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TECHNICAL SPECIFICATION

colour inside

Photovoltaic power systems (PVPS) – Information model for availability

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PHOTOVOLTAIC POWER SYSTEMS (PVPS) – INFORMATION MODEL FOR AVAILABILITY

FOREWORD

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

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

IEC TS 63019, which is a Technical Specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this International Standard is based on the following documents:

DTS	Report on voting
82/1447/DTS	82/1505A/RVDTS

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

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

Information model categories are written in capital letters.

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

- 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- withdrawn,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 publication using a colour printer.

INTRODUCTION

This technical specification (TS) defines a common basis for the exchange of information on photovoltaic power system (PVPS) availability metrics among owners, utilities, lenders, operators, manufacturers, engineer/procure/construction firms, specifiers/designers, consultants, regulatory bodies, certification bodies, insurance companies, and other stakeholders. From this diverse group of stakeholders, external and internal interfaces arise in the operation and delivery of power. Although these are mostly power- and energy-related, some are informational or for power system control. The intention is for information exchange on capability- and energy-related data to form a nucleus for separate information needed by stakeholders, as illustrated in Figure 1.

It identifies external and internal elements related to the capability, health, and condition of components, subsystems, and the system itself, as well as energy production, plant operation, and asset management, which also benefit from a defined set of terms. This is achieved by providing an information model specifying how (PVPS) time designations shall be assigned by information categories. An information model facilitates how the unavailability of time of components, subsystems, and systems, as well as the lost power and other capabilities affect the PVPS. The ability to estimate the resulting lost energy and/or loss of PVPS capability forms the basis for how to allocate time for reporting availability metrics or, more directly, unavailability.

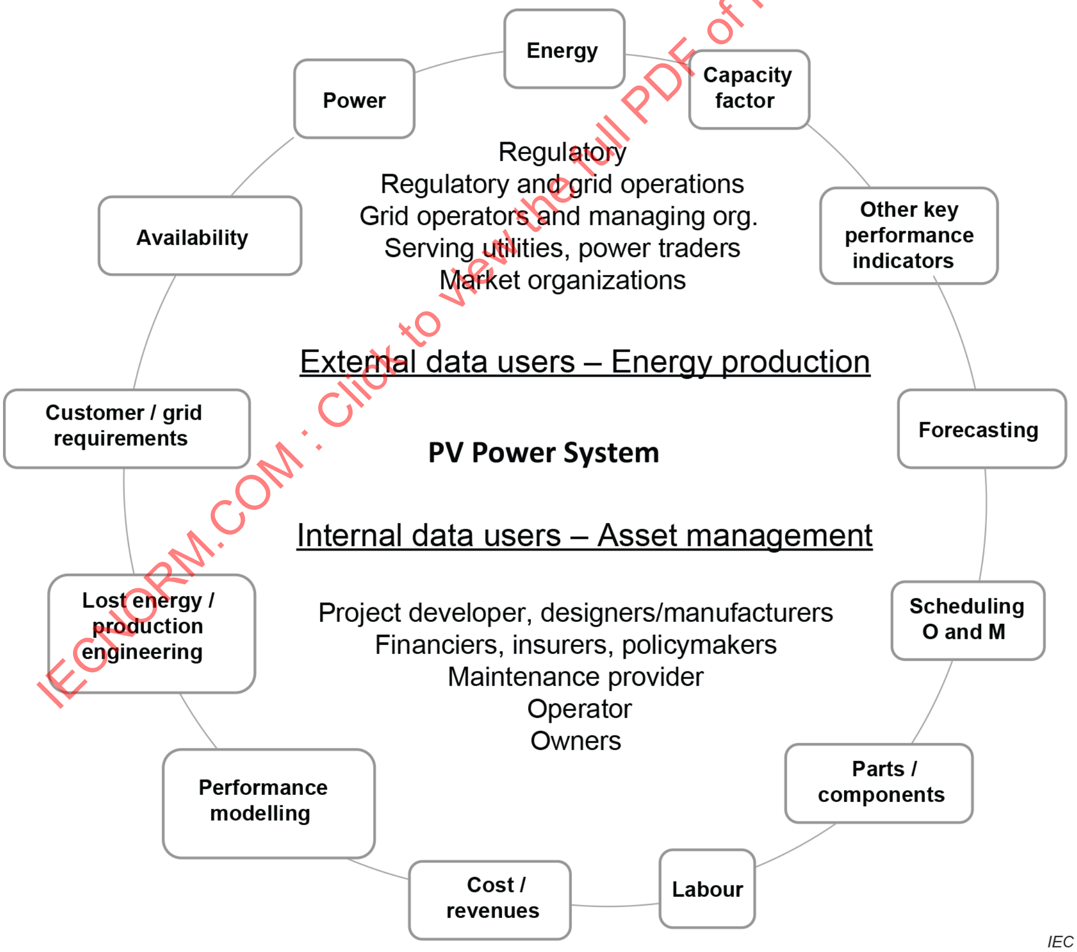

Figure 1 – Data stakeholders for a PVPS

PHOTOVOLTAIC POWER SYSTEMS (PVPS) – INFORMATION MODEL FOR AVAILABILITY

1 Scope

A common basis of understanding results from defined metrics that can be useful to the stakeholders, populated by data collected in the operation of the PVPS:

a) To provide a standarized approach to characterize availablity and unavailablity for a PVPS.

b) To provide standard methodologies for determining the appropriate forms of availability of the PVPS during varying time periods, including real-time capability assessment or longer, for reporting availablity metrics to stakeholders.

Table 1 – Stakeholder roles and objectives for reliability and maintenance data

Roles	Objective
Owner	Decision support for investments
Operator	Reporting performance indicators
	Determining availability and weaknesses
	Identifying maintenance strategies
Service provider	Maintenance optimization
	Optimizing keeping stock of spare parts
Original equipment manufacturers/ supplier	Design optimization
Financier/insurer	Risk assessment
Grid operator	Highly reliable and stable bulk power system
Source: International Energy Agency (IEA)	

This document provides a framework from which the availability metrics of a PVPS can be derived and reported. It describes how data are categorized and defines generic information categories to which time can be assigned for a PVPS considering internal and external conditions based on fraction of time, system health, and condition by specifying the following:

- generic information categories of a PVPS considering availability and production.
- information category priority to discriminate between concurrent categories.
- entry and exit point for each information category to allocate designation of time.

The PVPS comprises all photovoltaic (PV) modules, inverters, DC and AC collection systems, grid interconnection equipment, the site, its infrastructure, and all functional service elements. This is further explained in 6.3 and 6.4.

Formulas in this document provide normative guidance for standardization. Beyond that, it is not the intention of this document to specify exactly how other undefined, time-based availability metrics shall be calculated. The annexes are examples and guiding principles for developing methods for calculation and estimation of availability metrics, subject to the knowledge and concurrence for use by the involved stakeholders. Estimates and calculations also have recommendations on how they are to be used as part of the informative function.

It is not within the scope of this document to determine the method of information acquisition. Relevant IEC documents on data collection and information acquisition are included in the following normative references. IEC 61724-1 has requirements and IEC TS 61724-3:2016, 6.2.5, specifically identifies measured data on this topic.

Data generated during the operation of a PVPS are valuable, establishing who owns the monitoring data and who will have access to the data and for what purpose should be established. Different stakeholders will have different needs, as summarized in Table 1 (IEA). In Annex E, the monitoring systems are addressed in greater detail.

Availability metrics cannot be derived without important outage information. Questions can require the PVPS operation to properly collect the requisite data, such as what equipment or portion of the plant is failing, how long, how often, and how much energy is being lost and categorized by the information model. Asset management questions include the source of the outage (i.e., Whose clock is it on? Was the outage due to internal or external forces? What power and energy was generated? And, what was expected?).

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 TS 61724-3:2016, *Photovoltaic system performance – Part 3: Energy evaluation method*

IEEE Std 762™-2006, *IEEE Standard definitions for use in reporting electric generating unit reliability, availability, and productivity*

3 Terms and definitions

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

The International Organization for Standardization (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
availability
where the PVPS, a subsystem, or a component is capable of providing service, regardless of whether it is actually in service and regardless of the capacity level that can be provided

Note 1 to entry: Specific definitions and characterizations are provided on availability and related terms throughout the annexes.

[SOURCE: IEEE 762:2006, 4.1.1, modified – Expansion of the term "unit" to more general applications for PVPS, subsystems and components.]

3.2
capability
degree to which the component, system, or subsystem is operative and functioning according to design specifications and control logic with no technical restrictions or limitations beyond the ones included in the specifications

3.3
constrained operation
mode of operation of a PVPS in which the outputs of all inverters are limited by the capability of the equipment rather than by the output from the PV array

[SOURCE: IEC TS 61724-2:2016, 3.1, modified – Definition tailored to the case of PVPS and references to DC and AC ratings omitted.]

3.4
curtailed operation
mode of operation of a PVPS in which the output is limited for an external reason, e.g., inability of the local grid to receive the power per contractual agreement

3.5
degradation
decrease in equipment operating characteristics or ability to perform due to physical- or chemical-related reduction in performance

3.6
derating
redefinition of capability due to external commands or constraints

3.7
downtime
total time that the equipment is not capable of operating per specification when it would otherwise be expected to do so

3.8
energy availability
energy generation of a PV system that is calculated with the same assumptions as those used in the predicted energy model using actual weather data collected at the site during operation of the system for the year in question

3.9
energy unavailability
metric that quantifies the energy lost when the system is not operating (as judged by an automatic indication of functionality, such as the inverter status flag indicating that the inverter is actively converting DC to AC electricity or not)

[SOURCE: IEC TS 61724-3:2016, 3.2. modified – The second sentence of the definition, on energy availability has been omitted, along with the note to entry.]

3.10
expected energy
energy of a PVPS that is calculated with the same specific performance model or approved equal with same assumptions, losses, and formulas as those used in the predicted energy model using actual weather data collected at the site during operation of the system (for the period in question)

[SOURCE: IEC TS 61724-3:2016, 3.5, modified – inclusion of assumptions, losses, and formulas if the original model is not readily available; deletion of Notes 1 and 2 to entry.]

3.11
failure
loss of ability to perform as required

[SOURCE: IEC 60050-192:2015, 192-03-01, modified – The domain and Notes 1 to 3 to entry have been omitted.]

3.12
masking
PVPS condition and situation where unidentified and/or not easily discernible deficiencies cause performance to diminish despite the appearance that the PVPS is operating as it was designed to operate

3.13
PVPS AC capacity
rated output of a PVPS, or, alternatively, its contractually obligated maximum, under specific designated conditions

3.14
photovoltaic power system
PVPS
electric power generating system, which uses the PV effect to convert solar power into electricity

3.15
rating
set of rated values and operating conditions

[SOURCE: IEC 60050-151:2001, 151-16-11]

3.16
reliability
probability that an item (component, assembly, or system) can perform its intended function for a specified interval under stated conditions

3.17
service
provision delivered by the PVPS

3.18
system
composite of equipment, skills, and techniques capable of performing or supporting an operational role or both

3.19
time
fundamental element used in developing the concept of availability, also used in many measures of reliability and maintainability (for unavailability)

3.20
unavailability
operational state when the equipment is not capable of operation because of operational or equipment failures, external restrictions, testing, work being performed, or some adverse condition

[SOURCE: IEEE 762:2006, 4.1.2, modified – use of the term "equipment" rather than "unit".]

3.21
uptime
amount of time that the system or component is operating during a defined period of time

Note 1 to entry: Other and more specific definitions are contained in the information categories as well as the annexes. Reliability, availability, maintainability (RAM) metrics have many specified availability definitions based on specific applications and are further explained in Annex C.

4 Overview

4.1 Understanding the use of this document

This document defines generic terms of PV systems and environmental constraints in describing PVPS operation and availabilities, restoration, time, and optional energy accounting criteria for operation and maintenance (O&M) and asset management. This document defines terminology and generic terms for reporting availability measurements. A PVPS includes all equipment up to the point of common coupling (interconnection point) to a grid or network that is buying the energy produced; however, PVPS availability can and often is affected by the grid and grid quality. Measurements are concerned with units of time affected; involved components, systems, and subsystems; and site and PVPS O&M. Unavailability measurements are also instrumental for measurement and/or estimation techniques for determining PVPS capabilities or, more specifically, capability loss.

The conditions – environmental and other site aspects – are considered for reporting the station condition and the impact those conditions have on the PVPS, including subsystems and components. Environmental aspects include solar irradiance and other weather and location-specific conditions at the site. System operating constraints due to differential site or as-built characteristics, which might affect or eventually affect energy system performance (typically energy production), are included in the energy calculus (e.g., availability model and energy reporting). This document defines terms for reporting fundamental availability metrics. Formulas and application methods are included in Clause 6 and Annex A and Annex B. The categories can apply to the whole system (with the grid interface also affecting it) or to subsystems and components, wherever the outages or reduced capability occur. It is observed that the more robust and granular data systems are, the better the knowledge of the issues affecting capabilities.

More generally, although this document is written to be applied to utility-scale PVPS, stakeholders will find that many of the document's elements have application to smaller systems, subsystems, or components. Residential and small commercial systems will also need enough data collection and maintenance logs in their operational phases to determine and document necessary uptime metrics and who should be receiving the data.

Multiple aspects of PVPS availability depend on the system quality and characteristics, system health, condition, and operational states. Therefore, it is essential to have clear knowledge and awareness of the operating and outage status of the power system's components. This is important for O&M and reliability as well as for financial and insurance purposes. As such, the data are collected for use. Performance, environmental, failure and outage, time-based O&M, and electrical parameters are included in the types of data that may be included in various aspects of the PVPS availability assessments. Levels of systems and consequential data needs are described in the informative annexes. Information management is addressed specifically in Annex E.

Night-time generation shutdown is not expected by definition; thus, PVPS cannot provide power except for those that include storage and are capable of providing night-time services. A similar definitional clarification – for example, a PVPS not operating because the array is covered in snow – is in an out-of-environmental specification state even though the PVPS components are fully functional and available. The information model presented in the document is designed to be useful in defining boundaries to facilitate contractual division of responsibilities.

The availability of the total sum of the system, subsystems, and components affects the performance of the PVPS. Typically, revenues depend on the energy delivered, and that energy depends on the availability. The proper functioning of the components is a function of the detailed design specifications and the O&M employed. Tracking downtime is a tool for asset management and reliability of the system. Figure 2 illustrates this interrelationship.

