addressed the durability of polymer backsheets. For glass-glass laminates, the UV exposure primarily affects the encapsulation material, but it can also have an effect on cells with certain architectures. IEC TS 63209 is described in detail in chapter 4.21.

The backsheet test sequence of the PVEL scorecard contains a UV branch that is almost identical to IEC TS 63209 and covers an irradiation of 195 kWh/m².

All UV tests mentioned so far address material degradation.

UV degradation of cells is mainly observed in younger cell architectures. Exposure to UV light results in a loss of cell performance. This degradation mechanism is not reliably recognized by the current UV tests in the IEC standards and specifications. TÜV Rheinland offers a test for UV sensitivity, especially of the front side of the cell, in accordance with TÜV SPEC 2 Pfg 2944. TÜV SPEC 2 Pfg 2944 specifies a UV dose of 120 kWh/m² on the front side and 60 kWh/m² on the back side.

In principle, UV sensitivity has not been sufficiently tested in the past. The new approaches differ in terms of the addressed defect mode. The design of the UV test sequences in particular has not kept pace with technical developments.

It must be checked in each individual case which test sequence is appropriate for testing a specific product. Depending on the issue at hand, it may make sense to adapt a test sequence to the state of the art.

5.17.2 Implementation

Specifications in TÜV SPEC 2 Pfg 2944:

- Cell type
- BOM to be checked, especially encapsulant and front/rear cover
- Pass/fail criterion STC Power loss

Specifications in IEC TS 63209 and the PVEL Scorecard:

- BOM to be checked, especially encapsulant and front/back cover
- Pass/fail criterion STC Power loss

5.18 Bifaciality test

5.18.1 Fundamentals

The measurement of the bifaciality factors is described in IEC TS 60904-1-2. In practice, the STC power of the front and rear is usually determined and the bifaciality of the STC power, short-circuit current and open-circuit voltage is calculated from this.

P_{max} $\phi_P = P_{maxr}/P_{maxf}$

I_{sc} $\phi_I = I_{SCr}/I_{SCf}$

U_{oc} $\phi_U = U_{OCr}/U_{OCf}$

As a rule, this information is sufficient in many cases. In cases where a high proportion of bifacial yield is to be achieved, it must be taken into account that the losses due to the series resistance do not increase linearly at currents above I_{MPPf}. In these cases, a more differentiated approach may be useful.

IEC TS 60904-1-2 recommends measuring a number of test specimens in order to record any scatter. A measurement uncertainty is not taken into account in these measurements.

5.18.2 Implementation

The specifications in chapter 4.1 apply to the two STC power measurements of the front and rear sides.

The most practical way to determine the bifaciality factors is to measure them in the laboratory. IEC TS 60904-1-2 also describes measurement methods using natural sunlight.

- Determination of the location and measuring device for determining the bifaciality factors.
- Definition of minimum values for the individual measurement and the average values of Φ_{Pmax} and Φ_{Uoc}.

5.19 Mechanical dimension

5.19.1 Fundamentals

The dimensions for the length, width and height as well as their tolerance are specified in the data sheets.

This information is not sufficient to rule out distortion of the PV module to the trapezoid. If the mounting system is sensitive to the geometric shape of the PV modules, a Geometrical Product Specification (GPS) can be carried out.

A shape tolerance can be defined more easily via the GPS than via narrow dimensional tolerances and thus lead to lower production costs.

5.19.2 Implementation

In order to agree a GPS, a drawing must be produced that contains the GPS symbols in accordance with ISO 1101.

5.20 Energy rating

5.20.1 Fundamentals

The IEC 61853-3 standard describes a method for determining the yield of PV modules for various climate profiles defined in IEC 61853-4.

The measurement of the required parameters of a PV module is defined in the IEC 61853-1 and IEC 61853-2 standards.

In IEC 61853-1, these are the power values at 15°C, 25°C, 50°C and 75°C with 100-1,100 W/m² irradiation in each case. Combinations that do not make sense are deleted from the standard.

IEC 61853-2 covers the determination of the spectral sensitivity, the dependence of the power on the angle of incidence and the operating temperature as a function of the operating conditions.

All values determined under IEC 61853-1 and IEC 61853-2 are heavily dependent on the properties of the raw materials used in the construction of the PV modules. If a parameter set is used to predict the yield of a PV module, care must be taken to ensure that the BOM of the DUT corresponds to that of the subsequent product.

The standards also specify methods for determining the parameters under sunlight. This is possible and also useful under certain conditions. As a rule, especially if a result is required within a defined period of time, these measurements are carried out in ISO IEC 17025 accredited test laboratories.

In any case, the parameters should be determined on a sufficient number of test specimens in order to be able to recognize possible scatter. It does not make sense to take measurement uncertainty into account and should be expressly excluded.

5.20.2 Implementation

The parameters that characterize a PV module in accordance with IEC 61853-1/2 can either be provided by the manufacturer or determined on a project-specific basis.

Should be defined:

- Specification of the BOM to be tested
- Selection of the test laboratory
- Optional: Definition of pass criteria that the supplied PV modules must fulfil

5.21 Visual inspection

5.21.1 Fundamentals

Visual inspection is defined as MQT 01 in IEC 61215-2. This form of visual inspection is aimed at clear manufacturing defects or damage caused by stress. IEC 61215-1 Clause 8 lists the anomalies that are considered major and/or critical visual defects.

A visual inspection in accordance with IEC 61215 MQT 01 is primarily carried out as part of the certification test. This procedure plays a subordinate role in quality assurance.

On the other hand, there are visual inspections, which are often carried out on the basis of extensive criteria catalogues at several points in production or by third parties as part of quality assurance. These criteria catalogues are usually provided by the manufacturer and, if necessary, adapted on the basis of individual contractual regulations.

The criteria catalogues for visual inspection in production or at goods receipt usually differentiate between minor, major and critical defects.

Both variants, a test according to IEC 61215 as well as according to agreed fault catalogues, are tests on individual test specimens. This type of test does not define a quota of test specimens that must be free of anomalies.

