PD IEC/TS 62727:2012

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Photovoltaic systems — Specifications for solar trackers

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National foreword

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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 secretary.

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Published by BSI Standards Limited 2012

ISBN 978 0 580 75803 4

ICS 27.160

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This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 June 2012.

Amendments issued since publication

Amd. No.	Date	Text affected

IEC/TS 62727

Edition 1.0 2012-05

TECHNICAL SPECIFICATION

colour inside

Photovoltaic systems – Specifications for solar trackers

INTERNATIONAL ELECTROTECHNICAL COMMISSION

PRICE CODE U

ICS 27.160

ISBN 978-2-83220-122-0

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC SYSTEMS – SPECIFICATIONS FOR SOLAR TRACKERS

FOREWORD

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- 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 62727, 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
82/651/DTS	82/711/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 publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site 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.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

PHOTOVOLTAIC SYSTEMS – SPECIFICATIONS FOR SOLAR TRACKERS

1 Scope and object

This technical specification provides guidelines for the parameters to be specified for solar trackers for photovoltaic systems and provides recommendations for measurement techniques. No attempt is made to determine pass/fail criteria for trackers.

The purpose of this test specification is to define the performance characteristics of trackers and describe the methods to calculate and/or measure critical parameters.

This specification provides industry-wide definitions and parameters for solar trackers. Each vendor can design, build, and specify the functionality and accuracy with uniform definition. This allows consistency in specifying the requirements for purchasing, comparing the products from different vendors, and verifying the quality of the products. In addition, this specification will clarify terminology and definitions for trackers and provide examples of measurement techniques.

This technical specification will be a foundation for other standards to follow, including (but not limited to) design qualification and reliability.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply. For additional tracker-specific terminology, see Clause 5.

2.1
photovoltaics
PV
devices that use solar radiation to generate electrical energy

2.2
concentrating photovoltaics
CPV
devices that focus magnified sunlight on photovoltaics to generate electrical energy. The sunlight could be magnified by various different methods, such as reflective or refractive optics, in dish, trough, lens, or other configurations.

2.3
concentrator module
CPV module
a group of receivers (PV cells mounted in some way), optics, and other related components, such as interconnections and mechanical enclosures, integrated together into a modular package. The module is typically assembled in a factory and shipped to an installation site to be installed along with other modules on a solar tracker.

Note 1 to entry: A CPV module typically does not have a field-adjustable focus point. In addition, a module could be made of several sub-modules. The sub-module is a smaller, modular portion of the full-size module, which might be assembled into the full module either in a factory or in the field.

2.4
concentrator assembly
a concentrator assembly consists of receivers, optics, and other related components that have a field-adjustable focus point and are typically assembled and aligned in field

EXAMPLE: A system that combines a single large dish with a receiver unit which must be aligned with the focal point of the disk.

Note 1 to entry: This term is used to differentiate certain CPV designs from the CPV modules mentioned above.

3 Specifications for solar trackers for PV applications

a) Specification template

All trackers complying with this specification should provide, as part of their product marking and documentation, a table in the form specified below (see Table 1). See later clauses and subclauses of this Technical Specification for further explanation of individual specifications.

Some of the specifications within the table are optional; however, if a tracker manufacturer chooses to include optional information, it should be reported and measured in the specific way shown in Table 1 (and in some cases, also described later in this Technical Specification).

Engineering safety factors should be dictated by appropriate local standards and applications details and documented by the tracker manufacturer.

The specification template below is a visual example only and should not be read as a list of requirements.

Table 1 – Tracker specification template

Characteristic	Example	Notes/Clause/Subclause
Manufacturer	The XYZ Company	
Model number	XX1090	
Type of tracker	CPV Tracker, Dual Axis	4.2, 4.3
Payload characteristics		
Minimum/maximum mass supported	100/1 025 kg	4.8.3
Payload center of mass restrictions	0-30 cm distance perpendicular to mounting surface	4.8.3
Maximum dynamic torques allowed while moving	Azimuth (Θ_z): 10 kN·m Θ_x, Θ_y: 5 kN·m [should provide a set of diagrams to clarify torques and which axes they are relative to]	4.13.2, 7.3
Maximum static torques allowed while in stow position	[should provide a set of diagrams]	4.13.1, 7.3
Installation characteristics		
Allowable foundation	Reinforced concrete	4.6.2
Foundation tolerance in primary axis	± 0,5°	4.9
Foundation tolerance in secondary axis	± 0,5°	4.9
Electrical characteristics		
Includes backup power?	No	N/A

Characteristic	Example	Notes/Clause/Subclause
Daily energy consumption	1 kWh typical 5 kWh maximum	4.7.1
Stow energy consumption	kWh typical 1 kWh maximum	4.7.2
Input power requirements	100-240 VAC, 50-60 Hz, 5 A	No specifics defined
Tracking accuracy		
Accuracy, typical (low wind, min deflect point)	0,1°	5.4.6
Accuracy, typical (low wind, max deflect point)	0,3°	5.4.6
Accuracy, 95th percentile (low wind, min deflect point)	0,5°	5.4.6
Accuracy, 95th percentile (low wind, max deflect point)	0,8°	5.4.6
Mean wind speed during the “low wind” test conditions	3 km/h	5.4.6
Accuracy, typical (high wind, min deflect point)	0,7°	5.4.6
Accuracy, typical (high wind, max deflect point)	1,0°	5.4.6
Accuracy, 95th percentile (high wind, min deflect point)	1,1	5.4.6
Accuracy, 95th percentile (high wind, max deflect point)	1,6°	5.4.6
Mean wind speed during the “high wind” test conditions	12 km/h	5.4.6
Weight and area of payload installed during testing	500 kg payload evenly distributed over a 50 m^2 area	5.4.2.1
Payload center of mass installed during testing	Payload center of mass 20 cm above the module mounting surface	5.4.2.1
Control characteristics		
Control algorithm	Hybrid	4.5
Control interface	None	4.8.9
External communication interface	Ethernet/TCP-IP	No specific description
Emergency stow provided?	Yes, at wind speeds 100 km/h	4.6.4, 4.12.3
Stow time	4 minutes	4.6.4
Clock accuracy	1 second per year	N/A
Mechanical design		
Range of motion, primary axis	± 160° azimuth	4.6.3.3
Range of motion, secondary axis	10°-90° elevation	4.6.3.3
System stiffness	Azimuth (Θ_z): 0,05° / 1 000 N·m, Θ_x: 0,1° / 1 000 N·m Diagrams attached show applied loads and observed deflection	6.3
Backlash	0,1° maximum	6.2
Environmental conditions		
Maximum allowable wind speed	Design values:	4.12.3