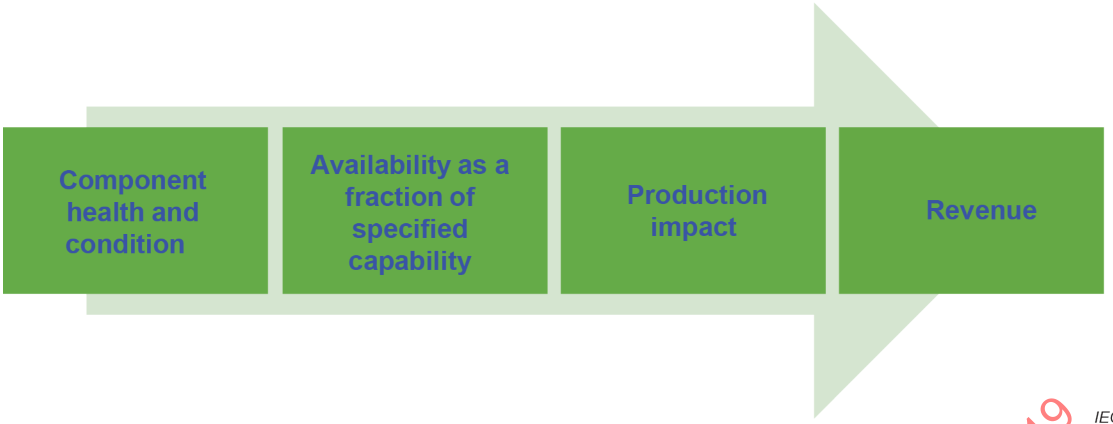

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Figure 2 – PVPS component-to-revenue path

Figure 2 presents a logical consequence of reduced capability impacting energy production. The energy production will be c metered, and, in addition, the energy flow may generally be monitored throughout the PVPS, as specified in the design of the monitoring systems. This logical balance between performance (energy) and availability (PVPS physical condition on a time basis) demonstrates the need to measure both in order to facilitate the assessment of required PVPS functions.

It is important to clarify the relationship between this document and the IEC 61724 series. Both address metrics of PVPS performance and the impact of reductions. IEC TS 61724-3 carefully defines energy unavailability so that the stakeholders can determine the losses in performance (according to the In-Service Energy Performance Index) separate from the losses caused by energy unavailability. This will be further explained after the process of using the information model to handle the granularity of component health and condition (Figure 2) is applied to lost capacity and energy. The complementary nature of this document with the IEC 61724 series is characterized in Annex D in verification scenario Clause D.7 – Energy: measured, expected, and lost.

Assessments of required PVPS functions are desirable because the IEC Renewable Energy (IECRE) system addresses certification requirements of PVPSs, and the mandatory reporting requirements of this document are candidates for IECRE procedures. This document is intended to facilitate application in multiple ways. The first is to provide consistency between definitions in measurements and reporting. The second is to support certification requirements that may be specified.

Mandatory information categories defined in the document are written in capital letters. The designation of mandatory applies to data collection but not necessarily the specific data reported because that is determined by the stakeholders' needs.

4.2 The information model

With restatement of the fundamental definitions given in 3.1 and 3.20, the information model follows logically in an expansion of the specific categories to be used in this document.

The "available state" is when a unit can provide service per specification regardless of whether it is in service and regardless of the capacity level and other capabilities that can be provided (based on IEEE 762, 4.1.1).

Equipment is in an "unavailable state" when the equipment is not capable of operation to specification due to equipment failures, external restrictions, testing, maintenance, or other plant work being performed or some adverse condition. The unavailable state persists until the unit is made available for operation by being synchronized to the system in service state (based on IEEE 762, 4.1.2).

These two definitions are fundamental for addressing the availability metrics described in this document. First, the state of being "available" recognizes that even while available there may be degrees of loss of the service capability due to internal and external elements. Second, there may also be customer contractual or power grid reasons for why operation is reduced or not allowed even though the system is capable of providing service. This document addresses multiple definitions of availability, including the design, O&M operator, power purchase agreement, and grid/contractual requirements, which are later clarified by formulas.

Even if the equipment or units are available, a parallel construct is evident wherein all uptime and downtime states are to be handled similarly, whether due to environment, site, and grid constraints or other factors that cause outages. This document creates an information model built on a category of availability descriptions with the needed granularity of these various states to calculate various availabilities, depending on stakeholder perspectives and scopes for overall asset management purposes. The various availabilities are explained in this document, and Annex C lists some of the forms and unique needs for different types of availability.

A general availability formula is:

$$\text{Availability} = \text{Uptime} / (\text{Uptime} + \text{Downtime}) \tag{1}$$

Uptime is the amount of time that the system or component is operating during a defined period of time (such as annually). Downtime is the total amount of time that the equipment is not operating per specification when it would otherwise be expected to do so. The information model further clarifies the condition states needed for calculating specific situations.

Successfully understanding the various states of availability that a system has or may have requires a time-series data acquisition system that tracks operating conditions at the lowest level of maintenance anticipated for the systems.

The information model comprises different information categories. The information categories describe expected condition states that can be anticipated in the operation of a PVPS:

- measured daylight hours and irradiance for energy production;
- number, location, and types of failures or other types of outages;
- maintenance downtime needed to maintain PVPS operation at contractual capacity;
- planned outages for preventive or scheduled maintenance;
- planned and unplanned cutbacks, constraints, and/or curtailments at the request of utility-sector stakeholders or customers.

With care and specificity during the design and planning phase of the system, the information model data will work for different services and levels of the plant, ranging from the individual components, to small subsidiary systems, to the full PVPS, including grid conditions.

The model allows for optional levels of information data categories to provide the user with more detailed data (i.e., O&M trends).

- Information category uniform definition and application or priorities facilitate the avoidance of double counting time and production for outages of uncertain assignment.
- Sorting outage data in these categories is useful for determining availabilities under contract terms.

This document benefits from how the IEC 61724 series addresses expected energy and performance modelling, which is an interface with the use of availability. Availability is a primary measure of systems' and components' capability to meet any number of specified and/or technical contract requirements. The energy performance is a primary metric for a PVPS, and both are needed. This document addresses system capacity availability through reliability block diagrams (RBD) and associated techniques for determining lost energy. IEC TS 61724-3 is useful for determining how well a PVPS is performing when it is working, and this document is useful for providing granularity in tracking causes when systems and components are experiencing lost energy events due to unavailability. Figure 3 illustrates this process.

The methodology is dependent on a process. For determination of availability indicators:

1. An event affecting the capability of the PVPS is detected. It may be due to many reasons that cause or result in downtime.
2. Criteria of the information model categories are applied to the event or action to see where it fits in the model. The information categories form the bulk of the model, and their definitions, examples, and entry and exit points are defined.
3. The event or action is characterized according to time, duration, and system or components affected and their time/duration in categories.
4. The PVPS monitoring and control signals are recorded for further analysis as needed for downtime characterization.
5. A determination of the PVPS levels of impact is identified. Basically, it is found how much of the array capacity is blocked from PVPS collection and delivery to the point of common coupling.
6. Specific availabilities are calculated and/or aggregated over time according to stakeholder needs.

Energy impact may optionally be correlated to events/incidents

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Figure 3 – Process for understanding the use of this document

To facilitate control and decision-making, and to support the life-cycle costing process, Clause E.6 includes cost information that may also be collected and reported consistent with the defined outage categories in Table 2.

There are many data stakeholders, as previously described. The availability, power, energy, capacity factor, and other key performance indicators are very important for utility grid stakeholders. This market sector is external to the operations of the PVPS but depends on operation where the PVPS asset management functions are performed, including responding to environmental factors, corrective and other forms of maintenance, monitoring and reporting, and financial functions. Understanding how well the PVPS is operating comes from time-series plant performance monitoring data, which may include meters, transformers, inverters, combiners, and strings. Understanding is needed for both internal and external users, and the robustness of these systems should be determined by the stakeholders involved in the PVPS. This understanding is derived from a common nucleus of data for these stakeholders. This common nucleus of data is needed to facilitate a common basis of understanding among PVPS stakeholders. This document is expected to be most effectively useful to utility-scale PVPS plants but has elements applicable to all PVPS classes.

Much of the information model and approach used in this document has been harmonized with wind energy document IEC 61400-26-1[1], and modified as appropriate to define terminology and generic terms for reporting PVPS availability metrics.

5 Information categories

5.1 General

The information model comprises different information categories that are designed to be all-inclusive on a time basis. The information categories describe expected condition states that can be anticipated in the operation of a power station. Information categories are counters for accumulation of time periods with specified attributes defined for a PVPS with the purpose of exchanging data. All calendar time shall be distributed into these information categories.

Each information category has an associated entry point and exit point. The entry point describes the criteria that should be fulfilled to allocate time into a specific information category. The exit point describes the criteria to be fulfilled to the end time allocation to a specific information category.

The information model is split into five levels. The hierarchy from Level 1 to Level 5 contains all attributes of overlaying information categories, which are inherited by underlying information categories. The time designations are allocated at the lowest mandatory level. Overlaying information categories shall contain the sum of the related information categories on the underlying level. The information categories are introduced in Table 2.

Table 2 shows an overview of the information categories defined in this document. The information model includes four mandatory data collection categories (identified by all-capitalized letters). The model also allows for additional optional levels of information categories to provide the user with more detailed data, some of which are also suggested and addressed in this document. Compliance with this document requires designation of time periods into the mandatory information categories defined in Level 1 to Level 4, as shown in Table 2. Information categories are counters for accumulation of time periods with specified attributes defined for a PVPS with the purpose of exchanging information on availability.

Any optional information categories that are defined are not required to comply with this specification; they are included to allow users to customize reporting details to meet their specific requirements. This specification imposes no limits on the number of optional information categories or levels added by individual users. All optional information categories shall be located on Level 5 or higher. Some likely candidate optional categories are topically addressed in the annexes. Forced outages are further described in Annex C.

In case entry conditions are fulfilled concurrently for two or more information categories, time shall be assigned only in the information category with the highest priority. Information category priorities are described in more detail in 5.4. The priority technique facilitates the avoidance of double counting time and production for outages of uncertain assignment.

Again, with care and specificity, the information model will work for different services and different PVPS levels, ranging from the full plant and including the grid to individual components.

[1] Under preparation. Stage at the time of publication: IEC PUB 61400-24-1:2019.

Table 2 – Information category overview for a PVPS

<table>
<tr><th colspan="5">Information categories</th></tr>
<tr><th>Mandatory
Level 1</th><th>Mandatory
Level 2</th><th>Mandatory
Level 3</th><th>Mandatory
Level 4</th><th>Optional
Level 5</th></tr>
<tr><td rowspan="12">INFORMATION AVAILABLE</td><td rowspan="7">OPERATIVE</td><td rowspan="3">IN SERVICE</td><td>FULL CAPABILITY</td><td></td></tr>
<tr><td>PARTIAL CAPABILITY</td><td>Degraded
Derated
Other</td></tr>
<tr><td>SERVICE SET POINTS</td><td></td></tr>
<tr><td rowspan="4">OUT OF SERVICE</td><td rowspan="2">OUT OF ENVIRONMENTAL SPECIFICATION</td><td>Irradiance received below threshold for energy conversion</td></tr>
<tr><td>Other</td></tr>
<tr><td>REQUESTED SHUTDOWN</td><td>Internal
External</td></tr>
<tr><td>OUT OF ELECTRICAL SPECIFICATION</td><td></td></tr>
<tr><td rowspan="4">NONOPERATIVE</td><td colspan="2">SCHEDULED MAINTENANCE</td><td>Specific services
Scope</td></tr>
<tr><td colspan="2">PLANNED CORRECTIVE ACTION</td><td>Retrofit
Upgrade</td></tr>
<tr><td colspan="2">FORCED OUTAGE</td><td>Response
Diagnostics
Logistics
Repair</td></tr>
<tr><td colspan="2">SUSPENDED</td><td></td></tr>
<tr><td colspan="3">FORCE MAJEURE</td><td></td></tr>
<tr><td colspan="4">INFORMATION UNAVAILABLE</td><td></td></tr>
<tr><td colspan="5">Green indicates ability to generate; pink indicates not generating due to a cause or reason.</td></tr>
</table>

Levels 1, 2, and 3 provide logic to help understand the state of the PVPS. INFORMATION AVAILABLE enables data that can confirm operation of the PVPS, whereas INFORMATION UNAVAILABLE occurs when insufficient information is available to confirm operative conditions and levels. The PVPS will be in either an OPERATIVE or NONOPERATIVE condition. The OUT OF SERVICE state includes reasons other than the malfunctions of the PVPS and components are occurring and keeping the PVPS from being IN SERVICE (typically active power). NONOPERATIVE is a state or condition wherein the opposite has occurred, and the PVPS and components, in full or part, are not available to perform their functions. As stated elsewhere, discrete component outages get rolled up to PARTIAL CAPABILITY at higher levels of the system. FORCE MAJEURE is reserved for events that are extraordinary or otherwise outside of the control of the parties. This grouping, especially in Level 4, is useful in tracking unavailability.

Descriptions of these information categories follow.

5.2 Information available (PVPS)[2]

Definition – The category INFORMATION AVAILABLE covers all time periods during which information on the PVPS and external conditions is retrieved, logged, and stored manually or automatically to the extent that at least one information category can be established.

It is recognized that there may be circumstances when information is partially or not available. Qualification for INFORMATION AVAILABLE requires sufficient information to determine that criteria for the mandatory Level 4 category are achieved.

Information to determine the mandatory information category can be derived from multiple sources. Sources can be:

- the information category from the individual inverters;
- supplemental supervisory control and data acquisition (SCADA) or other data acquisition system (DAS);
- metering information;
- manual entries.

For example, the information category can be determined as INFORMATION AVAILABLE if data transmission from every single inverter of a PVPS is interrupted as long as data from a measurement system still give adequate information to determine the category of the PVPS.

The INFORMATION AVAILABLE category is mandatory.

Entry point – The PVPS operating status data are available to the extent that a PVPS category at Level 4 can be determined, logged, and stored.

Exit point – It is no longer possible to determine, log, or store the Level 4 category of the PVPS.

It is strongly recommended that the data capabilities can record all the production (power) data on time for the implementation of this document. The IEC 61724 series for data quality addresses relevant considerations. Users are also referred to Clause D.11 to address lost data.

5.3 Operative

Definition – The PVPS is in the category OPERATIVE when it can perform the intended functions regardless of whether it is active and regardless of the capacity levels or other required capabilities that could be provided.

The OPERATIVE category is underlying the INFORMATION AVAILABLE category and has two underlying information categories:

- IN SERVICE
- OUT OF SERVICE.

The OPERATIVE category is mandatory.

Entry point – The PVPS can perform the intended functions regardless of whether it is actually active and regardless of the capability level that can be provided.

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[2] The term PVPS is used generally in these information categories; however, the applicability can be for the whole plant or subsystems or individual components. When examining downtime events, outages will need a description of which part of the PVPS is included. Subclause 6.3 includes more information on the physical nature of the PVPS levels and functions.

Exit point – The PVPS is not able to maintain the intended functions.

5.4 In service

Definition – The PVPS is IN SERVICE when it can perform the intended functions.

The IN SERVICE category is an underlying category of the OPERATIVE category and has three underlying mandatory information categories:

- FULL CAPABILITY
- PARTIAL CAPABILITY
- SERVICE SET POINTS.

The IN SERVICE information category is mandatory.

Entry point – The PVPS starts performing the intended functions.

Exit point – The PVPS stops performing the intended functions.

