

Subject 61724-1

July 27, 2018

## **SUMMARY OF TOPICS**

***The following new UL IEC-Based Standard is being proposed:***

***1. First Edition of the UL IEC-Based Standard for Photovoltaic System Performance – Part 1: Monitoring, UL 61724-1.***

**STP BALLOTS AND ALL COMMENTS DUE: September 25, 2018**

**1. First Edition of the UL IEC-Based Standard for Photovoltaic System Performance – Part 1: Monitoring, UL 61724-1.**

## **RATIONALE**

Proposal submitted by: Kent Whitfield, UL LLC

Currently, there are no US National consensus standards for the monitoring of photovoltaic system performance. US industry, including the USTAG for IEC TC 82, and other stakeholders, have indicated the need for these requirements, which are well covered and internationally accepted under the current first edition of IEC 61724-1. The adoption of the first edition of IEC 61724-1 as a consensus UL/ANSI standard will meet these needs.

Therefore, UL proposes to adopt the Standard for Photovoltaic System Performance – Part 1: Monitoring, IEC 61724-1, with minimal National Differences as UL 61724-1.

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**Bibliography**

## NATIONAL DIFFERENCES

National Differences from the text of International Electrotechnical Commission (IEC) Publication IEC 61724-1 are indicated by notations (differences) and are presented in bold text. The national difference type is included in the body.

There are five types of National Differences as noted below. The difference type is noted on the first line of the National Difference in the standard. The standard may not include all types of these National Differences.

**D1** – These are National Differences which are based on **basic safety principles and requirements**, elimination of which would compromise safety for consumers and users of products.

**D2** – These are National Differences based on **safety practices**. These are differences for IEC requirements that may be acceptable, but adopting the IEC requirements would require considerable retesting or redesign on the manufacturer's part.

**DC** – These are National Differences based on the **component standards** and will not be deleted until a particular component standard is harmonized with the IEC component standard.

**DE** – These are National Differences based on **editorial comments or corrections**.

**DR** – These are National Differences based on the **national regulatory requirements**.

Each national difference contains a description of what the national difference entails. Typically one of the following words is used to explain how the text of the national difference is to be applied to the base IEC text:

**Addition / Add** - An addition entails adding a complete new numbered clause, subclause, table, figure, or annex. Addition is not meant to include adding select words to the base IEC text.

**Deletion / Delete** - A deletion entails complete deletion of an entire numbered clause, subclause, table, figure, or annex without any replacement text.

**Modification / Modify** - A modification is an altering of the existing base IEC text such as the addition, replacement or deletion of certain words or the replacement of an entire clause, subclause, table, figure, or annex of the base IEC text.

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

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### PHOTOVOLTAIC SYSTEM PERFORMANCE – Part 1: Monitoring

## FOREWORD

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International Standard IEC 61724-1 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This first edition cancels and replaces the first edition of IEC 61724, published in 1998. This edition constitutes a technical revision.

This edition (in conjunction with IEC TS 61724-2:2016 and IEC TS 61724-3:2016) includes the following significant technical changes with respect to IEC 61724:

- a) IEC 61724 is now written with multiple parts. This document is IEC 61724-1, addressing PV system monitoring. IEC TS 61724-2 and IEC TS 61724-3 address performance analysis based on the monitoring data.
- b) Three classes of monitoring systems are defined corresponding to different levels of accuracy and different intended applications.
- c) Required measurements for each class of monitoring system are stated, along with the required number and accuracy of sensors.
- d) Options for satellite-based irradiance measurement are provided.
- e) Soiling measurement is introduced.
- f) New performance metrics are introduced, including temperature compensated performance ratios and others.
- g) Numerous recommendations and explanatory notes are included.

The text of this standard is based on the following documents:

|              |                  |
|--------------|------------------|
| FDIS         | Report on voting |
| 82/1215/FDIS | 82/1248/RVD      |

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

This publication 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 document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

## INTRODUCTION

This International Standard defines classes of photovoltaic (PV) performance monitoring systems and serves as guidance for various monitoring system choices.

