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TECHNICAL SPECIFICATION

Photovoltaic system performance –
Part 2: Capacity evaluation method

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PHOTOVOLTAIC SYSTEM PERFORMANCE –

Part 2: Capacity evaluation method

FOREWORD

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- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 61724-2, which is a technical specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
82/1101/DTS	82/1159/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61724 series, published under the general title *Photovoltaic system performance*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

The performance of a PV system is dependent on the weather, seasonal effects, and other intermittent issues, so measurement of the performance of a PV system is expected to give variable results. IEC 62446-1, *Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance – Part 1 Grid connected – Documentation, commissioning tests and inspection*, describes a procedure for ensuring that the plant is constructed correctly, but does not attempt to verify that the output of the plant meets the design specifications. IEC 61724-1[1], *Photovoltaic system performance – Part 1: Monitoring*, defines the performance data that may be collected, but does not define how to analyze that data in comparison to predicted performance. ASTM E2848-13 *Standard test method for reporting photovoltaic non-concentrator system performance* describes a method for determining the power output of a photovoltaic system based on a regression. IEC TS 61724-3 *Photovoltaic system performance – Part 3: Energy evaluation method* describes a one-year test that evaluates performance over the full range of operating conditions and is the preferred method for evaluating system performance. However, it is essential that plant performance can also be quantified with a shorter test, even if there can be higher uncertainty associated with that test. This document is designed to complete an evaluation in a short time as a complement to IEC TS 61724-3. As a capacity test, it measures power (not energy) at a specified set of reference conditions (which can differ from standard test conditions that have been designed to facilitate indoor measurements). The method in IEC TS 61724-2 is a non-regression-based method for determining power output.

This method uses the design parameters of the plant to quantify a correction factor for comparing the plant’s measured performance to the performance targeted under reference conditions. In other words, the measured performance, adjusted by the correction factor, is then compared with the target plant performance to identify whether the plant operates above or below expectations at the target reference conditions.

Multiple aspects of PV system quality are dependent on both the weather and the system's quality, so it is essential to have a clear understanding of the system being tested. For example, the module temperature is primarily a function of irradiance, ambient temperature, and wind speed, all of which are weather effects that can be difficult to simulate precisely. However, the module-mounting configuration also affects the module temperature, and the mounting is an aspect of the system that is being tested. This document presents a process for test development and clarifies how measurement choices can affect the outcome of the test so that users can benefit from streamlined test design with consistent definitions, while still allowing flexibility in the application of the test so as to accommodate as many unique installations as possible.

It is to be noted that when the output of a PV system exceeds the capability of the inverter, the output of the system is defined more by the inverter operation than by the PV modules. In this case, the measurement of the capacity of the plant to generate electricity is complicated by the need to differentiate situations in which the inverter is saturated and when the output of the PV system reflects the module performance. For PV plants with high DC-to-AC power ratios, the operation of the plant can reflect the capability of the inverters for the majority of the day, with the capability of the DC array only being measurable for a short time in the morning and in the evening. In this case, it can be necessary to disconnect parts of the DC array to reduce the DC-to-AC power ratio during the measurement period.

IEC TS 61724-2 is applicable to times when the system is fully available.

Methods presented in this document can be used in place of ASTM E2848-13 to determine photovoltaic system performance.

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1 Under preparation. Stage at time of publication: IEC/FDIS 61724-1:2016

PHOTOVOLTAIC SYSTEM PERFORMANCE –

Part 2: Capacity evaluation method

1 Scope

This part of IEC 61724 defines a procedure for measuring and analyzing the power production of a specific photovoltaic system with the goal of evaluating the quality of the PV system performance. The test is intended to be applied during a relatively short time period (a few relatively sunny days).

In this procedure, actual photovoltaic system power produced is measured and compared to the power expected for the observed weather based on the design parameters of the system. The expected power under reference and measured conditions are typically derived from the design parameters that were used to derive the performance target for the plant as agreed to prior to the commencement of the test. For cases when a power model was not developed during the plant design, a simple model that increases transparency is presented in the annexes as a possible approach.

The intent of this document is to specify a framework procedure for comparing the measured power produced against the expected power from a PV system on relatively sunny days. This test procedure is intended for application to grid-connected photovoltaic systems that include at least one inverter and the associated hardware.

The performance of the system is quantified both during times when the inverters are maximum-power-point tracking and during times when the system power is limited by the output capability of the inverter or interconnection limit, reducing the system output relative to what it would have been with an inverter with generation freely following irradiance, if this condition is relevant.

This procedure can be applied to any PV system, including concentrator photovoltaic systems, using the irradiance (direct or global) that is relevant to the performance of the system.

This test procedure was designed and drafted with a primary goal of facilitating the documentation of a performance target, but it can also be used to verify a model, track performance (e.g., degradation) of a system over the course of multiple years, or to document system quality for any other purpose. The terminology has not been generalized to apply to all of these situations, but the intent is to create a methodology that can be used whenever the goal is to verify system performance at a specific reference condition chosen to be a frequently observed condition. A more complete evaluation of plant performance can be accomplished by using the complementary Technical Specification IEC TS 61724-3, *Photovoltaic system performance – Part 3: Energy evaluation method*.

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.

IEC 61724-1[2], *Photovoltaic system performance – Part 1: Monitoring*

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols*

ISO/IEC Guide 98-1, *Uncertainty of measurement – Part 1: Introduction to the expression of uncertainty in measurement*

ASME, *Performance Test Code 19.1*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 61724-1, IEC TS 61836, the ASME Performance Test Code 19.1 and the following and definitions apply.