5.21.2 Implementation

A visual inspection is always carried out end-of-line by the manufacturer on each module as part of quality assurance. In some cases, this is carried out by internal QA staff, while in others, camera-based AI systems are used for these tasks.

After completion of the product, visual inspections are typically carried out at the following locations:

Production site

Modules that have already been packed are unpacked by third parties and subjected to a visual inspection. Suitable areas and aids are provided in the production facilities for this product inspection.

Warehouse/port

After sea transport, handling and, if necessary, storage can take place. In these warehouses, modules can be visually inspected by third parties or by the customer. Some logistics companies specializing in PV modules offer suitable space, equipment and support staff.

Construction site

A visual inspection can be carried out at the incoming goods department on the construction site. These inspections are often carried out by specially authorized third parties or by the employees who are responsible for the installation work.

In addition to the location of the visual inspections, the underlying catalogue of criteria must also be agreed.

5.22 Testing for increased reliability

5.22.1 Fundamentals

5.22.1.1 IEC TS 63209-1

IEC TS 63209-1:2021 is a specification that describes five test branches that go well beyond the type approval testing of IEC 61215 series and the safety related standards as per IEC 61730 series.

The type approval standards are not designed to test whether products have a sufficiently long technical service life with a reasonable probability. IEC TS 63209 closes this gap to a certain extent. Even this specification cannot test towards a specific service life, nor are all known or even possible failure modes covered by the test sequences. In particular, the environmental conditions during operation are not known.

The specification maps the most important error modes, which are complex to test, in a way that should enable a high level of confidence in the products, at least in temperate climate zones.

The structure of the test branches is such that a characterization with STC power measurement, EL imaging, wet leakage current measurement and iso-measurement is carried out at the beginning and end. These measurements are mostly taken from the IEC 61215-2 tests. In between, the modules are loaded with the respective stressors (again, mostly based on the tests foreseen in IEC 61215-2, but with different severity and sequence). The number of test specimens is not specified within IEC TS 63209-1.

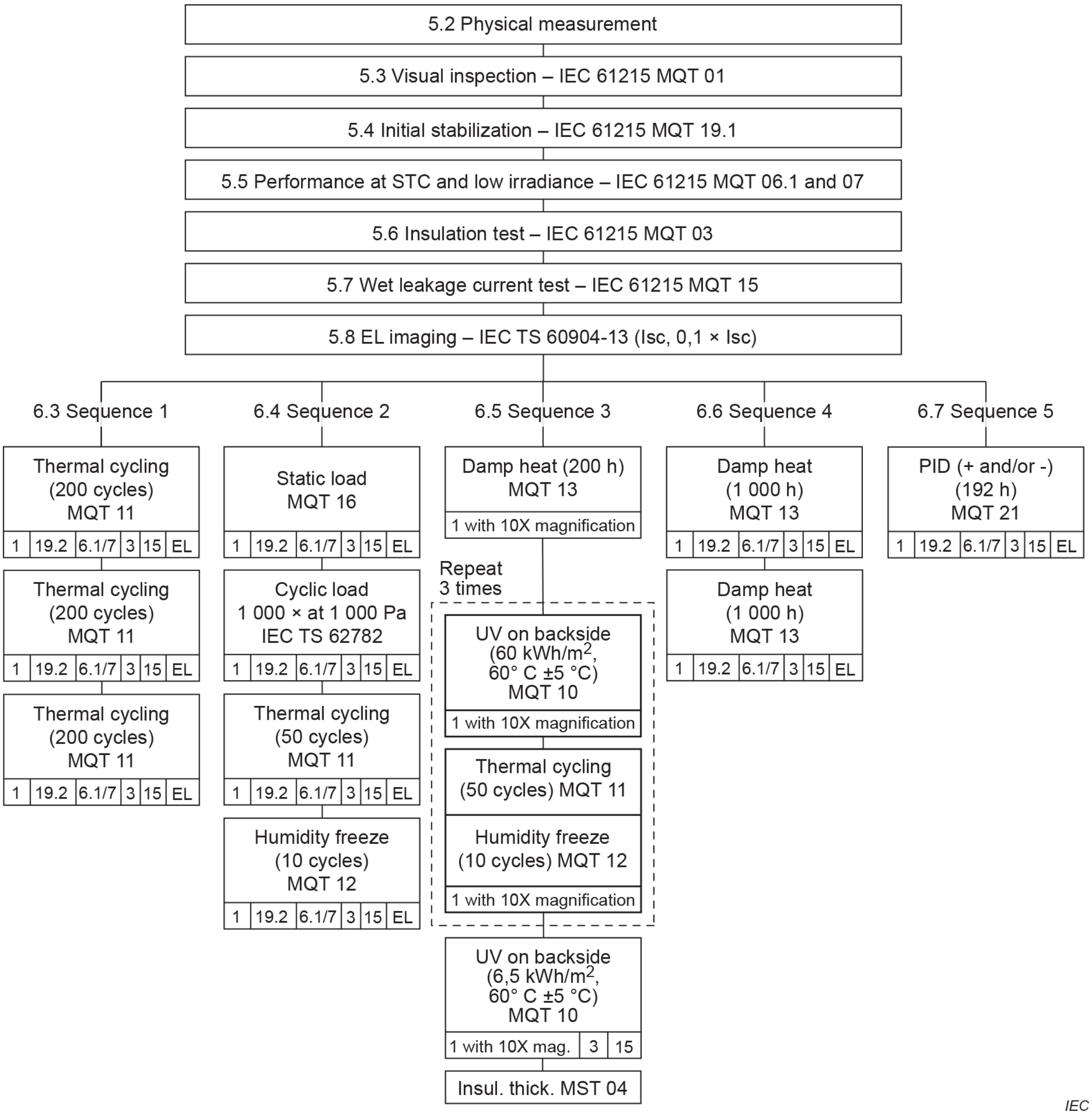

Figure 1 – Test scheme of IEC TS 63209 ((c) IEC)

IEC TS 63209-1 only describes the test procedure; no pass/fail criteria are specified: These must be defined separately for each test branch if necessary. However, a quantity of min. 2 samples per test sequence 1 through 4 appears to be a reasonable balance, whereas min. 4 samples for test sequence 5 would be appropriate (positive and negative testing with each min. 2 samples).