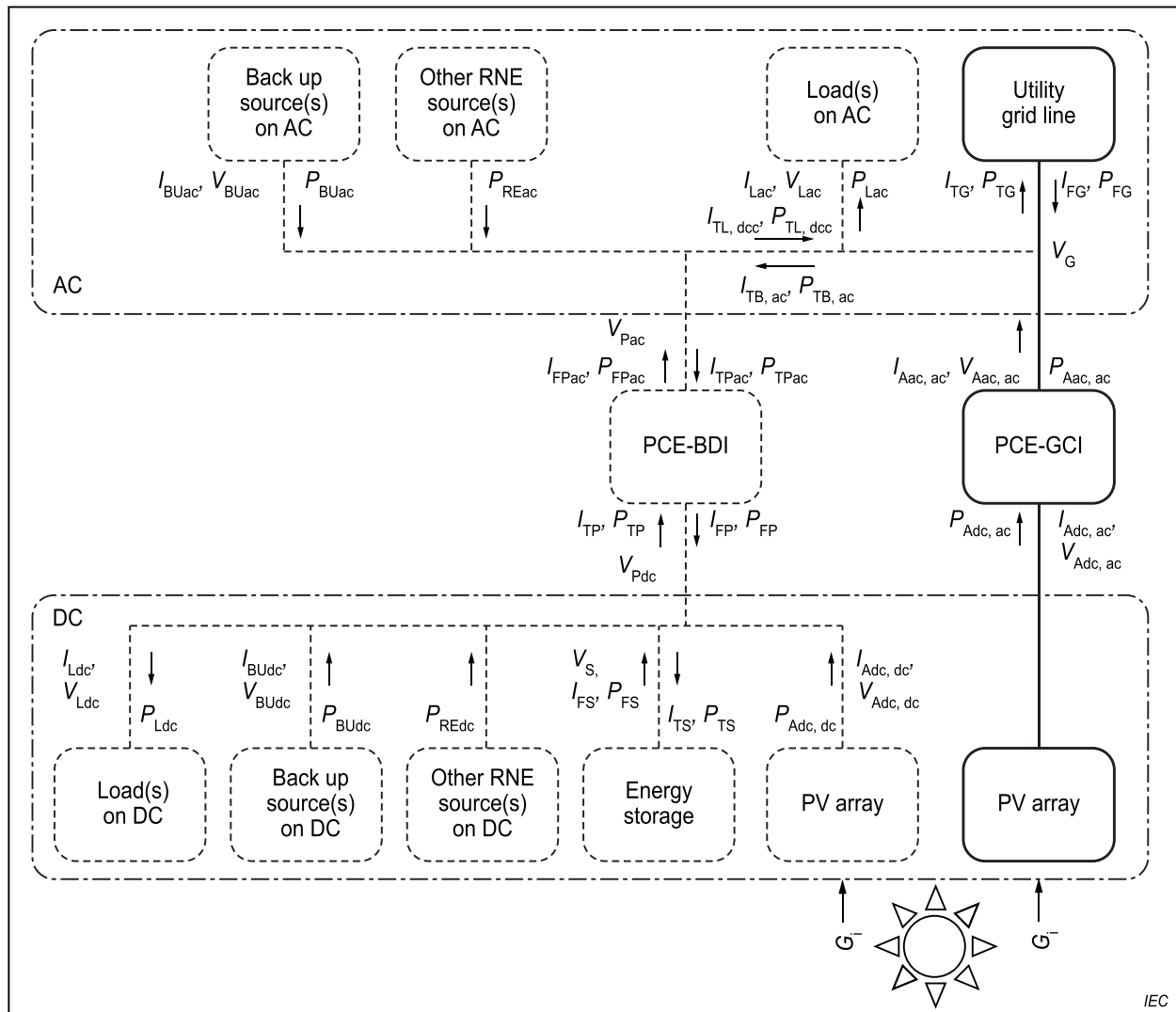
Figure 1 illustrates possible major elements comprising different PV system types. The PV array may include both fixed axis and tracking systems and both flat plate and concentrator systems. Module-level electronics, if present, may be a component of the monitoring system.

For simplicity, the main clauses of this document are written for grid-connected systems without local loads, energy storage, or auxiliary sources, as shown by the bold lines in Figure 1. Annex D includes details for systems with additional components.