Characteristic	Example	Notes/Clause/Subclause
during tracking	80 km/h with 0 % terrain slope, open country, 60 km/h with 8 % terrain slope, suburban, urban Tested to: 60 km/h with 0 % terrain slope, open country	
Maximum allowable wind speed in stow	Design values: 150 km/h horizontal wind, 120 km/h with 10 % slope Tested to: 80 km/h with 0 % slope	4.12.4
Temperature operational range	–20 °C to +50 °C	4.12.1
Temperature survival range	–40 °C to +60 °C	4.12.2
Snow rating	Up to 20 kg/m^2 of snow load allowed	4.12.5

For an alternate template for the presentation of accuracy specifications see Table 2.

4 Tracker definitions and taxonomy

4.1 General

Solar trackers are mechanical devices used to point PV modules towards the sun or to direct sunlight on PV cells or modules. Photovoltaic trackers can be classified into two types: standard photovoltaic (PV) trackers and concentrated photovoltaic (CPV) trackers. Each of these tracker types can be further categorized by the number and orientation of their axes, their actuation architecture and drive type, their intended applications, and their vertical supports and foundation type.

4.2 Payload types

4.2.1 Standard photovoltaic (PV) module trackers

4.2.1.1 Uses

Standard photovoltaic trackers are used to minimize the angle of incidence between incoming light and a photovoltaic module. This increases the amount of energy produced from a fixed amount of power generating capacity.

4.2.1.2 Type of light accepted

Photovoltaic modules accept both direct and diffuse light from all angles. This means that systems implementing standard photovoltaic trackers produce energy even when not directly pointed at the sun. Tracking in standard photovoltaic systems is used to increase the amount of energy produced by the direct component of the incoming light.

4.2.1.3 Accuracy requirements

In standard photovoltaic systems, the energy contributed by the direct beam drops off with the cosine of the angle between the incoming light and the module. Thus trackers that have accuracies of ± 5° can deliver more than 99,6 % of the energy supplied by the direct beam. As a result, high-accuracy tracking is not typically used.

4.2.2 Concentrated photovoltaic (CPV) module trackers

4.2.2.1 Uses

Concentrated photovoltaic trackers are used to enable the optics used in CPV systems. These trackers point the concentrator modules at the sun or focus sunlight on PV collectors.

4.2.2.2 Type of light accepted

Direct solar radiation, as opposed to diffuse solar radiation, is the primary energy source for CPV modules. Optics are designed specifically to focus the direct radiation on photovoltaic cells. If this focus is not maintained, power output drops substantially.

If the CPV module concentrates in one dimension, then single axis tracking is required. If the CPV module concentrates in two dimensions, then two axis tracking is required.

4.2.2.3 Accuracy requirements

In concentrator modules, tracking accuracy requirements are typically related to energy production through the module acceptance angle. When the sun-pointing error is less than the acceptance angle, the modules will typically deliver 90 % or more of the rated power output.

4.3 Rotational axes

4.3.1 General

Photovoltaic trackers can be grouped into classes by the number and orientation of the tracker’s axes.

4.3.2 Single axis trackers

4.3.2.1 General

Single axis trackers have one degree of freedom that acts as an axis of rotation.

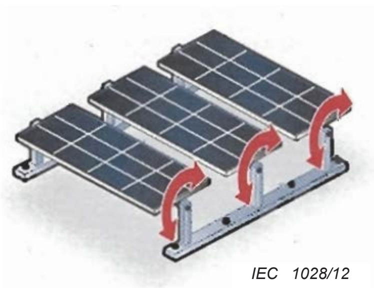
4.3.2.2 Single axis tracker implementations

4.3.2.2.1 General

There are several common implementations of single axis trackers. These include horizontal single axis trackers, vertical single axis trackers, and tilted single axis trackers.

4.3.2.2.2 Horizontal single axis tracker (HSAT)

The axis of rotation for a horizontal single axis tracker is horizontal with respect to the ground.



4.3.2.2.3 Vertical single axis tracker (VSAT)

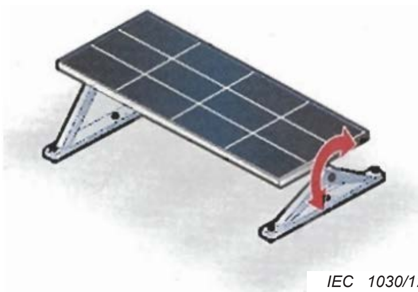
The axis of rotation for vertical single axis trackers is vertical with respect to the ground. These trackers rotate from east to west over the course of the day.

IEC 1029/12

4.3.2.2.4 Tilted single axis tracker (TSAT)

All trackers with axes of rotation between horizontal and vertical are considered tilted single axis trackers. Tracker tilt angles are often limited to reduce the wind profile and decrease the elevated end's height off the ground.

The polar aligned single axis tracker (PASAT) is a specific version of the tilted single axis tracker. In this particular implementation, the tilt angle is equal to the latitude of the installation. This aligns the tracker's axis of rotation with the earth's axis of rotation.



IEC 1030/12

4.3.2.3 Orientation – cardinal direction

The axis of rotation of single axis trackers is typically aligned along a true North meridian. It is possible to align them in any cardinal direction with advanced tracking algorithms.

4.3.2.4 Module orientation with respect to rotational axis

The orientation of the module with respect to the tracker axis is important when modelling performance.

Horizontal and tilted single axis trackers typically have the face of the module oriented parallel to the axis of rotation. As a module tracks, it sweeps a cylinder that is rotationally symmetric around the axis of rotation.

Vertical single axis trackers typically have the face of the module oriented at an angle with respect to the axis of rotation. As a module tracks, it sweeps a cone that is rotationally symmetric around the axis of rotation.

4.3.3 Dual axis trackers

4.3.3.1 General

Dual axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to one another. The axis that is fixed with respect to the ground can be considered the primary axis. The axis that is referenced to the primary axis can be considered the secondary axis.

4.3.3.2 Dual axis tracker implementations

4.3.3.2.1 General

There are several common implementations of dual axis trackers. They are classified by the orientation of their primary axes with respect to the ground. Two common implementations are tip-tilt trackers and azimuth-altitude trackers (see Figure 1).

