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TECHNICAL SPECIFICATION

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Wind energy generation systems –
Part 26-4: Reliability for wind energy generation systems

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Part 26-4: Reliability for wind energy generation systems

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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WIND ENERGY GENERATION SYSTEMS –

Part 26-4: Reliability for wind energy generation systems

FOREWORD

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IEC TS 61400-26-4 has been prepared by IEC technical committee 88: Wind energy generation systems. It is a Technical Specification.

Throughout this document, mandatory information categories as defined in IEC 61400-26-1 are written in capital letters (e.g. FULL PERFORMANCE, OUT OF ENVIRONMENTAL SPECIFICATION).

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
88/954/DTS	88/1024/RVDTS

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

The language used for the development of this Technical Specification is English.

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

A list of all parts in the IEC 61400 series, published under the general title *Wind energy generation systems*, can be found on the IEC website.

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

- reconfirmed,
- withdrawn, or
- revised.

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WIND ENERGY GENERATION SYSTEMS –

Part 26-4: Reliability for wind energy generation systems

1 Scope

This part of IEC 61400, which is a Technical Specification, specifies terms and information categories for identification and reporting of reliability metrics. The definitions are applicable to key components, any number of wind turbines, fleets of wind turbine types, a wind power station or a portfolio of wind power stations. The wind power station is made up of all WTGSs (Wind Turbine Generator Systems), functional services and balance of plant elements as seen from the point of common coupling.

This document provides guidelines regarding reliability methodologies with informative annexes regarding use.

It expands on the information model in IEC 61400-26-1, recognizing that availability and reliability are interrelated.

It does not assign specific reliability specifications, constraints or targets but rather provides standardized means of categorizing and prioritizing data and illustrates the use of the model and metrics in informative annexes.

It does not specify the method of information acquisition or specific use. Beyond that, it is not the intention of this document to specify exactly how to calculate other undefined or performance-based reliability metrics.

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 61400-26-1, *Wind energy generation systems – Part 26-1: Availability for wind energy generation systems*

IEC 60050-192, *International Electrotechnical Vocabulary (IEV) – Part 192: Dependability*

IEC 61703, *Mathematical expressions for reliability, availability, maintainability and maintenance support terms*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-192, IEC 61400-26-1 and the following apply.

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

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

3.1.1
failure
loss of ability to perform to specification

Note 1 to entry: EN 13306 defines failure as "termination of the ability of an item to perform a required function".

Note 2 to entry: After failure the item has a fault, which can be complete or partial.

Note 3 to entry: "failure" is an event, as distinguished from "fault", which is a state.

[SOURCE: IEC 60050-192:2015, 192-03-01, modified – Notes to entry have been changed.]

3.1.2
MACMT
mean active corrective maintenance time
expectation of the active corrective maintenance time

[SOURCE: IEC 60050-192:2015, 192-07-22]

3.1.3
MAD
mean administrative delay
expectation of the administrative delay

[SOURCE: IEC 60050-192:2015, 192-07-26]

3.1.4
downtime
expectation of the down time

[SOURCE: IEC 60050-192:2015, 192-08-10]

3.1.5
fault detection time
FDT
time interval between failure and detection of the resulting fault

[SOURCE: IEC 60050-192:2024, 192-07-11, modified – Notes and figures have been deleted]

3.1.6
MLD
mean logistic delay
expectation of the logistic delay

[SOURCE: IEC 60050-192:2015, 192-07-27]

3.1.7
reliability
ability to perform to specification, without failure, for a given time interval, under given conditions

Note 1 to entry: The time interval duration can be expressed in units appropriate to the item concerned, e.g., calendar time, operating cycles, distance run, etc., and the units should always be clearly stated.

Note 2 to entry: Given conditions include aspects that affect reliability, such as: mode of operation, stress levels, environmental conditions, and maintenance.

Note 3 to entry: Reliability can be quantified using appropriate measures, see IEC 60050-192, 192-05-05, Reliability related concepts: measures.

Note 4 to entry: A general definition of reliability is provided in EN 13306: "ability of an item to perform a required function under given conditions for a given time interval."

[SOURCE: IEC 60050-192:2015, 192-01-24, modified – Note 3 to entry has been changed and Note 4 to entry has been added.]

3.1.8
repair
direct action taken to effect restoration

EXAMPLE 1: To restore equipment damaged, faulty or worn to a serviceable condition.

Note 1 to entry: IEC 60050-192 further defines several subsets of availability, e.g., "instantaneous availability" (192-08-01), "inherent availability" (192-08-02) and "operational availability" (192-08-03).

Note 2 to entry: Repair also includes fault localization and function checkout.

[SOURCE: IEC 60050-192:2015, 192-06-14, modified – Note 1 to entry has been changed, an example and Note 2 to entry have been added.]

3.1.9
mean repair time
MRT
expectation of the repair time

[SOURCE: IEC 60050-192:2015, 192-07-21]

3.1.10
technical delay
TD
delay incurred in performing auxiliary technical actions associated with, but not part of, the maintenance action

EXAMPLE Rendering the equipment safe (such as immobilising, cooling, isolation and grounding).

[SOURCE: IEC 60050-192:2015, 192-07-15]

3.1.11
MTBF
mean operating time between failures
expectation of the duration of the operating time between failures

Note 1 to entry: Mean operating time between failures should only be applied to repairable items. For non-repairable items, see mean operating time to failure (192-05-11).

[SOURCE: IEC 60050-192:2015, 192-05-13]

3.1.12
mean time to failure
MTTF
expectation of the operating time to failure

Note 1 to entry: In the case of non-repairable items with an exponential distribution of operating times to failure (i.e. a constant failure rate) the MTTF is numerically equal to the reciprocal of the failure rate. This is also true for repairable items if after restoration they can be considered to be "as-good-as-new".

Note 2 to entry: See also operating time to failure (192-05-01).

[SOURCE: IEC 60050-192:2015, 192-05-11]

3.1.13
mean time to restoration
MTTR
expectation of the time to restoration

Note 1 to entry: IEC 60050-191:1990 (now withdrawn; replaced by IEC 60050-192) defined the term "mean time to recovery" as a synonym, but restoration and recovery are not synonyms.

[SOURCE: IEC 60050-192:2015, 192-07-23]

3.1.14
MUT
mean up time
expectation of the up time

[SOURCE: IEC 60050-192:2015, 192-08-09]

3.2 Abbreviated terms

ACMT	active corrective maintenance time
AD	administrative delay
DT	down time
FDT	fault detection time
IA	INFORMATION AVAILABLE
IANO	NON-OPERATIVE
IAFM	FORCE MAJEURE
IAO	OPERATIVE
IANOFO	FORCED OUTAGE
IANOPCA	PLANNED CORRECTIVE ACTION
IANOS	SUSPENDED
IANOSM	SCHEDULED MAINTENANCE
IAOOS	OUT OF SERVICE
IAOOSEN	OUT OF ENVIRONMENTAL SPECIFICATION
IAOOSTS	TECHNICAL STANDBY
IAOS	IN SERVICE
IAOSFP	FULL PERFORMANCE
IAOSPP	PARTIAL PERFORMANCE
IAOSRS	READY STANDBY
IAOOSEL	OUT OF ELECTRICAL SPECIFICATION

IAOOSRS	REQUESTED SHUTDOWN
LD	logistic delay
MACMT	mean active corrective maintenance time
MAD	mean administrative delay
MDT	mean down time
MFDT	mean fault detection time
MLD	mean logistic delay
MRT	mean repair time
MTBF	mean operating time between failures
MTD	mean technical delay
MTTF	mean operating time to failure
MTTR	mean time to restoration
MUT	mean up time
RT	repair time
TBF	time between failures
TD	technical delay
TTF	time to failure
TTR	time to restoration
UT	up time
WEGS	wind energy generation system
WTGS	wind turbine generator system

4 Preamble

The key aspect of this document is that a reliability interpretation of the information model specified in IEC 61400-26-1 is achieved by creating counters, one for each information category at each mandatory level, optionally expanded with level 5 and level 6 categories.

These accumulated figures are in the present document used as the basis for data needed for deriving reliability metrics for a WEGS.

The methodology illustrated is made only on the time-based modelling specified in IEC 61400-26-1. A production-based approach is generally not implementable as standardised reliability terms and definitions applicable to the production-based model are not developed.

5 Reliability terms derived from the information model

5.1 Information categories applied in reliability metrics

Each level of the information model defined in IEC 61400-26-1 (see Figure 1) represents mutually exclusive and collectively exhaustive states for a WEGS. The information model can be regarded as a collection of state-transition machines; for each column/level, there are several operational states as each information category represents one state.