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**Key**

RNE renewable energy

PCE power conditioning equipment

BDI bi-directional inverter

GCI grid-connected inverter

Bold lines denote simple grid-connected system without local loads, energy storage, or auxiliary sources.

**Figure 1 – Possible elements of PV systems**

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The purposes of a performance monitoring system are diverse and can include the following:

- identification of performance trends in an individual PV system;
- localization of potential faults in a PV system;
- comparison of PV system performance to design expectations and guarantees;
- comparison of PV systems of different configurations; and
- comparison of PV systems at different locations.

These diverse purposes give rise to a diverse set of requirements, and different sensors and/or analysis methods may be more or less suited depending on the specific objective. For example, for comparing performance to design expectations and guarantees, the focus should be on system-level data and consistency between prediction and test methods, while for analysing performance trends and localizing faults, there may be a need for greater resolution at sub-levels of the system and an emphasis on measurement repeatability and correlation metrics rather than absolute accuracy.

The monitoring system should be adapted to the PV system's size and user requirements. In general, larger and more expensive PV systems should have more monitoring points and higher accuracy sensors than smaller and lower-cost PV systems. This document defines three classifications of monitoring system with differentiated requirements which are appropriate to a range of purposes.

# Photovoltaic System Performance – Part 1: Monitoring

## 1 Scope

This part of IEC 61724 outlines equipment, methods, and terminology for performance monitoring and analysis of photovoltaic (PV) systems. It addresses sensors, installation, and accuracy for monitoring equipment in addition to measured parameter data acquisition and quality checks, calculated parameters, and performance metrics. In addition, it serves as a basis for other standards which rely upon the data collected.

## 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 60050-131, *International Electrotechnical Vocabulary – Part 131: Circuit theory*

IEC 60904-2, *Photovoltaic devices – Part 2: Requirements for photovoltaic reference devices*

IEC 60904-3, *Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*

IEC 60904-5, *Photovoltaic devices – Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method*

IEC 60904-10, *Photovoltaic devices – Part 10: Methods of linearity measurement*

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

IEC 61557-12, *Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing measuring or monitoring of protective measures – Part 12: Performance measuring and monitoring devices (PMD)*

IEC 62053-21, *Electricity metering equipment (a.c.) – Particular requirements – Part 21: Static meters for active energy (classes 1 and 2)*

IEC 62053-22, *Electricity metering equipment (a.c.) – Particular requirements – Part 22: Static meters for active energy (classes 0,2 S and 0,5 S)*

IEC 62670-3, *Photovoltaic concentrators (CPV) – Performance testing – Part 3: Performance measurements and power rating*

IEC 62817:2014, *Photovoltaic systems – Design qualification of solar trackers*

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

ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO 9060, *Solar energy – Specification and classification of instruments for measuring hemispherical solar and direct solar radiation*

ISO 9488, *Solar energy – Vocabulary*

ISO 9846, *Solar energy – Calibration of a pyranometer using a pyrhelimeter*

ISO 9847, *Solar energy – Calibration of field pyranometers by comparison to a reference pyranometer*

WMO No. 8 , *Guide to meteorological instruments and methods of observation*

ASTM G183, *Standard Practice for Field Use of Pyranometers, Pyrhemimeters and UV Radiometers*

**2DV DR Addition of the following:**

**ANSI C12.1, Electric Meters – Code for Electricity Metering**

**ANSI C12.20, Electricity Meters 0.1, 0.2 and 0.5 Accuracy Classes**

**3 Terms and definitions**

For the purposes of this document, the terms and definitions given in IEC 60050-131, IEC TS 61836, ISO 9488 and the following 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**

**sample**

data acquired from a sensor or measuring device

**3.2**

**sampling interval**

time between samples

**3.3**

**record**

data recorded and stored in data log, based on acquired samples

**3.4**

**recording interval**

$\tau$

time between records

3.5

**report**

aggregate value based on series of records

3.6

**reporting period**

time between reports

3.7

**irradiance***G*

incident flux of radiant power per unit area

Note 1 to entry: Expressed in units of  $\text{W}\cdot\text{m}^{-2}$ .