One convention for azimuth angle is “degrees east of north” (e.g. 0° azimuth is pointing north, and 90° azimuth is pointing east).

One convention for altitude angle is “degrees up from the horizon” as illustrated below. Zenith angle is the complement of altitude angle (zenith = 90° – altitude).

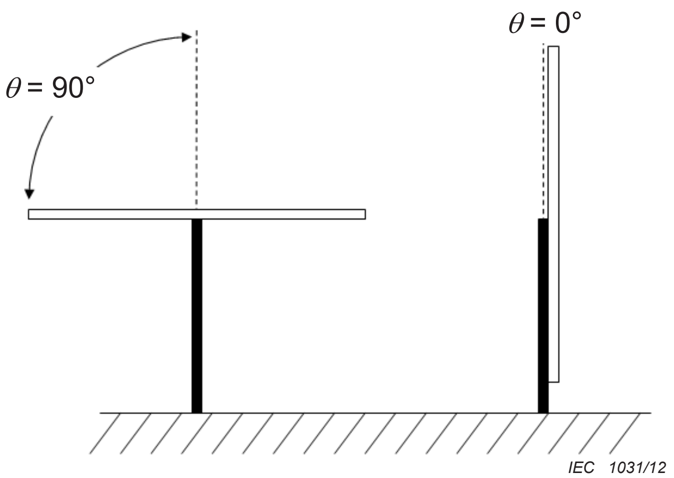


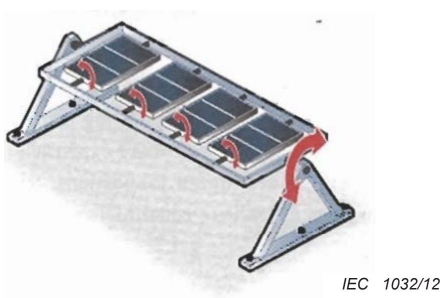
Figure 1 – θ = Altitude angle = 0° (zenith angle = 90°) occurs when a vector normal to the module face is pointing to the horizon. Altitude angle = 90° (zenith angle = 0°) occurs when the module is facing the sky

The above sign conventions are assumed to be the ones used to describe angles, but a different convention can be used as long as it is described. For example, the range of motion of a tracker could be described as “azimuth from +20° to +340°,” or alternately, “azimuth ± 160° from south”.

4.3.3.2.2 Tip-tilt dual axis tracker

A tip- tilt dual axis tracker (TTDAT) has its primary axis horizontal to the ground. The secondary axis is then typically normal to the primary axis.

The polar-style dual axis tracker is a particular type of TTDAT.



4.3.3.2.3 Azimuth-altitude dual axis tracker

An azimuth-altitude dual axis tracker (AADAT) has its primary axis vertical to the ground. The secondary axis is then typically normal to the primary axis.

IEC 1033/12

4.3.3.3 Orientation – cardinal direction

The axes of rotation of tip-tilt dual axis trackers are typically aligned either along a true north meridian or an east-west line of latitude. It is possible to align them in any cardinal direction with advanced tracking algorithms.

4.3.3.4 Module orientation with respect to rotational axes

The orientation of the module with respect to the tracker axis is important when modelling performance. Dual axis trackers typically have modules oriented parallel to the secondary axis of rotation.

4.4 Actuation and control

4.4.1 Architecture

4.4.1.1 General

There are two common actuation and control architectures: distributed actuation and ganged actuation. These are implemented in many ways.

4.4.1.2 Distributed actuation

In a distributed actuation architecture, each tracker and each axis of rotation is independently actuated and controlled.

4.4.1.3 Ganged actuation

In a ganged actuation architecture, many axes of rotation are simultaneously driven with a single actuation system. This can be multiple axes on a single tracker or multiple trackers in an array.

4.4.2 Drive types

4.4.2.1 General

There are three drive types used with solar trackers.

4.4.2.2 Electric drive

Electric drive systems transfer electrical energy to AC motors, DC brushed motors, or DC brushless motors to create rotational motion. These motors interface with gearboxes that reduce the rotational speed in exchange for additional torque. The final gearbox stage delivers either rotary or linear motion that is used to drive a tracker axis.

4.4.2.3 Hydraulic drive

Hydraulic drive systems use pumps to generate hydraulic pressure. The hydraulic pressure is transferred through valves, pipes, and hoses to a hydraulic motor or cylinder. The hydraulic motor and cylinder adjust the mechanical advantage as needed to deliver the rotary or linear motion to drive a tracker axis.

4.4.2.4 Passive drive

Passive drive systems use differential fluid pressure to drive a tracker axis. The pressure differential is created by thermal gradients created by differential shading. The tracker moves to bring the pressure differentials to equilibrium.

4.5 Types of tracker control

4.5.1 Passive control

Passive solar tracking typically relies on environmental forces to produce changes in fluid density, which provide internal forces that can be used for mechanical advantage to position the payload.

4.5.2 Active control

4.5.2.1 General

Active solar tracking uses supplied power to drive circuitry and actuators (motors, hydraulics, and others) to position the payload.

4.5.2.2 Open loop control

Open loop control is an active method of tracking that does not use direct sensing of the sun position, module power, et cetera as feedback. It uses mathematical calculations of the sun position (based on the time of day, date, location, and so on) to determine where the tracker should be pointing and drives actuators accordingly.

Note that open loop control in this context does not imply that the actuators themselves do not provide feedback; the actuators could be servo motors with encoders and could themselves be controlled via a closed-loop PID or similar controller.

Open loop in the context of tracker control refers to the control algorithm having no direct feedback on the actual tracking error.

4.5.2.3 Closed loop control

This is an active method of tracking that utilizes some sort of feedback (such as an optical sun position sensor or the module power output) to determine how to drive the actuators and position the payload.

4.5.2.4 Hybrid control

This is an active method of tracking that combines the mathematical sun position calculations (open loop ephemeris code) with the type of sensor data used in a closed feedback loop. There are many different approaches to hybrid control.

4.5.3 Backtracking

Backtracking refers to intentionally positioning trackers somewhat off-sun, typically to reduce shading from adjacent trackers in a close-packed installation during the early morning and late afternoon when the sun is low on the horizon.