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

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

3.1
constrained operation
operation of a plant in a condition when all inverters are limited by the capability of the inverters (otherwise referred to as inverter saturation) rather than by the output from the PV array, as is observed for a system with high DC rating relative to the AC rating and when the irradiance is high

3.2
correction factor
ratio of the power expected for the reference conditions to the power expected for the measured conditions

3.3
curtailed operation
output of the inverter(s) is limited due to external reasons such as inability of the local grid to receive the power or contractual agreement

3.4
expected power
power generation of a PV system that is expected for actual weather data collected at the site during operation of the system based on the design parameters of the system

3.5
measured power
electric power that is generated by the PV system

Note 1 to entry: See also 3.14 to define the location of measurement.

3.6
model
simulation model used to calculate the predicted or expected PV power generation based on the design parameters of the system

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[2] Under preparation. Stage at time of publication: IEC/FDIS 61724-1:2016.

3.7
parties to the test
individuals or companies that are applying the test

Note 1 to entry: Commonly, these parties may be the PV customer and the PV installer, with the test method applied to define completion of a contract, but the test method may be applied in a variety of situations and the parties to the test may in some cases be a single individual or company.

3.8
performance target
power generation expected from a PV system under reference conditions based on the design parameters of the system

3.9
POA
plane of array
physical plane in which the modules are deployed according to the orientation of the system under test

3.10
system operation
attributes of the system performance that can be traced to the quality of operations and maintenance service provided

Note 1 to entry: For example, low availability of the system may be a result of slow response to a disruption.

Note 2 to entry: If different entities are responsible for the installation and the operations, then it is useful to distinguish between aspects of the performance that are traced to the initial installation and those that are traced to the operation.

3.11
system quality
attributes of the system performance that can be traced to the quality of the system design, the quality of the system components and the quality of installation

Note 1 to entry: Generally, the installer is held responsible for the system quality.

3.12
target power
power generation expected from a PV system at target reference conditions (TRC) based on the design parameters of the system

3.13
target reference conditions
TRC
reference conditions at which the expected power is the target power, which include irradiance, ambient temperature, wind, and any other parameter used to define the target performance

Note 1 to entry: See 6.1.3.

3.14
test boundary
physical differentiation between what is considered to be part of the system under test and what is outside of the system

Note 1 to entry: In addition to defining the physical boundaries and which electricity meter is quantifying the electricity production, the test boundary definition includes the location, type, and accuracy class of all measurement devices.

Note 2 to entry: To facilitate the description of the test method, this document defines a default test boundary. Ambient temperature and wind speed lie outside of this default test boundary. When this standard is applied using class A (high precision) measurements as defined in IEC 61724-1, soiling will lie inside of the default test boundary, consistent with the IEC 61724-1 class A requirement that the sensors be cleaned, quantifying the irradiance without interference from soiling. When this standard is applied using class B (medium precision) measurements as defined in IEC 61724-1, soiling will lie outside of the default test boundary and it is expected that sensors will not be cleaned, allowing soiling to be considered as part of the weather. The alignment of the array is brought inside of the test boundary by confirming the alignment of the plane of array sensor. The parties to the test may define the test boundary however they wish; the default test boundary is defined only as a tool to clarify the application of the test method described here and as an example for how to define the test boundary. However, if the purpose of application of the test is to measure degradation rates on small systems, it may be preferable to measure module temperature in consistent locations on the modules.

3.15
unconstrained operation
outputs of all inverters freely following the DC array's capability to respond to the solar insolation rather than being limited by the capability of the inverters or curtailing influences

3.16
maximum-power-point tracking
inverter accurately maximizing the DC array's output

4 Test scope, schedule and duration

This test may be applied at one of several levels of granularity of a PV plant. The users of the test shall agree upon the level(s) at which the test will be applied. The smallest level at which the test may be performed is the smallest level of AC power generating assembly capable of independent on-grid operation.

When PV plant construction is divided into phases, it is recommended that the test be applied at the highest level, that which encompasses the entire PV project. However, the test may be applied to smaller subsets of the plant as they become available for interconnection. If desired, upon full plant completion the test may be applied again in a way that encompasses the entire plant, taking into account expected degradation in accordance with the model accepted by the parties to the test as well as soiling levels if not able to wash the entire array before testing. In every case, the system boundary and test boundary shall be explicitly defined.

Some PV modules show measurable performance changes within hours or days of being installed in the field; others do not. The time duration of the test should be negotiated between the parties using the manufacturer's guidance for the number of days of exposure or the irradiance exposure needed for the plant to reach the targeted performance along with the details of the actual installation and interconnection dates. Any metastability (variation in module efficiency that depends on previous operating conditions) and degradation assumptions (including those with short and long time constants) should be agreed to by all parties and documented as part of the target description.

NOTE 1 Newly installed modules can undergo light induced degradation (LID), a transient effect that reduces the photovoltaic conversion efficiency of the modules when exposed to light.

NOTE 2 The efficiency of some modules can vary over a year depending on irradiation and temperature history due to metastabilities.

It is recommended that the test include data from at least two days if sufficient stable data are acquired. The test may be extended to seven or more days if desired to assess repeatability or if weather is volatile. The filtering criteria for selecting relatively stable times are described in Clause 6.

The test may be completed at any time of year, though the deviation from reference conditions and the effects of variable angle of incidence may increase the uncertainty at some times of the year.

All parties to the test should agree on a detailed test procedure before the test commences as described in Clauses 5 and 6.

5 Equipment and measurements

Measurement equipment and procedures for all measured parameters are recommended to conform to class A requirements in IEC 61724-1. However, a class B or class C evaluation may also be completed and documented in the final report.

Using the default test boundary, the weather is characterized by:

- plane of array irradiance (global for flat-plate and direct for concentrator systems; for systems with multiple orientations, see Annex C);
- ambient temperature;
- wind speed.

If additional characterization of the weather is required for implementation of the agreed-upon model, these data shall be collected in a manner consistent with the derivation of the targeted performance and documented in the detailed test procedure.

