



BSI Standards Publication

Photovoltaic system performance

Part 1: Monitoring

National foreword

This British Standard is the UK implementation of EN IEC 61724-1:2021. It is identical to IEC 61724-1:2021. It supersedes BS EN 61724-1:2017, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/82, Photovoltaic Energy Systems.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Date	Text affected
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English Version

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(IEC 61724-1:2021)

Performances des systèmes photovoltaïques - Partie 1:
Surveillance
(IEC 61724-1:2021)

Betriebsverhalten von Photovoltaik-Systemen - Teil 1:
Überwachung
(IEC 61724-1:2021)

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Comité Européen de Normalisation Electrotechnique
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European foreword

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The following dates are fixed:

- latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2022-05-25
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2024-08-25

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The text of the International Standard IEC 61724-1:2021 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following note has to be added for the standard indicated:

IEC 60904-3 NOTE Harmonized as EN IEC 60904-3

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

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.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60050-131	-	International Electrotechnical Vocabulary- (IEV) - Part 131: Circuit theory		-
IEC 60904-2	-	Photovoltaic devices - Part 2: Requirements for photovoltaic reference devices	2:EN 60904-2	-
IEC 60904-5	-	Photovoltaic devices - Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method	5:EN 60904-5	-
IEC 60904-7	-	Photovoltaic devices - Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices	EN IEC 60904-7	-
IEC 61215	series	Terrestrial photovoltaic (PV) modules Design qualification and type approval	-EN IEC 61215	series
IEC 61557-12	-	Electrical safety in low voltage distribution-systems up to 1 000 V AC and 1 500 V DC - Equipment for testing, measuring or monitoring of protective measures - Part 12: Power metering and monitoring devices (PMD)		-
IEC/TS 61724-2		Photovoltaic system performance - Part 2: Capacity evaluation method		
IEC/TS 61724-3		Photovoltaic system performance - Part 3: Energy evaluation method		
IEC/TS 61836		Solar photovoltaic energy systems - Terms, definitions and symbols		-
IEC 62053-22	-	Electricity metering equipment - Part 22: Static meters for AC active energy (classes 0,1S, 0,2S and 0,5S)	EN IEC 62053-22	-

EN IEC 61724-1:2021 (E)

IEC 62670-3	-	Photovoltaic concentrators (CPV) –EN 62670-3	-
		Performance testing - Part 3: Performance measurements and power rating	
IEC 62817	2014	Photovoltaic systems - Design qualification of solar trackers	2015
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	2018	Solar energy - Specification and classification of instruments for measuring hemispherical solar and direct solar radiation	
ISO 9488		Solar energy - Vocabulary	EN ISO 9488

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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 second edition cancels and replaces the first edition, published in 2017. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- Monitoring of bifacial systems is introduced.
- Irradiance sensor requirements are updated.
- Soiling measurement is updated based on new technology.
- Class C monitoring systems are eliminated.
- Various requirements, recommendations and explanatory notes are updated.

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

FDIS	Report on voting
82/1904/FDIS	82/1925/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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 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.

INTRODUCTION

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

Figure 1 illustrates major elements comprising different PV system types. 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 E includes some details for systems with additional components.

The PV array may include both fixed-axis and tracker systems and both flat-plate and concentrator systems.