One method involves moving all the trackers in a field to a slightly higher elevation angle to avoid shading. Another approach is for every other row to be inactive and positioned at 0° (pointing at the sky) to allow the other rows clear line-of-sight to the sun without shading. This is useful mainly in designs that do not have access to enough land area to be spaced far enough apart to avoid shading in the early morning and late afternoon. Backtracking is typically not applicable to CPV.

4.6 Structural characteristics

4.6.1 Vertical supports

4.6.1.1 General

Vertical supports transfer the load of the structure to the foundation. There are two common types of vertical supports.

4.6.1.2 Pole-mounted trackers

A pole-mounted tracker transfers the load to the foundation via one or more poles. These poles attach to or continue into one or more foundations.

All types of trackers (single axis and dual axis) can be mounted on poles.

4.6.1.3 Carousel-mounted trackers

A carousel-mounted tracker transfers the load to the foundation via a ring. This ring is then attached to the foundation at multiple points.

Vertical single axis trackers and azimuth-altitude dual axis trackers are the only trackers that can be carousel mounted.

4.6.2 Foundation types

4.6.2.1 General

The load placed on the tracker structure shall be sustained through its foundation.

Trackers can be mounted on roofs, ground/earth, and water and will be subject to location-specific loading. As a result, there are many types of foundations used with trackers. The foundation type used will depend on site-specific characteristics and the codes of the local jurisdiction.

Foundation types are often categorized by whether or not they penetrate into the mounting surface.

4.6.2.2 Penetrating foundations

4.6.2.2.1 Pile foundations

Pile foundations (also known as deep foundations) come in a wide variety of types. These include but are not limited to concrete piles, driven piles, and drilled piles.

Pile foundations are common in ground-mounted and water-mounted applications. Hole diameters, depth, concrete mixtures, rebar requirements, thread type, and other characteristics are all determined by local site conditions.

4.6.2.3 Non-penetrating foundations

4.6.2.3.1 Ballasted foundations

Ballasted foundations (also known as shallow foundations) come in a wide variety of types.

Ballasted foundations are found in ground mount and roof mount applications. The area in contact with the surface, total mass, material type, rebar requirements, and other characteristics are all determined by local site conditions.

4.6.3 Tracker positions

4.6.3.1 Stow

The stow position is the position the tracker moves to when adverse weather conditions (e.g., high wind or heavy snow) are present or expected in order to avoid loads that might damage the tracker or payload. Not all trackers will have a stow position, and the exact position will vary depending on the tracker design.

4.6.3.2 Maintenance

The maintenance position is the position the tracker moves to for operations such as cleaning, module installation, servicing, and so on. It could be the same position as the stow position or a different position, and there could be multiple maintenance positions. When in this position, there should be a safety interlock preventing sudden tracker motion without operator interaction.

4.6.3.3 Range of motion

The range of motion is defined by the maximum motion of the tracker in each direction, in each axis.

For example, a turret-style primary axis might have a range of motion of ± 135° from true south [or in the reference frames defined above, +45° to +315° azimuth (east of north)]. An elevation-style secondary axis might have a range of motion of 0° to 90°.

The range of motion specified in the requirements of Table 1 shall be tested and documented.

Note that the range of motion is not only defined by any mechanical limits: the presence of electronic limit switches or software settings may be used to further restrict the range of motion for reasons such as safety or reduction of shading.

If the tracker includes a controller, the range of motion should refer to the maximum range of motion that can be commanded by the combination of hardware and software.

4.6.4 Stow time

The stow time is the time for the tracker with a standard payload to move from the position farthest from the stow position to the stow position.

4.7 Energy consumption

4.7.1 Daily energy consumption

The daily energy consumption of a tracker is defined as the amount of energy in kWh that is required to perform a full 24 h day of tracking (from start to stop at a typical tracking speed and back to start by whatever speed is standard for that tracker) carrying a standard load. The energy consumption will likely vary based on the wind loading and possibly also on cloud cover and other weather conditions. The energy consumption will also vary depending on the time of year.

4.7.2 Stow energy consumption

The stow energy consumption of a tracker is defined as the amount of energy in kWh that is required for the tracker to move from the position farthest from the stow position to the stow position.

4.8 External elements and interfaces

4.8.1 Foundation

The foundation is the support structure that is nominally fixed with respect to the terrain. It is equivalent to the mechanical “ground” symbol.

4.8.2 Foundation interface

The foundation interface attaches the tracker to the ground or rooftop. The tracker design will allow some maximum misalignment between the tracker and the foundation for correct operation.

4.8.3 Payload

The payload is the object being moved by the tracker, typically an array of PV or CPV modules combined with some mounting structure (but not including the tracker itself). The tracker shall specify a minimum and maximum weight of the carried payload as well as any restrictions on weight distribution and center of mass.

Accuracy testing (detailed in a later section) will be carried out with a payload installed (either an array of actual modules or an array of weights that simulate the mass, mass distribution, and wind resistance of these modules).

4.8.4 Payload interface

The payload interface is the boundary between the payload and the tracker. It is defined by the method of attachment between the payload and the tracker and the method(s) for transmitting loads between the payload and the tracker.

4.8.5 Payload mechanical interface

Provisions for managing wires across rotational interfaces are considered a mechanical interface issue, not an electrical one.

4.8.6 Payload electrical interface

The payload electrical interface includes any electrical connections between the tracker and the payload. Generally, electrical signals are not passed through trackers (except in a purely mechanical manner). For some tracker control schemes, however, electrical behaviour(s) of the payload are used as feedback, e.g., PV module output current or module output power.

4.8.7 Grounding interface

The grounding interface includes connections for the tracker to be grounded in case of a fault and for electrostatic discharge (ESD) protection.

4.8.8 Installation effort

4.8.8.1 General

The installation effort includes the man hours necessary to install the tracker. This should also include the equipment needed to install the tracker.

4.8.8.2 Range of latitude installation

This specifies the range of latitudes between 0° and 90° that the tracker design accommodates. Note that the tropics region requires that the tracker go past 90° elevation at certain times of the year.

If the tracker control software is only designed for operation in one hemisphere, this should also be mentioned.

4.8.9 Control interface

4.8.9.1 Human/manual interface

This describes any methods for an operator who is physically present at the tracker to control some of the functions. This could include switches or buttons to control motors, or an emergency stop button to halt motion. Each tracker design may provide different levels of manual interface.