The system output is characterized by:

- real AC power delivered to the grid or load at the system/test boundary;
- reactive AC power or power factor if real power is dependent on changes in power factor;
- the inverter state (whether the inverter is tracking the maximum power or whether it is operating in a constrained mode, limited by its output capacity).

The definition of the AC power, including the point of measurement (such as at a utility-grade meter at the point of interconnection) is documented as part of the "test boundary" definition (3.14). If parasitic loads outside the system boundary exist (e.g. trackers), the contract or test definition defines whether adjustments are made for these, and, if so, how these adjustments are characterized.

All details of data collection (including sensor number, calibration, installation location, and cleaning) shall follow IEC 61724-1 according to the chosen class of measurement with the exception of the following.

- The type of sensor and sensor positioning shall be consistent with the power performance model that is being used for the test (which may differ from the energy performance model). Temperature sensors should measure ambient temperature in order to account for the effects of module mounting. However, modelling of module temperature may vary from day to day due to variation of sky temperature and other conditions, increasing uncertainty in the measurement, and motivating the use of the module temperature if it is viewed to provide better reproducibility. If module temperature is to be measured, the location of the measurement should be agreed upon in advance by the parties of the test.

  NOTE Often the final uncertainty of the measurement is dominated by the uncertainty of the irradiance measurement, so high-accuracy sensors are desired.

- The time record for the visual inspection and cleaning by hand of irradiance sensors during the test shall be documented.
- Irradiance sensor(s) are mounted in the plane of the array with an alignment accuracy as specified by class A, B, or C in IEC 61724-1. For the case of arrays with modules that are not all within one plane, see Annex C.
- When irradiance sensors are deployed on a tilted plane, the ground albedo for the area near the sensors should be representative of the ground albedo throughout the array. Any anomalies in ground albedo should be discussed in the uncertainty analysis of the test.
- For class A tests, because the irradiance measurement is so crucial to the test, the calibrations should be independently verified either by using sensors calibrated at different test locations or at different times so as to prevent a systematic bias to the calibration.

- Data shall be filtered to identify times of stable operation under full sun as described in Clause 6.
- Data are collected both for “unconstrained” and “constrained” operation, if relevant. Any periods affected by grid outages or other anomalous states should be removed from the analysis.

6 Procedure

6.1 Documentation of the performance targets under “unconstrained” and “constrained” operation

6.1.1 General

The expected power output and the associated reference conditions shall be defined both for “unconstrained” operation and for “constrained” operation, if relevant, as described in 6.1.2 to 6.1.8.

6.1.2 Definition of test boundary to align with intended system boundary

This test method is intended to quantify the performance of a system, but the result of the test can depend on what is considered to be part of the system. The parties to the test shall agree on the definition of the system including:

- the meter(s) that defines the output of the system;
- aspects of system design that are being tested such as whether modules are mounted according to the design (tilt, azimuth, height, racking design) allowing the expected cooling and capture of sunlight;
- aspects of system operation that are being tested such as whether the soiling level will be considered as part of the test.

The test boundary shall be aligned with the system boundary in order to have the result of the test reflect the performance of the system under test.

6.1.3 Definition of the reference conditions for “unconstrained” operation

Target reference conditions (TRC) for unconstrained operation are defined for the performance target (see 6.1.4). TRC should be chosen so as to result in unconstrained operation (i.e. within the inverter’s capability) and the irradiance condition may differ from 1 000 W/m^2 if the plant is designed to be constrained by the inverter’s capability at 1 000 W/m^2. Preferably, the TRC are chosen to reflect an ambient temperature and wind speed that are frequently observed at the site and the highest irradiance that is unlikely to cause constrained operation (when the inverter has reached the limit of its capability) for the lowest temperature expected to be included in the test. The optimal choice of TRC may depend on the weather during the test. However, use of the design parameters for the plant as the basis for the model should reduce the error of correcting for the variations in conditions, reducing the need to have the TRC align exactly with the conditions during the measurement. The TRC should be agreed upon by all parties to the test before commencement of the test.

The sources of the irradiance, ambient temperature, wind speed, and any other meteorological data shall be described so that the definition of the TRC will be unambiguous. Data collection requirements defined in IEC 61724-1 shall be followed according to the desired monitoring class A, B, or C except as noted in Clause 5. These should be documented as specifically as possible in the detailed test procedure before the test commences (e.g. sensor type, location, cleaning and calibration, and any additional relevant information).

6.1.4 Definition of the performance target under "unconstrained" and "constrained" operation

The targeted system output is defined for "unconstrained" operation under the TRC defined in 6.1.3 and a model that defines how the power varies with irradiance, temperature, and wind using the design parameters of the plant. The rationale for the performance target shall be agreed to by all parties of the test. For situations when the plant design was developed based on a model for the energy output, translating that energy model into a power model or deriving a power model from measured data on a similar plant can introduce anomalies in the power model. For example, application of linear regression to subsets of data during different times of the year may result in variable observed temperature coefficients. In this case, where a power model was not created during the initial design of the system, it is recommended that the rationale be described by using a simple model that starts with the name plate rating and applies loss factors that can be clearly understood such as loss factors for inverter efficiency, cabling losses, mismatch losses, etc. and applies a temperature coefficient that can be directly related to the module performance. It is to be noted that a model that includes shading losses is important for predicting the energy from a plant, but this capacity test is intended to document performance when there is no shading, so a simple model can replace the more complex model, increasing the transparency of the test procedure.

Typically, it is assumed that the plant is being assessed in an "as-installed" state that is nominally clean. If the assessment is completed at a time when the plant may have become soiled, the soiling loss may either be included as one of the loss factors or the plant has to be cleaned before the assessment.

If a complex model is used, the model may be defined as described in IEC TS 61724-3 and the test applied ensuring that the model is consistently applied for both the target and measured conditions.