The WEGS can be only in one state at each level. At level 1, the WEGS can be only in IA or IU. At level 2, the WEGS can be only in IAO, IANO, IAFM or IU. The same principle applies to level 3 and 4. The prioritization of the information categories defined in IEC 61400-26-1 shall apply to the state machine approach too. The logic shall also apply to implementations with optional levels (illustrated in Figure 1 with level 5 added).

EXAMPLE 1: A WEGS experiences a situation at PARTIAL PERFORMANCE and a transition to OUT OF ENVIRONMENTAL SPECIFICATION is made. At level 3, the WEGS will transition from IN SERVICE to OUT OF SERVICE, but at levels 1 and 2 no change takes place.

EXAMPLE 2: A WEGS experiences a situation at FULL PERFORMANCE where a technical fault is detected by the turbine controller. At level 4, a transition to FORCED OUTAGE is made. At level 3, the WEGS will transition from IN SERVICE to FORCED OUTAGE, and at level 2, a transition from OPERATIVE to NON-OPERATIVE is made, but at level 1 no change takes place; IA remains.

5.2 Derivation of parameters for reliability metrics

5.2.1 General

IEC 61400-26-1 requires that the actual state of all mandatory levels is determined, meaning that even though level 4 defines the more detailed information, the preceding (upper) levels shall also be determined and documented. These upper states are used for the derivation of parameters for reliability metrics.

<table>
<tr><th colspan="7">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><th>Optional level 5</th><th>Level 5 priority</th></tr>
<tr><td rowspan="21">INFORMA-TION AVAILABLE (IA)</td><td rowspan="9">OPERATIVE (IAO)</td><td rowspan="4">IN SERVICE (IAOS)</td><td>FULL PERFORMANCE (IAOSFP)</td><td>1</td><td></td><td></td></tr>
<tr><td rowspan="2">PARTIAL PERFORMANCE (IAOSPP)</td><td rowspan="2">2</td><td>derated</td><td>2.1</td></tr>
<tr><td>degraded</td><td>2.2</td></tr>
<tr><td>READY STANDBY (IAOSRS)</td><td>3</td><td></td><td></td></tr>
<tr><td rowspan="5">OUT OF SERVICE (IAOOS)</td><td>TECHNICAL STANDBY (IAOOSTS)</td><td>4</td><td></td><td></td></tr>
<tr><td rowspan="2">OUT OF ENVIRONMENTAL SPECIFICATION (IAOOSEN)</td><td rowspan="2">5</td><td>calm winds</td><td>5.1</td></tr>
<tr><td>other environmental</td><td>5.2</td></tr>
<tr><td>REQUESTED SHUTDOWN (IAOOSRS)</td><td>6</td><td></td><td></td></tr>
<tr><td>OUT OF ELECTRICAL SPECIFICATION (IAOOSEL)</td><td>7</td><td></td><td></td></tr>
<tr><td rowspan="11">NON-OPERATIVE (IANO)</td><td colspan="2">SCHEDULED MAINTENANCE (IANOSM)</td><td>8</td><td></td><td></td></tr>
<tr><td colspan="2" rowspan="3">PLANNED CORRECTIVE ACTION (IANOPCA)</td><td rowspan="3">9</td><td>retrofit</td><td>9.1</td></tr>
<tr><td>upgrade</td><td>9.2</td></tr>
<tr><td>other corrective action</td><td>9.3</td></tr>
<tr><td colspan="2" rowspan="4">FORCED OUTAGE (IANOFO)</td><td rowspan="4">10</td><td>response</td><td>10.1</td></tr>
<tr><td>diagnostic</td><td>10.2</td></tr>
<tr><td>logistic</td><td>10.3</td></tr>
<tr><td>failure repair</td><td>10.4</td></tr>
<tr><td colspan="2" rowspan="3">SUSPENDED (IANOS)</td><td rowspan="3">11</td><td>suspended scheduled maintenance</td><td>11.1</td></tr>
<tr><td>suspended planned corrective action</td><td>11.2</td></tr>
<tr><td>suspended forced outage</td><td>11.3</td></tr>
<tr><td colspan="3">FORCE MAJEURE (IAFM)</td><td>12</td><td></td><td></td></tr>
<tr><td colspan="4">INFORMATION UNAVAILABLE (IU)</td><td>13</td><td></td><td></td></tr>
</table>

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Figure 1 – IEC 61400-26-1 information model

5.2.2 Additional state information required

To derive reliability metrics, it is necessary to obtain a further granularity than that provided by the counters defined in IEC 61400-26-1 giving only aggregated numbers for a full given period. For each unbroken period, when the state at a given level has been constant, it is necessary to know the duration, the preceding state, and the succeeding state. To provide a basis for more complex analyses (e.g., dependency on time-of-day, day-of-week, etc,), information about the duration of a period shall be completed with timestamps for the start and end of said period.

Data to be collected for each level in the information model consists of a set of data points that each describe an uninterrupted period when the state did not change. The set of data points shall include the following elements:

- information category level number,
- designation of state,
- timestamp for entry to state,
- designation of preceding state,
- timestamp for exit from state,
- designation of succeeding state,
- duration of state,
- number of events (within a specified period of time).

The set of data points shall make account for all time and all state changes for each level in the period being analysed.

The specification of level is required because it cannot unambiguously be deducted from the category names. For example, a transition from IANOFO to IANOS could be at either level 3 or level 4.

5.2.3 Reliability terms derived from information categories – normative levels

Some of the time counters for the operational information categories defined by IEC 61400-26-1 can directly be associated with commonly used reliability metrics. Supplementing with event counters for each state, even more reliability metrics can be derived. With the addition of the set of data points specified in this document, many of the commonly used reliability metrics can be derived.

Using the terminology developed in IEC 61703 and IEC 60050-192, the parameters below can be derived.

From the mandatory information categories (see Figure 1):

- DT and MDT, downtime, is derived directly from counting time and number of events in NON-OPERATIVE (level 2).
- UT and MUT, uptime, is derived directly from counting time and number of events in OPERATIVE (level 2).
- TBF and MTBF, time between failure, is derived from counting time between occurrences and number of events in FORCED OUTAGE.
- TTR and MTTR, time to restoration, is derived directly as the combination of time spent and number of events in FORCED OUTAGE + SUSPENDED (levels 3 and 4).
- TTF and MTTF, time to failure, is derived from a subset counter, and derived from time spent in OPERATIVE, provided that the state transition is to FORCED OUTAGE.

NOTE DT is the individually measured/counted 'downtime' of the item. MDT is the mean value that can be calculated based on additional data from the event counter.

UT is the individually measured/counted 'uptime' of the item. MUT is the mean value that can be calculated based on additional data from the event counter. (MUT + MDT do not add-up to the total time as FORCE MAJEURE and INFORMATION UNAVAILABLE are not included).

TBF is the individually measured/counted time elapsing between two consecutive failures (not necessarily the same failures). MTBF is the mean value of TBFs.

TTR is the individually measured/counted total time 'spent' on restoring the item in case of an incident. MTTR is the mean value. According to IEC 61703, MTTR can be considered the sum of MFDT + MAD + MLD + MACMT, but this requires involvement of optional categories (see 5.2.4).

TTF is the individually measured/counted time to fail. MTTF is the mean time to fail.

Users shall decide on how to incorporate transitions to SCHEDULED MAINTENANCE and PLANNED CORRECTIVE ACTION. Users shall choose between adding one or both state transitions to the counter stop criteria or leaving them out. Similarly, users shall decide on how FORCE MAJEURE shall be used for reliability metrics. Some of these aspects are discussed in Annex D.

Figure 2 illustrates from what information categories reliability terms can be derived directly. The 'arrow' in each cell points to what reliability parameters can be derived when the data point and the specified approach is applied. Not all information categories hold information that directly associates with commonly used reliability terms (the white- and orange-colored cells). It is however not ruled out, that these information categories can contribute to specific reliability studies.

The cell marked green in Figure 2 indicates the 'uptime state'. The red colored cells indicate the non-operative states providing the immediate downtime parameters associated with failures and repair.