Certain fault modes that are already covered by other IEC specifications are not included in IEC TS 63209-1. In contrast to the tests included in IEC TS 63209-1, these additional tests can all be carried out in a period of less than three weeks.

The most important are

- LeTID, IEC TS 63342:2022
- Salt spray IEC 61701:2020
- Ammonia IEC 62716:2013
- Extended hail test

The test results can only be applied to PV modules produced with the same materials and the same manufacturing processes. The tested materials are not visible in the certificates. However, the associated test report should contain a reference to a document in which the materials used are listed. As a rule, the test specimens should be manufactured under the supervision of the test laboratory or other suitable third parties so that consistent, independently prepared documentation is available.

5.22.1.2 Proprietary standards

The California-based PV Evolution Lab offers a test set under the name Scorecard, which essentially corresponds to IEC TS 63209 but has been expanded to include an LID/LeTID and a hail test that exceeds the minimum requirement of IEC 61215 (D=50mm / v = 32m/s instead of D=25mm / v = 23m/s) but does not achieve the most stringent hail test of IEC 61215.

There are other test sequences aimed at increased reliability according to internal standards of private providers, which hardly differ in content from the two specifically named ones.

International standards and specifications such as those of the IEC have the advantage that they are developed in a transparent process involving all stakeholders.

The standards are also stable over time and generally accessible. Changes are made in a public process. A particular advantage is that recognized certifiers issue certificates based on tests according to IEC standards and specifications. These certificates make it possible to verify at a glance that the complete test program has been completed.

5.22.1.3 Comparison between IEC TS 63209 and proprietary standards

This comparison refers to existing test reports for the 12 months prior to the publication of this VDE SPEC.

Examination	**IEC TS 63209**	**PVEL**
Temperature Cycling (TC)	TC 600	TC 600
Damp Heat (DH)	DH 2000	DH 2000
Mechanical Load	SML2.400, DML1.000, TC50, HF10	SML2.400, DML1.000, TC50, HF10
UV	DH200+3*(UV60, TC50, HF10) + UV6.5	DH1,000 + 3*(UV65, TC50, HF10) + UV6.5
PID	2*IEC61215:2021 (192h)	2*IEC61215:2021 (192h)
LID + LeTID	N/A	3*162h
Hail	N/A	D=50mm / v = 32m/s

Examination	**IEC 61215**	**PVEL**
Diameter [mm]	25/35/45/55/65/75	50
Velocity	23,0/27,2/30,7/33,9/36,7/39,5	32,0

5.22.2 Implementation

Specifications for testing/assessment in accordance with IEC TS 63209.

- BOM to be defined, especially encapsulant and front/rear cover
- Number of test specimens for each test sequence
- Pass/fail criterion STC Power loss for each test sequence
- EL error catalogue with pass/fail criteria for selected test sequences

5.23 Operating conditions with increased module temperature

5.23.1 Fundamentals

The test conditions of IEC 61215-1 and IEC 61730-1 are based on the assumption that the so-called 98th percentile temperature of T_{98} = 70° is reached for a maximum of 2% of the year, i.e. 172.5 hours.

Under certain installation conditions or in certain regions, higher T_{98} temperatures can be reached.

In IEC TS 63126, temperature levels 1 and 2 are defined as T_{98} = 80° and T_{98} = 90° respectively.

IEC TS 63126 does not define any new tests, but adapts the test sequences of the following standards to the increased requirements:

- IEC 61215
- IEC 61730
- IEC 62788-1-7
- IEC 62788-2-1
- IEC 62852
- IEC 62790

5.23.2 Implementation

Specifications for testing in accordance with IEC TS 63126:

- BOM to be checked, especially encapsulant and front/back cover.
- Temperature level to be tested

5.24 Hail test

5.24.1 Fundamentals

The hail test of IEC 61215-2 stipulates a minimum load with test specimens of 25 mm diameter and a speed of 23.0 m/s.

Depending on the place of use, it must be checked whether this resistance to hail is sufficient. IEC 61215-2 specifies a total of six load classes. The test report for the IEC 61215 certificate states the ice ball diameter and impact velocity with which the PV module was tested.

Diameter [mm]	Test speed [m/s]
25	23,0
35	27,2
45	30,7
55	33,9
65	36,7
75	39,5

If the hail test is not sufficient for a location in the course of product certification, an individual test in accordance with IEC 61215-2, MQT17 can be carried out.

The pass/fail criteria of IEC 61215 are aimed at safety aspects. If performance or service life aspects are to be taken into account, this must be agreed.

5.24.2 Implementation

Specifications:

- BOM to be defined
- Test sharpness (diameter/test speed)
- Max. permissible loss of STC power
- EL imaging and, if applicable, EL error catalogue with pass/fail criteria

5.25 Non-uniform snow load test

The non-uniform snow load test is standardized in IEC 62938. Testing in accordance with IEC 62938 only makes sense in a few regions. For ground-mounted systems, this standard is only used very rarely and then in very specific applications, so it is not considered in detail here. If this is carried out, then a test can only be meaningfully carried out in relation to a specific object and a specific installation situation. In this case, an appropriate time and cost framework must be planned in good time.

5.26 Salt mist corrosion testing

Testing in accordance with the IEC 61701 standard for salt spray corrosion is useful for PV modules used in a humid and corrosive environment where the module is exposed to salt. This applies in particular, when the modules are planned to be exposed close to the coastline and a major immersion of salt and humidity is obvious.

This can be near the sea or other large bodies of water with salt water. However, installation, e.g. in noise barriers at the roadside where road salt is used in winter, can also lead to salt contamination of the PV modules.