The performance target under "constrained" operation is typically defined by the capability of the inverter. If this value is independent of operating conditions, verification of operation in the "constrained" state is straightforward and may not be of concern for the parties of the test. However, if a system is intended to operate in the "constrained" state for many hours of the year, it is highly recommended to confirm correct operation in the "constrained" state.

6.1.5 Definition of the temperature dependence of the plant output under "unconstrained" operation

If a temperature model has been defined for the plant, this should be used preferentially.

If the model uses wind speed as an input, the location (including height) of the wind sensor should be specified.

If a temperature model has not been defined, a possible model is provided in Annex A. It is preferable to use a temperature model based on ambient temperature and wind speed rather than measuring the back-of-module temperature because the assessment then includes some aspects of the module mounting that could cause the modules to run hot and because it avoids the challenges of characterizing the module temperature, which may be highly variable across the field. However, although the model in Annex A has been demonstrated to provide accurate modelling of the average cell temperature, from day to day it may result in variable accuracy caused by variation in sky temperature or other conditions. The parties to the test should choose the approach that provides the best result for the given situation. If measuring the module temperature rather than the ambient temperature is chosen, then there may be a separate verification to ensure that the modules are operating at a temperature that is consistent with the plant's design specification. Suggestions on how to accurately measure the back-of-module temperature may be found in Annex B of IEC 61724-1:2016.

In any case, the model shall be agreed to by the parties to the test before the test and documented in the test report; IEC TS 61724-3 provides guidance on documenting a complex model.

6.1.6 Definition of irradiance dependence

The plant output as a function of irradiance shall be defined by the power model agreed to by the parties of the test. Practitioners should choose a power model based on the design parameters of the system. If a complex computer program is used as the power model, the power model should be documented as described in IEC TS 61724-3 along with the performance target. The irradiance filter applied with Table 1 should be verified to be consistent with the functional range of the model used to determine the correction equations. For example, the plant output may be assumed to be linear with irradiance in a limited irradiance range, such as ±20 %. Any added uncertainty should also be documented. An example of a simple model is given in Annex B.

6.1.7 Definition of the performance target under “constrained” operation

The performance under “constrained” operation may be equivalent to the AC rating of the inverter adjusted for any losses between the inverter and measurement location for AC power and is documented as such. If the performance under “constrained” operation can depend on the ambient temperature or other condition, this shall be documented as well.

If the performance under “curtailed” conditions is controlled by an external party, the assessment of performance under such conditions may be excluded from the assessment, with agreement from both parties to the test.

Measurement under the “constrained” condition may be omitted, at the discretion of those requesting the test.

6.1.8 Uncertainty definition

Test uncertainty should be computed as described in 6.5. The uncertainty definition and its role in defining the pass/fail test outcome comparing the targeted and measured power shall be agreed upon. It is highly recommended that this agreement be documented prior to the test.

NOTE Typically, the uncertainty agreed to by the parties typically forms a dead band around any target. This dead band is to the disadvantage the all parties of the test, so should be kept as small as possible. A 95 % confidence interval is a common industry practice.

Strategies for reducing uncertainty include:

- use of higher quality irradiance sensors and/or use data from multiple sensors for each weather station deployed, first discarding erroneous data from malfunctioning or shaded sensors, then averaging the remaining data points for each measurement;
- use of multiple sensors either to add redundancy or to document variability of that parameter;
- paying special attention to possible shading and soiling of irradiance sensors, as well as correct in-plane adjustment;
- comparing data to other similar measurements obtained nearby to detect and resolve problems quickly; on relatively sunny days, data may be compared directly; on cloudy days, comparison of integrated data may provide better identification of problems depending on the distance between sensors.

6.2 Measurement of data

6.2.1 General

The power output, irradiance, temperature, wind speed, state of cleanliness of both the sensors and PV systems, and any other data are collected over several days.

6.2.2 Data checks for each data stream

Each data stream shall be checked for data out of range or unreasonable trends as described in IEC 61724-1. A recommendation for application of this procedure for this application is given in more detail in Table 1 with values suggested when the collected data have been averaged over 15-min time periods. Depending on the local conditions, the details of the plant design, the addition of other data streams and the frequency of data collection, the filtering criteria may be modified, but all four types of filters (range, dead value, abrupt change/stability and inverter status, as outlined in Table 1) shall be applied and documented as part of the final report.

The inverter's self-reported output power or inverter's self-reported status flags are used to identify when the inverter operation is constrained. If the status flags are not available, the data may be screened for reporting values near the maximum capability of the inverter. Records are categorized according to whether zero inverters are constrained, all inverters are constrained, or some, but not all, are constrained. In the first case, data records can be treated as unconstrained. In the second case, data records can be treated as constrained. In the third case, data records cannot be used for evaluating system performance. If the state of any inverter changes during the recording period, that data point shall be excluded from the analysis.

Table 1 – Data validation and filtering criteria

		Suggested criteria for flagging rejected data (15-min data)			
Flag type	**Description**	**Irradiance** (W/m^2)	**Ambient temperature** (°C)	**Wind speed** (m/s)	**Power (AC power rating)**
Range	Value outside of acceptable bounds	< 0,5·TRC irradiance or > 1,2·TRC [b]	> 50 or < −10 [a]	>15 or < 0,5	> 1,02·rating or < −0,01·rating
Dead value	Values stuck at a single value over time. Detected using derivative.	Derivative < 0,000 1 while value is > 5	< 0,000 1 and > −0,000 1	< sensitivity of sensor	< 0,1 % change in 3 readings
Abrupt change and stability	Values change unacceptably between data points. Detected using derivative for temperature and wind speed.	Assuming 15 min data derived from at least 1 min data, standard deviation > 5 % of average	> 4	> 10	Assuming 15 min data derived from at least 1 min data, standard deviation > 5 % of average
Inverter status	The states of the inverters are inconsistent (not all are constrained – see text)	Not applicable	Not applicable	Not applicable	Not applicable

NOTE 1 The irradiance filtering may be adjusted to align with the range of linear system performance with irradiance. Flagged data are considered for exclusion and documented in the test report regarding the rationale for exclusion.