Mandatory level 1	Mandatory level 2	Mandatory level 3	Mandatory level 4	Mandatory priority
INFORMA-TION AVAILABLE **(IA)**	OPERATIVE (IAO) ↓ **UT** **(time counted)**	IN SERVICE (**IAOS**)	FULL PERFORMANCE (**IAOSFP**)	**1**
			PARTIAL PERFORMANCE (**IAOSPP**)	**2**
			READY STANDBY (**IAOSRS**)	**3**
		OUT OF SERVICE **(IAOOS)**	TECHNICAL STANDBY (**IAOOSTS**)	**4**
			OUT OF ENVIRONMENTAL SPECIFICATION **(IAOOSEN)**	**5**
			REQUESTED SHUTDOWN (**IAOOSRS**)	**6**
			OUT OF ELECTRICAL SPECIFICATION **(IAOOSEL)**	**7**
	NON-OPERATIVE (IANO) ↓ **DT** **(time counted)**	SCHEDULED MAINTENANCE **(IANOSM)**		**8**
		PLANNED CORRECTIVE ACTION (**IANOPCA**)		**9**
		FORCED OUTAGE (IANOFO) ↓ **TBF (time between entries)** **TTR (time counted)** **TTF (time from IAO entry to IANOFO entry)**		**10**
		SUSPENDED (IANOS) ↓ **TTR (time counted)**		**11**
	FORCE MAJEURE (IAFM)			**12**
INFORMATION UNAVAILABLE **(IU)**				**13**

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Key

white-coloured states not used in reliability terms

orange-coloured states not used in reliability terms

green-coloured states commonly used in reliability terms

red-coloured states commonly used in reliability terms

Figure 2 – Reliability terms derived from the information model – normative levels

Annex A (informative) sets up three scenarios to illustrate the methodology introduced in this document.

1) a simple scenario for illustration of an immediate derivation of some reliability parameters based on the approach presented above,
2) an example on how to consider SCHEDULED MAINTENANCE and PLANNED CORRECTIVE ACTION in the stop criteria, and
3) a scenario with an example on how to leave out SCHEDULED MAINTENANCE and PLANNED CORRECTIVE ACTION stop criteria.

Annex B (informative) illustrates some aspects to consider when implementing counter data for normative and optional information categories. Annex B also introduces commonly used reliability engineering terms and a brief discussion on application of these terms. Annex C illustrates the methodology for assessing reliability parameters at system and component level. Annex D further addresses considerations when deciding on how to implement information category data and to what level information will be needed for a proper implementation.

5.2.4 Reliability terms derived from the information model – optional levels

When one or more optional levels are introduced, further reliability metrics can be derived. Again, introducing the terminology developed in IEC 61703 and IEC 60050-192, the parameters listed below are examples of optional reliability parameters derived from the optional information categories. For more information on these optional information categories, refer to IEC 61400-26-1.

- AD and MAD, administrative delay, this is not defined in IEC 61400-26-1 but is a possible level 5 or 6 category (not normative). AD could be considered as a component of response. AD could also be considered a component of one or all three categories suspended scheduled maintenance, suspended planned corrective action and suspended forced outage (all non-normative), all representing break-down components of SUSPENDED.
- LD and MLD, logistic delay, correspond with the optional category logistic, a break-down component of FORCED OUTAGE (not normative). LD could also be considered a component of one or all three categories suspended scheduled maintenance, suspended planned corrective action and suspended forced outage (all non-normative).
- RT and MRT, repair time, correspond with the optional category failure repair, a break-down component of FORCED OUTAGE (non-normative).
- TD and MTD, technical delay, correspond with the optional category diagnostic, a break-down component of FORCED OUTAGE (non-normative).
- ACMT and MACMT, active corrective maintenance time, this is not defined in IEC 61400-26-1 but can be derived as the sum of MTD+MRT.
- FDT and MFDT, fault detection time, can be interpreted as a component of the optional category response, a break-down component of FORCED OUTAGE (non-normative).

NOTE AD is an individually measured/counted administrative delay during the restoration time for a faulty item. MAD is the mean value.

LD is an individually measured/counted logistic delay taking place before repairs during the individual incident. MLD is the mean delay time.

RT is the individually measured/counted time spent performing repairs during the individual incident. MRT is the (expected) mean repair time.

TD is an individually measured/counted technical (planning) delay taking place before repairs during the individual incident. MTD is the mean delay time.

Users shall decide and agree on how to incorporate counters and/or timestamps based on the optional information categories and for what reliability parameters – if at all. Users shall identify the optional information categories that will form the basis of the respective reliability terms, and the start and stop criteria that are to be applied.

IEC 60050-192 defines a wide range of parameters (not just the ones listed above) that users can consider for implementation. Users shall keep in mind that counters for these parameters always shall be implementable and that these counters also shall be defined as (new) optional information categories items at level 5 or level 6.

5.2.5 Failure frequency and other aggregated reliability terms

When the data points introduced in 5.2.2 are implemented, frequencies of various parameters can be calculated as required. The failure frequency, for example, can be calculated from counting the number of times the item enters the FORCED OUTAGE state (based on the event counter).

Other calculations such as minimum, maximum. variance, standard deviation, etc. (depending on probability distribution) can be made. Requirement of methods is not within the scope of this document.

NOTE In this context, frequency of failure or failure intensity is understood as the number of times that an item fails during a specified period.

5.3 Applicability to WEGS, systems and components

In full compliance with IEC 61400-26-1, the above directions can be applied to a WEGS in the sense that "...the document can be used for a single wind turbine (WTGS), as well as for any number of WEGSs combined with additional components to represent a complete wind power station (WPS)."

Moreover, the information model can be expanded to apply at either system or component levels. If a WEGS is seen as consisting of several systems and components, individual 'sheets' of the information model can be assigned to any number of systems and components. In this case, the methodologies of IEC 61400-26-1 and this document shall also be applied. Annex C (informative) illustrates an example of assessment principles for reliability parameters at system and component level.

Annex A
(informative)

Illustrative examples

A.1 Scenario 1 – Determination of MFDT, MRT, MTD, MTBF and MDT for reporting reliability

This example illustrates registration of reliability parameters in an operational (fictitious) sequence for a cluster of two wind turbines.

Case: failures of the pitch motors at two different wind turbines is experienced five times in total. The report in Table A.1 is made in accordance with the approach set out in 5.2. The example illustrates recording of MTBF and MTTR for the pitch motors and illustrates a discarding of data in the process of determining MTBF when no data on this parameter is recorded at these instances (first two incidents).

Table A.1 – Registration of FDT, RT, TD, TBF and DT

WTGS	FORCED OUTAGE – Response / Repair (level 5)	FORCED OUTAGE – Diagnostic (level 5)	Reliability analysis
#1	Response (FDT): Start: 20xx-01-10 02:15 End: 20xx-01-10 09:00 (6h45) Repair (RT): Start: 20xx-01-10 11:45 End: 20xx-01-10 15:15 (3h30) Total: 10h15	Diagnostics (TD): Start: 20xx-01-10 09:00 End: 20xx-01-10 11:45 (2h45)	Time since occurrence of the last failure: n/a FDT: 6h45 RT: 03h30 TD: 2h45 TBF: n/a DT: 13h00
#1	Response (FDT): Start: 20xx-02-08 04:45 End: 20xx-02-08 10:15 (5h30) Repair (RT): Start: 20xx-02-08 11:00 End: 20xx-02-08 14:45 (3h45) Total: 9h15	Diagnostics (TD): Start: 20xx-02-08 10:15 End: 20xx-02-08 11:00 (0h45)	Time since occurrence of the last failure: 722h30 FDT: 5h30 RT: 03h45 TD: 0h45 TBF: 722h30 DT: 10h00
#1	Response (FDT): Start: 20xx-03-10 05:30 End: 20xx-03-10 09:00 (3h30) Repair (RT): Start: 20xx-03-10 09:30 End: 20xx-03-10 12:30 (03h00) Total: 6h30	Diagnostics (TD): Start: 20xx-03-10 09:00 End: 20xx-03-10 09:30 (0h30)	Time since occurrence of the last failure: 720h45 FDT: 3h30 RT: 03h00 TD: 0h30 TBF: 720h45 DT: 7h00
#1		Average (mean values) of parameters for the three events on WTGS #1	MFDT: 5h15 MRT: 3h25 MTD: 1h20 MTBF: 721h38 MDT: 10h00

WTGS	FORCED OUTAGE – Response / Repair (level 5)	FORCED OUTAGE – Diagnostic (level 5)	Reliability analysis
#2	Response (FDT): Start: 20xx-01-10 02:45 End: 20xx-01-10 09:00 (5h45) Repair (RT): Start: 20xx-01-11 08:00 End: 20xx-01-11 11:15 (3h15) Total: 9h00	Diagnostics (TD): Start: 20xx-01-10 09:00 End: 20xx-01-11 08:00 (23h00)	Time since occurrence of the last failure: n/a FDT: 5h45 RT: 03h15 TD: 23h00 TBF: n/a DT: 32h00
#2	Response (FDT): Start: 20xx-02-08 03:30 End: 20xx-02-08 10:15 (6h45) Repair (RT): Start: 20xx-02-08 11:00 End: 20xx-02-08 14:45 (3h45) Total: 10h30	Diagnostics (TD): Start: 20xx-02-08 10:15 End: 20xx-02-08 11:00 (0h45)	Time since occurrence of the last failure: 792h45 FDT: 6h45 RT: 3h45 TD: 0h45 TBF: 792h45 DT: 11h15
#2		Average (mean values) of parameters for the two events on WTGS #2	MFDT: 6h15 MRT: 3h30 MTD: 11h53 MTBF: 792h45 MDT: 21h38

A.2 Scenario 2 – Incorporation of transitions to SCHEDULED MAINTENANCE and PLANNED CORRECTIVE ACTION in the aggregated TTF counter stop criteria

When an operative WEGS (in OPERATIVE) moves to either a fault state (FORCED OUTAGE), scheduled maintenance is being performed (SCHEDULED MAINTENANCE) or transitions to a different state for some other reason (see Figure A.1), the cause is relevant for the reliability assessment.