4.8.9.2 Remote interface

A remote interface for the tracker could involve wired or wireless communications and a variety of communications protocols and user interfaces. One example is a remote web-based interface.

4.9 Internal tolerances

4.9.1 Primary axis tolerance

Primary axis tolerance is the total acceptable manufacturing and installation error between the specified primary axis vector and the actual vector of the primary axis upon final installation. The tolerance can be defined in milliradians or degrees (see Figure 2).

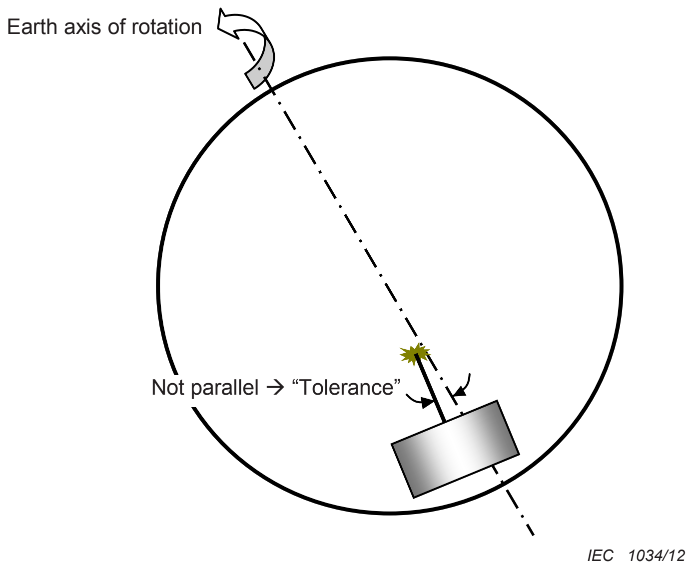


Figure 2 – Illustration of primary axis tolerance for a polar tracking axis

The tolerance is also used as a method to indicate how accurately the primary axis shall be manufactured and installed. For example, a tracker manufacturer might specify that the tracker will perform within specification as long as the primary axis is installed within one degree of the nominal position.

4.9.2 Secondary axis tolerance

The secondary axis tolerance is defined as the total acceptable error, in milliradians or degrees, between a vector which is perpendicular to the primary axis and the actual vector which is the secondary axis.

4.10 Tracker system elements

4.10.1 Mechanical structure

The mechanical structure supports the photovoltaic modules or assemblies. It provides the strength and stiffness necessary to survive exposure conditions traceable to the foundation.

4.10.2 Tracker controller

The tracker controller consists of all control electronics such as the microprocessor, motor drivers, power supply/transformer, and communication links. It usually does not include positional sensor, such as encoders or limit switches.

4.10.3 Sensors

Sensors include ones that allow for closed loop control (sun position sensor, module power output) and ones that allow precise positioning of the drive train (encoders, inclinometers, and so on) as well as ones that provide additional weather data for either system control or monitoring (temperature, wind speed and direction, etc.).

4.11 Reliability terminology

4.11.1 General

Failure: any state of the tracker that does not meet the requirement to track during daily use.

Critical failure: any state of the tracker which causes a safety concern or major damage to the tracker system or foundation.

Maintenance delay: time during which the tracker is not functional due to waiting for parts or service personnel.

Facility delay: time during which the tracker is not functional due to no power, water, or other facility issues.

Total downtime: maintenance delay + facilities delay + repair time.

Tracker uptime: time that the tracker is functional.

Repair time: time for service personnel to repair equipment once parts and people are on site.

% Tracker uptime = tracker uptime / (total time – (maintenance delay + facility delay)) × 100.

4.11.2 Mean time between failures (MTBF)

MTBF is defined as the average number of hours the tracker operates without failure requiring maintenance. It may be constructed of yearly data and shall be bounded by a statistical analysis. Each component of the tracker should have clearly identified MTBF data. However, the combination of this data into one statistical metric shall be done with an averaging scheme, representing the tracker as a system of components. Tracker documentation shall describe the MTBF strategy in terms of this averaging.

Estimated MTBF = tracker uptime / number of tracker failures that occur during productive time.

4.11.3 Mean time between critical failures (MTBCF)

MTBCF is defined as the average number of hours the tracker operates without failure that can be considered a safety hazard or that causes major damage to the tracking system or foundation. It may be constructed of yearly data and shall be bounded by a statistical analysis. Each component of the tracker should have clearly identified MTBF data. However, the combination of this data into one statistical metric shall be done with an averaging scheme, representing the tracker as a system of components. Tracker documentation shall describe the MTBF strategy in terms of this averaging.

Estimated MTBCF = tracker uptime / number of tracker critical failures that occur during productive time.

4.11.4 Mean time to repair (MTTR)

MTTR is how long it takes, on average, for a piece of the solar tracker to be removed, fixed, and reinstalled, or removed and reinstalled with a new unit. It is constructed of yearly data and shall be bounded by a statistical analysis. Each component of the tracker should have clearly identified MTTR data.

Estimated MTTR = total repair time for tracker related failure / No. of tracker related failures.

4.12 Environmental conditions

4.12.1 Operating temperature range

This bounds the temperature in which the design may be operated while still meeting the other product specifications, e.g., accuracy.

4.12.2 Survival temperature range

This bounds the temperatures within which the design can be operated without damage, though possibly without continuing to meet the other product specifications (accuracy or speed might be reduced, for example).

4.12.3 Maximum wind during operation

This should include both the rated (design value) for maximum wind and specify the maximum wind speed under which the tracker has been actually tested (not counting modelling). It is recommended that this rating also specifies the terrain slope under which this wind rating applies (manufacturers may want to specify separate wind ratings for flat ground and terrain with a given slope, for example).

4.12.4 Maximum wind during stow

This should include both the rated (design value) for maximum wind and specify the maximum wind speed under which the tracker has been actually tested (not counting modelling).

4.12.5 Snow load

The tracker can be rated for snow load in kg/m^2.

4.13 Functional tests

4.13.1 Static load test

The load provided in the specification template as presented in Clause 4 shall be statically applied to the tracker, which is mounted to its foundation, as to be the same as the loading that a frame with modules or just a module will exert on the tracker. The safety factor is specified by the manufacturer.

4.13.2 Moment testing

The moments provided in the specification template as presented in Clause 4 shall be tested on a tracker that is mounted to its foundation, as to be the same as the moments that the tracker will see during operation. The moments may be administered by a lever arm and forces applied to the lever arm in the appropriate direction(s).