NOTE 2 Potential-induced degradation (PID) effects may start to reduce the power output at low irradiance conditions remarkably, without a measurable effect at high irradiance. Early detection of evidence of PID is outside the scope of this test.

[a] May be adjusted depending on the season of data acquisition.

[b] The maximum irradiance included in the analysis may be adjusted to account for the possibility of cloud edge effects, whereby light is scattered by a nearby cloud and can cause irradiance readings up to approximately 1 500 W/m^2. For most systems, these conditions will cause saturation of the inverter, and will typically be excluded from the evaluated data by the stability filter.

The stability filter recommended here calculates the average of at least 15 data points (measured at least every minute during 15 min) and confirms that the standard deviation for those data points is less than 5 % of the average of the same data points. Applying the stability filter to both the irradiance and power data is recommended.

The number of data points identified as meeting the criteria in Table 1 will affect the uncertainty of the test. As a guide to determining an adequate, yet reasonable, number of data points, Table 2 may be used. The larger number of data points during the summer reflects the ease of collecting more data on longer days and is expected to result in a higher accuracy measurement, depending on the local weather. Locations that seldom experience clear, sunny days may require longer data collection times or reduction of the targeted number of data points, resulting in higher test uncertainty. For CPV applications, Table 2 is not directly relevant. For CPV, after filtering for stable conditions, the data collected should include at least 30 data points (assuming 15 min averages) or at least 7,5 h of filtered data if averages for a different time period are used.

For systems with high DC-to-AC power ratios, the number of data points acquired for “unconstrained” operation may be an insufficient sample size. If the test cannot be completed because of this, or if there is concern that the characterization only during early morning and late afternoon will cause bias in the results, the definition of the system boundary and the TRCs should also direct that a fraction of the PV strings will be temporarily disconnected to reduce the DC-to-AC power ratio.

Table 2 – Example guide for seasonal minimum stable irradiance requirements for flat-plate applications

Season (northern hemisphere)	**Dates**	**Minimum POA irradiance** (W/m^2)	**Required number of 15-min average data points**
Winter	22/11 to 21/1	450	20
Spring	22/1 to 23/3	550	30
Summer	24/3 to 21/9	650	60
Autumn	22/9 to 22/11	550	40

The data may also be screened according to normal function of the system. Time periods for which tracker malfunction or system soiling would affect the results of the test may be omitted or included depending on the purpose of application of the test. These inclusions or exclusions should be reported as part of the test report (see Clause 8, item 8)).

6.2.3 Shading of irradiance sensor

Because of the sensitivity of the test to the irradiance data, special attention shall be given to the irradiance data. Specifically, irradiance data that may result from accidental shading of a sensor or sensor malfunction should be removed before taking the average of the data from the remaining sensors. The use of multiple sensors at each weather station is especially helpful for identifying issues with shading of some sensors.

Additionally, if an irradiance sensor is not correctly oriented (e.g. if mounted on a tracker and the tracker stops), the data from this sensor should be rejected.

6.2.4 Calibration accuracy

All sensors shall have accurate calibrations to provide a test result with low uncertainty consistent with the requirements described in IEC 61724-1 for the desired class of measurement.

6.2.5 Using data from multiple sensors

6.2.5.1 General

In the case where multiple sensors have been used, if data inspection identifies errors in the output of a sensor, that data should be discarded before taking the average of the data pool. This action should be done only with mutual consent of the parties.

6.2.5.2 Multiple irradiance sensors

The irradiance used as input to the power model should be the average of the available measurements, except where a measurement is determined to be erroneous, in which case the input to the model should be the average of the remaining measurements, as described previously.

6.2.5.3 Multiple ambient temperature sensors

The ambient temperature used as input to the model should be the average of the available measurements, except where a measurement is determined to be erroneous, in which case the input to the model should be the average/median of the remaining measurements.

6.2.5.4 Multiple PV module temperature sensors

Any PV module temperature used as input to the model should be the average of the available measurements, except where a measurement is determined to be erroneous, in which case the input to the model should be the average/median of the remaining measurements.

6.2.6 Unconstrained operation and constrained operation when the output limit of the inverter is reached

As described in 6.1, data shall be flagged depending on whether all inverters were maximum-power-point tracking or all inverters limited the output because their output capabilities were reached. All other data are discarded.

If the inverters limit the output in different ways depending on the operating conditions, then the data shall be binned to identify those that are all under the operating condition of interest.

6.3 Calculation of correction factor

6.3.1 General

The correction factor is calculated to adjust the measured power to the conditions used for the performance target. Subclauses 6.3.2 to 6.3.7 provide a step-by-step procedure.

6.3.2 Measure inputs

Measure all variable inputs, including meteorological data and plant-specific parameters necessary to define the measurement conditions.

6.3.3 Verify data quality

As necessary, validate the measured variable input data as per 6.2.

6.3.4 Calculate the correction factor for each measurement point

Input measured meteorological data into the system’s model and calculate the correction factor needed to translate the measured data to the temperature, wind and irradiance conditions specified by the TRC for all points measured during “unconstrained” stable operation.

Calculate the correction factor for each point using the power model and Equation (1):

$$CF = P_{\mathrm{Predtarg}}/P_{\mathrm{Predmeas}} \tag{1}$$

where

CF is the correction factor;

P_{Predtarg} is the power predicted at the target conditions;

P_{Predmeas} is the power predicted at the measured conditions.

Both predicted powers are taken from the model agreed to by the parties. See the annexes for an example model.