Active power is the predominant service in most PVPSs. Services may include but are not limited to the supply of active energy, grid automatic generation control, reactive energy, constrained operation, communications, and support of electrical stability of the grid. Other services are examined in the following subclauses.

5.5 Full capability

Definition – The PVPS is operative and functioning according to design specifications with no technical restrictions or limitations beyond those specified in the design.

No lost production shall be associated with the respective information category when the PVPS is operating at FULL CAPABILITY.

This may include, but is not limited to, the following examples:

- Periods of measurement of full capability and without any internal or external derating.
- All inverters are performing according to design specification and any regulation in power to maintain the design or rated capacities of the PVPS. Note that the clipping per the PVPS operating specification is not unavailability.
- All inverters are delivering active power according to design array power curve.
- All energy collection systems/equipment are performing the intended designed function at rated capacity.
- All inverter functions are delivering within all site environmental condition specifications.

The FULL CAPABILITY category is an underlying category of IN SERVICE and has no predefined underlying mandatory information categories.

The FULL CAPABILITY category is mandatory.

Entry point – The PVPS is performing all intended functions at the full system ratings at the given conditions.

Exit point – The PVPS is not delivering the intended functions with full capability at the given conditions.

5.6 Partial capability

Definition – Some intended functions of the PVPS may be operating at reduced performance due to internal or external conditions. If unable to detect downstream outages, they will not be included in calculations of partial capability.

This may include, but is not limited to, the following examples:

- information is not available to ensure that the PVPS is in FULL CAPABILITY.
- technical fault or safety-related events (e.g., shutdown of individual inverters).
- electrical energy collection system deficiencies.
- reduced load capability (string or string-level failures).
- reduced capability or production capacity due to unexpected inverter and/or other defects, degradation, deterioration, anomalies, faults, or failures (See Clause D.4 for an example of subsystem outage impact).
- reduced capability to production capacity due to inadequate thermal management of inverter components or beyond design specification.
- forced outage of DC availability/solar field. Reduction in subarray capacity due to (failure) of any of the subcomponents.
- differences in modelled/expected inverter clipping.
- degradation and derating (see C.5.6 and C.5.7).
- other (see C.5.8).

In general, events and incidents that do not affect the whole PVPS may be tracked separately at the appropriate component level and information model category but when "rolled up" to the full PVPS result in PARTIAL CAPABILITY. The PVPS will be expected to be in PARTIAL CAPABILITY for significant fractions of time if there is a backlog of FORCED OUTAGE repairs. PARTIAL CAPABILITY occurs when a component below the level at which we are measuring does not affect the higher level system of component availability.

Partial capability can occur with degradation where capability is reduced over time. At some point, if it is not corrected, the level of degradation would reduce the capability of the PVPS.

PARTIAL CAPABILITY is to be used at a level in the PVPS that is higher than that of a subcomponent not working and which is also measured.

The PARTIAL CAPABILITY category is mandatory.

Entry point – The PVPS is not providing the intended function with the full specified and/or expected capability and is also detected.

Exit point –The conditions for being in PARTIAL CAPABILITY no longer exist.

5.7 Service set points

Definition – The PVPS is in the category SERVICE SET POINTS when ready to respond to a predefined event.

This may include, but is not limited to, required or optional services or operational constraints, including or beyond those defined in the initial PVPS design or contractual terms, which are competing with the PVPS primary function of active power, such as the following examples:

- automatic generation control;
- constrained operation;

- a low-frequency compensation service;
- volt-ampere reactive compensation system having elements disconnected but ready to engage;
- source or sink energy from/to storage;
- a load-following or unique "spinning reserve" type of operation
- reduction in power due to following a power factor set point at the point of interconnection;
- an external reduction in power output due to direction or regulatory criteria (partial curtailment order);
- variable settings due to the interaction of many systems in distributed generation settings;
- external control and/or approved commands/decisions, including changes in regulatory policy.

These items may be internally or externally controlled. For purposes of grid control, the PVPS may be asked to variably reduce production or otherwise respond to grid signals. In this case, the PVPS is operating in the SERVICE SET POINTS category, but it may also be stated that the PVPS is derated with an energy impact that deviates from expectations and needs to be accounted.

All set points should be "clocked" with time-series data. It is recognized that some PVPSs will have AC capacity limitations to comply with interconnection agreements and that inverter-level power factor settings will compensate for the PVPS internal reactive power.

SERVICE SET POINTS are not generally applicable for active power service because that is the presumed normal state.

The 5.7 SERVICE SET POINTS category is an underlying category of IN SERVICE and has no predefined underlying mandatory information categories.

The 5.7 SERVICE SET POINTS category is mandatory.

Entry point – The service is active and responding to a predefined event or action of a control signal.

Exit point – The service is no longer able or requested to respond to a predefined event that the control signal has stopped.

It is recognized that operation in SERVICE SET POINTS is not in an unavailability state unless it fails to operate as designed or by control signals; however, it is important to track time in this state.

It is noted that per-design, contractual, obligated AC capacity limitations to comply with interconnection agreements or inverter-level power factor set points to achieve a nominal, per-design power factor at the point of interconnection for compensation for the plant's internal reactive power are specified. Features such as these may be the preferred operational state. This state and those that deviate from it should have time-series data collected.

5.8 Out of service

Definition – The category OUT OF SERVICE is obtained when the PVPS is OPERATIVE but not IN SERVICE.

The OUT OF SERVICE category is an underlying category of OPERATIVE and has three predefined underlying mandatory information categories:

- OUT OF ENVIRONMENTAL SPECIFICATION
- REQUESTED SHUTDOWN
- OUT OF ELECTRICAL SPECIFICATION.

The OUT OF SERVICE category is mandatory.

Entry point – The PVPS is OUT OF SERVICE due to one of the restrictive conditions described in the underlying information categories.

Exit point – All restrictive conditions in all underlying categories are cleared.

5.9 Out of environmental specification

Definition – The category OUT OF ENVIRONMENTAL SPECIFICATION is obtained when the PVPS is operative but not in service because the conditions of the environment are out of the design specifications.

This may include, but is not limited to, the following examples:

- solar irradiance below specified "wake-up" for energy conversion;
- above "cut-out" voltage under specific circumstances of temperature, irradiance, and design-specific operating voltage limitations;
- ambient temperature above or below specifications allowing the PVPS to operate (see verification scenario Clause D.4);
- snow or ice buildup on PV modules beyond operational limits;
- environmental conditions in excess or otherwise outside the operating limits of the equipment;
- out of operational specification due to inappropriate application (i.e., inverter installed directly in the sun in the desert).

The OUT OF ENVIRONMENTAL SPECIFICATION category is an underlying category of OUT OF SERVICE and has no predefined underlying mandatory information categories.

The OUT OF ENVIRONMENTAL SPECIFICATION category is mandatory.

Entry point – One or more of the environmental conditions go out of design specification of the PVPS, prohibiting all or part of the PVPS from functioning.

Exit point – All of the natural environmental conditions change to be within the PVPS design specification, and the PVPS either returns to normal operation or transitions to another information category. It is acknowledged that inverters may need resets, possibly manually. This time accrues to the event that caused the outage.

Lack of night-time conversion is not considered an unavailability event because it is neither expected nor included in the expected energy performance modelling. However, 24 h functions, for example, communications, Var support, and cabinet heaters may be expected or required at night and treated accordingly with regard to unavailability events. Operation of the equipment outside of specified performance ranges is not a limiting factor for technical availability but may impact the reliability of the equipment if cumulative damage is possible. Operations approaching the limits of ranges with reduced output ratings, but still functioning within the design specifications are both available and functioning in full capability if no other issues are manifested.

5.10 Requested shutdown

Definition – The category REQUESTED SHUTDOWN is obtained when the PVPS is operative but not functioning because it has been stopped by a request, typically external to the PVPS or individual stakeholder scope. Determinations of internal or external inclusions or exclusion may impact the assignment of unavailability time depending on the division of availability and stakeholder boundaries. This category is not to be used for downtime due to SCHEDULED MAINTENANCE, PLANNED CORRECTIVE ACTIONS, or FORCED OUTAGE.

This may include, but is not limited to, the following examples:

- external or grid operator requested curtailment;
- training;
- safety-related events/inspections;
- discretionary component testing.

The REQUESTED SHUTDOWN category is an underlying category of OUT OF SERVICE and has no predefined underlying mandatory information categories.

The REQUESTED SHUTDOWN category is mandatory.

Although externally directed, stoppages may result in full curtailment. Select component outages may occur as the result of deliberate decisions for outages due to internal causes. If so, the allocation of unavailable time due to internal causes may need to be differentiated from external causes.

Entry point – The PVPS is ordered to shut down by request.

Exit point – All active external requests to shut down are cleared.

5.11 Out of electrical specification

Definition – The category OUT OF ELECTRICAL SPECIFICATION is active when the PVPS is operative but not functioning because the electrical parameters of the PVPS or components are out of design specifications. This may be caused by GRID parameters exceeding operational specifications or internal faults in the PVPS. Equipment may be inoperable due to unavailability of the grid, AC or DC collection systems, or electrical conditions outside the operating limits of the equipment. When the grid is in a forced outage, the PVPS is put into an out-of-electrical specification for operation.

This may include, but is not limited to, the following examples:

- grid failure;
- poor power quality;
- voltage, including transients;
- frequency;
- phase imbalance;
- a short circuit in energy collection elements;
- above "cut-out" voltage under specific circumstances of temperature, irradiance, and design-specific operating voltage limitations (this combined interaction of environment and voltage should be allocated only once, and care should be taken to not double count);
- discovery of out-of-electrical limits though testing, inspections, or other external O&M activities.

OUT OF ELECTRICAL SPECIFICATION events may occur at the full PVPS level or at the individual component level. For instance, a grid outage due to any reason puts the PVPS into OUT OF ELECTRICAL SPECIFICATION. At the subsystem level, if AC switchgear is in a forced outage and its function is needed for a downstream inverter to connect, then that inverter is in an OUT OF ELECTRICAL SPECIFICATION state because there is no voltage/frequency to synch to. Likewise, a combiner box failure may prevent an inverter from receiving the energy from the subarray, which from a data perspective appears to be an inverter failure but is not.

The OUT OF ELECTRICAL SPECIFICATION category is an underlying category of OUT OF SERVICE and has no predefined underlying mandatory information category.

The OUT OF ELECTRICAL SPECIFICATION category is mandatory.

Entry point – One or more of the electrical parameters of the PVPS go out of the operational and/or design specifications, prohibiting the PVPS or a portion of the PVPS from functioning.

Exit point – All electrical parameters of the PVPS change to be within the operational and/or design specifications.

A grid outage forces the PVPS into an OUT OF ELECTRICAL SPECIFICATION category and most likely will be excluded from the operational attribution of outage, but the all-in result is still a period of no power delivery and likely loss of revenue and needs to be documented. It is acknowledged that inverters may need to be reset.

Operation of the equipment outside of specified performance metrics may not be an immediate limiting factor for technical availability; however, operation outside of performance specification may cause cumulative damage at risk of reduced reliability.

5.12 Nonoperative

Definition – The NONOPERATIVE category covers all situations when a PVPS is not capable of performing the intended functions.

The NONOPERATIVE category is an underlying category of INFORMATION AVAILABLE and has four underlying mandatory information categories:

- SCHEDULED MAINTENANCE
- PLANNED CORRECTIVE ACTION
- FORCED OUTAGE
- SUSPENDED.

The NONOPERATIVE category is mandatory.

Entry point – The PVPS is not operating or it stops operating due to one of the restricting conditions described in the underlying information categories.

Exit point – All restricting conditions in all underlying categories are cleared.

5.13 Scheduled maintenance

Definition – The category SCHEDULED MAINTENANCE is entered during scheduled maintenance of elements of the PVPS (e.g., inverter), which prevents the entire or select portions of the PVPS from performing the intended functions.

This may include, but is not limited to, periods of SCHEDULED MAINTENANCE on the AC components or DC components if that maintenance leads to an outage of the equipment.

The SCHEDULED MAINTENANCE category is an underlying category of NONOPERATIVE and has no predefined underlying mandatory information categories.

The SCHEDULED MAINTENANCE category is mandatory.

Entry point – The PVPS functioning is stopped or prohibited with the intention of performing scheduled maintenance.

Exit point – The PVPS exits this category by manual intervention, confirming that the scheduled maintenance has been interrupted or completed.

5.14 Planned corrective action

Definition – The category PLANNED CORRECTIVE ACTION is entered during actions required to retain, restore, or improve the intended functions of the PVPS when these actions are not part of normal scheduled maintenance. PLANNED CORRECTIVE ACTION is active when such work is ongoing simultaneously on inverters or on elements of the PVPS (e.g., energy collection system), which prevents the PVPS from performing the intended functions.

PLANNED CORRECTIVE ACTION may include retrofits and upgrades or required corrective actions identified through condition-based maintenance, inspections, or investigations and is intended to account for corrective actions where the need is identified prior to any actual failure and early enough to be planned and completed before resulting in a possible FORCED OUTAGE. This state may be useful in the allocation of methods of procedure where critical work requires approval. This category includes outages due to retrofits, upgrades, or other improvements to the PVPS other than those that did not lead to an outage. Investigation of damage due to lightning may be an example of actions taken to retain or restore function.

The PLANNED CORRECTIVE ACTION category is an underlying category of the NONOPERATIVE category and has no predefined underlying mandatory information categories.

The PLANNED CORRECTIVE ACTION category is mandatory.

Entry point – The PVPS functioning is stopped or prohibited with the intention of performing planned corrective actions.

Exit point –The PVPS exits this category by manual intervention, confirming that the planned corrective actions are interrupted or completed.

5.15 Forced outage

Definition – The category FORCED OUTAGE is obtained when damage, fault, failure, or alarm has disabled components or systems. This can be detected manually or automatically. FORCED OUTAGE is active when such events occur simultaneously on inverters or on other components/ elements of the PVPS, which prevents all or parts of the PVPS from performing the service or functions.

Examples:

- general component failures,
- inverter failure,
- cable fault,
- control failure,
- circuit breaker trip,
- tracker stoppage,

- outage time during response, diagnostics, logistics, and repair.

The FORCED OUTAGE category is an underlying category of NONOPERATIVE and has no underlying mandatory information categories.

The FORCED OUTAGE category is mandatory.

Entry point – The PVPS operation is disabled because of damage, faults, or failures or an alarm.

Exit point – The PVPS exits this category when causes for the outage are cleared.

5.16 Suspended

Definition – The category SUSPENDED covers all situations when activities in SCHEDULED MAINTENANCE, PLANNED CORRECTIVE ACTION, and FORCED OUTAGE need to be interrupted or cannot be initiated due to conditions that compromise personal safety or equipment integrity.

The SUSPENDED category includes, but is not limited to, the following examples:

- authority stops;
- access limitations because of ice, snow, storm, and flooding;
- severe weather conditions, such as lightning, tornados, hurricanes, flooding, and hail;
- reduction of risks initiated by activities such as bush fires;
- safety of personnel or permitting of operations;
- public authorities' orders for suspension of the work because of personal safety;
- site working conditions are not met;
- conditions affecting the PVPS potentially from either a site or external incident that cause damage or constraints to the PVPS that need to be addressed.