3.8

**in-plane irradiance***G<sub>i</sub>* or *POA*

the sum of direct, diffuse, and ground-reflected irradiance incident upon an inclined surface parallel to the plane of the modules in the PV array, also known as plane-of-array (POA) irradiance

Note 1 to entry: Expressed in units of  $\text{W}\cdot\text{m}^{-2}$ .

3.9

**global horizontal irradiance***GHI*

direct plus diffuse irradiance incident on a horizontal surface

Note 1 to entry: Expressed in units of  $\text{W}\cdot\text{m}^{-2}$ .

3.10

**circumsolar**

immediately surrounding the solar disk

3.11

**direct normal irradiance***DNI*irradiance emanating from the solar disk and from the circumsolar region of the sky within a subtended full angle of  $5^\circ$  falling on a plane surface normal to the sun's raysNote 1 to entry: Some *DNI* measurement instruments have a field of view with a subtended full angle of up to  $6^\circ$ .Note 2 to entry: Expressed in units of  $\text{W}\cdot\text{m}^{-2}$ .

3.12

**circumsolar ratio***CSR*fraction of measured direct normal irradiance (*DNI*) emanating from the circumsolar region of the sky, i.e. within the angular acceptance of the *DNI* sensor but outside the solar disk

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## 3.13

**diffuse horizontal irradiance** $G_d$  or  $DHI$ 

global horizontal irradiance excluding the portion emanating from the solar disk and from the circumsolar region of the sky within a subtended full angle of  $5^\circ$

Note 1 to entry: Some diffuse irradiance measurement instruments exclude a circumsolar region within a subtended full angle of up to  $6^\circ$ .

Note 2 to entry: Expressed in units of  $\text{W}\cdot\text{m}^{-2}$ .

## 3.14

**in-plane direct beam irradiance** $G_{i,b}$ 

in-plane irradiance emanating from the solar disk and from the circumsolar region of the sky within a subtended full angle of  $5^\circ$ , excluding scattering and reflections.

Note 1 to entry: The in-plane direct beam irradiance  $G_{i,b} = \cos(\theta) \times DNI$ , where  $\theta$  is the angle between the sun and the normal to the plane. When the plane of array is normal to the sun,  $G_{i,b} = DNI$ .

Note 2 to entry: Expressed in units of  $\text{W}\cdot\text{m}^{-2}$ .

## 3.15

**in-plane diffuse irradiance** $G_{i,d}$ 

in-plane irradiance excluding the direct beam irradiance

Note 1 to entry:  $G_{i,d} = G_i - G_{i,b}$

Note 2 to entry: Expressed in units of  $\text{W}\cdot\text{m}^{-2}$ .

## 3.16

**irradiation** $H$ 

irradiance integrated over a specified time interval

Note 1 to entry: Expressed in units of  $\text{kW}\cdot\text{h}\cdot\text{m}^{-2}$ .

## 3.17

**standard test conditions**

STC

reference values of in-plane irradiance ( $1000 \text{ W}\cdot\text{m}^{-2}$ ), PV cell junction temperature ( $25^\circ\text{C}$ ), and the reference spectral irradiance defined in IEC 60904-3

## 3.18

**soiling ratio** $SR$ 

ratio of the actual power output of the PV array under given soiling conditions to the power that would be expected if the PV array were clean and free of soiling

3.19

**soiling level***SL*fractional power loss due to soiling, given by  $1 - SR$ 

3.20

**active power***P*

under periodic conditions, mean value, taken over one period, of the instantaneous product of current and voltage

Note 1 to entry: Under sinusoidal conditions, the active power is the real part of the complex power.

Note 2 to entry: Expressed in units of W.

3.21

**apparent power***S*

product of the r.m.s. voltage between the terminals of a two-terminal element or two-terminal circuit and the r.m.s. electric current in the element or circuit

Note 1 to entry: Under sinusoidal conditions, the apparent power is the modulus of the complex power.

Note 2 to entry: Expressed in units of VA.

3.22

**power factor** $\lambda$ under periodic conditions, ratio of the absolute value of the active power *P* to the apparent power *S*:

$$\lambda = |P| / S$$

**4 Monitoring system classification**

The required accuracy and complexity of the monitoring system depends on the PV system size and user objectives. This document defines three classifications of monitoring systems providing varying levels of accuracy, as listed in Table 1.