Re-testing of project modules is rather unusual. As a rule, the certificate for an IEC 61701 test is requested if required. Here too, an IEC 61701 certificate is only meaningful if the parts list of the test specimen matches that of the PV modules supplied, at least for the components that may be exposed to salt mist attack or direct saltwater wetting.

Depending on the specific exposure to salt corrosion, one of the test methods 5-8 may be useful to assess the suitability of the PV modules. As a rule, methods five and six will be appropriate for stationary mounted PV modules. Methods seven and eight have been developed for vehicles. Their direct applicability would therefore appear to be particularly useful if PV modules are used on vehicles or ships. However, the choice of the appropriate method should always depend on a case-by-case assessment.

5.27 Ammonia corrosion testing

Testing according to the IEC 62716 standard for ammonium corrosion is useful for PV modules that are used in an environment that is humid and corrosive with ammonia contamination. A retest of project modules is rather uncommon. The total duration of the test is almost one month. As a rule, the certificate for an IEC 62716 test will be requested if required. In this case too, an IEC 62716 certificate is only meaningful if the BOM of the DUT matches that of the PV modules supplied, at least for the components that may be exposed to ammonia attack.

6 Standard market QA schemes

6.1 Sample Testing

A standard market procedure has emerged for sample testing of PV modules in the area of small and medium-sized ground-mounted systems.

The quantities are roughly based on ISO 2859 with level S-4 for STC power and EL and level S-1 for the more complex tests. For systems up to 10 MWp, the scope is reduced below level S-1 with 3 test specimens per test.

For reasons of practicality, the S-4 quantities are rounded to whole pallets so that the original packaging can be used for transport to the laboratory.

In the case of large power plants, the number of test specimens is often reduced to a value below the S-1 level for cost-intensive tests such as PID or LeTID.

In relation to the pure module costs, the costs are roughly estimated at between 2% for a 2 Mp system and 0.2% for a 50 MWp system.

Power	STC	EL	P@200 W/m²	STC back	PID	LeTID	Crosslinking	Peel-Off
MWp	Pallets	Pallets	Piece	Piece	Piece	Piece	Piece	Piece
2	1	1	3	3	3	3	3	3
10	1	1	3	3	3	3	3	3
20	2	2	5	5	5	5	5	5
50	3	3	8	8	8	8	8	8

The following pass/fail values must also be agreed:

- Average STC power in relation to the rating plate
- Relative efficiency at 200 W/m² (average)
- Minimum rear STC power in relation to the STC power according to the rating plate (average)
- Maximum loss of STC power in the PID test. It is recommended that no measurement uncertainty is taken into account
- Maximum loss of STC power in the LeTID test. It is recommended that no measurement uncertainty is taken into account
- Minimum degree of cross-linking. In order to agree on a criterion here, it is necessary to know the embedding material
- Minimum pull-off force of the embedding material from the glass. This test is not required for glass-glass modules

Note: This example is based on the practice of laboratory testing, as is currently common in the recipient country.

Further tables are provided in Annex B in order to fine-tune the quantities for both system-related and batch-related testing.

6.2 Incoming goods on the construction site

Today, there is no standardized treatment of whether or not an incoming goods inspection is carried out on the construction site.

One way would be to take a random sample per truck for incoming goods inspections at the construction site (e.g. visual inspection, 2 modules for power measurement and/or 5 modules for EL measurement) The testing is sometimes not necessarily executed by an accredited laboratory.

Ultimately, all of this is dependent on contractual agreements between manufacturer and customer and this leads to a large variety observed in the market today.

6.3 STC-power measurement with increased confidence

Project-specific reference modules can be used for large power plant projects. The fact that these are almost identical ensures STC power measurement that is as precise as is currently economically possible.

The manufacturer produces at least five PV modules that are identical to the later products in terms of the cells and the parts list. This must take place approx. 1-2 months before the start of production in order to allow sufficient time for the calibration process. These modules must be completely free of microcracks. In addition, two test specimens must be produced for a spectral response measurement according to the specification of the selected calibration laboratory. The PV modules are stabilized by the manufacturer.

The modules are sent to an ISO IEC 17025 accredited calibration laboratory, which can also offer a spectral response measurement in 10 nm steps.

Three of the modules are selected according to their suitability as reference modules and, if necessary, re-stabilized. For very large projects, it may make sense to order several reference modules.
The STC power measurement at the front side is then carried out with high precision.
The maximum permissible measurement uncertainty (k=2) of the STC power is 1.4%.
There are also calibration laboratories that offer precision measurements with a measurement uncertainty of 1.1%, 1.0%, 0.9% and 0.8%. The costs rise sharply with every 0.1% step, so that an optimum must be sought here.

One of the three modules is selected randomly and sent directly to the customer by the test laboratory, while the others are sent to the manufacturer.

Of the two reference modules that the manufacturer receives, one is used to produce the silver references that are used to calibrate the solar simulators in production. The manufacturer is responsible for the correct realization of the front side measurement.

The other reference module must be kept in production. This module is used to calibrate the sun simulator in production, which is intended for remeasurement of the STC performance by a customer inspector. At the customer's discretion, this remeasurement can be organized with auxiliary equipment in such a way that a front-only measurement is carried out by covering the rear sides. The test specimens can either be removed from the warehouse or taken directly from production after the final measurement. In relation to daily production, a daily random sample of level S-1 of ISO 2859 can be taken for this control measurement.

Annex A: Check-List

The Annex lists the customary or senseful characteristics of the above criteria for each section.

The characteristics that are either recommended by standards or represent an average characteristic are shown in bold.