6.3.5 Correct measured power output

Correct the measured power by the correction factor for all points measured during "unconstrained" stable operation as calculated from the power model that describes the plant using Equation (2):

$$P_{\text{corr}} = P_{\text{meas}}\, CF \tag{2}$$

6.3.6 Average all values of corrected power

Taking care to consider only the data that were included after data filtering (see 6.2.2), average all corrected power output values taken under "unconstrained" operating conditions, and separately average all power values measured during constrained operation.

6.3.7 Analyse discrepancies

If an individual averaged corrected power deviates from the average by more than 5 %, then a root cause diagnosis should be completed for the data point to see if any outlier situation was in effect and not caught by the data filtering.

If the averaged power values deviate from the performance target values significantly (as established by the parties to the test), then a root cause diagnosis should be completed. The test report shall comment on whether the test should still be considered valid.

6.4 Comparison of measured power with the performance target

The average measured corrected power (see 6.3) and performance target can be compared either as a simple difference, percent difference, or ratio calculation.

Difference calculation:

$$P_{\text{corr}} - P_{\text{Target}} \tag{3}$$

Percent difference calculation:

$$[P_{\text{corr}} - P_{\text{Target}}] \cdot 100 \;/\; P_{\text{Target}} \tag{4}$$

Ratio (performance index for power):

$$P_{\text{corr}} \;/\; P_{\text{Target}} \tag{5}$$

Ratio (units of %):

$$(P_{\text{corr}} \cdot 100) \;/\; P_{\text{Target}} \tag{6}$$

A similar comparison is made of the average power generated during times of constrained operation relative to the performance target's definition of expected generation during times of constrained operation. If the output capability of the inverter is dependent on the inverter temperature or other factor, the performance should be evaluated in that context.

For systems that frequently have constrained operation and when the parties to the test agree to include it, the test report shall include two test results to reflect both the unconstrained and constrained operation. The use of these two test results is chosen by the user of the test and should be defined before the application of the test. If a single number is desired, one approach is to use typical weather data to identify how much energy is expected to be generated in unconstrained and constrained operation, and then derive a composite result that applies to these typical energy values to obtain a weighted average of the two test results.

The comparison of P_{corr} and the performance target shall include a consideration of the uncertainties calculated in 6.5, as guided by the initial agreement.

6.5 Uncertainty analysis

As part of the performance target or test plan, the agreement shall state how the uncertainty of the measurement is considered. Thus, it can be essential to quantify the uncertainty of the measurement as part of determining whether the measured performance meets expectations. Regardless of whether the uncertainty is used as part of determining the test result, uncertainty analysis should be part of the assessment.

The data are collected with an accuracy that is consistent with, or better than, the descriptions provided in IEC 61724-1 for the chosen class of measurement. While the measurement accuracy defines the class of the measurement, the final uncertainty associated with the conclusion of the test will also depend on the fraction of data that is discarded and other factors that are not defined in IEC 61724-1. This subclause provides some additional guidance regarding the uncertainty analysis.

The uncertainty is determined for P_{corr}, not for the performance target. Uncertainties associated with the model used for the original prediction are neglected. However, uncertainties associated with the measured weather data will introduce uncertainty in P_{corr}.

Both systematic (bias) and random (precision) uncertainties are included in the analysis. The contributions to the uncertainty depend on the model that is used, but generally include uncertainty in the measurements of the irradiance, temperature, wind speed, and electricity generated as well as uncertainties in corrections of these.

All measurements and associated uncertainties are tabulated and combined using standard propagation of errors as described in:

- ASME Performance Test Code 19.1;
- ISO 5725;
- ISO/IEC Guide 98-1.

The uncertainties associated with each sensor are taken from the manufacturer's specification and/or from the calibration report provided by the calibration laboratory.

The uncertainty analysis should also include systematic errors that may arise from misplacement or inappropriate installation of the sensors including:

- irradiance sensor placement (tilt, azimuth, and height);
- positioning of temperature sensors relative to power model;
- positioning of wind sensor relative to power model;

- soiling that has not been addressed;
- spatial variation when a subset of point measurements may not capture the true array bulk values (e.g. wind speed).

Data acquisition device uncertainties should also be considered.

The uncertainty evaluation should include a review of the range of conditions that were successfully sampled during the test. For example, bias related to spectrum, angle of incidence, etc. may be introduced if the measurement is confined to a short time in the morning and a short time in the afternoon when the DC output is within the capability of the inverter.

The thermal model described in Annex A and other thermal models are typically designed to provide estimates that correspond to average temperatures over a prolonged period. Because this test collects data for a relatively short time period, the temperatures calculated for module temperatures may deviate from the actual temperatures. The uncertainty analysis should include an evaluation of the sensitivity of the final result to the selected temperature model.

The output of a system is not always linear. Table 1 defines an irradiance filter that is ±20 % of the TRC irradiance. The uncertainty analysis should include documentation of the linearity of the system performance in the ±20 % range around the TRC irradiance and/or should investigate the effect on the result associated with revising the irradiance filter in Table 1.

NOTE Nonlinear system output may be specific for the technology, or caused by degradation of the parallel resistance, or caused by thin-film metastabilities.

7 Test procedure documentation

This document attempts to strike a balance between providing prescriptive and specific guidance for testing and allowing the flexibility needed to accommodate each individual and unique system. As a result, it is necessary to define a detailed system-specific test plan for each application of this test method prior to the test's commencement. This test procedure includes all specific requirements and agreements for test execution and data reduction. All parties to the test shall have a sufficient opportunity to review and approve this test procedure. It is recommended that the test procedure documentation contain the following sections:

a) purpose;
b) target values and basis including definition of intended system boundary and related test boundary;
c) test schedule;
d) parties to the test and respective roles and responsibilities for details of installation, operation, and data analysis, including responsibility for:
    i) calibrations;
    ii) cleaning of sensors;
    iii) cleaning of array;
    iv) detection of system issues;
    v) resolution of system issues;
    vi) determination of constrained operation (if applicable);
    vii) analysis of data;
    viii) writing/review of final report;
    ix) any other relevant roles.
e) plant operating requirements including cleaning, inspection for evidence of wildlife interaction, build-up of debris, etc.;

f) instrumentation;

g) pre-test uncertainty analysis;

h) detailed data treatment and reduction methods;

i) criteria for a successful test;

j) instrumentation cut-sheets and calibration certificates;

k) historical meteorological data as a reference and/or electronic file.