The SUSPENDED category is an underlying category of the NONOPERATIVE and has no underlying mandatory information category.

The SUSPENDED category is mandatory.

Entry point – This category is entered by manual intervention when work is suspended according to defined conditions.

Exit point – This category is terminated by manual intervention when the conditions suspending the work have been cleared.

5.17 Force majeure

Definition – The category FORCE MAJEURE covers all situations where an extraordinary event or circumstance beyond the control of the parties involved prevents the parties from fulfilling their obligations.

FORCE MAJEURE is a common clause in contracts, which essentially frees concerned parties from their liability or obligation when an extraordinary event or circumstance beyond the control of the parties occurs.

FORCE MAJEURE is not intended to excuse negligence or other malfeasance of a party, as where nonperformance is caused by the usual and natural consequences of external forces or where the intervening circumstances are specifically contemplated.

The FORCE MAJEURE information category is underlying the INFORMATION AVAILABLE information category on Level 2 and has no underlying mandatory information categories.

The FORCE MAJEURE category is mandatory.

Entry point – This category is entered by manual (i.e., civil authority notification or recorded incident into SCADA) intervention when a FORCE MAJEURE situation is detected according to contract text.

Exit point – This category is terminated by manual intervention when a FORCE MAJEURE situation has been cleared according to contract text.

A FORCE MAJEURE event may result in damage and the need for repair to restore service of parts of the PVPS. This will result in loss of PVPS capability, and care should be exercised in logging and assigning lost time and energy with an interface with PLANNED CORRECTIVE ACTION and considered in reporting, including "all-in" availability. Insurance considerations may also apply in these circumstances.

FORCE MAJEURE events may cause periods of unavailability due to a situation that was unforeseen, uncontrollable, or beyond capability to manage.

Although this definition is intended to make the information categories all-encompassing and allow for assignment of time, it is acknowledged that contract legal terms will govern, and the use in this category should be coordinated to take into account that fact.

5.18 Information unavailable (PVPS)

Definition – The category INFORMATION UNAVAILABLE covers all time periods when the category INFORMATION AVAILABLE is not applicable. Losses of critical data result in the inability to assign periods in the required information levels.

The INFORMATION UNAVAILABLE information category is on Level 1 and as such has no overlying information category. In addition, this information category has no underlying mandatory information categories.

The INFORMATION UNAVAILABLE category is mandatory.

Entry point – It is not possible to determine, log, or store the Level 4 category of the PVPS.

Exit point – The PVPS operating status data are available to the extent that a PVPS category at Level 4 can be determined, logged, and stored.

6 Information model for PVPS

6.1 Time-based capability information model

This model accumulates time in the information categories individually by event. The time-based capability data model for the PVPS works on the principle of allocating event time to information categories. The key to determining the proper information category of events is by evaluating compliance with exit and entry criteria (measured time) defined in this document. After identification and logging of an event, its category is assigned. The temporal unavailability of many components will result in power not produced or delivered (i.e., lost energy). It is also recognized that data systems will not always clock all outages because some will be discovered by inspection, testing, data analysis, or other means. It is observed that data collection capabilities will have an important role for the implementation of this document. As indicated in the introduction, criteria for selected granularity levels of the tracking thresholds need prior stakeholder determination.

6.2 Time-based total PVPS capacity availability

Capacity (for active power) is a physical property of the PVPS and installed components (even using summer/winter ratings, it is still essentially static for the reporting period). Capacity will be reduced only when a component integral to power production fails (and becomes unavailable). These components will also have associated capacities. The PVPS capacity will comprise the total of all component capacities. Capacity can then be used as an input to compute full PVPS availability because that is an expected usual goal. With that as a premise, use the following formula:

$$\text{PVPS Availability} = 1 - \frac{1}{\text{H}_{\text{ttp}} \times KW_{np}} \times \left(\sum_{Incident} \left(H_{un} \times KW_{dr} \right) \right) \quad (2)$$

where

H_{ttp}:

The theoretical total production time in hours in the period when the solar irradiance meets the minimum specifications for the inverters to operate.

Array power (KW_{np}):

The expected DC power of the array for the entire solar generating facility determined by the sum of each module nameplate kWp rating. PVPS ratings by aggregated module nameplate are common.

Component unavailability time (H_{un}):

The hours in the period when solar irradiance is sufficient to power the inverters, yet a component within the facility is not available to generate power due to an equipment fault or failure. The component unavailability can be measured at different PVPS levels, depending on the granularity of measurement desired or available.

Incident: Every outage incident during the measurement period.

NOTE KW_{dr} describes the capacity reduction as a consequence of the events.

This approach is further expanded in Annex A to address operational and technical availability perspectives for varying stakeholders and areas of PVPS operation. Annex B also extends this energy assessment of unavailability and energy assessment methodology.

This approach is not a measure of the power capacity of the PVPS, and users are referred to IEC TS 61724-2 if the methods of this document indicate that capacity varies from that assumed in the performance model and expected energy calculations.

6.3 Application of the information model to different plant levels

The PVPS may be considered broadly to consist of components, equipment, subsystems, and systems in a hierarchical and modular design form. Some adverse events will have an impact at a full PVPS level, whereas others will be at a component level and may not be immediately discernible and/or inconsequential. In this document, the entry and exit points indicate duration and depend on the extent of the PVPS infrastructure affected. This will be helpful in determining the associated capability or capacity impact.

The PVPS consists of various levels (Figure 4), including modules, DC collection systems, inverters, and AC collection systems, and components such as transformers, switchgear, and system protection. It is expected that the conventional aspects of utility infrastructure will function at high reliability and availability. An understanding of the consequences of outages at various points in the PVPS is needed to appropriately mitigate consequences. All failures or events that result in service outages should be allocated in the information model. Planning for expected outages during specification and design may include provisions to facilitate availability improvements during operations. For instance, isolating an inverter for both planned and forced outages should not require the shutdown of all inverters but rather the disconnection of a single inverter through an isolation switch.

See example RBDs for a reliability perspective of the major components in Annex B and Annex D.

Levels will also be evident in the monitoring system. For instance, providing additional instrumentation of the source circuit levels may likely identify more availability issues but possibly indicate reduced availability because the identification was enhanced. Without such instrumentation, the issues may not be discovered in a timely manner but would still be reflected in the performance. This is a cost and design decision, and undiscovered unavailability will be reflected in reduced energy if not otherwise determined. This is generally addressed in Clause E.6.

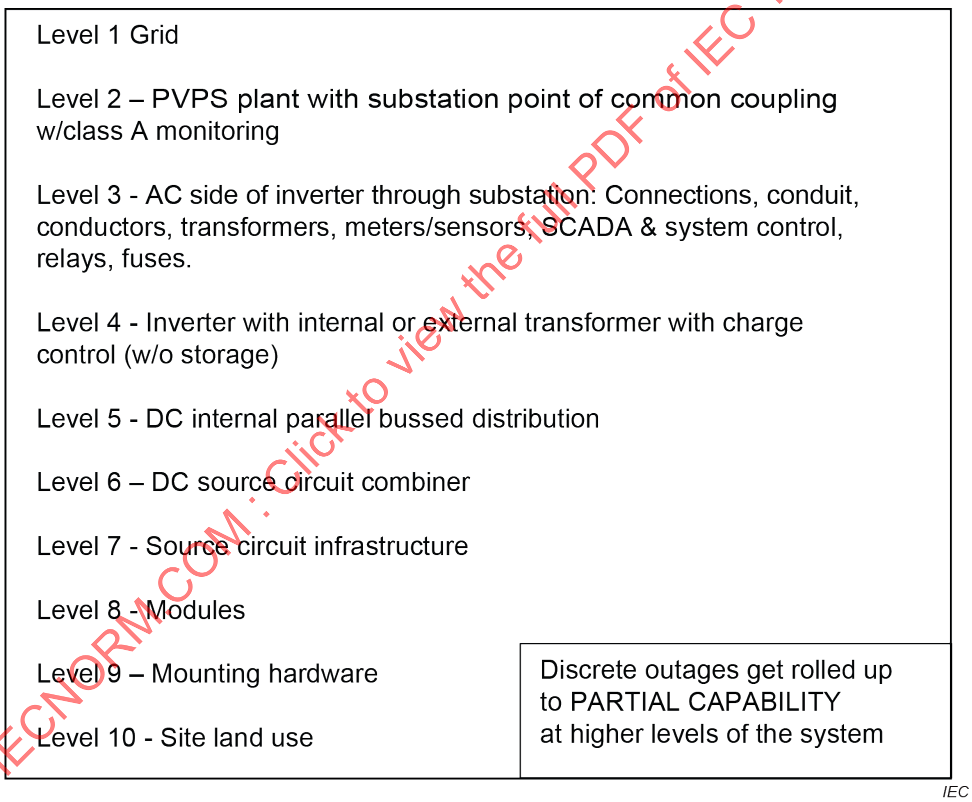

Figure 4 – PVPS plant levels

The PV component list and PV system configuration vary according to the application and could also include the following subsystems: power conditioning, storage, system monitoring and control, and utility grid interface.

6.4 Asset management functions of the PVPS

Other capabilities exist that support the O&M services, such as SCADA and data tracking systems, civil plant, and roads. Some of these functions may be considered to serve both internal and external purposes. In addition to operations and the provision of electrical services of the PVPS, asset management will be needed. Asset management functions may be varied but will certainly include the human factors needed for O&M of the PVPS and the management of activities and information. Communications with grid operators, except for required automated information streams, will be performed as part of the internal asset management function and will be accomplished at the PVPS site or perhaps a remote corporate site.

The O&M function is broad and includes management and technical staff with equipment such as fleet vehicles and tools/parts/consumables. Reporting key availability metrics and other required information to stakeholders is also part of operations. In terms of PVPS system and component availability, repairs, replacements, and restoration of component functionality depends on an efficient asset management function. Intervention in anticipation of plant needs and conduct of upkeep and repairs to keep components and systems available and operating is a common part of maintenance.

Further, off-takers, grid authorities, energy markets, owners, managers, and operators will need information about PVPS status and future performance expectations. Examples include forecasting and real-time capacity, availability, generation capacity, production rating, and scheduling. Note that some of these are an automated function of the PVPS, whereas others are the result of human processing of information.

Note that the provision of some of these services for smaller, nonutility-sector systems will still be necessary and are to be provided by the market participants as can be predetermined.

6.5 Limitations

It is not within the scope of this document to specify the method of information acquisition and how to estimate the production terms.

During nongenerating periods, the PVPS may be consuming power (parasitic losses). This is not considered for the model because this is not contributing to the provision of services.

Production during the transition from one information category to the next is not considered because this is insignificant.

6.6 Information category priority

Time present in the information categories shall be exclusive and continuous. If the conditions for allocating a time period to more than one information category can be fulfilled, then the information category priorities determine which category takes precedence (higher disruption or control factor) for the allocation of the time period being considered. Assignment of priorities to the information categories provides a uniform and transparent method for the designation of time.

The order of priorities as specified in Table 3 is mandatory for compliance with this model. The priorities are ranked from 1 to 12, with 1 as the lowest and 12 as the highest priority. Priorities for optional information categories can be introduced for specific purposes. In such cases, the mandatory priorities can be extended with a priority for the optional information category.

Table 3 illustrates the information category priority for the PVPS, and Clause D.5 verification scenario provides an example of its use.

Table 3 – Information category priority for PVPS

<table>
<tr><th colspan="5">Information categories</th></tr>
<tr><th>Mandatory Level 1</th><th>Mandatory Level 2</th><th>Mandatory Level 3</th><th>Mandatory Level 4</th><th>Mandatory Priority</th></tr>
<tr><td rowspan="11">INFORMATION AVAILABLE</td><td rowspan="6">OPERATIVE</td><td rowspan="3">IN SERVICE</td><td>FULL CAPABILITY</td><td>**1**</td></tr>
<tr><td>PARTIAL CAPABILITY</td><td>**2**</td></tr>
<tr><td>SERVICE SET POINTS</td><td>**3**</td></tr>
<tr><td rowspan="3">OUT OF SERVICE</td><td>OUT OF ENVIRONMENTAL SPECIFICATION</td><td>**4**</td></tr>
<tr><td>REQUESTED SHUTDOWN</td><td>**5**</td></tr>
<tr><td>OUT OF ELECTRICAL SPECIFICATION</td><td>**6**</td></tr>
<tr><td rowspan="4">NONOPERATIVE</td><td colspan="2">SCHEDULED MAINTENANCE</td><td>**7**</td></tr>
<tr><td colspan="2">PLANNED CORRECTIVE ACTION</td><td>**8**</td></tr>
<tr><td colspan="2">FORCED OUTAGE</td><td>**9**</td></tr>
<tr><td colspan="2">SUSPENDED</td><td>**10**</td></tr>
<tr><td colspan="3">FORCE MAJEURE</td><td>**11**</td></tr>
<tr><td colspan="4">INFORMATION UNAVAILABLE</td><td>**12**</td></tr>
</table>

Use of the category prioritizations will provide a method for avoiding the attribution of outages. External factors may result in accounting for time in the categories. For example, an external event may cause the grid to suffer a forced outage, resulting in the PVPS being in the OUT OF ELECTRICAL SPECIFICATION. Depending on the expected duration, there may be an opportunity to perform maintenance that would normally require an outage. By the priorities shown in Table 3, the FORCED OUTAGE is a higher priority. This is because when the grid is restored to service, there is an expectation that the capacity will be as previously predicted. If the maintenance activity outage is undeclared and not returned to service, then the operation may be legally out of compliance with grid operating requirements. These situations may be negotiated and defined in contract terms; the priority logic provides both a guide and examples on how to handle multiple and sequential events and is adjustable when in accord with the stakeholders.

a) Night-time and low irradiance

Night-time (or when the solar irradiance is less than inverter turn on at times near dusk or dawn) does not count against (it is excluded) the availability calculation. Other causes of low irradiance or other forms of OUT OF ENVIRONMENTAL SPECIFICATION (i.e., snow or biofouling) are to be recorded.

b) SERVICE SET POINTS

This information category is not strictly an equipment unavailable state because the PVPS is performing according to design and specification; however, operationally, it may limit production and result in lost (by expectations) operational availability of energy production. The time in this state should be recorded, and the energy impact is recommended to be assessed and quantified against expected energy assumptions. Cleaning may be an O&M mitigation.

Annex A
(informative)

Information category-based availability indicators

A.1 General

This annex describes examples of how to determine various measures of inclusion or exclusion of the availability of PVPS capability based on the information categories defined in this document. The following provides a tool for accounting for these inclusions and exclusions considering three types of information categories:

a) information categories considered as available time;

b) information categories considered as unavailable time;

c) information categories not to be considered in the availability calculation.

The constituents of each of these three types of information categories are defined for each measure of availability in its respective section. Users may find other arrangements of the categories to calculate availability specifically for their need.