Clause	Item	Characteristics	
5.1	5.1.2.1 STC power during production	Origin of reference module	☐ WPVS calibration laboratory ☐ **ISO 17025 calibration laboratory** ☐ ISO 17025 test laboratory Reference is traceable to: Note:
		Uncertainty of measurement of the laboratory providing the reference module	☐ max. 2,2% ☐ **max. 1,5%** ☐ max. 1,0%
		Golden reference module matches the module and cell type, size and power class (± 10 Wp)	☐ **Yes** ☐ No
		Silver reference for use in production. Witness calibration	☐ Yes ☐ No Note:
		Control procedure applied for the correct consideration of bifaciality	☐ Yes ☐ No
		Silver Reference module matches the module and cell type, size and power-class (± 10 Wp)	☐ **Yes** ☐ No Note:
		Data provided	☐ **Calibration report of golden reference** ☐ BOM of golden reference ☐ Handling of bifaciality ☐ Spectral response (SR) ☐ BOM of silver reference ☐ Record of stabilisation process
		Note:	

Clause	Item	Characteristics	
5.1	5.1.2.2 – 5.1.2.5 STC power measurement after production	Place of measurement	☐ witness measurement in the accredited laboratory in the production ☐ ISO 17025 accredited laboratory pre-shipment ☐ **ISO 17025 accredited laboratory post-shipment** ☐ Harbour test centre ☐ ISO 17025 accredited laboratory Mobile test device on construction site ☐ Mobile test device on construction site ☐ **Other**
		Origin of reference module/ reference cell (WPVS cell)	☐ **WPVS calibration laboratory** ☐ **ISO 17025 calibration laboratory** ☐ ISO 17025 test laboratory Reference is traceable to: Note:
		Uncertainty of measurement of the laboratory providing the reference module/reference cell	☐ max. 2,2% ☐ max. 1,8% ☐ max. 1,5% ☐ **max. 1,0%** ☐ max. 0,5%
		Uncertainty of measurement of the STC power measurements	☐ max. 7,0% (outdoor measurement only) ☐ max. 5,0% (outdoor measurement only) ☐ max. 3,0% ☐ **max. 2,2%** ☐ max. 1,8% ☐ max. 1,5% ☐ Other:
		Is the uncertainty of measurement calculated or verified by an ISO 17025 accredited laboratory	☐ **Yes** ☐ No
		Reference module matches the module and cell type, size and power class (± 10 Wp)	☐ Yes ☐ No
			If no, is there a spectral mismatch correction ☐ Yes ☐ No

Clause	Item	Characteristics	
		Data provided	☐ **Accreditation** ☐ Calibration report of golden reference ☐ BOM of reference or Spectral response or EQE ☐ Handling of bifaciality ☐ Record of stabilisation process
		Sampling:	☐ ISO 2859-1, General Level I ☐ ISO 2859-1, General Level II ☐ **ISO 2859-1, Level S4** ☐ Other: Specification of how the test specimens are selected**:**
		Calculation of average STC power	☐ **The measurement uncertainty is assumed to be 0% for a sample size of more than 50 modules** ☐ The measurement uncertainty of the laboratory is multiplied by a factor of 1,65/2,00 before it is applied to the measurement result ☐ The measurement uncertainty of the laboratory is applied to the measurement result
		Cost for STC-measurement	☐ Costs are borne by the supplier ☐ Costs are shared between supplier and customer ☐ Costs are borne by the customer ☐ Other specification:
		Note:	

Clause	Item	Characteristics	
5.2	5.2.2.1 Electroluminescence (EL) during production	Current	☐ I_{SC} ☐ 10 A ☐ Other:
		Resolution of the Camera-Sensor	☐ min. 6 MPixel ☐ **min. 12 MPixel** ☐ min. 20 MPixel
		EL-Reference module	☐ Yes ☐ **No**
		Sharpness class, IEC TS 60904-13:2018, clause 4.2.1.2	☐ **N/A** ☐ ≤ 0,5 mm ☐ ≤ 1,5 mm ☐ ≤ 5,0 mm
		Signal to noise ratio (SNR), IEC TS 60904-13:2018, clause 4.3	☐ **N/A** ☐ SNR_{50} ≥ 5 (outdoor) ☐ SNR_{50} ≥ 15 (Industrial/process control/QA) ☐ SNR_{50} ≥ 45 (Laboratory/certification)
		Access to EL images	☐ **EL-images accessible for inspection in the factory** ☐ EL-images provided for download daily ☐ **EL-images provided for download weekly** ☐ EL-images provided for download after production run ☐ N/A
		Data provided	☐ Accepted Temperature (ambient) ☐ **EL defect catalogue incl. Pass/Fail criteria** ☐ Sharpness class ☐ SNR ☐ EL image of EL-reference module
		Defect catalogue	☐ Suppliers catalogue (version) ☐ **Catalogue agreed by the parties (version)**
		Rate of modules free of animalities	☐ 98% ☐ **99%** ☐ 99,5% ☐ 99,8%
		Note: (definition of anomalies)	

Clause	Item	Characteristics	
5.2	5.2.2.2 – 5.2.2.5 Electroluminescence (EL) for QA	Location of the examination	☐ Harbor/Warehouse ☐ **Construction site** ☐ After assembly
		Service provider	☐ Accredited third parties ISO 17020 or 17025 ☐ Other third party ☐ By customer
		Current	☐ I_{SC} ☐ **10 A** ☐ Other:
		Resolution of the Camera-Sensor	☐ min. 6 MPixel ☐ **min. 12 MPixel** ☐ min. 20 MPixel
		EL-Reference module	☐ Yes ☐ **No**
		Sharpness class, IEC TS 60904-13:2018, clause 4.2.1.2	☐ **N/A** ☐ ≤ 0,5 mm ☐ ≤ 1,5 mm ☐ ≤ 5,0 mm
		Signal to noise ratio (SNR), IEC TS 60904-13:2018, clause 4.3	☐ **N/A** ☐ SNR_{50} ≥ 5 (outdoor) ☐ SNR_{50} ≥ 15 (Industrial/process control/QA) ☐ SNR_{50} ≥ 45 (Laboratory/certification)
		Access to EL images	☐ EL-images provided for download daily ☐ **EL-images provided for download weekly** ☐ EL-images provided for download after the QA process. ☐ N/A
		Data provided	☐ Accepted Temperature (ambient) ☐ EL defect catalogue incl. Pass/Fail criteria ☐ Sharpness class ☐ SNR ☐ EL image of EL-reference module
		Failure catalogue	☐ Suppliers catalogue (version) ☐ **Catalogue agreed by the parties (version)** ☐ Other:

Clause	Item	Characteristics	
5.3	Performance at low irradiance IEC 61215 MQT 07	Minimum value for η_{rel200}	☐ 95% ☐ **96%** ☐ 97% ☐ 98% ☐ Other: _______%
		Considered measurement uncertainty	☐ **0,0%** ☐ 0,5% ☐ Other: _______%

Clause	Item	Characteristics	
5.4	PID IEC TS 62804-1	Method	☐ **Method A** ☐ Method B
		Simplified procedure	☐ **Yes** ☐ No
		Deviating parameters	☐ No ☐ 85°C, 85 RH, 96h ☐ Specify:
		Max. STC-power loss	☐ 2% ☐ **3%** ☐ 5%
		Uncertainty of measurement	☐ **0%** ☐ 0,5% ☐ Other: _______%

Clause	Item	Characteristics	
5.5	LeTID IEC TS 63342:2022	Simplified procedure	☐ **Yes** ☐ No
		Max. STC-power loss CID	☐ **1,0%** ☐ 1,5% ☐ 2,0% ☐ Other: _______%
		Max. STC-power loss LeTID	☐ 1,0% ☐ **1,5%** ☐ 2,0% ☐ Other: _______%
		Uncertainty of measurement	☐ **0%** ☐ 0,5% ☐ Other: _______%

Clause	Item	Characteristics	
5.6	LID IEC 61215 MQT 19	Simplified procedure IEC TS 63342, clause 6.4 (CID)	☐ **Yes** ☐ No
		Max. STC-power loss	☐ **0,8%** ☐ **1,0%** ☐ 1,5% ☐ Other: _______%
		Uncertainty of measurement	☐ **0%** ☐ 0,5% ☐ Other**:** _______%

Clause	Item	Characteristics	
5.7	Crosslinking IEC 62788-1-6	Simplified procedure	☐ **Yes** ☐ No
		Encapsulant	☐ EVA ☐ POE ☐ EPE ☐ mix ☐ N/A
		Crosslinking rate (material combination to be considered)	☐ 65% ☐ 70% ☐ **75%** ☐ 80% ☐ 85% ☐ Other: _______%
		Uncertainty of measurement	☐ **5%** ☐ Other**:** _______%

Clause	Item	Characteristics	
5.8	Peel test Interface encapsulant-glass	Test sample	☐ PV Module ☐ Special test sample Specification:
		Measuring device	☐ Hand-held device (drag indicator) ☐ **Automatic pull test**
		Relevant value	☐ Peak-value ☐ **Average value of peel-off plateau**
		Minimum peel-off force, at 175° +/- 5° direction [N/10mm]	☐ 60 N/10mm ☐ 80 N/10mm ☐ **100 N/10mm** ☐ Other: ________ N/10mm

Clause	Item	Characteristics	
5.9	Insulation test IEC 61215 MQT 03	Max. system voltage	☐ 1.000 V ☐ 1.500 V ☐ Other:
		Simplified procedure	☐ No ☐ **Yes, specification:**

Clause	Item	Characteristics	
5.10	Wet Leakage Current Test IEC 61215 MQT 15	Max. system voltage	☐ 1.000 V ☐ 1.500 V ☐ Other:
		Permissible deviation of the water temperature	☐ ± 2°C ☐ **± 5°C** ☐ ± 10°C
		PASS Criterium	☐ 40 MΩ·m^2 ☐ **750 MΩ** ☐ 1.000 MΩ· ☐ Other**:** ___________ MΩ·m^2
		Testing incl. Connectors submerged	☐ **Yes** ☐ No

Clause	Item	Characteristics	
5.11	Connector Wet Leakage Current Test IEC 61215 MQT 15	Max. system voltage	☐ 1.000 V ☐ 1.500 V ☐ Other:
		Permissible deviation of the water temperature	☐ **± 5°C** ☐ 15-30°C
		PASS Criterium	☐ **750 MΩ** ☐ 1.000 MΩ· ☐ Other**:** ___________ MΩ

Clause	Item	Characteristics	
5.12	Static mechanical load test IEC 61215 MQT 16	Is the mounting situation specified	☐ standard mounting situation according to installation manual of the manufacturer: ☐ Yes, specification:
		Positive test load, pressure (+) (test load)	☐ 2.400 Pa ☐ 3.600 Pa ☐ **5.400 Pa** ☐ 8.100 Pa ☐ Other:__________ Pa
		Negative test load, suction (-) (test load)	☐ **2.400 Pa** ☐ 3.600 Pa ☐ 5.400 Pa ☐ 8.100 Pa ☐ Other: __________ Pa
		Safety factor γm	☐ 1,25 ☐ **1,5** ☐ 2,0 ☐ 2,5 ☐ Other: __________
		Max. STC-power loss	☐ 1,0**%** ☐ **1,5%** ☐ 2,0**%** ☐ Other: _______ %
		EL acceptance criteria	☐ none ☐ Suppliers catalogue (version): ☐ **Catalogue agreed by the parties (version):**

Clause	Item	Characteristics	
5.13	Cyclic dynamic load test IEC TS 62782:2016	Is the mounting situation specified?	☐ No ☐ Yes, specification:
		Max. STC-power loss	☐ 1,0% ☐ **1,5%** ☐ 2,0% ☐ Other: _______ %
		EL acceptance criteria	☐ none ☐ Suppliers catalogue (version): ☐ **Catalogue agreed by the parties (version):**

Clause	Item	Characteristics	
5.14	Damp Heat Test IEC 61215 MQT 13	BOM defined as in purchase contract	☐ **Yes** ☐ No
		Max. STC-power loss after DH1.000	☐ **1,0%** ☐ 1,5% ☐ 2,0% ☐ Other: _______ %
		Extension	☐ DH 1500 ☐ **DH 2000**
		Max. STC-power loss after extension	☐ 1,0% ☐ 1,5% ☐ **2,0%** ☐ Other: _______ %