8 Test report

The final test report shall include both the test procedure (either explicitly or by reference) as well as the following items:

1) description of the party doing the test;
2) description of the site being tested, including latitude, longitude, and altitude;
3) description of the system being tested; specific note should be made of whether there are parasitic loads and how these are documented by the test;
4) a summary of the performance target made for “unconstrained” and “constrained” operation, including definition of the TRC and associated power model;
5) a summary of the definition of the meteorological data taken during the test, including calibration data for all sensors (sensor identification, test laboratory, date of test) and sensor location, including photographs for documenting the sensor location and ground conditions like rough or smooth vegetation or snow and records of sensor cleaning;
6) a summary of the definition of the system output data collected during the test, including records of completed calibrations;
7) the raw data that were collected during the test, including note of which data met the stability and other criteria;
8) an explanation of why data that met the filter criteria (if any) were removed;
9) for CPV tests, the average (irradiance-weighted) air mass that was experienced during the test shall be reported;
10) a list of any deviations from the test procedure and why these were taken;
11) a summary of the correction factors that were calculated for the filtered data;
12) a summary comparison of the performance targets and average measured, corrected power values as calculated in 6.3 for both “unconstrained” and “constrained” operation, if relevant;
13) a description of uncertainty analysis and statement of uncertainty associated with the correction factors, based on the uncertainty of the weather measurements (see 6.5) and uncertainty of the model assumptions such as the temperature model and the assumption of linear response to irradiance;
14) a description of uncertainty analysis and statement of the uncertainty associated with the measured performance (see 6.5) including an analysis of any uncertainty introduced by extrapolation (all data points falling on a single side of the TRC);
15) a summary version of the test results may be provided containing:
    a) the P_{corr} under “unconstrained” operation;
    b) the P_{corr} under “constrained” operation;
    c) the reference conditions for unconstrained operation (TRC) and target power associated with those conditions;
    d) the performance index under TRC (ratio of P_{corr} to target power, expressed in %).

For items that are duplicated on both lists, the final report should duplicate the original information, verify that the project was executed as originally planned, or note modifications that occurred during the test period.

Annex A
(informative)

Example of model for module temperature calculations

A.1 General

Generally, there are two parts to defining the temperature dependence of the power output of a PV system: 1) relating the weather conditions to the module temperature and 2) the power output as a function of module temperature.

The module temperature can be measured directly using a sensor on the back of the module as described in IEC 61829 or in Annex B of IEC 61724-1:2016, or an infrared camera that has been carefully calibrated for the emissivity of the module, but the module temperature reflects both the weather conditions and the quality of the installation or design, since improper installation of modules or a poor mounting design may cause modules to operate at elevated temperatures when compared to design expectations. To include module operating temperature within the test, the ambient temperature and wind speed may be used to calculate an expected average module temperature. If measurements from IEC 61853-2 are available, these may inform the model for calculating the module temperature from the ambient temperature and wind speed.

A.2 Example heat transfer model to calculate expected cell operating temperature

This section presents a heat transfer model that has demonstrated good results. However, other models exist, and practitioners should choose the model that best fits their situation. Of great importance is using identical heat transfer models for setting the capacity performance target as well as the target reference conditions.

The module and cell temperatures may be described by Equations (A.1) and (A.3):

$$T_{\text{m}} = G_{\text{meas}} \cdot [\text{e}^{(a+b \cdot WS)}][\text{°C m}^2\text{/W}] + T_{\text{a}} \quad \text{(A.1)}$$

where

T_{m}	is the calculated module back surface temperature (°C);
G_{meas}	is the measured POA irradiance (W/m^2);
T_{a}	is the measured ambient temperature (°C);
WS	is the wind speed corrected to 10 m height (m/s);
a	is the module glazing coefficient (see Table A.1);
b	is the forced convection glazing coefficient (s/m);
e	is the natural logarithm base.

$$WS = WS_{\text{meas}} \cdot [\ H\ /\ H_{\text{meas}}\ ]\ \alpha \quad \text{(A.2)}$$

where

WS	is the the wind speed corrected to a 10 m height or to the height that is relevant to the power model;
WS_{meas}	is the as measured wind speed;
H	is the height used by performance model (m) (typically 10 m);
H_{meas}	is the above grade anemometer height (m);

α is the resistance coefficient for ground cover or the Hellmann exponent (see Table A.2) (unitless).

The conductive temperature drop between the module's back surface and interior PV cell can then be calculated from Equation (A.3).

$$T_c = T_m + (G_{meas}/1000\ W/m^2) \cdot dT_{cond}\ [°C] \quad (A.3)$$

where

T_c is the calculated cell temperature (°C);

dT_{cond} is the conduction temperature coefficient to determine the difference between module surface and cell centre (°C).

The coefficients a, b, and dT_{cond} are defined as part of defining the temperature dependence. These may be derived from measured data or taken from the literature for similar configurations, such as those given in Table A.1. If the measured and model-input wind speed data were taken at the same height, the wind speed correction in Equation (A.2) may be omitted.

Table A.1 – Empirically determined coefficients used to predict module temperature

Module type	Mount	a	b (s/m)	dT_{cond} (°C)
Glass/cell/glass	Open rack	−3,47	−0,059 4	3
Glass/cell/glass	Close roof mount	−2,98	−0,047 1	1
Glass/cell/polymer sheet	Open rack	−3,56	−0,075 0	3
Glass/cell/polymer sheet	Insulated back	−2,81	−0,045 5	0
Polymer/thin-film/steel	Open rack	−3,58	−0,113	3
22× linear concentrator	Tracker	−3,23	−0,130	13
NOTE Wind speed was measured at the standard meteorological height of 10 m.				