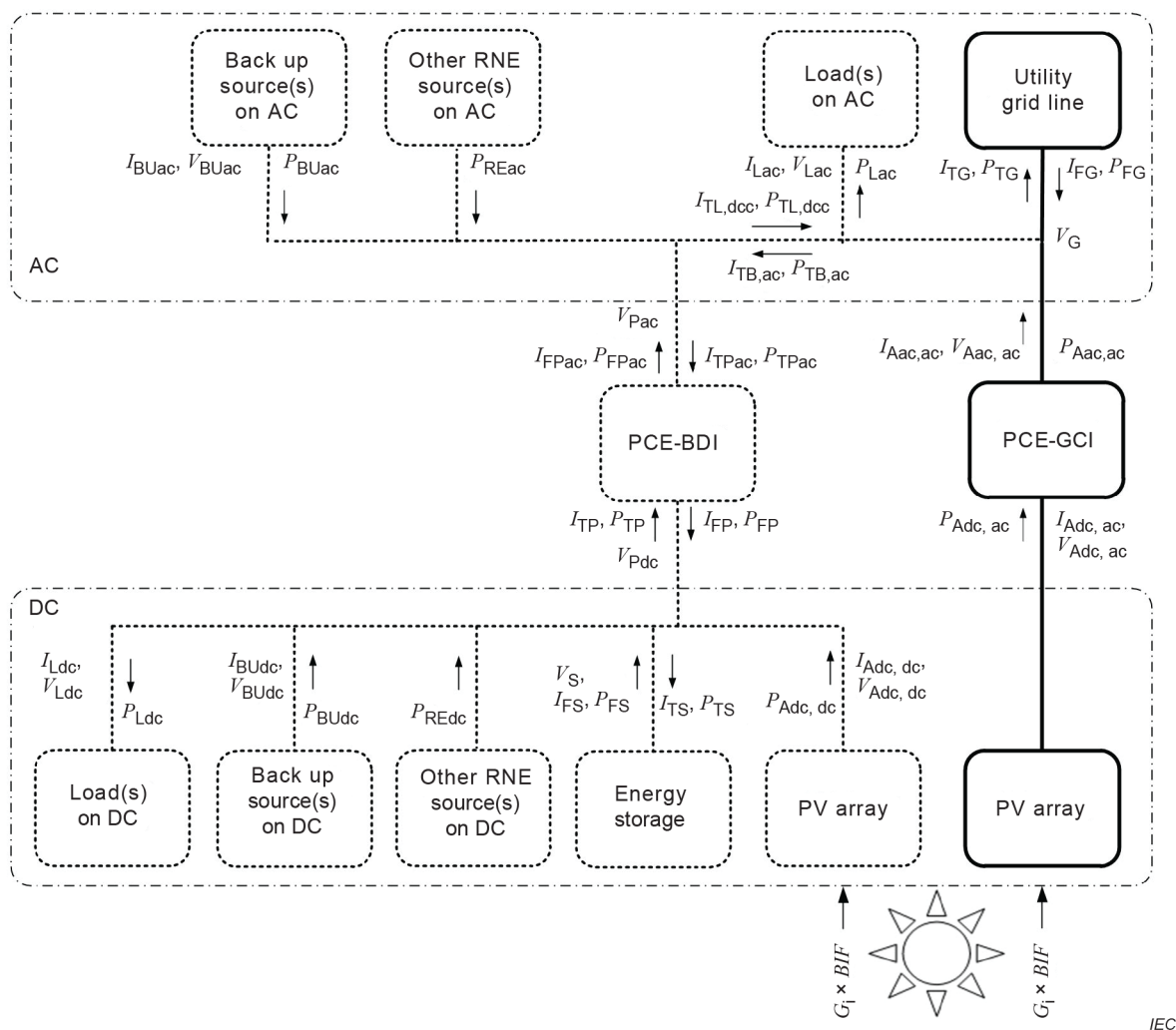


Figure 1 – Possible elements of PV systems

The purposes of a performance monitoring system are diverse and could include comparing performance to design expectations and guarantees as well as detecting and localizing faults.

For comparing performance to design expectations and guarantees, the focus should be on system-level data and consistency between prediction and test methods.

For detecting and localizing faults there should be greater resolution at sub-levels of the system and an emphasis on measurement repeatability and correlation metrics.

The monitoring system should be adapted to the PV system's size and user requirements. In general, larger PV systems should have more monitoring points and higher accuracy sensors than smaller and lower-cost PV systems.

PHOTOVOLTAIC SYSTEM PERFORMANCE –

Part 1: Monitoring

1 Scope

This part of IEC 61724 outlines terminology, equipment, and methods for performance monitoring and analysis of photovoltaic (PV) systems. It also 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 (IEV) – Part 131: Circuit theory*

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

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 60904-7, *Photovoltaic devices – Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices*

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

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

IEC TS 61724-2, *Photovoltaic system performance – Part 2: Capacity evaluation method*

IEC TS 61724-3, *Photovoltaic system performance – Part 3: Energy evaluation method*

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

IEC 62053-22, *Electricity metering equipment – Particular requirements – Part 22: Static meters for AC active energy (classes 0,1S, 0,2S and 0,5S)*

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 9060:2018, *Solar energy – Specification and classification of instruments for measuring hemispherical solar and direct solar radiation*

ISO 9488, *Solar energy – Vocabulary*

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

3.4

recording interval

τ

time between records

3.5

report

aggregate value based on series of records

3.6

reporting period

time between reports

3.7

front side

side of a surface which normally faces the sky

3.8

rear side

side of a surface which normally faces the ground

3.9

monofacial PV device

PV device in which only the front side is used for power generation

3.10

bifacial PV device

PV device in which both front side and rear side are used for power generation

3.11

bifaciality coefficient

φ

ratio between an I-V characteristic of the rear side and the front side of a bifacial device, typically at Standard Test Conditions (STC), unless otherwise specified

Note 1 to entry: Bifaciality coefficients include the short-circuit current bifaciality coefficient $\varphi_{I_{sc}}$, the open-circuit voltage bifaciality coefficient $\varphi_{V_{oc}}$ and the maximum power bifaciality coefficient $\varphi_{P_{max}}$.

Note 2 to entry: Bifaciality coefficients are defined in IEC TS 60904-1-2.