4.13.3 Limit switch operation

If limit switches exist, limit switch operation should be tested by driving the tracker to each limit and verifying that the motion automatically stops.

4.13.4 Manual operation

Manual operation tests should be completed by tracker-supplier-defined switches and mechanical movement from switches.

5 Tracker accuracy characterization

5.1 Overview

This section makes a clear distinction between instantaneous pointing error and reported tracking accuracy. Methods are described for measuring pointing error and a description is given on how to process the data to statistically report tracking accuracy.

5.2 Pointing error (instantaneous)

The pointing error of a solar tracker is the angle between the pointing vector of the module (in many cases, this is the vector normal to the face of the module) and the pointing vector of the sun (See Figure 3). Note that pointing error is not just the accuracy of a subsystem (such as the gear box, algorithm, or controller) but it is the sum of all subsystem errors: that is, the actual difference in angle between where the tracker is pointing and where the sun is at that moment in time.

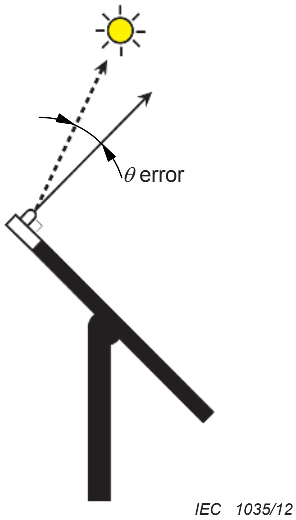


Figure 3 – General illustration of pointing error

5.3 Measurement

5.3.1 Overview

Pointing error should be directly measured (not theoretically calculated from a model of the tracker or from the values reported by the tracker controller). Pointing error is measured with a sensor which mounts on the tracker in the same plane as the solar modules and measures the relative sun position.

5.3.2 Example of experimental method to measure pointing error

Experimental tracking accuracy is a method of determining actual pointing error of a tracker over a specified time. Experimental tracking accuracy measurements can be obtained by using two flat parallel planes that are a specified distance from each other, one having a pinhole in it so as to project the sun's location in a measurable format (see Figure 4 below).

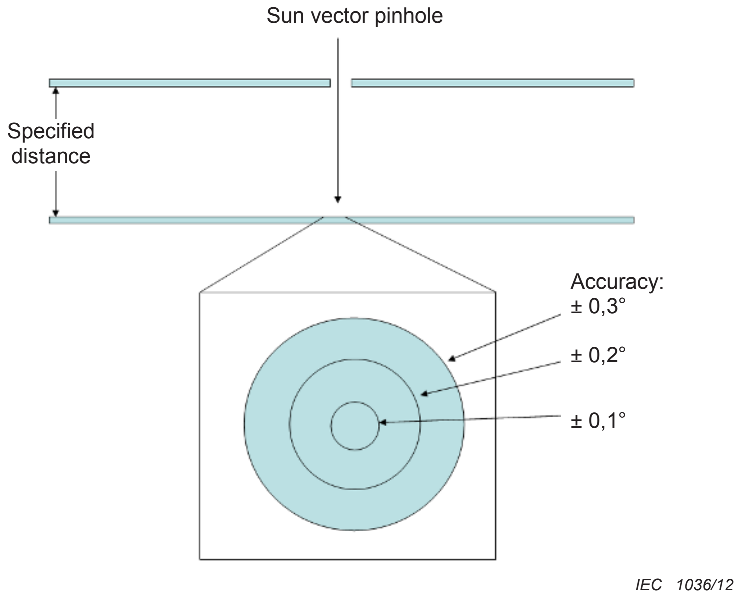


Figure 4 – Two flat parallel plates at a specified distance, one having a pin hole for sunlight to be tracked on specified-diameter circles that ultimately measure 0,1°, 0,2°, and 0,3° accuracy rings (more if necessary)

Alternately, a lens or other optics could be used to cast an image of the sun on the detector.

The projected image of the sun may be recorded and analyzed with photosensitive paper, a photodiode array, an image sensor, or other appropriate sensors.

Another alternative is measure the current generated by the sun’s direct beam on split detectors. When pointing error is zero, each detector should receive equal radiation and therefore generate equal currents. When pointing error is not zero, one sensor or the other will generate more current. A calibration factor and a simple calculation translate the measured currents to a pointing error.

5.3.3 Calibration of pointing error measurement tool

The tool used to measure pointing error (whether it be a photodiode, camera, or other sensor) shall be separately calibrated to an accuracy at least three times the tracker accuracy it will be used to measure. For example, if a tracker pointing error of 0,06° is reported, the measurement device shall be calibrated and verified to 0,02° or better accuracy.

The calibration should be performed either with sunlight or under an artificial light source with intensity at least 100 W/m^2 and collimation 1° or smaller.

Accuracy under at least 10 different sun locations (ranging from the center to the corner of the sensor field of view) shall be verified during this calibration process.

5.4 Calculation of tracker accuracy

5.4.1 Overview

- Measure data using a pointing error sensor and measurement method (as described earlier) over a minimum of 5 days.
- Divide the data into a high and low wind speed bin based on a 4 m/s threshold.

- Filter the data (for example, remove data taken during low irradiance conditions).
- Calculate statistics on each set of data and report tracking accuracy.

5.4.2 Data collection

5.4.2.1 Tracker setup

The tracker should be installed according to the manufacturer recommendations.

The maximum rated payload shall be installed on the tracker for accuracy testing with mass per area and center of mass location matching the end application within ± 20 %.

Payload weight, center of mass, number of units, and any air gaps between units should be documented in the test results, and a photograph of the test setup should be included.

5.4.2.2 Sensor mounting

One pointing error sensor should be mounted on the estimated location for maximum deflection of the tracking plane (typically the corner or edge of the tracking plane).

It is suggested to mount a second pointing error sensor in the center of the tracking plane or the point of minimum deflection. If this sensor is omitted, this portion of the specification table should read “not measured.”

5.4.2.3 Data recording parameters

Recorded data should include:

- Tracker pointing error
- Direct normal irradiance (DNI)
- Global irradiance
- Wind speed
- Date and time

Tracker pointing error should be recorded in 1 min instantaneous increments.

Irradiance measurements should be recorded in 1 min average increments.

The 10 min mean and 10 m height wind speed should be recorded in 1 min increments; the wind can either be measured at 10 m above the ground or it can be measured at the tracker height and corrected to a height of 10 m.