Scenarios 2 and 3 illustrate the importance of having predefined the implication of incorporating SCHEDULED MAINTENANCE and PLANNED CORRECTIVE ACTION in the aggregated TTF counter 'stop criteria'. Scenario 2 is an example on how counters can be used when incorporating these two information categories in the stop criteria; scenario 3 illustrates an example where the two information categories are NOT considered in the stop criteria.

The two scenarios are studied for the service "active energy" introduced in IEC 61400-26-1. The assumption in scenario 2 is that scheduled maintenance and planned corrective actions are assumed to be an "unreliable situation". For scenario 3, however, activities for scheduled maintenance and for planned corrective actions do not constitute an "unreliable situation" for the active production service (taking place in situations when no active production is possible anyway). This is illustrated by the difference in the accounting of the FTT in the two scenarios.

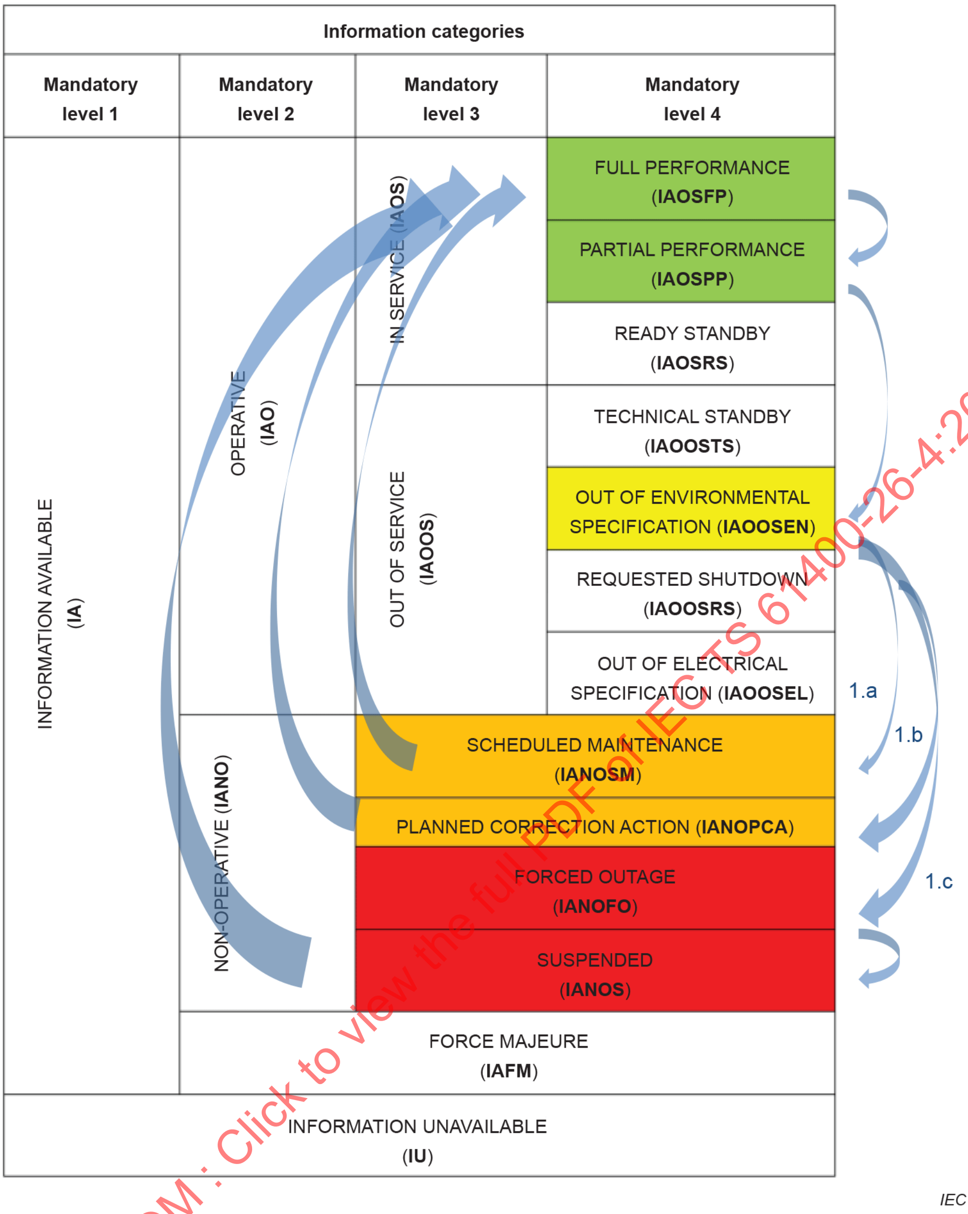
Scenario 2: a WTGS transitions from an operational state (information category) in FULL PERFORMANCE through PARTIAL PERFORMANCE, OUT OF ENVIRONMENTAL SPECIFICATION to one of three situations (1a): SCHEDULED MAINTENANCE, (1b): PLANNED CORRECTIVE ACTION or (1c): FORCED OUTAGE. For (1c), a further step into SUSPENDED is experienced. All situations (1a), (1b) and (1c) end by the WTGS returning to FULL PERFORMANCE, see Figure A.2.

Information categories				
Mandatory level 1	**Mandatory level 2**	**Mandatory level 3**	**Mandatory level 4**	**Mandatory priority**
INFORMATION AVAILABLE (**IA**)	OPERATIVE (**IAO**)	IN SERVICE (**IAOS**)	FULL PERFORMANCE (**IAOSFP**)	**1**
			PARTIAL PERFORMANCE (**IAOSPP**)	**2**
			READY STANDBY (**IAOSRS**)	**3**
		OUT OF SERVICE (**IAOOS**)	TECHNICAL STANDBY (**IAOOSTS**)	**4**
			OUT OF ENVIRONMENTAL SPECIFICATION (**IAOOSEN**)	**5**
			REQUESTED SHUTDOWN (**IAOOSRS**)	**6**
			OUT OF ELECTRICAL SPECIFICATION (**IAOOSEL**)	**7**
	NON-OPERATIVE (**IANO**)	SCHEDULED MAINTENANCE (**IANOSM**)		**8**
		PLANNED CORRECTIVE ACTION (**IANOPCA**)		**9**
		FORCED OUTAGE (**IANOFO**)		**10**
		SUSPENDED (**IANOS**)		**11**
	FORCE MAJEURE (**IAFM**)			**12**
INFORMATION UNAVAILABLE (**IU**)				**13**

IEC

Figure A.1 – Examples of transitions from IN SERVICE

The operational sequences and relevant counters for all three situations, 1a, 1b and 1c, are illustrated in Table A.2. The table also illustrates relevant reliability parameters derived in accordance with the approach in Clause 5. For simplicity, timestamps at entry and exits of states/categories are not illustrated but could just as well be used as basis for the recordings illustrated.



Key

orange-coloured states	non-operative states
green-coloured states	'uptime states'
red-coloured states	non-operative states
yellow-marked state	contributes with a counter to the example

Figure A.2 – Illustration of the transition sequences in scenario 2 and 3

Figure A.2 illustrates transition sequences in scenarios 2 and 3. The cells marked green indicate the 'uptime states'. The red- and orange-colored cells indicate the non-operative states. The yellow-marked cell contributes with a counter as illustrated in the scenario example.