The Hellmann coefficient is dependent on the stability of the air and the shape of the terrain. Values from Table A.2 may be selected. The uncertainty analysis should include an estimation of the sensitivity of the final result to the value selected from Table A.2 or other model assumption.

Table A.2 – Hellmann coefficient, α, for correction of wind speed according to measured height, if values in Table A.1 are used

Location or situation	α
Unstable air above flat open coast	0,11
Neutral air above flat open coast	0,16
Unstable air above human inhabited areas	0,27
Neutral air above human inhabited areas	0,34
Stable air above flat open coast	0,40
Stable air above human inhabited areas	0,60

For some designs, the temperature coefficients may have a strong dependence on wind direction. If so, measuring the wind direction and adjusting the temperature model accordingly may improve the accuracy of the test.

If the system and test boundaries have been defined to allow direct measurements of the back-of-module temperature, then only Equation (A.3) is needed with T_{m} set to the measured temperature. In this case, the back-of-module temperature should be measured according to IEC 61829 and Annex B of IEC 61724-1:2016. It is also possible to use IEC 60904-5 to determine the junction temperature, but this is usually difficult when evaluating the performance of a continuously operating system since IEC 60904-5 uses the measured open-circuit voltage. It should be noted that junction temperature calculated from measured open circuit voltage will reflect the rapid fluctuation of the cell temperature during rapid changes of irradiance due to high wind and cloud speed in the sky that is not in accordance with the directly measured temperature of the rear surface. Therefore, the electrical output power evaluation of the system should be performed when the irradiation is stable as required by the filtering described in Table 1.

Additionally, the power coefficient relating the cell temperature to the relative change in system output is defined and the power is corrected according to Equation (A.4).

$$CF_{\mathrm{Tcell}} = 1 + \delta\,(T_{\mathrm{c}} - T_{\mathrm{TRC}}) \tag{A.4}$$

where

CF_{Tcell} is the operating temperature cell correction factor;

δ is the PV power − cell temperature coefficient taken from the product literature (note that this coefficient has a negative value (1/°C));

T_{c} is the cell temperature calculated from measured meteorological conditions using a heat transfer model or from measured module temperature;

T_{TRC} is the cell temperature associated with the TRC. This should be calculated with the same model used to determine the target power for the given target reference conditions (TRC).

Annex B
(informative)

Example of model for system power

B.1 General

The model for the electrical power output of a system can be fairly simple or complex. A simple example is given here.

B.2 Example model

As an example of implementation of a linear assumption, if the plant power is defined by Equation (B.1), then the correction factor for irradiance is applied by Equation (B.2) including module temperature effects according to a linear assumption for temperature correction.

$$P_{\mathrm{Pred}} = (P_{\mathrm{PredTarg}}) \cdot (G_{\mathrm{meas}} / G_{\mathrm{TRC}}) + P_{\mathrm{zero}} \cdot (1 - G_{\mathrm{meas}} / G_{\mathrm{TRC}}) \quad \text{(B.1)}$$

where

P_{Pred} is the predicted power;

P_{PredTarg} is the predicted power at targeted conditions;

G_{meas} is the measured irradiance;

G_{TRC} is the rating irradiance used to specify the target power;

P_{zero} is the (negative) intercept often observed when plotting the output power as a function of irradiance when inverters require a minimum power input to function.

Adding a temperature correction to Equation (B.1) and neglecting the P_{zero} term results in the following relationship to predict power from measured irradiance and cell temperatures:

$$P_{\mathrm{Pred}} = (P_{\mathrm{PredTarg}}) \cdot (G_{\mathrm{meas}} / G_{\mathrm{TRC}}) \cdot [1 + \delta (T_{\mathrm{C}} - T_{\mathrm{TRC}})] \quad \text{(B.2)}$$

where

δ is the temperature coefficient taken from the product literature;

T_{TRC} is the cell temperature calculated by the thermal model at the TRC conditions;

T_{C} is the cell temperature calculated for each measurement point (see Annex A for an example of how this may be calculated).

See 6.3.4 for use of Equation (B.2) in calculating the correction factor.

Annex C
(informative)

Inconsistent array orientation

The orientation of an array may vary because of:

- unintentional variation in workmanship;
- unintentional variation due to tracker malfunction or misalignment for part of an array;
- intentional variation to follow the local terrain in an uncontrolled way;
- intentional variation to specified orientations, such as on a roof with two different orientations.

Defining methods for dealing with each of these situations is outside of the scope of this document. The purpose of this annex to provide guidance rather than specific methods.

Although an energy test has been defined relative to a specific defined orientation, suggesting that an energy test should be applied relative to the designed orientation, application of this capacity test to reflect the designed orientation instead of the installed orientation could lead to an erroneous assessment of the system.

The irradiance sensor(s) should be placed to reflect the alignment of the array. If a system is large and the alignment is not well controlled, there may be benefit in including irradiance sensors for each section of the plant. The number of sensors, the locations (chosen to reflect the various orientations), and the weighting of the measured data from the multiple sensors (chosen to reflect the fraction of modules for each orientation) should be chosen to be able to discern the average irradiance experienced by the array under test. These details should be agreed to by the parties to the test.

Ordinarily, the test is not applied during a time when a tracker is malfunctioning, but, in the case when an array is not consistently aligned, the strategy defined in the previous paragraph may be used.

In the case where different parts of a system are oriented differently, if each of these is connected to a different inverter, it is preferable to apply the test separately to the different parts of the system. If multiple arrays with different orientations are connected to the same inverter, then the irradiance measurements should be weighted to reflect the fractions of the array that are in each orientation.

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