When calculating the measure of availability, the following general equation shall be applied:

$$\text{Availability} = \frac{\text{Time item is operating}}{\text{Time item is operating} + \text{time item is not operating}} \qquad \text{(A.1)}$$

A.2 Operational availability

Definition – System operational availability is the fraction of a given period of time (e.g., month) in which a PVPS is actually generating. This is primarily an operator's, user's, or owner's view of a PVPS as a whole and measures how often the asset was actually generating power. The reasons for allocation of the lost operating hours are less important than the overall view that operation and production have been lost. This may also be known as "raw" or "all-in" availability.

This applies only to the solar day. Irradiance levels less than the turn-on threshold are not included; however, when enough sunlight exists to allow the inverters to reach the input voltage needed to operate, the time clock will begin. This distinction is made between lost operating hours due to unavailable solar resource and hours lost due to other operating conditions beyond the design specifications of components. Lost operating hours due to any other outage reason are included as unavailability. If a storage system or another system is to be operated on the bases of 24 h per day, necessary adjustments to inclusions and exclusions will be needed for the availability indicators for those systems. Fractional PVPS outages are included according to capacity or capability and are addressed and/or can also be assigned at lower levels.

In this definition, time considered available includes:

- FULL CAPABILITY
- PARTIAL CAPABILITY
- SERVICE SET POINTS.

Time considered unavailable includes:

- OUT OF ENVIRONMENTAL SPECIFICATION (with previously cited exception)
- REQUESTED SHUTDOWN
- OUT OF ELECTRICAL SPECIFICATION
- SCHEDULED MAINTENANCE
- PLANNED CORRECTIVE ACTION
- FORCED OUTAGE
- SUSPENDED
- FORCE MAJEURE.

Time not included in the calculation includes:

- INFORMATION NOT AVAILABLE.

Because no information about the PVPS is known in the INFORMATION UNAVAILABLE category, these periods are not included as available or unavailable and are excluded entirely from the calculation.

A.3 Technical availability

Definition – Technical availability is the fraction of a given period of time in which a PVPS is operating. Fractional PVPS outages are included according to capacity or capability and/or can also be assigned at lower levels.

PVPS technical availability differs from operational availability in that categories generally beyond the control of the PVPSs, subsystems, components, or subcomponents are excluded from consideration. For instance, PVPS performance is not being evaluated during hours when the operator has requested a shutdown, an electrical connection is not available, or a force majeure event has occurred.

This is primarily the O&M service provider's view of a PVPS and measures how often the PVPS operated. Lost production outages due to maintenance as specified, environmental conditions outside the specifications, and standby for internal checks, for example, are not considered unavailable in the definition.

In this definition, time considered available includes:

- FULL CAPABILITY
- PARTIAL CAPABILITY
- SERVICE SET POINTS
- OUT OF ENVIRONMENTAL SPECIFICATION
- REQUESTED SHUTDOWN
- OUT OF ELECTRICAL SPECIFICATION.

Time considered unavailable includes:

- PLANNED CORRECTIVE ACTION
- FORCED OUTAGE.

Time not included in the calculation includes:

- SCHEDULED MAINTENANCE
- SUSPENDED
- FORCE MAJEURE

- INFORMATION UNAVAILABLE.

A.4 Use of the tool

For each outage or downtime scenario to be considered, time is distributed into the mandatory information categories, as depicted in Table A.1. Colours indicate how the individual mandatory information categories are included in the availability calculations, with green indicating that the time is available, red indicating that the time is unavailable, and grey indicating hours that are excluded from the period hours and are not included in the calculation of the performance metric.

Table A.1 – Allocation to information categories

	Mandatory — Information categories												Availability = 1 – unavailability/ (availability + unavailability)	
MEANING OF COLOURS: **GREEN** = available **RED** = unavailable **GREY** = excluded from period hours	**Full performance**	**Partial performance**	**Service set points**	**Out of environ. spec.**	**Requested shutdown**	**Out of electrical spec.**	**Scheduled maintenance**	**Planned corrective action**	**Forced outage**	**Suspended**	**Force majeure**	**Information unavailable**	**Operational availability**	**Technical availability**
Operational availability	GREEN	GREEN	GREEN	RED	RED	RED	RED	RED	RED	RED	RED	GREY	X	
Technical availability	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREY	RED	RED	GREY	GREY	GREY		X

Note that the operational availability accounts for all outages. A service set point limit of 50 % is not a technical unavailability incident; however, due to the complicated nature of services and when they may be employed, they may have an impact on energy production and are further discussed in verification scenario, Clause D.10. While in service set point operation, when deviating from the expected performance model case(s), the PVPS is still technically available, but it is important to maintain a time clock for operation in all information categories if not sufficiently addressed in the performance model or if actual operating cases are outside of defined parameters.

It is not the guidance of this document to determine all time or contract inclusions. Determinations of assignments should be documented. It is expected that an O&M service provider also has a contractual performance requirement and its technical availability may exclude categories and/or systems and components from certain calculations. PLANNED CORRECTIVE ACTIONS may or may not be within the contracted work scope of inclusions or exclusions. SCHEDULED MAINTENANCE will be previously determined, and outage time may be expected and how it is to be accounted. It is not the position that the allocations of inclusions and exclusions shown Table A.1 are fixed. The stakeholders are encouraged to adjust allocations of risk to the scope of the parties involved. Utility-sector stakeholders may require reporting requirements of 24 h per day (i.e., capacity payments), and the tool can be adjusted as needed.

The technical availability can be determined for specific components in a PVPS. For example, the full complement of inverters in a PVPS can be examined. Their availability can be measured based on the available hours of all inverter units divided by the overall hours for that time period (see verification scenario, Clause D.3). The availability of any major component can be treated similarly. This will be useful if the availability is a contractual performance requirement. Caution should be exercised on how time is to be recorded.

Annex B
(informative)

Energy-based tracking

B.1 General

Production-based tracking for the PVPS works for the same model and categories as those specified for capability- or capacity-based tracking. The information categories are applied to systems, subsystems, components, and subcomponents as appropriate for the outage and how the energy conversion, conditioning, collection, and production may have been limited. Time and energy impacts are not necessarily proportional or perhaps even correlated to incidents.

For lost energy that is a consequence of unavailability, note that the IN SERVICE (typically generating) categories will represent positive values of production, and the nonoperating and nongenerating areas are areas of lost energy. Production will be metered, but lost energy will need to be determined through a methodology agreed to by the contract stakeholders. With the determination of the values for expected and actual production data, a loss analysis can be "binned" in accordance with the information categories within a PVPS. A functional approach for this process follows. For PVPS components and services where production is not the appropriate measure of capability, that model holds, but the terms will need to be described differently (i.e., a tracker system performance is in terms of position accuracy and has an energy impact that needs estimations). See verification example, Clause D.5.

B.2 Specific resource and modelling-based performance (using IEC TS 61724)

If required, the expected energy production shall be calculated by performance modelling in accordance with IEC TS 61724-3, which includes actual weather and operating constraints. The energy is to be measured and losses calculated based on the PVPS functional operating and contractual specifications, which may be useful for revenue valuations. Of specific note, guidance is provided in the application of:

- Resource measurement and performance model
- Simplified power curve
- IEC 61724 expected energy calculation.

B.3 Energy-weighted availability approach

One method to calculate energy-weighted availability is by using the following formula:

$$\text{Availability} = 1 - \frac{1}{\text{kWh}_{\text{TotalSimulated}}} \times \left(\sum\nolimits_{\text{incident}} \text{kWh}_{\text{unavailable}}\right) \qquad \text{(B.1)}$$

and:

$$\text{kWh\_Unavailable} = \text{kWh\_Event Simulated} \times \left(\frac{\text{kW\_dr}}{\text{kW\_np}}\right) \qquad \text{(B.2)}$$

where

kWh TotalSimulated = total net PVPS energy simulated using the performance model with the measured meteorological data throughout the test measurement period (kWh)

Incident = each unavailability event

kWh_EventSimulated = total net PVPS energy simulated from the performance model only during the unavailability event (kWh)

Nameplate power (kW_np) = the nameplate power rating of the entire solar-generating facility determined by the sum of each module's DC nameplate kWp rating

Derated system power (kW_dr) = the value for derated (by incidents) system power will be calculated by the amount of unavailable DC nameplate capacity for the period and is determined by the sum of each module's nameplate kWp rating for that given unavailable component. Derated system power here applies only to unavailability contributors identified, not to performance deficiencies.

Energy-weighted availability considers the energy generation opportunity loss that occurs during an unavailability event. For example, a 1-h outage during the early morning or during a heavy rainstorm would have a much smaller impact than if the same event occurred in full sun at solar noon. There are a few methods to calculate this. One method is documented in IEC TS 61724-3. Another method is presented in this document.

B.4 Fractional power estimation techniques

This clause describes examples of how to calculate various measures of energy loss in a PVPS due to outages. This technique is based on a determination of the fractional outage (such as the energy-weighted availability approach) of component outages through comparison with representative or average sections remaining in full capability. An RBD, a one-line diagram in appearance and characterization of an electrical system, illustrates this; see Figure B.1.

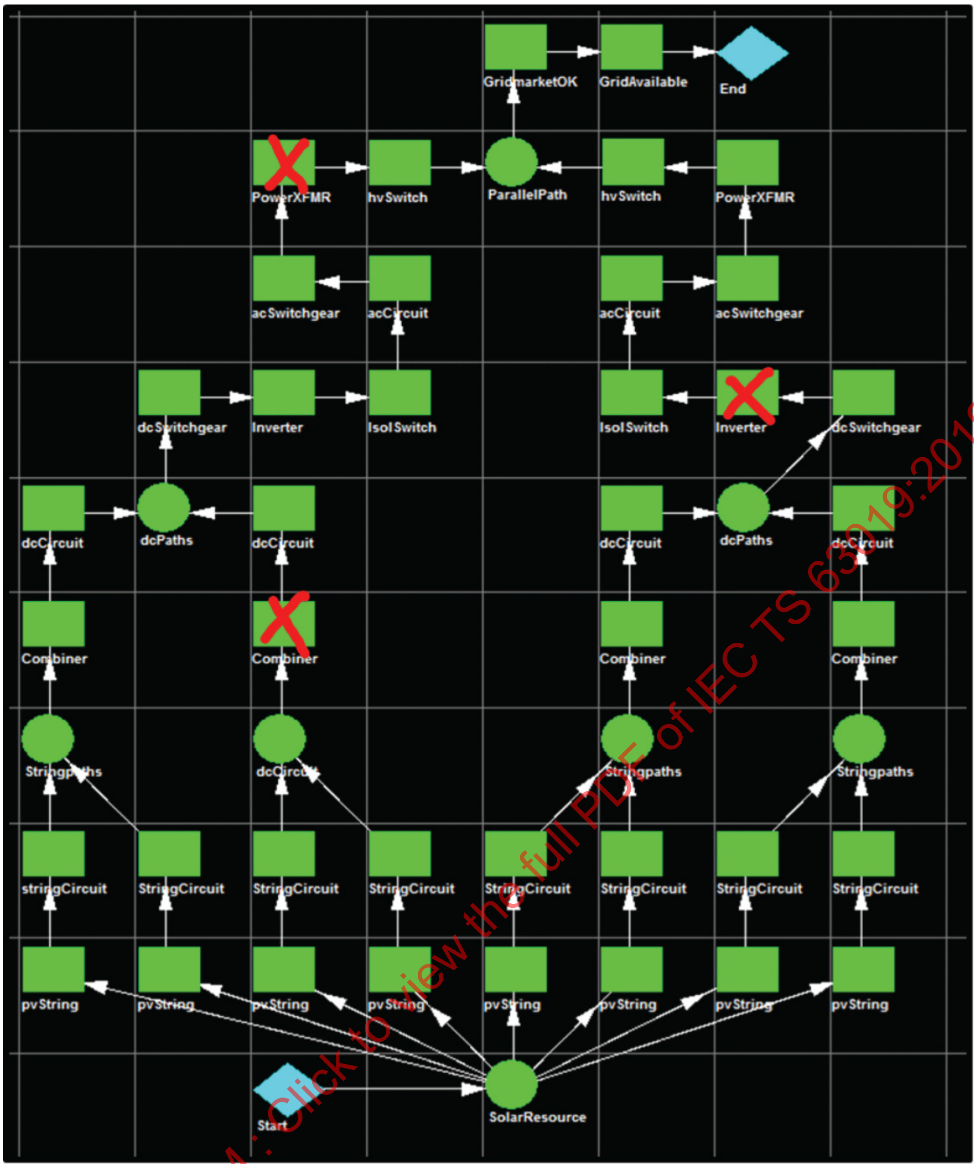

Figure B.1 – RBD of a PVPS

Given the many energy pathways and the opportunity for failures at any location, a certain portion of the modules will be blocked from being able to collect and deliver power to the point of common coupling. The RBD in Figure B.1 shows this by using Xs at select failure points. For this example, using a simple representation of a PVPS, the failures occur at a power transformer, an inverter, and a combiner box. The expected energy can be modelled or the lost energy can be compared to the remaining production of unaffected like systems, physically neighbouring like systems, or even averages of like systems. Care should be exercised because multiple outages can happen at the same time, and some will affect the same areas of the system and be on the same pathway to the point of common coupling. If the two failures represented on the left occur simultaneously, the transformer is 50 % of the capacity and the combiner box is 25 %; however, it is downstream from the transformer. In this case, care should be exercised to avoid double counting. This validates the nomenclature of the energy-weighted availability approach that calculates the amount of unavailable DC nameplate capacity. The energy consequence will be able to be measured if "twinned systems" have sufficient instrumentation and monitoring capability.

These outages and other events are illustrated in verification scenario, Clause D.7. The RBD is a simplified representation, and large PVPSs will have much greater numbers of PV strings, combiners, inverters, and energy with many more pathways in the DC and larger AC collection systems.

Users may find other optional categories or definitions of energy-based tracking more specific to their needs. Users should also be aware of IEC 61078, which includes much more information on RBD use and how reliability techniques can be used to evaluate the availability, reliability, failure frequency, and other dependability measures as may be applicable to a given system or component.

B.5 Addressing lost production in the information model

The information model is strictly based on the one specified in this document and applied to production to capture lost energy. The main characteristics of this model are summarized as follows, and the model has been extended to allow for production to be calculated. The extension is done by adding two additional columns, as shown in Table B.1.