Table A.2 – Scenario 2

Event	Transition	Time	'Present category'	DT	UT	TTR	TTF	RT (optional)	TD (optional)	FDT (optional)
The WTGS has been producing at full rating for some time ('the previous'). The WTGS active power setpoint is reduced, causing a transition in state/category	FULL PERFORMANCE to PARTIAL PERFORMANCE	Day X, 09:00	Counter for IAOSPP starts	Counter for IANO is unaffected (not counting)	Counter for IAO is unaffected (keeps counting), in this example UT is 1 012 hours	Counters for IANOFO and IANOS are unaffected (not counting)	The 'aggregated counter for TTF' keeps on counting uninterrupted. In this example the counter is 1 960 hours when the transition happens. The counter started at the previous entry to OPERATIVE (IAO)	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) is unaffected (not counting)
The ambient temperature exceeds the designed (operational) envelope, causing an interruption of the active power production	PARTIAL PERFORMANCE to OUT OF ENVIRONMENTAL SPECIFICATION	Day X, 15:00	Counter for IAOSPP stops at 6 hours. Counter for IAOOSEN starts	Counter for IANO is unaffected (not counting)	Counter for IAO is unaffected (keeps counting), UT is now 1 018 hours	Counters for IANOFO and IANOS are unaffected (not counting)	The 'aggregated counter for TTF' keeps on counting uninterrupted. The counter is now 1 966 hours	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) is unaffected (not counting)

Event	Transition	Time	'Present category'	DT	UT	TTR	TTF	RT (optional)	TD (optional)	FDT (optional)
1.a. The WTGS service organization decides to carry out a (minor) scheduled maintenance activity as the turbine is not likely to produce active power for some time ('heat wave')	OUT OF ENVIRONMENTAL SPECIFICATION to SCHEDULED MAINTENANCE	Day X+1, 11:00	Counter for IAOOSEN stops at 20 hours. Counter for IANOSM starts	Counter for IANO starts counting	Counter for IAO stops counting, UT stops at 1038 hours	Counters for IANOFO and IANOS are unaffected (not counting)	The 'aggregated counter for TTF' stops. The counter is now 1 986 hours	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) is unaffected (not counting)
1.a. The WTGS service organization completes the scheduled maintenance activity. The turbine is returned to normal operation	SCHEDULED MAINTENANCE to FULL PERFORMANCE	Day X+1, 17:00	Counter for IANOSM stops at 6 hours, 0 minutes and 0 seconds	Counter for IANO stops counting, DT stops at 6 hours	Counter for IAO is reset and UT starts counting (for a new period)	Counters for IANOFO and IANOS are unaffected (not counting)	The 'aggregated counter for TTF' is reset. The counter starts counting (for a new period)	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) is unaffected (not counting)
1.a. Values counted for this period (starting at previous entry to UT)		Time elapsed for this sequence: 32 hours. Total time this period: 1 044 hours		Total: 6 hours	Total: 1 038 hours	Total: 0 hours	Total: 1 986 hours	Total: 0 hours	Total: 0 hours	Total: 0 hours

Event	Transition	Time	'Present category'	DT	UT	TTR	TTF	RT (optional)	TD (optional)	FDT (optional)
1.b. The WTGS service organization decides to carry out a (major) planned corrective activity as the turbine is not likely to produce active power for some time ('heat wave')	OUT OF ENVIRONMENTAL SPECIFICATION to PLANNED CORRECTIVE ACTION	Day X+1, 11:00	Counter for IAOOSEN stops at 20 hours. Counter for IANOPCA starts	Counter for IANO starts counting	Counter for IAO stops counting, UT stops at 1 038 hours	Counters for IANOFO and IANOS are unaffected (not counting)	The 'aggregated counter for TTF' stops. The counter is now 1 986 hours	Counter for IANOFO$_F$ (failure repair) is unaffected (not counting)	Counter for IANOFO$_D$ (diagnostic) is unaffected (not counting)	Counter for IANOFO$_R$ (response) is unaffected (not counting)
1.b. The WTGS service organization completes the planned corrective activity. The turbine is returned to normal operation	PLANNED CORRECTIVE ACTION to FULL PERFORMANCE	Day 3, 17:00	Counter for IANOPCA stops at 52 hours	Counter for IANO stops counting, DT stops at 52 hours	Counter for IAO is reset and UT starts counting (for a new period)	Counters for IANOFO and IANOS are unaffected (not counting)	The 'aggregated counter for TTF' is reset. The counter starts counting (for a new period)	Counter for IANOFO$_F$ (failure repair) is unaffected (not counting)	Counter for IANOFO$_D$ (diagnostic) is unaffected (not counting)	Counter for IANOFO$_R$ (response) is unaffected (not counting)
1.b. Values counted for this period (starting at previous entry to UT)		Time elapsed for this sequence: 80 hours. Total time this period: 1 092 hours		Total: 52 hours	Total: 1 038 hours	Total: 0 hours	Total: 1 986 hours	Total: 0 hours	Total: 0 hours	Total: 0 hours
1.c. The WTGS controller system encounters a technical fault and conducts a shutdown	OUT OF ENVIRONMENTAL SPECIFICATION to FORCED OUTAGE	Day X, 19:00	Counter for IAOOSEN stops at 4 hours. Counter for IANOFO starts. Counter for IANOFO$_R$ starts also	Counter for IANO starts counting	Counter for IAO stops counting, UT stops at 1 022 hours	Counter for IANOFO starts counting	The 'aggregated counter for TTF' stops. The counter is now 1 970 hours	Counter for IANOFO$_F$ (failure repair) is unaffected (not counting)	Counter for IANOFO$_D$ (diagnostic) is unaffected (not counting)	Counter for IANOFO$_R$ (response) starts counting.

Event	Transition	Time	'Present category'	DT	UT	TTR	TTF	RT (optional)	TD (optional)	FDT (optional)
1.c. The WTGS service organization is unable to carry out the next remedying steps because of bad weather	FORCED OUTAGE to SUSPENDED	Day X, 21:00	Counter for IANOFO stops at 2 hours. Counter for IANOS starts	Counter for IANO keeps counting. The counter is now 2 hours	UT remains at 1 022 hours	Counter for IANOFO stops counting at 2 hours. Counter for IANOS starts	The 'aggregated counter for TTF'' remains at 1 970 hours	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) stops at 2 hours
1.c. The WTGS service organization resumes work to bring the WTGS back to operation. The first two hours are spent on identifying the cause	SUSPENDED to FORCED OUTAGE	Day X+1, 21:00	Counter for IANOS stops at 24 hours. Counter for IANOFO resumes counting at 2 hours	Counter for IANO keeps counting. The counter is now 26 hours	UT remains at 1 022 hours	Counter for IANOFO resumes counting. TTR is counting at 26 hours	The 'aggregated counter for TTF' remains at 1 970 hours	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) starts counting	Counter for $IANOFO_R$ (response) remains at 2 hours
1.c. The WTGS service organization starts repair work	Diagnostic to failure repair – no transition on mandatory levels	Day X+1, 23:00	Counter for IANOFO counting at 4 hours	Counter for IANO keeps counting. The counter is now 28 hours	UT remains at 1 022 hours	Counter for IANOFO continues counting, now at 4 hours. TTR is counting at 28 hours	The 'aggregated counter for TTF' remains at 1 970 hours	Counter for $IANOFO_F$ (failure repair) starts counting	Counter for $IANOFO_D$ (diagnostic) stops counting at 2 hours	Counter for $IANOFO_R$ (response) remains at 2 hours
1.c. The WTGS service organization has completed activities carried out during FORCED OUTAGE. The turbine is returned to normal operation	FORCED OUTAGE to FULL PERFORMANCE	Day X+2, 11:00	IANOFO stops counting at 16 hours Counter for IAOSFP starts	Counter for IANO stops counting, DT stops at 40 hours	Counter for IAO is reset and UT starts counting (for a new period)	Counters IANOFO stops at 16 hours	The 'aggregated counter for TTF' is reset and starts counting (for a new period)	Counter for $IANOFO_F$ (failure repair) stops counting at 12 hours – and reset	Counter for $IANOFO_D$ (diagnostic) is reset	Counter for $IANOFO_R$ (response) is reset

Event	Transition	Time	'Present category'	DT	UT	TTR	TTF	RT (optional)	TD (optional)	FDT (optional)
1.c. Values counted for this period (starting at previous entry to UT)		Time elapsed for this sequence: 50 hours. Total time this period: 1 062 hours		Total: 40 hours	Total: 1 022 hours	Total: 40 hours	Total: 1 970 hours	Total: 12 hours	Total: 2 hours	Total: 2 hours

NOTE In the example, counters for optional sub-levels (level 5) for FORCED OUTAGE are used. Optional sub-levels for PLANNED CORRECTIVE ACTION and for SUSPENDED are not used.

A.3 Scenario 3 – SCHEDULED MAINTENANCE and PLANNED CORRECTIVE ACTION not incorporated in the aggregated TTF counter stop criteria

Scenario 3: the operational sequence is the same as for scenario 2 but this time the counter for TTF is used differently.

The operational sequences and relevant counters for all three situations, 1a, 1b and 1c, are illustrated in Table A.3. The table also illustrates relevant reliability parameters derived in accordance with the approach in Clause 5. For simplicity, timestamps at entry and exits of states/categories are not illustrated but could just as well be used as basis for the recordings illustrated.