Data should be recorded for a minimum of 5 days with a minimum direct normal irradiance per day of 2 400 Wh/m^2 (for example, at least 6 h of a DNI of 400 W/m^2 or greater).

The date and location of the test should be reported to facilitate assessment of adequacy of the data collection, particularly with respect to range of motion.

5.4.3 Data binning by wind speed

The data is to be separated into a low wind speed bin if less than or equal to the wind threshold of 4 m/s and separated into the high wind speed bin if greater than 4 m/s.

Two bins represent a compromise to minimize test duration, complexity, and cost. The manufacturer may choose to report tracking accuracy statistics for additional wind speed bins and include relationship with wind direction.

5.4.4 Data filtering

5.4.4.1 General

All data filtering shall be documented within the tracking accuracy test report.

5.4.4.2 Filter data for range of motion

If the tracker manufacturer specifies a maximum range of motion, remove all data that occurred during times when the sun was out of this specified range of motion.

5.4.4.3 Filter data for minimum irradiance (optional)

- Remove all data recorded when the direct normal irradiance is less than 250 W/m^2.
- Remove all data recorded when the ratio of direct normal irradiance to the global normal irradiance is less than 0,25.
- Opting out of irradiance filtering may be appropriate when specifying a tracker for non-concentration or low-concentration applications.

5.4.4.4 Other data filtering

If any additional filtering is performed on the data, this shall be specifically noted in the report. For example:

- "3 h of data were removed due to the observation of a leaf shading the sun sensor during this time."
- "2 h of data were not recorded on one of the measurement days due to a failure in the datalogging system."
- "30 min of data on one of the measurement days was discarded because of a tracker mechanical stall during that time."

5.4.5 Data quantity

For each of the four data sets ("low wind, minimum deflection measurement," "high wind, maximum deflection measurement," and so on), ensure there are a sufficient number of data points.

The data from each pointing error sensor should satisfy these criteria:

- At least 360 data points after the above filtering.
- Data from at least 5 separate days, with at least 50 data points per day.
- Number of points at high wind speed (180).
- At least 50 data points before noon and 50 points after noon.

5.4.6 Accuracy calculations

For each of the data sets, calculate the following two values:

Typical accuracy: The median value of the pointing error over the filtered data set.

95th percentile accuracy: The 95th percentile value of the pointing error over the filtered data set. That is, 95 % of the measured data points fall below this error.

These calculated accuracy values may be tabulated as shown below. The average wind speeds for the "low wind" and "high wind" bins should be reported as shown.

Table 2 – Alternate tracking accuracy reporting template

	Low wind*		High wind**	
	Typical accuracy	95^{th} percentile accuracy	Typical accuracy	95^{th} percentile accuracy
Min deflection point	0,4°	0,8°	0,5°	1,0°
Max deflection point	0,7°	1,2°	0,8°	1,4°

* Low wind = wind speed < 4 m/s (measured mean = 2,6 m/s).

** High wind = wind speed > 4 m/s (measured mean = 6,3 m/s).

6 Mechanical characterization

6.1 General

This clause describes measurement of the stiffness and backlash of the tracker. Note that these measurements are separate from the accuracy measurement above: the accuracy measurement characterizes the entire system in real-world conditions, including structure, electronics, algorithms, and sensors. The backlash and stiffness measurements typically characterize only the mechanical aspects of the tracker.

6.2 Backlash

Backlash is defined by the free movement in the drive system of the tracker. Backlash will be specified relative to each axis of motion for the given tracker and will specify the complete envelope of free movement, in degrees, for each axis. Backlash can occur due to clearance between mating teeth, movement in pin or other mechanical joints, elasticity in hydraulic fluid, or other mechanisms that are system specific, and may manifest themselves more significantly under high winds.

Backlash should be measured while the tracker is secured on its defined foundation or a manufacturer-approved alternative (indoor backlash testing). A lever arm should be attached directly to each of the primary axes of rotation. A 10 % of maximum torque load should be applied to the lever arm as each axis is rotated through its envelope of movement.

It is not required to mount the payload or the payload support structure to the tracker for backlash testing as backlash is testing free movement in the drive mechanisms and not deflection in the payload structure. If testing is done with the payload in place, the tracker should be oriented such that the payload is in a balanced position.

It is important that the lever not be attached to the payload structure but rather at the payload interface to the rotating axes. Incorrectly attaching the lever arm to the payload can result in a measurement that is a combination of structural elastic deflection and backlash. It is also critical that a lever arm be used that will not show significant deflection under the specified backlash test torque.

6.3 Stiffness

Stiffness is inversely proportional to the deformation of the specific part under load.

The stiffness of the tracker may be identified by mounting the tracker to a ground or full reaction ground unit that is considered to have infinite stiffness (i.e., large metal plate on a concrete floor); a lever arm is placed coincident to each axis to be tested by movement by an external force. Stiffness is influenced by the gear drive system, the frame and the modules attached to it, and the pedestal (which may add stiffness to the tracker).Therefore, stiffness should be tested with a module payload in place. It is suggested that each axis be tested independently to determine the full stiffness of the system.

7 Reliability testing

7.1 Corrosion

Coatings should be specified. If the coating is applied according to an industry standard, the standard should be specified.

If any corrosion testing is done, the test method should be specified.

Estimated lifetime of the materials without maintenance should be specified.

7.2 Component durability

Life cycle testing for the drive system should be carried out for moving parts with a load representative of the maximum tracker load.

Reasonable test duration is equivalent to 10 years of life or longer. Since the actuator only cycles once per day on a solar tracker, the testing can be accelerated by cycling many times per day.

Testing should be done outdoors or in an environmental chamber. Conditions should be recorded in the test report.

Accuracy, backlash, and stiffness should be measured and reported both before and after life cycle testing is completed.

7.3 Extreme conditions tests

These tests are intended to provide information about the performance of the tracker under extreme environmental conditions such as wind load and snow load. Extreme environmental conditions can have an impact on the electrical production of modules on trackers.

Maximum static loads and torque testing are done with no tracker movement. The maximum load is applied to the tracker. After the load is removed, the tracker is put back into operation and pointing error is measured over the course of a single day.

Maximum dynamic loads and torque test is done during tracker operation. The maximum load is applied to the tracker during operation. Pointing error is measured under the maximum dynamic load over the course of a single day. After the load is removed, the pointing error should be measured again for a single day. The loaded and unloaded pointed error should be presented on a single plot.