Clause	Item	Characteristics	
5.15	Temperature Cycling Test IEC 61215 MQT 11	BOM defined as in purchase contract	☐ **Yes** ☐ No
		Max. STC-power loss after TC200	☐ **1,0%** ☐ 1,5% ☐ 2,0% ☐ Other: _______ %
		Extension	☐ TC400 ☐ **TC600** ☐ TC800

Clause	Item	Characteristics	
5.15	Temperature Cycling Test IEC 61215 MQT 11	Max. STC-power loss after extension	☐ 1,0% ☐ 1,5% ☐ **2,0%** ☐ Other: _______ %

Clause	Item	Characteristics	
5.16	Humidity Freeze Test IEC 61215 MQT 12	BOM defined as in purchase contract	☐ **Yes** ☐ No
		Max. STC-power loss after HF10	☐ **1,0%** ☐ 1,5% ☐ 2,0% ☐ Other: _______ %
		Extension	☐ HF20 ☐ **HF30** ☐ HF50
		Max. STC-power loss after extension	☐ 1,0% ☐ 1,5% ☐ **2,0%** ☐ Other: _______ %

Clause	Item	Characteristics	
5.17	UV Test IEC 61730 MQT 54	BOM defined as in purchase contract	☐ **Yes** ☐ No
		Extension front side	☐ **60 kWh/m²** ☐ 90 kWh/m²
		Max. STC-power loss after MQT 54	☐ **1,5%** ☐ 2,0% ☐ 2,5% ☐ Other: _______ %
		Extension front side	☐ **120 kWh/m²** ☐ 180 kWh/m²
			☐ 1,5% ☐ **2,0%** ☐ 3,0% ☐ Other: _______ %

Clause	Item	Characteristics	
5.18	Bifacial Factor IEC TS 60904-1-2	Number of DUT	☐ 1 ☐ 3 ☐ 5 ☐ Other: _______
		ϕ_{Pmax}	☐ 95% ☐ 90% ☐ 80% ☐ Other: _______ %
		ϕ_{Isc}	☐ 95% ☐ 90% ☐ 80% ☐ Other: _______ %
		ϕ_{Uoc}	☐ 95% ☐ 90% ☐ 80% ☐ Other: _______ %

Clause	Item	Characteristics	
5.19	Geometrical Product Specification (GPS) ISO 1101	Is a GPS agreed	☐ Yes ☐ **No**
		If yes, name document of specification	

Clause	Item	Characteristics	
5.20	Energy rating IEC 61853-1	Origin of parameters	☐ supplier ☐ **ISO 17025 test laboratory** ☐ ISO 17025 calibration laboratory
		BOM specified	☐ **Yes** ☐ No
		Are Pass/Fail criteria agreed on?	☐ **Yes** ☐ No If yes, specify document with the criteria:
	Energy rating IEC 61853-2	Origin of parameters	☐ supplier ☐ **ISO 17025 test laboratory** ☐ ISO 17025 calibration laboratory

Clause	Item	Characteristics	
5.20	Energy rating IEC 61853-2	BOM specified	☐ **Yes** ☐ No
		Are Pass/Fail criteria agreed on?	☐ **Yes** ☐ No If yes, specify document with the criteria:

Clause	Item	Characteristics	
5.21	Visual Inspection (VI)	Criteria	☐ IEC 61215, MQT01 ☐ Criteria catalogue of the manufacturer ☐ Project specific criteria catalogue Note:
		Place of the inspection	☐ **Production site** ☐ Harbour, on arrival ☐ **Construction site, on arrival** ☐ Other: ________________

Clause	Item	Characteristics	
5.22	Photovoltaic modules - Extended-stress testing, IEC TS 63209-1	BOM defined	☐ **Yes** ☐ No
		Number of DUT sequence 1	☐ **2** ☐ 3 ☐ 5 ☐ Other: _______
		Number of DUT sequence 2	☐ **2** ☐ 3 ☐ 5 ☐ Other: _______
		Number of DUT sequence 3	☐ **2** ☐ 3 ☐ 5 ☐ Other: _______

Clause	Item	Characteristics	
5.22	Photovoltaic modules - Extended-stress testing, IEC TS 63209-1	Number of DUT sequence 4	☐ **2** ☐ 3 ☐ 5 ☐ Other: _______
		Number of DUT sequence 5	☐ **2** ☐ 3 ☐ 5 ☐ Other: _______
		Max. STC-power loss after sequence 1	☐ 3,0% ☐ **2,0%** ☐ 1,5% ☐ Other: _______ %
		Max. STC-power loss after sequence 2	☐ 3,0% ☐ **2,0%** ☐ 1,5% ☐ Other: _______ %
		Max. STC-power loss after sequence 3	☐ 3,0% ☐ **2,0%** ☐ 1,5% ☐ Other: _______ %
		Max. STC-power loss after sequence 4	☐ 3,0% ☐ **2,0%** ☐ 1,5% ☐ Other: _______ %
		Max. STC-power loss after sequence 5	☐ 3,0% ☐ **2,0%** ☐ 1,5% ☐ Other: _______ %

Clause	Item	Characteristics	
5.23	Guidelines for qualifying PV modules, components and materials for operation at high temperatures IEC TS 63126	BOM defined	☐ **Yes** ☐ No
		Temperature Level	☐ Temperature Level 0 < 70°C ☐ Temperature Level 1 < 80°C ☐ Temperature Level 2 < 90°C

Clause	Item	Characteristics	
5.24	Hail Test IEC 61215-2 MQT 17	BOM defined	☐ **Yes** ☐ No
		Ice balls, diameter [mm]	☐ 25 ☐ 35 ☐ **45** ☐ 55 ☐ 65 ☐ 75
		Velocity[m/s]	☐ 23,0 ☐ 27,2 ☐ **30,7** ☐ 33,9 ☐ 36,7 ☐ 39,5
		Max. STC-power loss	☐ 0,8% ☐ **1,0%** ☐ 1,5**%** ☐ 2,0**%** ☐ Other: _______ %
		EL acceptance criteria	☐ none ☐ Suppliers catalogue (version): ☐ **Catalogue agreed by the parties (version):**