Table A.3 – Scenario 3

Event	Transition	Time	'Present category'	DT	UT	TTR	TTF	RT (optional)	TD (optional)	FDT (optional)
The WTGS has been producing at full rating for some time (the previous). The WTGS active power setpoint is reduced, causing a transition in state/category	FULL PERFORMANCE to PARTIAL PERFORMANCE	Day X, 09:00	Counter for IAOSPP starts	Counter for IANO is unaffected (not counting)	Counter for IAO is unaffected (keeps counting), in this example UT is 1 012 hours	Counters for IANOFO and IANOS are unaffected (not counting)	The 'aggregated counter for TTF' keeps on counting uninterrupted. In this example the counter is 1 960 hours when the transition happens. The counter started at the previous entry to OPERATIVE (IAO)	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) is unaffected (not counting)
The ambient temperature exceeds the designed (operational) envelope, causing an interruption of the active power production	PARTIAL PERFORMANCE to OUT OF ENVIRONMENTAL SPECIFICATION	Day X, 15:00	Counter for IAOSPP stops at 6 hours. Counter for IAOOSEN starts	Counter for IANO is unaffected (not counting)	Counter for IAO is unaffected (keeps counting), UT is now 1 018 hours	Counters for IANOFO and IANOS are unaffected (not counting)	The 'aggregated counter for TTF' keeps on counting uninterrupted. The counter is now 1 966 hours	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) is unaffected (not counting)

Event	Transition	Time	'Present category'	DT	UT	TTR	TTF	RT (optional)	TD (optional)	FDT (optional)
1.a. The WTGS service organization decides to carry out a (minor) scheduled maintenance activity as the turbine is not likely to produce active power for some time ('heat wave')	OUT OF ENVIRONMENTAL SPECIFICATION to SCHEDULED MAINTENANCE	Day X+1, 11:00	Counter for IAOOSEN stops at 20 hours. Counter for IANOSM starts	Counter for IANO starts counting	Counter for IAO stops counting, UT stops at 1 038 hours	Counters for IANOFO and IANOS are unaffected (not counting)	The 'aggregated counter for TTF' keeps on counting uninterrupted. The counter is now 1 986 hours	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) is unaffected (not counting)
1.a. The WTGS service organization completes the scheduled maintenance activity. The turbine is returned to normal operation	SCHEDULED MAINTENANCE to FULL PERFORMANCE	Day X+1, 17:00	Counter for IANOSM stops at 6 hours, 0 minutes and 0 seconds	Counter for IANO stops counting, DT stops at 6 hours	Counter for IAO is reset and UT starts counting (for a new period)	Counters for IANOFO and IANOS are unaffected (not counting)	The 'aggregated counter for TTF' keeps on counting uninterrupted. The counter is now 1 992 hours. This counter keeps on counting into the next period	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) is unaffected (not counting)
1.a. Values counted for this period (starting at previous entry to UT)		Time elapsed for this sequence: 32 hours. Total time this period: 1 044 hours		Total: 6 hours	Total: 1 038 hours	Total: 0 hours	Total: 1 992 hours	Total: 0 hours	Total: 0 hours	Total: 0 hours

Event	Transition	Time	'Present category'	DT	UT	TTR	TTF	RT (optional)	TD (optional)	FDT (optional)
1.b. The WTGS service organization decides to carry out a (major) planned corrective activity as the turbine is not likely to produce active power for some time ('heat wave')	OUT OF ENVIRONMENTAL SPECIFICATION to PLANNED CORRECTIVE ACTION	Day X+1, 11:00	Counter for IAOOSEN stops at 20 hours. Counter for IANOPCA starts	Counter for IANO starts counting	Counter for IAO stops counting, UT stops at 1 038 hours	Counters for IANOFO and IANOS are unaffected (not counting)	The 'aggregated counter for TTF' keeps on counting uninterrupted. The counter is now 1 986 hours	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) is unaffected (not counting)
1.b. The WTGS service organization completes the planned corrective activity. The turbine is returned to normal operation	PLANNED CORRECTIVE ACTION to FULL PERFORMANCE	Day 3, 17:00	Counter for IANOPCA stops at 52 hours	Counter for IANO stops counting, DT stops at 52 hours	Counter for IAO is reset and UT starts counting (for a new period)	Counters for IANOFO and IANOS are unaffected (not counting)	The 'aggregated counter for TTF' keeps on counting uninterrupted. The counter is now 1 992 hours	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) is unaffected (not counting)
1.b. Values counted for this period (starting at previous entry to UT)		Time elapsed for this sequence: 80 hours. Total time this period: 1 092 hours		Total: 52 hours	Total: 1 038 hours	Total: 0 hours	Total: 2 040 hours	Total: 0 hours	Total: 0 hours	Total: 0 hours
1.c. The WTGS controller system encounters a technical fault and conducts a shutdown	OUT OF ENVIRONMENTAL SPECIFICATION to FORCED OUTAGE	Day X, 19:00	Counter for IAOOSEN stops at 4 hours. Counter for IANOFO starts. Counter for $IANOFO_R$ starts also	Counter for IANO starts counting	Counter for IAO stops counting, UT stops at 1 022 hours	Counter for IANOFO starts counting	The 'aggregated counter for TTF' stops. The counter is now 1 970 hours	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) starts counting

Event	Transition	Time	'Present category'	DT	UT	TTR	TTF	RT (optional)	TD (optional)	FDT (optional)
1.c. The WTGS service organization is unable to carry out the next remedying steps because of bad weather	FORCED OUTAGE to SUSPENDED	Day X, 21:00	Counter for IANOFO stops at 2 hours. Counter for IANOS starts	Counter for IANO keeps counting. The counter is now 2 hours	UT remains at 1 022 hours	Counter for IANOFO stops counting at 2 hours. Counter for IANOS starts	The 'aggregated counter for TTF' remains at 1 970 hours	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) is unaffected (not counting)	Counter for $IANOFO_R$ (response) stops at 2 hours
1.c. The WTGS service organization resumes work to bring the WTGS back to operation. The first two hours are spent on identifying the cause	SUSPENDED to FORCED OUTAGE	Day X+1, 21:00	Counter for IANOS stops at 24 hours. Counter for IANOFO resumes counting at 2 hours	Counter for IANO keeps counting. The counter is now 26 hours	UT remains at 1 022 hours	Counter for IANOFO resumes counting. TTR is counting at 26 hours	The 'aggregated counter for TTF' remains at 1 970 hours	Counter for $IANOFO_F$ (failure repair) is unaffected (not counting)	Counter for $IANOFO_D$ (diagnostic) starts counting	Counter for $IANOFO_R$ (response) remains at 2 hours
1.c. The WTGS service organization starts repair work	Diagnostic to failure repair – no transition on mandatory levels	Day X+1, 23:00	Counter for IANOFO counting at 4 hours	Counter for IANO keeps counting. The counter is now 28 hours	UT remains at 1 022 hours	Counter for IANOFO continues counting, now at 4 hours. TTR is counting at 28 hours	The 'aggregated counter for TTF' remains at 1 970 hours	Counter for $IANOFO_F$ (failure repair) starts counting	Counter for $IANOFO_D$ (diagnostic) stops counting at 2 hours	Counter for $IANOFO_R$ (response) remains at 2 hours
1.c. The WTGS service organization has completed activities carried out during FORCED OUTAGE. The turbine is returned to normal operation	FORCED OUTAGE to FULL PERFORMANCE	Day X+2, 11:00	IANOFO stops counting at 16 hours Counter for IAOSFP starts	Counter for IANO stops counting, DT stops at 40 hours	Counter for IAO is reset and UT starts counting (for a new period)	Counters IANOFO stops at 16 hours	The 'aggregated counter for TTF' is reset and starts counting (for a new period)	Counter for $IANOFO_F$ (failure repair) stops counting at 12 hours – and reset	Counter for $IANOFO_D$ (diagnostic) is reset	Counter for $IANOFO_R$ (response) is reset

Event	Transition	Time	'Present category'	DT	UT	TTR	TTF	RT (optional)	TD (optional)	FDT (optional)
1.c. Values counted for this period (starting at previous entry to UT)		Time elapsed for this sequence: 50 hours. Total time this period: 1 062 hours		Total: 40 hours	Total: 1 022 hours	Total: 40 hours	Total: 1 970 hours	Total: 12 hours	Total: 2 hours	Total: 2 hours
NOTE In the example, counters for optional sub-levels (level 5) for FORCED OUTAGE are used. Optional sub-levels for PLANNED CORRECTIVE ACTION and for SUSPENDED are not used.										

Annex B
(informative)

Reliability engineering considerations

B.1 General

Reliability analysis assumes a system status is binary, as-in up or down, on or off, functioning or failed, available or not available, reliable or unreliable. There is no partially reliable state or status. But systems in wind power stations are complex, and they can have several functional requirements. At any given time, the system can satisfy all requirements, just some requirements, or none. Reliability analysis serves stakeholders looking to understand the likelihood of meeting their requirements, or more often the likelihood of failing to meet their requirements throughout the system life cycle. Stakeholders and users know the functions and requirements of their systems, and they should mutually agree to identify the categories and conditions that are acceptable to allocate as system 'uptime', or reliable time for their systems. These reliable periods and their conditions can be defined within the information model as a reliability layer specific to each functional requirement of the stakeholder’s system.