Table B.1 – Information categories and additional layers of measured, expected, and lost production

Information categories – Layer 1				Layer 2	Layer 3	Layer 2 subtracted from Layer 3
Mandatory Level 1	Mandatory Level 2	Mandatory Level 3	Mandatory Level 4	Measured Production	All-In Expected Production	Lost Production
INFORMATION AVAILABLE (IA)	OPERATIVE (IAO)	GENERATING (IAOG)	FULL CAPABILITY	$IAOGFCP_A$ Measured	$IAOGFCP_P$	0
			PARTIAL CAPABILITY	$IAOGPCP_A$ Measured	$IAOGPCP_P$	$IAOGPCP_P$ - $IAOGPCP_A$
			SERVICE SET POINTS	$IAOGSP_A$ Measured	$IAOGSP_P$	$IAOGSP_P$
		NONGENERATING (IAONGO)	OUT OF ENVIRONMENTAL SPECIFICATION	0	$IAONGENP_P$	$IAONGENP_P$
			REQUESTED SHUTDOWN	0	$IAONGRSP_P$	$IAONGRSP_P$
			OUT OF ELECTRICAL SPECIFICATION	0	$IAONGELP_P$	$IAONGELP_P$
	NONOPERATIVE (IANO)	SCHEDULED MAINTENANCE		0	$IANOSMP_P$	$IANOSMP_P$
		PLANNED CORRECTIVE ACTION		0	$IANOPCAP_P$	$IANOPCAP_P$
		FORCED OUTAGE		0	$IANOFOP_P$	$IANOFOP_P$
		SUSPENDED		0	$IANOSP_P$	$IANOSP_P$
	FORCE MAJEURE			0	$IAFMP_P$	$IAFMP_P$

Information categories – Layer 1	Layer 2	Layer 3	Layer 2 subtracted from Layer 3
INFORMATION UNAVAILABLE	*	*	*

Colour codes:

Green: Positive production – metered

Service set points will be mixed but generally reductions and lost production are allocated here. Positive production will be allocated under partial production because that will be metered. If the performance model adequately models the service set points' operation and expected performance is met, then no further assessment is necessary.

Pink: Lost production due to unavailability

Grey: Data not available to determine values

The abbreviations may be useful for accounting, and the organization is based on the higher level systems. For example, the FORCED OUTAGE abbreviation is derived from INFORMATION AVAILABLE (FA), NONOPERATIVE (NO) FORCED OUTAGE (F0); P_P represents production potential expected. In assembled form, it is $IANOFOP_P$.

* In the category INFORMATION UNAVAILABLE, for data that are missing or cannot be quantified, a value cannot be determined.

Measured production, rather than time, is recorded in the second column. SERVICE SET POINTS is measured (metered) at the full PVPS level with the other causes of PARTIAL PRODUCTION. Column 3 contains information on the amount of all-in expected production and should be consistent with IEC TS 61724-3 expected energy. By subtraction, the lost production can be calculated by methods already described and assigned by information categories. Through this technique, differentiation can be made between energy lost by unavailability and performance deficiencies, as illustrated in verification scenario, Clause D.7.

Lost energy and attribution to cause is the desired metric. Tabulation of lost energy by the categories combined with performance shortfall is useful to discriminate among energy impacts of outages or other forms of reduced performance. Table B.1 demonstrates the utility of accumulating lost energy by information category and is designed to be useful to differentiate availability or energy for contract purposes. If active energy is the service, Figure B.1 can apply. If other services are under consideration, the category can be identified as a different service, such as reactive power.

This annex does not specify or recommend any method for determining lost energy, but it identifies several possibilities and lists issues to be considered for each method. It is up to the users and stakeholders to define the method to be used, depending on the extent of the subsystem outage, data availability and quality, and other factors.

Annex C
(informative)

Reliability, availability, maintainability (RAM) definitions/formulas, availability/stakeholder types, data, and optional categories

C.1 General

Availability and performance are in large part determined by the reliability of components and subcomponents and the ability of the O&M process to repair or maintain the plant in operable condition. Plant failures, both hardware and software, fall under the category of FORCED OUTAGE. Failure in this context is any malfunction regardless of the source that results in a loss of power production capability other than uncontrollable external influences. After FORCED OUTAGES occur, reliability and maintainability metrics can, to a certain extent, be derived from the activities and time taken to perform them. Examining the subcategories leads to handling response, diagnostics, logistics, and repair and restoration, among other considerations. Degradation falls under the category of PARTIAL CAPABILITY and derating under SET POINT SERVICES. These optional categories may be useful in understanding trends in PVPS conditions.

Availability may be both a reported (through historical tracking) and predictive metric that stakeholders use to numerically characterize their requirements. Various stakeholders' availability metrics may require somewhat different PVPS attributes to satisfy their needs for detection of failure trends that lead to detriments in the ability to produce power.

Starting with the definition of reliability, which is the probability that an item (component, assembly, or system) can perform its intended function for a specified interval under stated conditions, the mission of a PVPS is to provide energy throughout its lifetime as efficiently and reliably as possible given the quality of the components and understanding of the site, grid, and environment. Maintainability includes how much time it takes a part, component, or system to return the failed item to service or to perform scheduled maintenance on an item. Availability, as defined and further characterized in this document, is a primary metric of this mission for reliability.

The available state is when the PVPS, a subsystem, or a component can provide service, regardless of whether it is in service and regardless of the capacity level that can be provided. Again, the mission is to have high availability throughout the lifetime of the PVPS given the constraints of operation at the site and the environmental limitations.

High availability is facilitated through efficient and timely maintenance and is a critical component of a PVPS. The information model includes categories for maintenance and the constraints of the external operating conditions.

The RAM methodology provides tools for assessment and improvement of the PVPS mission.

Another characterization of the energy mission of the PVPS is to understand that the probability of producing power is a function of availability, resource, grid capability, and demand.

Users are advised that mathematical expressions for RAM and maintenance support terms are found in IEC 61703.

C.2 RAM definitions and metrics applicable to forced and maintenance outages

Reliability is the probability that an item can perform its intended function for a specified interval under stated conditions. Some measurable metrics are:

- Mean time between failure for repairable items (MTBF)
- Mean time to failure for nonrepairable items (MTTF)
- Mean time between maintenance (MTBM), including scheduled and unscheduled maintenance.

These terms are useful for the categories of FORCED OUTAGE (see Clause C.3) and SCHEDULED MAINTENANCE for preventive and other regular maintenance that maintains equipment and components. This includes replacing air filters, cleaning PV modules, and repairing corrosion-damaged parts by finding and removing items before they fail.

Maintainability is characterized by the relative ease and economy of time and resources with which an item can be retained in, or restored to, a specified condition when maintenance is performed by personnel having specified skill levels using prescribed procedures and resources at each prescribed level of maintenance and repair. Some measurable metrics are:

- mean time to repair (MTTR) if all tools, spares, support equipment, and personnel are available to perform maintenance;
- mean logistics delay time (MLDT), including all delays associated with obtaining (ordering and receiving) spares, support equipment, travel time to the site, and other non-touch labour delays;
- mean downtime (MDT), the average time a system is unavailable for use due to a failure. Time includes the actual repair time plus all delay time associated with a repair person arriving with the appropriate replacement parts.

Note that MDT = MTTR + MLDT.

Availability is a measure of the degree to which an item is in an operable and committable state. Because the function of production depends on availability, resource, grid capability, and demand, this document addresses these states as part of the information model as categorized.

Completing availability requires reliability and maintainability data. In this document, the time is tracked in the categories to determine the availability metrics. For purposes beyond the scope of this document, the data, along with deeper examination and expanded calculations, allow for trend analysis, cost estimating, maintenance projections, spare projections, and more, as may be needed by various stakeholders.

C.3 Stakeholders and types of availability

There are many different types of availability, and they depend on the stakeholders' perspectives of how the PVPS is operating and delivering services. These all require the definition of the period of time. The use of uptime and downtime encompasses all causes. This is applicable to many circumstances, ranging from control signals, operational decisions, site factors related to environmental and grid state, even natural disasters. Many maintenance activities will require outages. Additionally, component outages usually require maintenance.

Availability is also predicated on the aspects of stakeholder perspective. As a result, there may be more specific definitions of availability to meet those needs, as was discussed in Annex A regarding operational and O&M availability perspectives.

a) Component vendors and designers

These parties are concerned about the direct reliability and maintainability (MTBF/MTTF and MTTR) attributes of the as-designed components, including, but not limited to, solar panels, arrays, combiners, inverters, and grid interface equipment.

Inherent availability ($A(i)$) is a direct measure of the inherent characteristics of the equipment assuming that all tools, support equipment, and spares are available for repair. The equation for inherent availability is:

$$A(i) = \frac{\text{MTBF}}{(\text{MTBF} + \text{MTTR})}$$

where MTBF (or MTTF) and MTTR are related to the individual components.

b) Owners/operators

These stakeholders are concerned about the ability of the PVPS to produce power. This is generally designated as operational availability ($A(o)$); see Annex A. As the term implies, operational accounts for all potential downtime (failure or scheduled maintenance) events that remove parts or portions of the PVPS power production. The formula for operational availability is:

$$A(o) = \frac{\text{Uptime}}{(\text{Uptime} + \text{downtime})}$$

Uptime is total time during a measurement period (generally weeks, months, or years) that the equipment is producing power. Downtime consists of all time during normal hours of power generation for which the unit is not in an operable state for all maintenance, scheduled and unscheduled. Note that this does not include night-time repair hours unless, for example, an inverter is used to generate parasitic power for the PVPS outside of normal power generation hours. Mean downtime consists of:

$$\text{MDT} = \text{MTTR} + \text{MLDT} + \text{Maintenance delay time}$$

Total time = Average hours of daylight per year (month of year) that could be used for power generation if the sun is shining, or, alternatively:

$$\text{Total time} = \text{Uptime} + \text{downtime (if the sun is shining)}$$

Downtime is further addressed in Clause C.5.

Contractual availability is a defined method to calculate the availability of the given data from the physical reliability of the plant, environmental models, and any derating assigned to allow for the variability of power production during a specified period.

c) O&M service provider

Demonstrated availability $A(d)$ based on the actual metrics derived from the field data. It may be partially based on measured uptime and downtime and combined with the electrical power measurements (metered energy). It may also provide the basis of determining levelized energy costs. Much of this information is used to determine through trend analysis the O&M costs, what kinds and/or types of spares are needed, where they should be located, and the type and size of the maintenance force.

d) Electrical utility or power purchasers

Electrical power availability $A(e)$ considers that the PVPS is available to produce power if the sun is shining at a sufficient level to produce electrical energy through solar conversion (light to electricity). Note that for utility-scale PVPS, the rated energy is often predicted for use in the utility sector operations.

e) Financial institutions

Capacity availability is defined in 6.2 for measuring overall capacity of the PVPS for many stakeholders.

Energy availability is defined in 3.8 and uses the process of IEC TS 61724-3 and actual conditions. Energy-weighted availability is the estimated energy available using the performance model that includes weather and operating constraints as considered in this document and described in Clause B.3.

Technical availability as put forward in Annex A may be a form of contractual availability. The scope of the PVPS included as well as operational constraints will be adjustable to the scope of contracts.

C.4 Data

Availability metrics highly depend on data gathered on the PVPS operation and failures. It can be described as a process where quality data are collected and analysed using reliability engineering principles and statistical methods. It primarily comprises two pieces:

a) a database that allows for proper serialization of PVPS components, recognizing the parent-child relationship of components connected in series and/or in parallel.

b) a failure reporting, analysis, and corrective action system that emphasizes continual improvements through a feedback process that aims to "close the loop", thus reducing the likelihood of recurring failures.

Forced outage incidents include failures, faults, or trips of PVPS components or systems that lead to outages and loss of availability. Forced outages can trigger significant amounts of data needs depending on the sophistication of the O&M process. Innocuous incidents, such as nuisance trips, may be quickly addressed without major effort, whereas failures causing loss of component function can necessitate greater repair or replacement actions. Table C.1 shows an example of information that is typically included in an incident report. What follows is an example of thorough asset management record keeping, which would be useful for determining unavailability time and the extent of FORCED OUTAGE metrics.

Table C.1 – Reliability metrics description

Incident description	A more detailed description of the incident. This would include information regarding how the failure manifested or the details of what prompted a planned event. This would also include information regarding any abnormal conditions related to either disturbances of the grid or environmental conditions (weather)
Occurrence date/time	The date and time that the incident occurred
Creation date	The date and time that the incident was created in the database
Warranty repair	Is the item currently covered by an active warranty?
Service response date	The date and time that maintenance personnel responded to the incident
Diagnostic time	Subcategories of FORCED OUTAGE restoration time
Logistic delay	Subcategories of FORCED OUTAGE restoration time
Repair time	Subcategories of FORCED OUTAGE restoration time
Incident status	The incident can be "open", "closed", or "under review"
Verify repair	Subcategories of FORCED OUTAGE restoration time
System status	Current operational status of the system affected by the incident – available, unavailable, degraded, etc.
Incident report type	Type of corrective maintenance or action as applicable
Incident category	A high-level description of the failure or maintenance action. Examples include hardware failure or environmental induced failure.
Restored to duty time/date	The date and time that the component associated with the incident was brought back to an operational state in the system. This assumes that all repairs and testing have been completed.
Source: Sandia National Laboratories, SAND2014-20612, clause 2.2.2	

C.5 Forced outage – optional categories

C.5.1 General

Availability is in large part determined by the reliability and maintainability of components and subcomponents. This falls under the category of FORCED OUTAGE. Examining the subcategories leads to response, diagnostics, logistics, and failure repair, among other considerations. These subtopics apply to repairable components.

The following optional information subcategories can be applied to increase the detail of the mandatory information category FORCED OUTAGE. The main purpose for this optional information is to provide generic terms for assigning responsibility for various stages of an outage workflow after detection of a component or system or issue and providing data for reliability analysis.

- Response
- Diagnostic time
- Logistic time
- Repair

The asset management function is to accomplish these steps as expeditiously as possible to maintain high availability. Although energy is captured when irradiance has met the threshold, O&M activities can occur at any time subject to the determination of the O&M providing organizations.

When a FORCED OUTAGE category is encountered, an outage workflow can be useful for monitoring the condition states of specific equipment items, subsystems, and the entire PVPS. This can aid in reliability analysis, i.e., root cause analysis, which can then be used to provide insight into the cause of equipment forced outages and the role of response time. The time terms to be observed can be as specified in this subclause. The overall workflow can be separated into the optional information categories, as depicted in Figure C.1.