Clause	Item	Characteristics	
5.25	Non-uniform snow load test IEC 62938	Applicable	☐ No ☐ Yes Document of specification:

Clause	Item	Characteristics	
5.26	Salt mist corrosion testing IEC 61701	Applicable	☐ No ☐ Yes Certificate No.:
		Conformity of the BOM	☐ No ☐ **Yes**
		Test method	☐ Method 5 ☐ **Method 6** ☐ Method 7 ☐ Method 8

Clause	Item	Characteristics	
5.27	Ammonia corrosion testing IEC 62716	Applicable	☐ No ☐ Yes Certificate No.:
		Conformity of the BOM	☐ No ☐ **Yes**

Annex B: (informative) Optional Template for Suitable Random Samples

Annex B provides an optional template for suitable random samples for both system-orientated and batch-orientated testing. Batch-oriented random sampling is based on an assumed number of seven batches. If there is a different number of product lots, the sample size can be easily adjusted by selecting the values from a higher or lower row.

Within a field of the tables below, there is a choice between reduced, normal, and tightened inspection.

An inspection procedure can be agreed in which the normal level is started and, depending on the progress, the level is adjusted to reduced or tightened after at least three inspection rounds.

Table B 1 – Number of samples for power plant-oriented testing. Reduced, normal and tightened inspection level

	STC	**EL**	**P@200 W/m²**	**STC rear**	**PID**	**LeTID**	**WL**	**cross link**	**Peel-Off**
waived	☐	☐	☐	☐	☐	☐	☐	☐	☐
MWp	**Pallets**	**Pallets**	**Piece**	**Piece**	**Piece**	**Piece**	**Piece**	**Piece**	**Piece**
2	1	1	☐ **2** ☐ 3 ☐ 4	☐ **2** ☐ 3 ☐ 4	☐ **2** ☐ 3 ☐ 4	☐ **2** ☐ 3 ☐ 4	☐ **2** ☐ 3 ☐ 4	☐ **2** ☐ 3 ☐ 4	☐ **2** ☐ 3 ☐ 4
20	☐ **1** ☐ 2 ☐ 3	☐ **1** ☐ 2 ☐ 3	☐ **3** ☐ 5 ☐ 8	☐ **3** ☐ 5 ☐ 8	☐ **3** ☐ 5 ☐ 8	☐ **3** ☐ 5 ☐ 8	☐ **3** ☐ 5 ☐ 8	☐ **3** ☐ 5 ☐ 8	☐ **3** ☐ 5 ☐ 8
50	☐ **2** ☐ 3 ☐ 4	☐ **2** ☐ 3 ☐ 4	☐ **5** ☐ 8 ☐ 13	☐ **5** ☐ 8 ☐ 13	☐ **5** ☐ 8 ☐ 13	☐ **5** ☐ 8 ☐ 13	☐ **5** ☐ 8 ☐ 13	☐ **5** ☐ 8 ☐ 13	☐ **5** ☐ 8 ☐ 13
100	☐ **3** ☐ 4 ☐ 5	☐ **3** ☐ 4 ☐ 5	☐ **8** ☐ 13 ☐ 20	☐ **8** ☐ 13 ☐ 20	☐ **8** ☐ 13 ☐ 20	☐ **8** ☐ 13 ☐ 20	☐ **8** ☐ 13 ☐ 20	☐ **8** ☐ 13 ☐ 20	☐ **8** ☐ 13 ☐ 20

Table B 2 – Number of samples for batch-oriented testing. Reduced, normal and tightened inspection level

	STC	EL	P@200 W/m²	STC rear	PID	LeTID	WL	cross link	Peel-Off
waived	☐	☐	☐	☐	☐	☐	☐	☐	☐
MWp	**Piece**	**Piece**	**Piece**	**Piece**	**Piece**	**Piece**	**Piece**	**Piece**	**Piece**
5	☐ **2** ☐ 3 ☐ 5	☐ **2** ☐ 3 ☐ 5	☐ **1** ☐ 2 ☐ 3	☐ **1** ☐ 2 ☐ 3	☐ **1** ☐ 2 ☐ 3	☐ **1** ☐ 2 ☐ 3	☐ **1** ☐ 2 ☐ 3	☐ **1** ☐ 2 ☐ 3	☐ **1** ☐ 2 ☐ 3
10	☐ **3** ☐ 5 ☐ 8	☐ **3** ☐ 5 ☐ 8	☐ **2** ☐ 3 ☐ 5	☐ **2** ☐ 3 ☐ 5	☐ **1** ☐ 2 ☐ 3	☐ **1** ☐ 2 ☐ 3	☐ **1** ☐ 2 ☐ 3	☐ **1** ☐ 2 ☐ 3	☐ **1** ☐ 2 ☐ 3
20	☐ **5** ☐ 8 ☐ 13	☐ **5** ☐ 8 ☐ 13	☐ **3** ☐ 5 ☐ 8	☐ **3** ☐ 5 ☐ 8	☐ **2** ☐ 3 ☐ 5	☐ **2** ☐ 3 ☐ 5	☐ **2** ☐ 3 ☐ 5	☐ **2** ☐ 3 ☐ 5	☐ **2** ☐ 3 ☐ 5
30	☐ **8** ☐ 13 ☐ 20	☐ **8** ☐ 13 ☐ 20	☐ **3** ☐ 5 ☐ 8	☐ **3** ☐ 5 ☐ 8	☐ **2** ☐ 3 ☐ 5	☐ **2** ☐ 3 ☐ 5	☐ **2** ☐ 3 ☐ 5	☐ **2** ☐ 3 ☐ 5	☐ **2** ☐ 3 ☐ 5

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