Users are referred to IEC 61703 and IEC 60050-192 on mathematical definitions for dependability and its influencing factors, reliability, availability, maintainability, and maintenance support, together with definitions of other related terms commonly used in this field. Some of these terms are measures of specific dependability characteristics, which can be expressed mathematically. If users plan to use these expressions, it is important to understand the mathematical meaning of those expressions, conditions, and limits for their use, and how they are established.

The IEC has produced standards on the topic of dependability (IEC 60300-1 and IEC 60300-3-3). These documents have a strong relationship to reliability, and while they list generic practices for any technology, they contain appropriate guidance and select considerations for use. The phases of a project have unique opportunities for addressing dependability and reliability issues and the resultant plans, designs and specifications will provide for means to make the WEGS more robust. Towards that end, these series standards on dependability are organized according to the stages of the life of projects (ranging across concept, development, realization, utilization, enhancement, and retirement) recognizing that the dependability discussion applies functionally, and care should be taken to consider risks throughout the stages of a WEGS project.

When implementing the approach illustrated in 5.2, actual data collected for a WEGS can contain subsets of data that have simultaneous or almost simultaneous timestamps. Such subsets could, for instance, occur when there is a failure in a WEGS component or in connection with fault-finding and repair. In preparation for an analysis, aiming at derivation of reliability metrics, some data filtering could be required to eliminate or group data points to reflect the logical state change that can be relevant for a particular analysis. The result of such a filtering exercise will be one or more calculated or 'synthetized' data points that reflect the combined effect of the data points of the subset used to create the 'synthetized' data point(s).

After the creation of any synthetized data point(s) and replacement of the subset data point(s) with the synthetized data point(s), the resulting 'set of filtered data points' shall still for each level collectively and unambiguously make account for all times and all state changes in the period being analyzed.

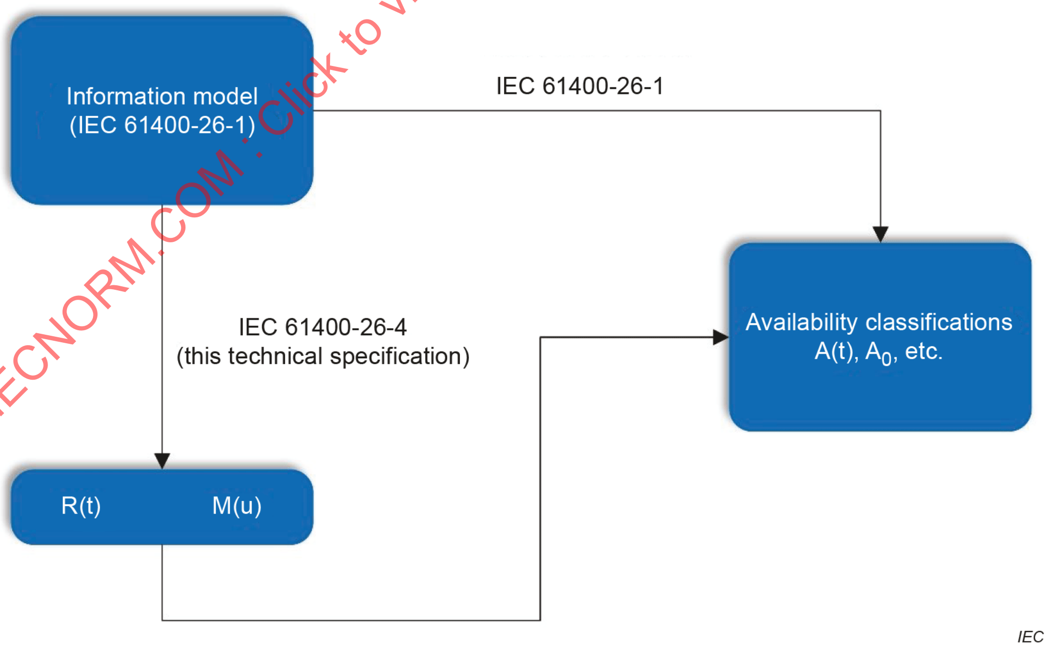
B.2 Reliability

As stated in the scope of this document, the reliability metrics identified apply to key components. Reliability is commonly understood as the probability or ability of a component or system performing its intended functions satisfactorily without failure (using a specified level of confidence) and within specified performance limits for a specified length of time, operating under specified environmental and operational conditions.

This definition addresses time and performance metrics, and the purpose of a generation plant needs to be further examined. More specifically, the usage profile of a WEGS is to provide energy over its lifetime as efficiently and reliably as possible given the quality of the components and understanding of the site, grid, and environment. Failures can be tolerated but the operational profile is to restore service as soon as possible. High availability is facilitated through reliable components and expedient maintenance. Both are critical system elements of a WEGS ability to generate energy.

Reliability and availability are impacted by contractual specifications, maintenance, external factors such as climate and grid conditions. Reliability is important for asset management and understanding failure trends, spares forecasting, manpower forecasting, and repeating component failures requiring a management focus to mitigate or eliminate. It is recommended that component failure and restoration database systems be utilized for reliability analyses for continuous reliability improvement practices as required and specified in contract documents.

Failure distributions, e.g., Weibull, and restoration times are useful measures for the frequency or repairs/replacements, maintainability and serviceability of components and systems. Repairs are dependent on spares inventories, logistics, labour and tool resources and these can be addressed by models. Availability is a higher-level metric that is derived from the combination of reliability function (R(t)) metrics regarding failures in accordance with this document, and then combined with the failure recovery efforts from the maintenance (M(t)) function response. These two functions will be integrated to form the availability function as shown in Figure B.1.



Key

R(t) reliability function (IEC 61703)

A(t) availability function (IEC 61703)

M(u) maintainability function (IEC 61703)

Figure B.1 – The information model as input provider for statistical analysis

Building on the information model (Figure 1), time data can already have been collected for the outages of components and systems. FORCED OUTAGES (the categories are in all-caps consistent with IEC 61400-26-1 nomenclature) have entry and exit points and underlying activities could include response, diagnostics, logistics, repairs/replacements, and other associated activities (as devised in IEC 61400-26-1 for optional levels). From this, availability can be calculated in accordance with IEC 61400-26-1.

Information categories						
Mandatory level 1	Mandatory level 2	Mandatory level 3	Mandatory level 4	Mandatory priority	Optional level 5	Level 5 priority
INFORMATION AVAILABLE (IA)	OPERATIVE (IAO) ↓ **UT** **(time counted)**	IN SERVICE **(IAOS)**	FULL PERFORMANCE **(IAOSFP)**	**1**		
			PARTIAL PERFORMANCE **(IAOSPP)**	**2**	**derated**	**2.1**
					degraded	**2.2**
			READY STANDBY **(IAOSRS)**	**3**		
		OUT OF SERVICE **(IAOOS)**	TECHNICAL STANDBY **(IAOOSTS)**	**4**		
			OUT OF ENVIRONMENTAL SPECIFICATION **(IAOOSEN)**	**5**	**calm winds**	**5.1**
					other environmental	**5.2**
			REQUESTED SHUTDOWN **(IAOOSRS)**	**6**		
			OUT OF ELECTRICAL SPECIFICATION **(IAOOSEL)**	**7**		
	NON-OPERATIVE (IANO) ↓ **DT** **(time counted)**	SCHEDULED MAINTENANCE **(IANOSM)**		**8**		
		PLANNED CORRECTIVE ACTION **(IANOPCA)**		**9**	**retrofit**	**9.1**
					upgrade	**9.2**
					other corrective action	**9.3**
		FORCED OUTAGE (IANOFO) ↓ **TBF (time between entries)** **TTR (time counted)** **TTF (time from IAO entry to IANOFO entry)**		**10**	**response** ↓ **AD, FDT (time counted)**	**10.1**
					diagnostic ↓ **TD (time counted)**	**10.2**
					logistic ↓ **LD (time counted)**	**10.3**