The monitoring system classification shall be stated in any conformity declarations to this standard. The monitoring system classification may be referenced either by its letter code (A, B, C) or its name (high accuracy, medium accuracy, basic accuracy) as indicated in Table 1. In this document, the letter codes are used for convenience.

Class A or Class B would be most appropriate for large PV systems, such as utility-scale and large commercial installations, while Class B or Class C would be most appropriate for small systems, such as smaller commercial and residential installations. However, users of the standard may specify any classification appropriate to their application, regardless of PV system size.

Throughout this document, some requirements are designated as applying to a particular classification. Where no designation is given, the requirements apply to all classifications.

**Table 1 – Monitoring system classifications and suggested applications**

| Typical applications                       | Class A<br>High accuracy | Class B<br>Medium accuracy | Class C<br>Basic accuracy |
|--------------------------------------------|--------------------------|----------------------------|---------------------------|
| Basic system performance assessment        | X                        | X                          | X                         |
| Documentation of a performance guarantee   | X                        | X                          |                           |
| System losses analysis                     | X                        | X                          |                           |
| Electricity network interaction assessment | X                        |                            |                           |
| Fault localization                         | X                        |                            |                           |
| PV technology assessment                   | X                        |                            |                           |
| Precise PV system degradation measurement  | X                        |                            |                           |

## 5 General

### 5.1 Measurement uncertainty

Where requirements on measurement uncertainties are stated in the document, they refer to the combined uncertainties of the measurement sensors and any signal-conditioning electronics.

Measurement uncertainties shall apply over the typical range of values of each measured quantity indicated in the document, as well as over the typical temperature range at which the system will operate. The effect of non-linearity of the measurement within the typical range shall be included within the stated uncertainty.

Measurement uncertainties can be calculated as outlined in ISO/IEC Guide 98-1 and ISO/IEC Guide 98-3.

### 5.2 Calibration

Sensors and signal-conditioning electronics used in the monitoring system shall be calibrated prior to the start of monitoring.

Recalibration of sensors and signal-conditioning electronics is to be performed as required by the manufacturer or at more frequent intervals where specified.

It is recommended to perform periodic cross-checks of each sensor against sister sensors or reference devices in order to identify out-of-calibration sensors.

### 5.3 Repeated elements

Depending on system size and user requirements, the monitoring system may include redundancy in sensors and/or repetition of sensor elements for different components or subsections of the full PV system. Accordingly, the measured and calculated parameters defined in this document may have multiple instances, each corresponding to a subsection or subcomponent of the PV system.

### 5.4 Power consumption

The parasitic power drawn by tracking, monitoring, and other ancillary systems required for operation of the PV plant shall be considered a power loss of the plant, not a load supplied by the plant.

### 5.5 Documentation

Specifications of all components of the monitoring system, including sensors and signal conditioning electronics, shall be documented.

User guides shall be provided for the monitoring system software.

All system maintenance, including cleaning of sensors, PV modules, or other soiled surfaces, shall be documented.

A log should be kept to record unusual events, component changes, sensor recalibration, changes to the data acquisition system, changes to the overall system operation, failures, faults, or accidents.

When a conformity declaration is made, documentation shall demonstrate consistency with the indicated class A, B, or C.

### 5.6 Inspection

For Class A and Class B the monitoring system should be inspected at least annually and preferably at more frequent intervals, while for Class C inspection should be per site-specific requirements. Inspection should look for damage to or displacement of exterior sensors, evidence of moisture or vermin in enclosures, loose wiring connections at sensors or within enclosures, detachment of temperature sensors, embrittlement of attachments, and other potential problems.