Several schemes have been proposed to generate these loads; artificial wind, sand bags, water bags, a system of pneumatic cylinders, or other schemes can be used. The loading technique and value should be recorded in the report.

8 Additional optional accuracy calculations

8.1 Typical tracking accuracy range

If it is desired to further simplify the table of eight accuracy values in the “Accuracy Calculations” presented in 5.4.6, the following process may be followed:

“Tracker accuracy (typical best)” is the result from the low wind, typical accuracy, and array min deflect point. For example, from the data in Table 2, this would be reported as 0,4°. This is one way of providing a quick value for a “typical good conditions with minimal deflection” error.

"Tracker accuracy (typical worst)" is the result from the high wind, 95th percentile accuracy, and array max deflect point. For example, in Table 2, this would be reported as 1,4°. This is one way of providing a single number as a roughly "worst case error" for design guidance, though it will not be an absolute worst possible case (this is intentional, to avoid the influence of one or two rare outlier data points).

These two values can be combined into a simplified metric for the accuracy range, "typical tracking accuracy: best-worst". For example, from the data set used to generate Table 2, the accuracy would be reported as "typical tracking accuracy range: 0,4°-1,4°."

8.2 Tracking error histogram

In addition to the above, pointing error can optionally also be graphed as a histogram, showing the frequency of different error magnitudes for the entire test period as shown in Figure 5 below.

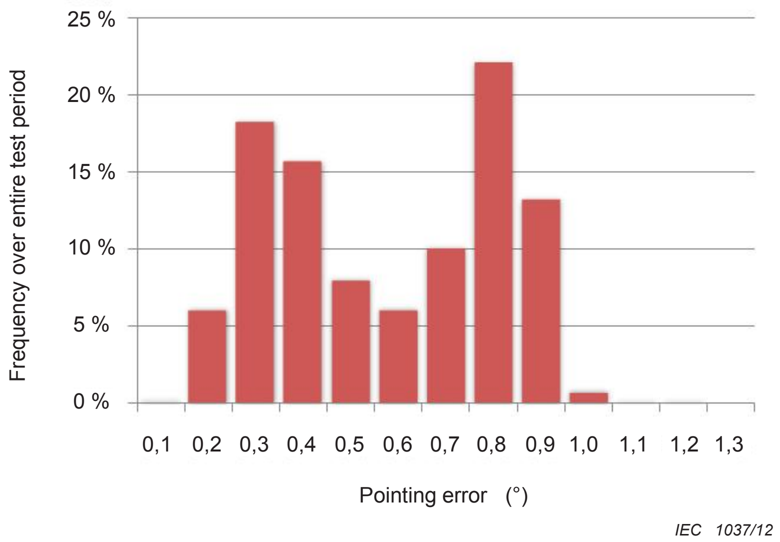


Figure 5 – Pointing error frequency distribution for the entire test period

8.3 Percent of available irradiance as a function of pointing error

Pointing error data can be combined with DNI data to generate a graph that weights measured pointing error based on the DNI that was present.

Sort the collected pointing error data by ascending tracking error.

For each pointing error, calculate the integral (or cumulative sum) of the direct normal irradiances at or below that error, and graph the results as shown in Figure 6 below.

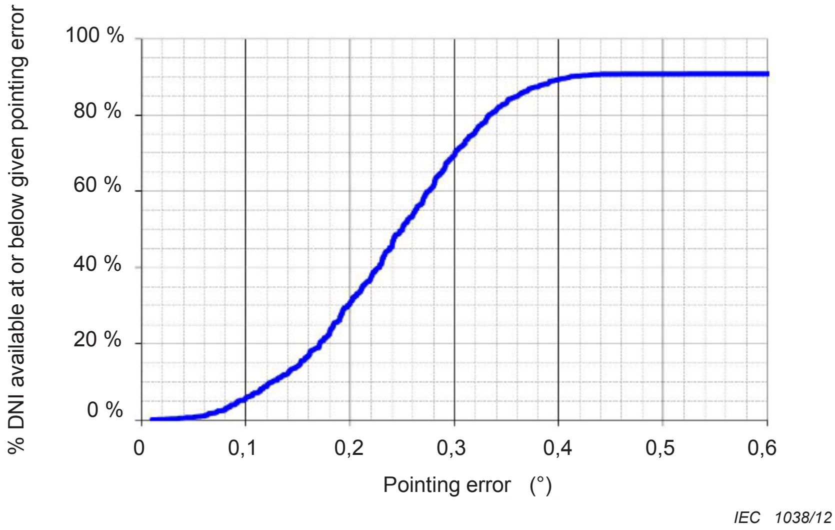


Figure 6 – Available irradiance as a function of pointing error

If desired, divide the initial data into bins by any parameter of interest (wind speed, for example), and perform the above process on each bin separately. An example is shown in Figure 7 below:

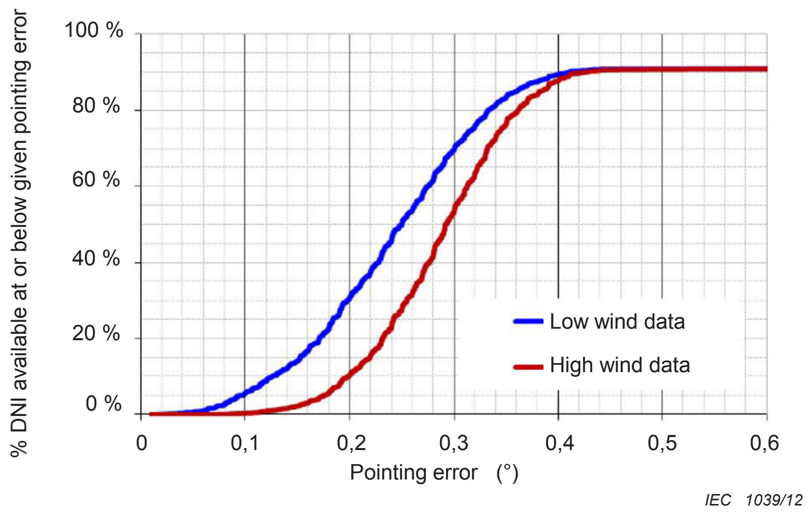


Figure 7 – Available irradiance as a function of pointing error with binning by wind speed

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