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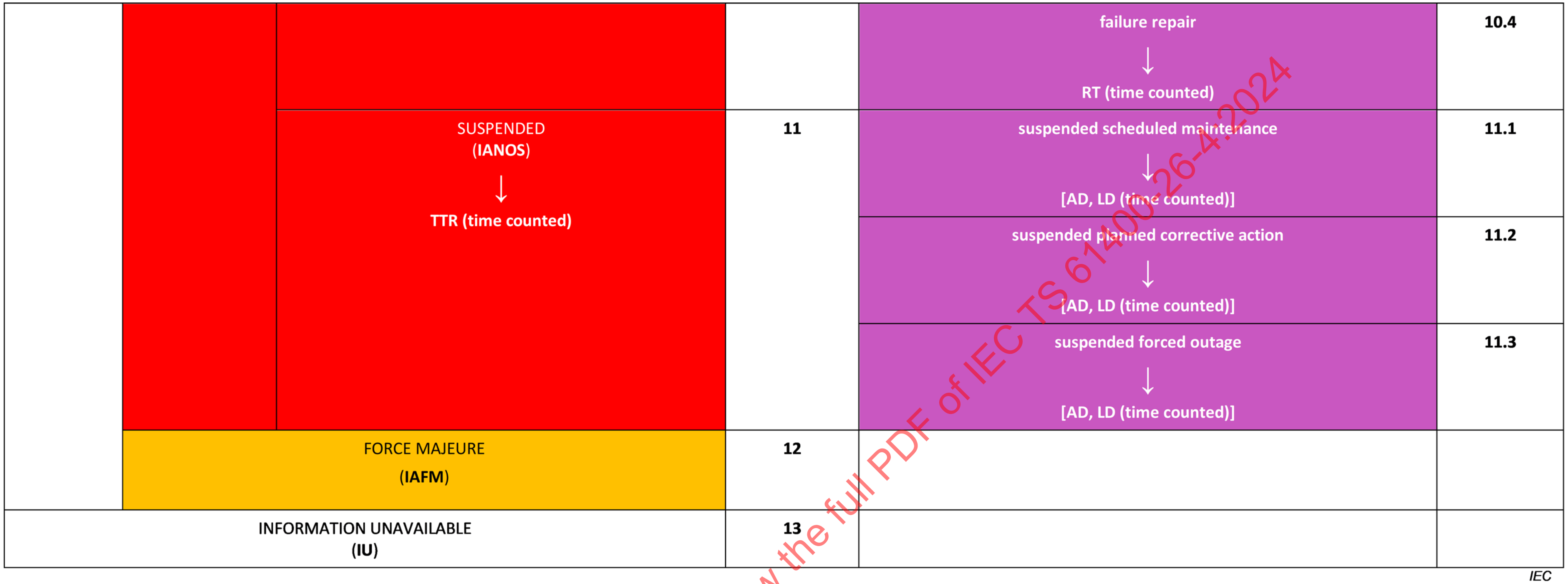

Key

white-coloured states	times in which the system is fault free with respect to reliability
orange-coloured states	times in which maintenance actions take place
green-coloured states	'uptime state'
red-coloured states	NON OPERATIVE states
pink-coloured states	optional information categories

Figure B.2 – Reliability terms derived from the information model – including optional levels

The coloured information categories in Figure B.2 highlight areas where reliability considerations exist. The 'arrow' in each cell points to what reliability parameters can be derived when the data point and the specified approach is applied. The cell marked green indicates the 'uptime state'. The red section is for NON-OPERATIVE and that is where damage, fault, failure, or alarm has disabled components or systems. The repetitive nature and frequency of these events are a measure of the reliability. The pink areas (in the optional levels only) information categories where users should carefully investigate and decide on how exactly to implement the counters representing the categories. This document recommends implementation as specified in Clause 5, but for some parameters a further detailing and even a choice of what exact data (counters) to use shall be made. Users are advised to consult IEC 61703 and IEC 60050-192 for further guidance and for a possible use of further terms than those identified in this document.

The orange highlighted information categories are where maintenance actions will require outages of components or systems. This is for necessary actions beyond the repairs or replacements under FORCED OUTAGES. As illustrated in Annex C, incorporation of these information categories in the registration for MTTF or not, shall be considered by the users.

Stakeholder's interests are primarily focused on FORCED OUTAGES (IANOFO) situations. Plant failures, both hardware and software, fall under the category of FORCED OUTAGE. Failure in this context is any malfunction regardless of 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 of response, diagnostics, logistics, mitigation, and repair and restoration among other considerations.

Time is often the basis for calculation of the reliability of a system. Most of the known metrics inherit the word time, like Mean Time Between Failures (MTBF), Mean Time to Failure (MTTF) or Mean Time to Restoration (MTTR). These and several other metrics and parameters are defined in IEC 61703 and IEC 60050-192. The information model developed in IEC 61400-26-1 is used in this document to specify the terminology for reporting some of these reliability indicators.

It is acknowledged that also other metrics exist. This includes metrics like MDBF (Mean Distance Between Failure) and MCBF (Mean Cycles Between Failure). In case another basis than time is used to determine the reliability of a WEGS, subsystem or component, an additional layer of the information model can be used, e.g., on counters for cycles or distances. In this case not time is summed up in each information category but perhaps rather registration of transitions in and out of entry points and exit points.

The mission or, more accurately, the usage profile of a WEGS is to provide energy over its lifetime as efficiently and reliably as possible given the quality of the components and understanding of the site, grid, and environment. The general term reliable, however, has little meaning or value since stating that something is reliable or more reliable implies a measurement that often does not exist, as we see in its use as a marketing term. Stakeholders in WEGS should understand that if the requirement exists for reliable equipment, then it is required that the term should be defined, and a measurement value such as failure criteria addressed in the specification along with how the requirement is to be verified.

Starting with the lowest level of repairability, the failure distribution should be established, and the definition of reliability specifically addressed. There are many variables that can affect the life of a part or component or assembly and depending on the specific technology, the reliability is heavily dependent on how the part is manufactured, how and where it is used, the operating environments, and the operating stresses.

Mathematical expressions for the probability of 'time to failure' are provided in IEC 61703.

B.3 Serviceability

Serviceability is a set of terms commonly understood as the ease with which a WEGS, system or component can be maintained and repaired. The sooner and with less effort (staff, tools, spare parts) a WEGS, component or system can be brought back into operation, the higher the serviceability is.

The main factors when determining the serviceability of a WEGS, system or component are:

Spare part strategy: The spare part strategy is fundamental to increase the serviceability of the WEGS, system or component. Keeping sufficient spare parts nearby reduces the MTTR and thus increases the serviceability. On the other hand, spare parts add to the overall costs of downtime.

Scheduled maintenance: The preventive maintenance time (PMT) is derived from the frequency and the time it takes to perform the scheduled maintenance.

Diagnostic time: The faster a failure can be diagnosed (or even predicted), the sooner the WEGS, component or system can be released to operation. Early detection of potential problems is critical in this respect.

Logistics: Logistics goes hand in hand with the spare part strategy. The faster a failed component can be procured and replaced, the sooner the WEGS, component or system can be released to operation.

Environmental factors: Environmental factors such as the weather have a big impact on the serviceability of a WEGS, component or system – e.g., offshore scheduled maintenance, planned corrective action and failure repair can only be conducted during certain periods of the year.

Information categories						
Mandatory level 1	Mandatory level 2	Mandatory level 3	Mandatory level 4	Mandatory priority	Optional level 5	Level 5 priority
INFORMA-TION AVAILABLE (IA)	OPERATIVE (IAO)	IN SERVICE (IAOS)	FULL PERFORMANCE (**IAOSFP**)	1		
			PARTIAL PERFORMANCE (**IAOSPP**)	2	derated	2.1
					degraded	2.2
			READY STANDBY (**IAOSRS**)	3		
		OUT OF SERVICE (IAOOS)	TECHNICAL STANDBY (**IAOOSTS**)	4		
			OUT OF ENVIRONMENTAL SPECIFICATION (**IAOOSEN**)	5	**calm winds**	**5.1**
					other environmental	**5.2**
			REQUESTED SHUTDOWN (**IAOOSRS**)	6		
			OUT OF ELECTRICAL SPECIFICATION (**IAOOSEL**)	7		
	NON-OPERATIVE (IANO)	SCHEDULED MAINTENANCE (IANOSM)		8	**PMT (time counted)**	
		PLANNED CORRECTIVE ACTION (IANOPCA)		9	**retrofit → TTR (time counted)**	**9.1**
					upgrade → TTR (time counted)	**9.2**
					other corrective action → TTR (time counted)	**9.3**
		FORCED OUTAGE (IANOFO)		10	**response → PMT, MTTR (time counted)**	**10.1**

IEC

				diagnostic → PMT, MTTR (time counted)	10.2
				logistic → PMT, MTTR (time counted)	10.3
				failure repair → PMT, MTTR (time counted)	10.4
		SUSPENDED (IANOS)	11	suspended scheduled maintenance → PMT, MTTR (time counted)	11.1
				suspended planned corrective action → PMT, MTTR (time counted)	11.2
				suspended forced outage → PMT, MTTR (time counted)	11.3
	FORCE MAJEURE (IAFM)		12		
INFORMATION UNAVAILABLE (IU)			13		

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Key

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pink-coloured states	optional information categories

Figure B.3 – Serviceability terms derived from the information model – including optional levels