## 6 Data acquisition timing and reporting

### 6.1 Sampling, recording, and reporting

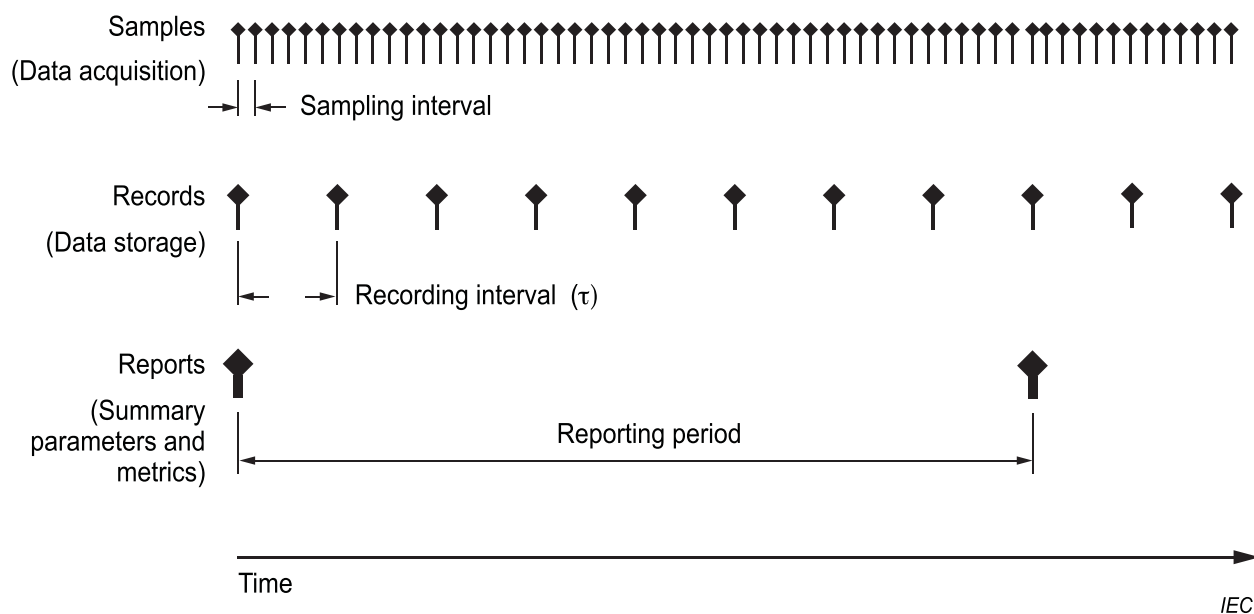
A sample is defined as data acquired from a sensor or measuring device, and the sampling interval is the time between samples. Samples do not need to be permanently stored.

A record is defined as data entered into a data log for data storage, based on acquired samples, and the recording interval, denoted by  $\tau$  in this document, is the time between records. The recording interval should be an integer multiple of the sampling interval, and an integer number of recording intervals should fit within 1 h.

The recorded parameter value for each record is the average, maximum, minimum, sum, or other function of the samples acquired during the recording interval, as appropriate for the measured quantity. The record can also include supplementary data such as additional statistics of the samples, number of missing data points, error codes, transients, and/or other data of special interest. (For wind data records, see statement in 7.3.3.)

A report is defined as an aggregate value covering multiple recording intervals, and the reporting period is the time between reports. Typically the reporting period would be chosen to be days, weeks, months, or years.

Figure 2 illustrates the relations between samples, records, and reports. Table 2 lists maximum values for sampling intervals and recording intervals. Further considerations relating to the sampling interval are addressed in Annex A.



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**Figure 2 – Sampling, recording, and reporting**

**Table 2 – Sampling and recording interval requirements**

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>Class A</b><br>High accuracy | <b>Class B</b><br>Medium accuracy | <b>Class C</b><br>Basic accuracy |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|-----------------------------------|----------------------------------|
| <b>Maximum sampling interval</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                 |                                   |                                  |
| For irradiance, temperature, wind*, and electrical output                                                                                                                                                                                                                                                                                                                                                                                                                                       | 3 s                             | 1 min**                           | 1 min**                          |
| For soiling, rain, snow, and humidity                                                                                                                                                                                                                                                                                                                                                                                                                                                           | 1 min                           | 1 min**                           | 1 min**                          |
| <b>Maximum recording interval</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 1 min                           | 15 min                            | 60 min                           |
| * See statement in 7.3.3 regarding including maximum and minimum readings in wind data records.                                                                                                                                                                                                                                                                                                                                                                                                 |                                 |                                   |                                  |
| ** The indicated sampling interval requirements for class B and class C apply to ground-based measurements, but do not apply when using satellite-based estimation of irradiance or meteorological parameters. (A ground-based instrument will require frequent samples to construct the proper average over a recording interval, e.g. in the case of partly cloudy conditions, while satellite-based estimation may derive the same average from a single image during the reporting period.) |                                 |                                   |                                  |

## 6.2 Timestamps

Each record and each report shall include a timestamp.