3.12

irradiance

G

incident flux of radiant power per unit area

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

3.13

in-plane irradiance

G_i or POA

sum of direct, diffuse, and ground-reflected irradiance incident upon the front side of 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 $W \cdot m^{-2}$.

3.14

horizontal albedo

ρ_H

proportion of incident light reflected by a ground surface as measured in a horizontal plane

Note 1 to entry: It is a property of a ground surface and is a dimensionless quantity on a scale from 0 to 1.

3.15

in-plane rear-side irradiance ratio

ρ_i

ratio of the irradiance incident on the rear side of the modules in the PV array to the irradiance incident on the front side

Note 1 to entry: It is a dimensionless quantity but can exceed a value of 1 since, in addition to reflected light, diffuse and direct components of the solar resource may also be measured on the rear-side of the plane of array.

3.16

spectrally matched in-plane rear-side irradiance ratio

ρ_i^{SP}

in-plane rear-side irradiance ratio per 3.15 when both irradiance quantities are measured with a spectrally matched reference device or with the application of spectral correction factors per IEC 60904-7

3.17

spectrally matched reference device

reference device such as a PV cell or module with spectral response characteristics sufficiently close to those of the PV modules in the PV array such that spectral mismatch errors are small under the typical range of incident spectra

3.18**in-plane rear-side irradiance** G_i^{rear} or POA^{rear}

sum of direct, diffuse, and ground-reflected irradiance incident on the rear side of the modules in the PV array, also known as rear-side plane-of-array irradiance

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

Note 2 to entry: (If measured via in-plane rear-side irradiance ratio): $G_i^{\text{rear}} = \rho_i \times G_i$ or $G_{i,SP}^{\text{rear}} = \rho_i^{\text{SP}} \times G_i$.

3.19**bifacial reference device**

bifacial PV device, such as a cell or module, having substantially the same properties, with respect to response to front-side and rear-side irradiance, as bifacial modules to be monitored

3.20**bifacial irradiance factor** BIF

dimensionless factor that can be directly multiplied by the front-side in-plane irradiance (G_i) to calculate the “effective” irradiance reaching a bifacial device from both the front and rear side collectively

Note 1 to entry: $BIF = (1 + \varphi_{pmax} \times \rho_i)$ or $BIF^{SP} = (1 + \varphi_{pmax} \times \rho_i^{SP})$. See 3.11, 3.15, 3.16.

Note 2 to entry: Rear-side POA irradiance can be measured simultaneously with front-side POA irradiance using a bifacial reference device. In that case, $BIF = G_i^{BIF \text{ Ref Device}} \div G_i$. For consistency, the front-side POA irradiance should be measured with the same or similar type of device as the bifacial reference device.

Note 3 to entry: “Effective” irradiance may include the effect of inhomogeneities in rear-side irradiance.

3.21**global horizontal irradiance** GHI

direct plus diffuse irradiance incident on the front side of a horizontal surface

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

Note 2 to entry: $GHI = DNI \cdot \cos Z + DHI$ where Z is the solar zenith angle.

3.22**circumsolar**

immediately surrounding the solar disk

3.23**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° falling on a plane surface normal to the sun's rays

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

Note 2 to entry: $GHI = DNI \cdot \cos Z + DHI$ where Z is the solar zenith angle.

3.24

circumsolar contribution

contribution of a specific portion of the circumsolar normal irradiance to the direct normal irradiance. The circumsolar contribution refers to a specific ring-shaped angular region described by an inner and the outer angular distance from the centre of the sun (see ISO 9488)

Note 1 to entry: If the inner angle describing this angular region is the half-angle of the sun disk the circumsolar contribution is also called circumsolar ratio.

Note 2 to entry: Depending on the circumsolar irradiance measurement instrument or the solar technology involved, different wavelength ranges are included. In order to describe circumsolar irradiance correctly, the wavelength range or the spectral response of the instrument or the involved technology has to be specified.

3.25

circumsolar ratio

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

3.26

sunshape

azimuthal average radiance profile as a function of the angular distance from the centre of the sun, normalized to 1 at the centre of the sun and considering the wavelength range of shortwave radiation (see ISO 9488)

3.27

diffuse horizontal irradiance

G_d or *DHI*

global irradiance on the front side of a horizontal surface excluding the portion emanating from the solar disk and from the circumsolar region of the sky within a subtended full angle of 5°

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

Note 2 to entry: $GHI = DNI \cdot \cos Z + DHI$ where *Z* is the solar zenith angle.

3.28

in-plane direct beam irradiance

$G_{i,b}$

in-plane irradiance incident upon the front side of an inclined surface parallel to the plane of the modules in the PV array emanating from the solar disk and from the circumsolar region of the sky within a subtended full angle of 5°

Note 1 to entry: The in-plane direct beam irradiance $G_{i,b} = \cos(\theta) \times DNI$, where θ 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 $\text{W}\cdot\text{m}^{-2}$.