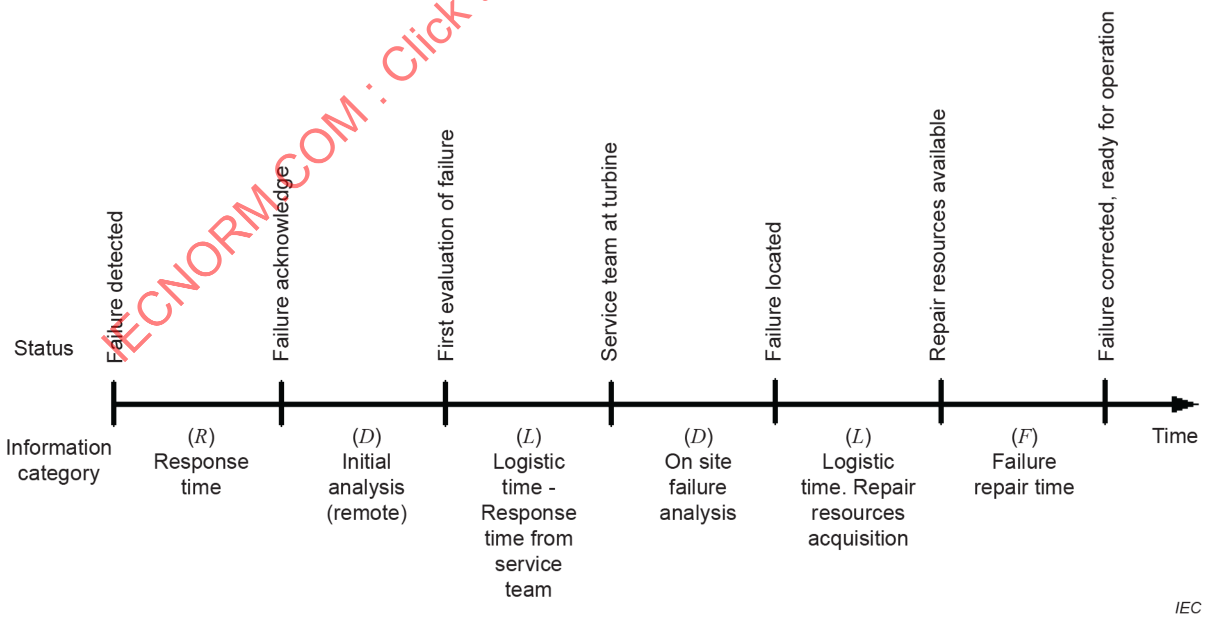

Figure C.1 – Typical flow time for failure/correction

As shown in the schematic workflow, the time period from when a fault in a PVPS is detected to when the failure is repaired, and all alarms/events are cleared can be assigned into the information model of four optional underlying information categories of response, diagnostics, logistics, and repair. The sum of the different information categories can be referred to as the total downtime for a forced outage event. This would be the same as the entry and points for the items in the forced outage information category defined in 5.15.

The exact day/time of failure detection may be hours, days, or months after the failure or event occurred. Unless estimated and included in the model by an approved process, it represents lost data and energy. See Annex E for considerations regrading levels of monitoring and verification scenario, Clause D.11.

The forced outage subset information categories defined are described in further detail.

C.5.2 Response time (*R*)

Definition – This can be used to accumulate time periods from the notification of any event until an action on the event has been initiated.

In the workflow breakdown following detection, this category could cover, but is not limited to:

- failure acknowledgement;
- notification time for service partner response;
- waiting time for approval to initiate a corrective action.

Entry point – An internal fault or external command is received or otherwise discovered, and the PVPS does not automatically return to the operative category.

Exit point – The operator detects and logs fault or status. A PVPS can exit this category only by manual intervention.

C.5.3 Diagnostic time (*D*)

Definition – This subtopic can be used to accumulate time periods spent to analyze a fault symptom, related measurements, and findings indicating a failure and planning corrective action. In the workflow breakdown, it covers, but is not limited to:

- initial analysis of fault detection data;
- remote detailed analysis of fault data by local or remote means;
- additional analysis;
- additional clarification or testing required;
- planning corrective actions;
- approval of corrective actions.

Entry point – The operator detects and logs fault or status. The PVPS can enter this mode only by manual intervention.

Exit point – The operator has completed analysis and determined required action. A PVPS can exit this category only by manual intervention.

C.5.4 Logistic time (*L*)

Definition – This subtopic can be used to accumulate time periods used for logistic activities such as, but not limited to:

- transportation of tools;
- service team setup;
- ordering support tools
- ordering spare parts;

- waiting time for resource allocation;
- lead time for tools and test equipment required;
- lead time for spare parts required;
- methods of procedure approvals;
- processing paperwork;
- funding, if applicable, and approvals.

Entry point – The operator has completed the analysis and determined the required action and has initiated actions such as ordering parts and calling the repair team. A PVPS can enter this category only by manual intervention.

Exit point – All the required actors and equipment are in place for the activities called for by the current diagnostics. A PVPS can exit this category only by manual intervention.

Logistics time can occur multiple times throughout the period of a forced outage recovery.

C.5.5 Repair time (F)

Definition – This subtopic can be used to accumulate time periods for implementation of repair activities for repairable or nonrepairable equipment such as, but not limited to:

- gain of access/isolation for work performance area;
- change of control software version;
- repair or replacement of component part;
- verification of return to specified operable state;
- inspection or audit related to repair activity;
- acceptance test for finalizing repair activity;
- placing the unit back into service;
- documentation.

Entry point – The repair activity begins either locally or by remote access. The PVPS can enter this mode only by manual intervention.

Exit point – This optional information category is terminated by manual intervention when the repair activity is completed.

Nonrepairable components: failed components that cannot be repaired and shall be replaced to restore full capacity.

C.5.6 Partial capability – optional category of degraded

The optional information categories are introduced to provide further understanding of the mandatory information category.

This subclause and Clause 5 briefly identify optional information categories that can be applied when more detailed information is required to address specific information needs. All optional information categories shall be located on Level 5 or higher to comply with this document.

The following is an optional category under the PARTIAL CAPABILITY category.

Definition – The information category of degraded can be used to accumulate time periods when a PVPS is operative and generating power with reduced performance because of internal constraints. Internal constraints could result from gradual material deterioration, component damage, or the need to prevent component damage, for example, inverter cooling subsystem issues.

Although not specifically measured or identified with a performance metric, the degradation factor is described and accounted for in the IEC 61724 series and is one of the metrics calculated in that series. Expected degradation is not to be assigned in this document because it is already characterized within acceptable ranges of degradation and is not an unavailability issue.

Even though it is not quantifiable with typical data collection systems, if the assessment of its impact is necessary, it should first be identified, characterized, and quantified positively as degradation. If the assessment result exceeds the degradation boundaries defined in the expected energy calculation, it can be accounted for as a loss of capacity availability in the PARTIAL CAPABILITY category as excess degradation.

Care should be exercised to avoid double counting. The assignment to availability should not be duplicated when reporting the future performance metrics used in IEC 61724.

The degraded optional information category is an underlying category of PARTIAL CAPABILITY and has no predefined underlying information categories.

Examples:

- component or module degradation;
- inverter bridge semiconductor degradation.

Entry point – When the degradation is detected and able to be quantified to have exceeded predefined limits.

Exit point – The causes of excess degradation are cleared and/or the capacity availability is re-rated and energy performance is recalculated (as a derating) and accepted. Degradation is caused by internal influences, and derating (addressed as follows) is influenced by external decisions.

Degradation is a loss of performance as a result of recoverable and nonrecoverable causes. Soiling is the common example of recoverable degradation. Wear-and-tear modes are common examples of nonrecoverable degradation. Recoverable degradation is typically remedied by cleaning (solar array wash controlled by O&M). Nonrecoverable degradation can be remedied by equipment overhaul.

Degradation is a loss of performance as a result of recoverable and nonrecoverable causes. Soiling is the common example of recoverable degradation. Wear-and-tear modes are common examples of nonrecoverable degradation.

Note that if some of the internal constraints are not cleared, then that part of the PVPS remains in an indefinite state of degradation. If this is the case, the observed degradation should be compared to the expected energy calculation results of the performance model in accordance with IEC TS 61724, for consistency and remaining management of contractual expectations. Verification scenario, Clause D.7 illustrates a process of accounting and recommendation for investigation for energy shortfalls.

C.5.7 Partial capability – optional category of derated

Definition – The optional information category derated can be used to accumulate time periods, specifically when a PVPS is operative and generating at reduced power because of constraints.

The derated optional category is an underlying category of PARTIAL CAPABILITY. The derated category is optional.

Entry point – An event or manual intervention prohibits a PVPS from operating at specified levels. At the component level, this derating will cause PARTIAL CAPABILITY at higher system levels.

Exit point – All constraints that prohibit a PVPS from operating at a specified capability are cleared.

If some of the internal constraints are not cleared, then that part of the PVPS may remain in an indefinite state. For some stakeholders, there may be enough impact from constraints or degradation, as described previously, that a derating or rerating of the PVPS or its components may be declared and accepted without repair or replacement.

C.5.8 Partial capability – optional category "other"

Definition – The optional information category "other" can be used to accumulate time periods specifically when a PVPS or component is operating at reduced power because of undefined and/or undetermined constraints.

The "other" optional category is an underlying category of PARTIAL CAPABILITY. The "other" category is optional.

Entry point – An undefined and/or undetermined situation prohibits a PVPS from operating at specified levels. At the component level, this derating will cause PARTIAL CAPABILITY at higher system levels

Exit point – All constraints that prohibit a PVPS from operating at a specified capability are cleared.

If the internal undefined and/or undetermined situational constraints are not cleared, then that part of the PVPS may remain in an indefinite state. If deemed significant, some investigation into cause, solution, and recategorization is warranted.

Annex D
(informative)

Verification scenarios

D.1 Grid outage

D.1.1 Scenario description

A PVPS is operating at full functionality without any forced outages or any other activities or situations that reduce its capability or availability. The grid that accepts the energy is on a radial feeder to the PVPS and suffers a heavy late spring ice storm that topples some towers. It takes the utility two weeks to restore service. What is the monthly availability of the PVPS?

D.1.2 Analysis and conclusion

The two-week duration occurs at a time of the year when the available resource is approximated by an average 10 h (notional data, typical for the verification scenarios – representative of data to be recorded from monitoring systems) of operating (or, in this case, outage) time per day with 300 h in the month. This is overly simplified; in reality, this depends on the site, latitude, and measured resource time and the performance model for the expected (lost) energy. However, in this case, we are concerned only with capacity and time period.

Table D.1 – Verification scenarios – grid event

MEANING OF COLOURS: GREEN = available; RED = unavailable; GREY = excluded from period hours			Mandatory Information Categories													
			Full performance	Partial performance	Service set points	Out of environ. spec	Requested shutdown	Out of electrical spec.	Maintenance	Plan corrective action	Forced outage	Suspended	Force majeure	Information unavailable	Operational availability	Technical availability
		Operational availability													X	
		Technical availability														X
Event or incident		Comments														
#1	The grid is lost for 140 h but during the month has another 160 h of operation for the month	The PVPS is fully operable but unable to feed power for the event. This PVPS is in the out of electrical specification state during that period.	160					140							53,3 %	100,0 %

As shown in Table D.1 for the grid/electrical network aspects scenario, there are 140 h when the network is not available to export power. This situation is considered unavailable from the system operator's perspective but not from the PVPS technical perspective because this is clearly beyond the control of the PVPS, which is fully functional. By definition, the PVPS is operative but not in service (generating). It is not functioning because the electrical parameters are out of the design specification (i.e., no voltage to synch to).

To report the PVPS as 100 % technically available during a month of many hours of OUT OF ELECTRICAL SPECIFICATION is an apparent contradiction to the low operational unavailability of 46,7 %. Practically speaking, the low operational availability will be excused because it was neither caused by nor under the control of the PVPS

D.2 Entry and exit points

A PVPS operates for one week of 50 h (notional data) of sufficient solar irradiance for operation. In that time, it experiences a grid event and a number of forced outage issues, which are tabulated in Table D.2, with durations indicated by the time period of duration between entry and exit of the information categories. The grid outage, like that previously described, occurs between hours 5 and 15. The main power transformer is also out of service because of an issue from hours 10 to 20. A combiner box has a 5 h outage from hours 25 to 30, and a string to that combiner box is out from hours 20 to 30.

Table D.2 – Verification scenarios – grid/electrical network aspects

Event/ Hour 0	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
Grid 1 of 1										
Power transformer 1 of 2										
Comb. box 1 of 4										
DC cable 1 of 8										
Full PVPS Instant op. avail.	100 %	0 %	0 %	50 %	87,5 %	75 %	100 %	100 %	100 %	100 %
Full PVPS Instantaneous technical availability	100 %	100 %	50 %	50 %	87,5 %	75 %	100 %	100 %	100 %	100 %

The entry and exit times are clearly shown in 5-h increments for simplicity sake. The entry and exit are clearly defined. Having multiple events complicates matters. To assess the impact on availability of PVPS capacity, one should assess the impact of each outage (downtime) and the PVPS impact represented by the incident. The PVPS is illustrated by the RBD in Clause B.4 (shown again as Figure D.1), and the discussion of the fractional power estimation techniques holds true.

There is only one point of common coupling with the grid, so its outage impact is 100 %.

There are two power transformers in the substation, so each is 50 %.

Three are four combiner boxes, and each represents 25 %.

With eight DC cables from the strings, each is 12,5 %.

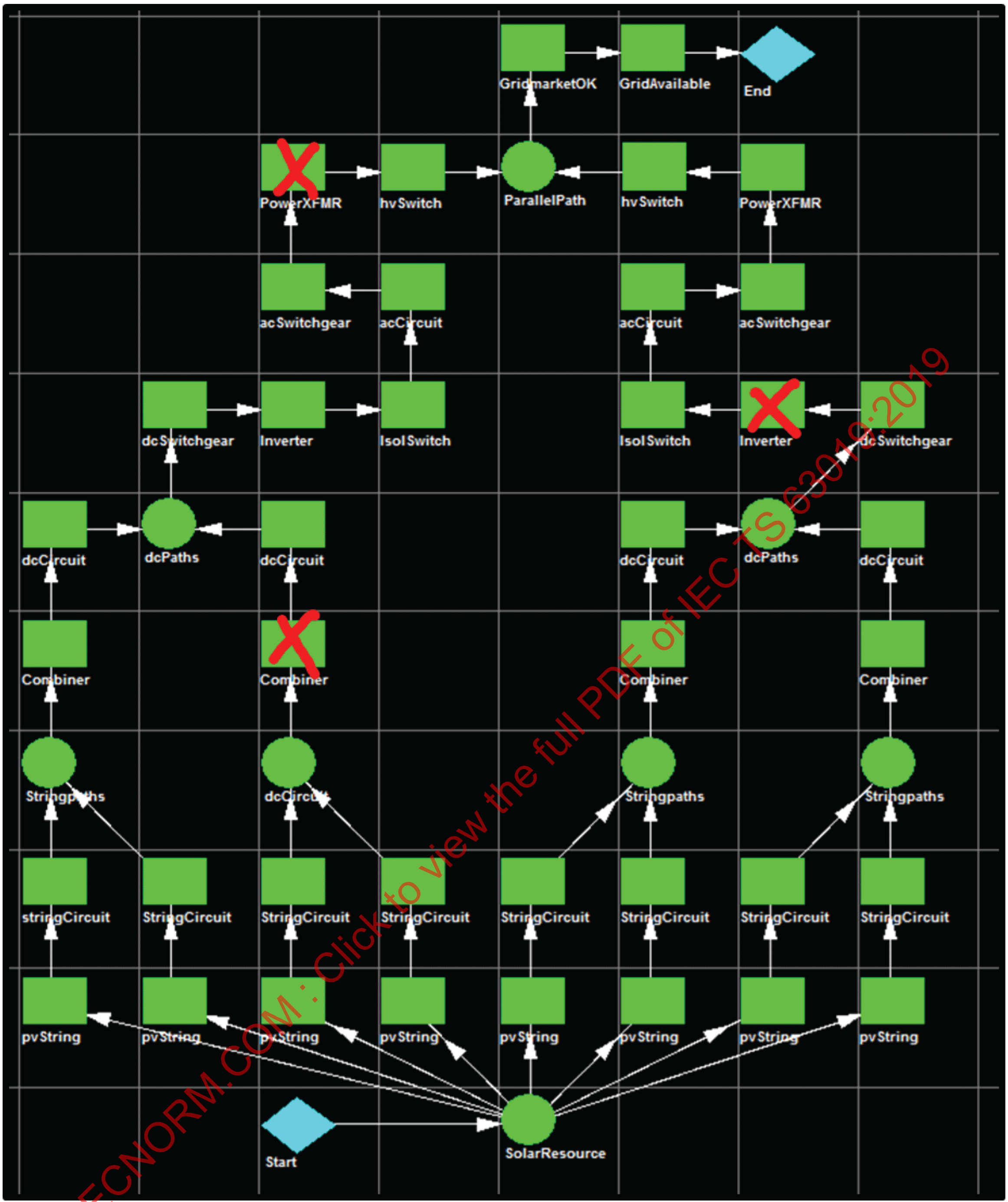

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Figure D.1 – RBD of PVPS with multiple outages

The power transformer outage occurs simultaneously with the grid outage for 5 h. In accordance with Table 3 – Information category priority for PVPS, the transformer outage takes priority for availability assignment. A FORCED OUTAGE is a higher priority than the OUT OF ELECTRICAL SPECIFICATION of the grid outage. It is recognized to have a major impact and is a priority for repair.