Timestamp data shall include the date and time corresponding to the beginning or end of the recording interval or reporting period and the choice shall be specified.

The time should refer either to local standard time (not daylight savings time) or universal time, to avoid winter/summer time changes, and the choice of time shall be specified.

Midnight shall be treated as the start of a new day and expressed as 00:00.

When multiple data acquisition units are involved that each independently apply timestamps, the clocks of the units shall be synchronized, preferably by an automated mechanism such as global positioning system (GPS) or network time protocol (NTP).

It is recommended that documentation of timestamps follow ISO 8601, *Data elements and interchange formats – Information interchange – Representation of dates and times*.

## 7 Measured parameters

### 7.1 General requirements

Table 3 lists measured parameters defined by this document and a summary of measurement requirements. The purpose of each monitoring parameter is listed in Table 3 in order to guide the user. More details and additional requirements are provided in the subsequent referenced subclauses.

A check mark (✓) in Table 3 indicates a required parameter to be measured on site, qualified by specific notes where included.

Table 3 lists the minimum number of on-site sensors, in many cases by reference to Table 4. Where no number is given, only one sensor is required, although redundant sensors are typically advisable. When multiple sensors are required, they shall be distributed throughout the PV plant, or placed at monitoring points indicated in the table. If the plant includes multiple sections that have different PV technology types or substantially different local geography, then at least one sensor shall be placed in each section.

The symbol “E” in Table 3 indicates a parameter that may be estimated based on local or regional meteorological data or satellite data, rather than measured on site.

Empty cells in Table 3 indicate optional parameters that may be chosen for specific system requirements or to meet project specifications.

**NOTE** The most significant and direct impacts on PV performance are in-plane irradiance received by the PV array, the PV cell temperature, and shading losses due to soiling or snow. Monitoring of meteorological parameters listed in Table 3 aids in estimating some of these factors independently, provides the ability to compare to historical meteorological data for the site, and can aid in identifying system design or maintenance problems. Additional parameters listed in Table 3 aid in fault localization and assessing utility grid interactions.