3.29

irradiation

H

irradiance integrated over a specified time interval

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

3.30

standard test conditions

STC

in-plane irradiance $1000 \text{ W}\cdot\text{m}^{-2}$, normal incidence, PV cell junction temperature 25 °C, and the reference spectral irradiance defined in IEC 60904-3

3.31**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

3.32**soiling level***SL*

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

3.33**soiling rate**

rate of change of soiling ratio, typically expressed in percent per day

3.34**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.

3.35**apparent power***S*

product of the rms voltage between the terminals of a two-terminal element or two-terminal circuit and the rms 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.

3.36**power factor***λ*

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

$$\lambda = \frac{|P|}{S}$$

4 Monitoring system classification

This document defines two classifications of monitoring system, Class A and Class B.

Class A is intended for large PV systems such as utility-scale or large commercial installations.

Class B is intended for smaller systems such as rooftop or small to medium-size commercial installations.

Users of the document may specify whichever classification is most appropriate to their application, regardless of PV system size.

The monitoring system classification shall be stated in any conformity declarations to this document.

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

5 General

5.1 Measurement precision and uncertainty

Measurement precision refers to repeatability and resolution, which have the meanings defined in the IEC Electropedia.

Measurement uncertainty refers to accuracy and otherwise has the meaning defined in the IEC Electropedia.

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

5.2 Calibration

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

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 any systems required for operation of the PV plant shall not be considered as a load supplied by the plant.

5.5 Documentation

Details of all components of the monitoring system shall be documented. All system inspection and maintenance, including cleaning, shall be documented.

5.6 Inspection

The monitoring system shall be inspected at least annually and preferably at more frequent intervals. Inspection should look for damage, deterioration, or disconnection of sensors and electrical enclosures, soiling or displacement of optical sensors, loose wiring connections, detachment of temperature sensors, embrittlement of attachments, and other potential problems.

6 Data acquisition timing and reporting

6.1 Samples, records, and reports

Figure 2 illustrates the relations between samples, records, and reports.

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

A record is data entered into data storage, based on acquired samples. The recording interval, denoted by τ 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 9.3.)

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

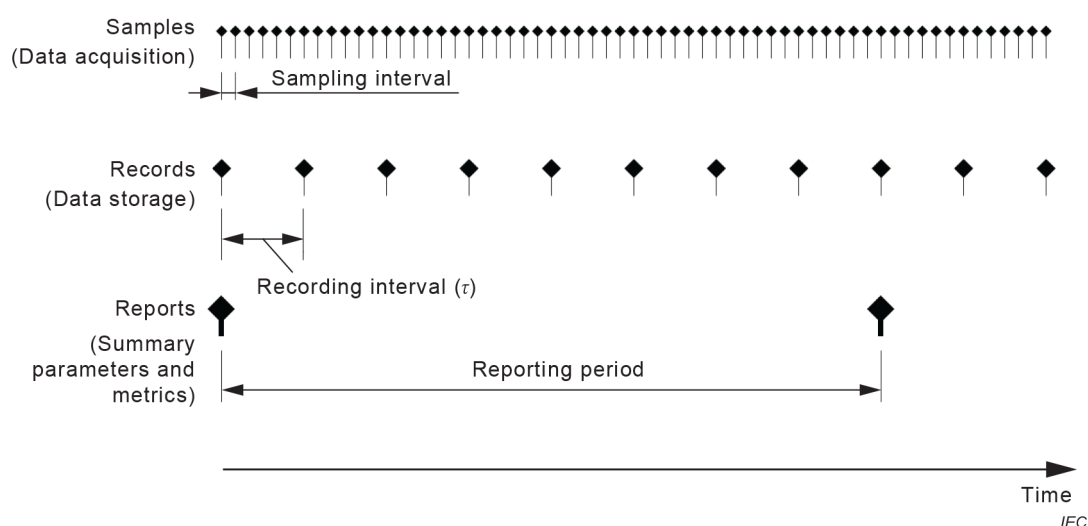


Figure 2 – Samples, records and reports

Table 1 lists maximum values for sampling intervals and recording intervals.

Further considerations relating to the sampling interval are addressed in Annex A. The maximum sampling interval for Class A is longer than the typical signal and instrument time constants for irradiance, wind and electrical output, however, the value is chosen for practicality considering common data acquisition systems.

The indicated sampling and recording interval recommendations apply to on-site ground-based measurements. For satellite-based measurement of irradiance, longer intervals of up to 1 h may be used. A ground-based instrument will require frequent samples to construct a valid time average over a recording interval, e.g. in the case of partly cloudy conditions, while satellite-based estimation uses the spatial average of many pixels in a single image as a substitute for time averaging.)