The concurrent DC cable outage with the combiner box needs more information. In this case, it is confirmed that the cable feeds into the failed combiner box, so care should be exercised so as not to double count the extent of the lost capacity. Both are FORCED OUTAGES, so there is no need to apply a priority rule.

For this simple example, the available times can be averaged. For more complex situations, the formulas in Clause 6 and Annex A can be applied with data that are not notional (i.e., measured).

For the week, the average operational availability is 71,25 %, and the average technical availability is 86,25 %.

D.3 Inverter outages

The operational and technical types of availability are further illustrated in this verification scenario.

The same PVPS is operating at full functionality without any forced outages or any other activities that reduce its capability or availability. An inverter fails and trips offline. The outage is due to a failure and is, by definition, a forced outage.

Again, the available resource is approximated by an average of 10 operating hours per day. In this PVPS model, this inverter is one of two of the same rating. The outage lasts 20 operating hours until service is restored. What is the monthly availability of the PVPS, and how does this fit into the information model?

Analysis and conclusion: The 20-h duration of the one inverter puts the PVPS into 50 % availability during the single inverter outage.

Table D.3 – Verification scenarios – inverter outage

			Mandatory Information categories													
MEANING OF COLOURS: GREEN = available; RED = unavailable; GREY = excluded from period hours			**Full capability**	**Partial capability**	**Service set point**	**Out of environ. spec.**	**Requested shutdown**	**Out of electrical spec.**	**Maintenance**	**Plan corrective action**	**Forced outage**	**Suspended**	**Force majeure**	**Information unavailable**	**Operational availability**	**Technical availability**
		Operational availability	GREEN	GREEN	GREEN	RED	RED	RED	RED	RED	RED	RED	RED	GREY	X	
		Technical availability	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREY	RED	RED	GREY	GREY	GREY		X
Event or incident		**Comments**														
#1 PVPS (full)	An inverter trips out and requires service. Outage time is 20 h.	Other than that, the PVPS is fully operable.	280	20							20				Capacity based is 96,7 %	Capacity based is 96,7 %
#2 Failed inverter	One inverter		280								20				93,3 %	93,3 %
#3 Inverter fleet (2)	Two inverters: hours are doubled		580	20							20				96,7 %	96,7 %

The availability of the PVPS for the month will be the same as the inverter fleet of 96,7 %. This can be measured. The energy lost will be approximately the same as the energy produced during the partial performance period of the one inverter outage time. Note that the 20 h of FORCED OUTAGE are simultaneously the 20 h of PARTIAL CAPABILITY because the outage brings the PVPS off FULL CAPABILITY.

The formula in 6.2 similarly uses the amount of unavailable DC nameplate capacity.

With more granularity (i.e., 5-min recording intervals), the actual numbers can be used instead of broad assumptions. Some of this is addressed in Annex E on information management practices.

D.4 Inverter overtemperature outage

D.4.1 General

A PVPS is designed for a high-temperature desert environment. It has one inverter with four sub-inverters. The specification for the selected inverter is for an ambient temperature rarely reached at the site and to be installed in outdoor enclosures in the direct sunlight in the array filed. The first summer of operation was exceedingly hot. One sub-inverter overheats and fails, which requires manual intervention before a restart (75 % capacity is available for this period). The failure occurs within the specified conditions of the operational window of the inverter. The site is unmanned, and it takes a period of 20 h of operational time to accomplish the restart. There were 50 h of operational time in the week of the event.

Table D.4 – Inverter overtemperature outage

MEANING OF COLOURS: **GREEN** = available **RED** = unavailable GREY = excluded from period hours			**Mandatory Information categories**													
			Full capability	**Partial capability**	**Service set point**	**Out of environ spec.**	**Requested shutdown**	**Out of electrical spec.**	**Maintenance**	**Plan corrective action**	**Forced outage**	**Suspended**	**Force majeure**	**Information unavailable**	**Operational availability**	**Technical availability**
Operational availability			GREEN	GREEN	GREEN	GREEN	RED	RED	RED	RED	RED	RED	RED	GREY	x	
Technical availability			GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREY	RED	RED	GREY	GREY	GREY		x
Event or incident		**Comments**														
Full PVPS	The PVPS was at 75 % during the sub-inverter outage.	The ambient temperature spec. was close but not exceeded.	30	20							20				100 %	100 %
Inverter	The inverter was at 75 % during the sub-inverter outage		30	20							20				100 % (90 % capacity avail.)	100 % (90 % capacity avail.)

D.4.2 Assessment and conclusion

It was determined that the outage was caused by an internal temperature trip for equipment self-protection. By the IEEE availability definition, the inverter was not in FORCED OUTAGE when the output is reduced but the sub-inverter was. Since the environmental temperature was not met, this event suggests that this non-conformance be assessed. The time to restore is assigned to the FORCED OUTAGE.

Care should be taken in the overheating of components as it may lead to damage and reduced life. Heat transfer and rejection may be a substantial issue. The resolution may be in reassessing both ambient temperature capability and heat effects in the enclosure at the site in direct sunlight. Should a decision be made to correct or mitigate the failure to meet specification, a PLANNED CORRECTION ACTION will be performed and if an outage is required then the downtime will be attributed to a PLANNED CORRECTIVE ACTION.

Further, if maintenance is required that could be assigned to a forced outage (i.e., plugged filter), then the availability should be accordingly adjusted. PVPS components, which through better design may have broader operating ranges, will have increased operational availability as expected because they will operate for more hours. Temperature specifications are an example of metadata that are common with components and their specifications.

This example illustrates how outage time impacts the capability of the PVPS as an earlier restoration would have minimized the outage time.

Finally, this example recognizes how different availability numbers fit into the information model at different levels of the PVPS. The formula of 6.2 recognizes this fact and capacity availability is useful in tracking PVPS capability for accumulated outages at all levels since discrete outages get rolled up to PARTIAL CAPABILITY at higher levels of the system.

D.5 Tracking system outage

D.5.1 Scenario description

The PVPS is operating at full functionality without any forced outages or any other activities that reduce its capability or availability. The same storm that hit the transmission system in the scenario in Clause D.1 passes through the PVPS with high winds at night. Two days later when inspected it is observed that one tracking system is out of position and not functional. The tracker is then secured into a horizontal position and restored to service by solar noon on the close of business of the fifth day after the storm. By definition it is a forced outage of the tracker. The system has a 1 MW DC rating and consists of 25 tacking systems. What is the monthly availability of the PVPS and how does this fit into the information model? This is the only incident for this month.

D.5.2 Analysis and conclusion

This is a difficult situation to assess. Looking at the RBD, it is observed that the role of a tracker is not one of current carrying capability but rather that of position. Like the position of the sun throughout the day, the energy loss due to a failed tracking function will be variable. Looking at the energy availability, we can see that there will be less than a 1/25th reduction because the array will still collect energy, and this will be mitigated even further once secured. Again, 10 h per day of PV operation is assumed.

Table D.5 – Tracking system outage

			Mandatory Information categories													
MEANING OF COLOURS: GREEN = included in period hours as available RED = included in period hours as unavailable GREY = excluded from period hours			Full capability	Partial capability	Service set point	Out of environ. spec.	Requested shutdown	Out of electrical spec.	Maintenance	Plan corrective action	Forced outage	Suspended	Force majeure	Information unavailable	Operational availability	Technical availability
		Operational availability	GREEN	GREEN	GREEN	RED	RED	RED	RED	RED	RED	RED	RED	GREY	X	
		Technical availability	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	GREY	RED	RED	GREY	GREY	GREY		X
Event or incident		**Comments**														
#1 PVPS full	One tracker fails out of 25 and is secured after 25 h and fixed at hour 50.	The PVPS is operable and available but not at full capability.	250	50*							50*				Capacity based is 99,3 %	Capacity based is 99,3 %
#2 Tracker			250	0							50				83,3 %	83,3 %
#3 Tracker fleet			7 450	50							50				99,3 %	99,3 %
*The 50 h of forced outage are the same hours that put the PVPS into partial capability.																

Operational availability and technical availability numbers are the same for forced outages.

The 50 h of the trackers' forced outage is the same time period (50, which results in PARTIAL CAPABILITY of the PVPS as it rolls up). There are 24 trackers still working for those five days, and those five days represent only one-sixth of the days, and the energy impact was perhaps (estimated) to be one-third (notional rough assumption but can be determined through data) for the five days on that tracker. This approach has a lot of assumptions, and if twinned system data are not available, the analyst could use the performance model to determine the expected energy impact. If the field is sufficiently instrumented, it could also be measured. (It depends on the resource, position, and time granularity to accurately determine the energy/revenue loss.) From an energy perspective, trackers in a horizontal position with clouds may lose 20 % to 25 % per day, but this is calculable.

At 99,3 % availability for five days, this was not a severe outage, but multiple outages accumulate to affect availability and energy. A more rapid response with sufficient and more granular instrumentation for detection and spare parts demonstrates how this outage could have an even more minimal impact on availability.

D.6 Information category priority

D.6.1 General

There will be times when multiple outages occur. The prioritization for these combined outages is provided in 5.6. As stated, the priority designation for events determines the precedence for assignment of the PVPS or affected components and a transparent designation of time. In the following scenario, a PVPS with a single inverter is out for a full week waiting on logistics in winter. During that time, snow covers the modules, beginning on Tuesday and lasting through Friday. On Wednesday, area conditions are so bad that the civil authorities close the only roads available to reach the PVPS. A chinook weather event (high wind but warming) hits the area early Thursday, which causes a grid outage for the daylight hours; however, the snow coving the modules melts by evening.

D.6.2 Assessment

Monday has one outage incident, and that is a logistics wait for parts and labour to solve the inverter problem. By definition, this is a FORCED OUTAGE. Tuesday finds that the modules are covered by snow, effectively reducing their output to zero. This is an OUT OF ELECTRICAL SPECIFICATION event for the modules. This occurs concurrently with the outage of the inverter. For the full PVPS, a forced outage is a higher priority, 9 vs. 4, and the PVPS remains in a FORCED OUTAGE state. On Wednesday, the civil authorities close the roads except to emergency vehicles; by definition, this puts the PVPS into a condition of SUSPENDED operations. This has a priority of 10, higher than a FORCED OUTAGE. Refer to Annex A for the operational vs. technical availability inclusions and exclusions and how a contract may have deviated from those assignments, but typically in a SUSPENDED stage all personnel operations will cease. Thursday brings high winds that cause a grid outage, an OUT OF ELECTRICAL event, priority 6, still lower than priority 9. But the chinook brings warming, and the snow is gone before Friday daybreak. The inverter parts and crew restore the inverter on Friday, and on Saturday normal operation is restored with full capability.

Table D.6 – Information category priority

Event	M	T	W	Th	F	Sat	Sun
Inverter out	FO	FO	FO	FO	FO		
Snow covering modules		Env	Env	Env			
Icy road closures			Susp				
Wind, grid out				Elect			
Priority	9	9	10	9	9	1	1

D.7 Verification scenario – Energy: measured, expected, and lost

D.7.1 Scenario description

A simple 500-kW PVPS is operating as distributed generation on a distribution circuit with heavy PV saturation. It does not function in constrained operation, although the operating utility does have dispatch control of the PVPS and other PV systems. This is because the circuit sometimes experiences high voltages exceeding required regulation. The PVPS operates for one week with 42 h of sufficient irradiance, and the expected production based on weather is 20 400 kWh; however, there were a few downtime incidents:

a) The inverter disconnected for 1 h due to delivered grid voltage out of specification.

b) There was also 1 h when the distribution grid operator curtailed production during general high voltage on the circuit.

c) A scheduled maintenance outage was required, and this effort took 2 h.

d) A maintenance-induced forced outage followed that took 1 h to correct.

   All events took down the full PVPS. None of these events occurred simultaneously. Energy units are in kWh.

Table D.7 summarizes these events in terms of lost energy.

The PVPS was previously suspected of having a performance problem. The energy lost due to known unavailability events was determined using techniques described in Clause B.4 and Clause B.5 and is shown in Table D.7 at a value of 1 400 kWh. The time durations were recorded and are listed later.

Table D.7 – Combined performance and availability

Events	Lost energy (all in kWh, Typ.)
REQUESTED SHUTDOWN	200
OUT OF ELECTRICAL SPECIFICATION	500
SCHEDULED MAINTENANCE	300
FORCED OUTAGE	200
Total lost	1 400

D.7.2 Assessment

The measured production of the system was 18 000. There was no partial production due to unavailability events. By use of the performance model, the "all-in" expected production should have been 20 400 kWh. According to Table D.7, the energy lost due to unavailability was assigned to information categories and totalled 1 400. "Performance losses" that were not attributed to unavailability are calculated. The result is 1 000, as shown in Table D.8.

Table D.8 – Key metrics

Measured production (while available)	"All-in" expected production	Lost production due to unavailability	Measured production plus accounted losses	Performance losses
18 000	20 400	1 400	18 000 + 1 400 = 19 400	20 400 – 19 400 = 1 000

The sum of the measured energy plus the energy lost due to poor performance plus the energy lost due to unavailability should equal the expected energy.

Overall PVPS performance is summarized in Table D.9. Performance is defined by two metrics: unavailability of components and reduced performance or losses. Availability is an indication of component status, and the energy measurement is also needed to confirm underperformance not detectable by lost availability. This example confirms two aspects relevant to both IEC documents. The methods of this document are shown in yellow, and the IEC TS 63019 approaches are shown in blue. Combined approaches are shown in green.