Table 3 – Measured parameters and requirements for each monitoring system class

| Parameter                                  | Symbol         | Units            | Monitoring purpose                                                | Required?                               |                                         |                           | Number of sensors |
|--------------------------------------------|----------------|------------------|-------------------------------------------------------------------|-----------------------------------------|-----------------------------------------|---------------------------|-------------------|
|                                            |                |                  |                                                                   | Class A<br>High Accuracy                | Class B<br>Medium Accuracy              | Class C<br>Basic Accuracy |                   |
| Irradiance (see 7.3)                       |                |                  |                                                                   |                                         |                                         |                           |                   |
| In-plane irradiance (POA)                  | $G_i$          | $W \cdot m^{-2}$ | Solar resource                                                    | ✓                                       | ✓ or E                                  | ✓ or E                    | Table 4 column 1  |
| Global horizontal irradiance               | $G_{HI}$       | $W \cdot m^{-2}$ | Solar resource, connection to historical and satellite data       | ✓                                       | ✓ or E                                  |                           | Table 4 column 1  |
| Direct normal irradiance                   | $DNI$          | $W \cdot m^{-2}$ | Solar resource, concentrator                                      | ✓ for CPV                               | ✓ or E for CPV                          |                           | Table 4 column 1  |
| Diffuse irradiance                         | $G_d$          | $W \cdot m^{-2}$ |                                                                   | ✓ for CPV with < 20× concentration      | ✓ or E for CPV with < 20× concentration |                           | Table 4 column 1  |
| Circumsolar ratio                          | $CSR$          |                  |                                                                   |                                         |                                         |                           |                   |
| Environmental factors (see 7.3)            |                |                  |                                                                   |                                         |                                         |                           |                   |
| PV module temperature                      | $T_{mod}$      | °C               | Determining temperature-related losses                            | ✓                                       | ✓ or E                                  |                           | Table 4 column 2  |
| Ambient air temperature                    | $T_{amb}$      | °C               | Connection to historical data, plus estimation of PV temperatures | ✓                                       | ✓ or E                                  | ✓ or E                    | Table 4 column 1  |
| Wind speed                                 |                | $m \cdot s^{-1}$ | Estimation of PV temperatures                                     | ✓                                       | ✓ or E                                  |                           | Table 4 column 1  |
| Wind direction                             |                | degrees          |                                                                   | ✓                                       |                                         |                           | Table 4 column 1  |
| Soiling ratio                              | $SR$           |                  | Determining soiling-related losses                                | ✓ if soiling losses expected to be >2 % |                                         |                           | Table 4 column 1  |
| Rainfall                                   |                | cm               | Estimation of soiling losses                                      | ✓                                       | ✓ or E                                  |                           | Table 4 column 1  |
| Snow                                       |                |                  | Estimation of snow-related losses                                 |                                         |                                         |                           |                   |
| Humidity                                   |                |                  | Estimation of spectral variations                                 |                                         |                                         |                           |                   |
| Tracker system (see 7.4)                   |                |                  |                                                                   |                                         |                                         |                           |                   |
| Error in dual-axis tracker primary angle   | $\Delta\phi_1$ | degrees          | Tracker system fault detection, dual-axis                         | ✓ for CPV with >20× concentration       |                                         |                           | Table 4 column 1  |
| Error in dual-axis tracker secondary angle | $\Delta\phi_2$ | degrees          |                                                                   | ✓ for CPV with >20× concentration       |                                         |                           | Table 4 column 1  |

Table 3 – Measured parameters and requirements for each monitoring system class Continued on Next Page

Table 3 – Measured parameters and requirements for each monitoring system class Continued

| Parameter                                  | Symbol          | Units   | Monitoring purpose                                                               | Required?                    |                            |                           | Number of sensors                                                 |
|--------------------------------------------|-----------------|---------|----------------------------------------------------------------------------------|------------------------------|----------------------------|---------------------------|-------------------------------------------------------------------|
|                                            |                 |         |                                                                                  | Class A<br>High Accuracy     | Class B<br>Medium Accuracy | Class C<br>Basic Accuracy |                                                                   |
| Single-axis tracker tilt angle             | $\phi_T$        | degrees | Tracker system fault detection, single-axis                                      | ✓<br>for single-axis tracker |                            |                           | Table 4 column 1                                                  |
| <b>Electrical output (see 7.5 and 7.6)</b> |                 |         |                                                                                  |                              |                            |                           |                                                                   |
| Array voltage (DC)                         | $V_A$           | V       | Energy output, diagnostics and fault localization                                | ✓                            |                            |                           | At each inverter (optionally at each combiner box or each string) |
| Array current (DC)                         | $I_A$           | A       |                                                                                  | ✓                            |                            |                           |                                                                   |
| Array power (DC)                           | $P_A$           | kW      |                                                                                  | ✓                            |                            |                           |                                                                   |
| Output voltage (AC)                        | $V_{out}$       | V       | Energy output                                                                    | ✓                            | ✓                          |                           | At each inverter and at system level                              |
| Output current (AC)                        | $I_{out}$       | A       |                                                                                  | ✓                            | ✓                          |                           |                                                                   |
| Output power (AC)                          | $P_{out}$       | kW      |                                                                                  | ✓                            | ✓                          | ✓                         |                                                                   |
| Output energy                              | $E_{out}$       | kWh     | Utility request compliance                                                       | ✓                            | ✓                          | ✓                         | At each inverter and at system level                              |
| Output power factor                        | $\lambda$       |         |                                                                                  | ✓                            | ✓                          |                           |                                                                   |
| Reduced load demand                        |                 |         | Determine utility or load request compliance and impact on PV system performance | If applicable                | If applicable              |                           | At system level                                                   |
| System output power factor request         | $\lambda_{req}$ |         |                                                                                  | If applicable                | If applicable              |                           |                                                                   |

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