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DNV GL WHITE PAPER

Definitions of Availability Terms for the Wind Industry

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List of abbreviations

Abbreviation	**Meaning**
BoP	Balance of plant
DNV GL	DNV GL - Energy, Renewables Advisory
EA	Energy Advisory
FO	Forced outage
GADS	Generating Availability Data System (under NERC)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
NERC	North American Electric Reliability Corporation
SCADA	Supervisory control and data acquisition
TS	Technical standard
TSA	Turbine supply agreement

ABSTRACT

Wind farm availability terms differ widely with the intended use; whenever an availability figure is referenced, it should be carefully defined. Any definition of availability must clarify the scope of analysis, and a prioritized list of states. This white paper offers a framework for understanding and comparing various forms of availability reporting.

1 INTRODUCTION: AVAILABILITY DEFINITIONS VARY

The term “availability,” as used in the wind industry, is a measure of the *potential* for a wind turbine or wind farm to generate electrical power. If the turbine is “available” and grid-connected, and the wind and other conditions are within the turbine specification, then power will be generated. The availability figure is used for many purposes, including energy estimates, revenue projections, turbine design performance evaluation, warranties, and performance bonuses or penalties.

The many uses of this key performance indicator have given rise to divergent methods of calculation, and with good reason: each is suitable for its own purpose. An understanding of the various definitions of availability is important because the resulting values differ and cannot necessarily be interchanged or easily compared. For instance, project developers may mistakenly use warranted turbine availability figures in ways that are not consistent with the definition of the value, which can lead to error in revenue projections. The choice of availability definition can have an influence on legal, financial, and technical matters.

This white paper offers a common basis to evaluate various availability calculation methods, and discusses the uses and implications of commonly used availability definitions.

2 TERMS USED TO DESCRIBE AVAILABILITY

Availability figures have several aspects, including how they are calculated, what they are used for, and what scope of equipment they are intended to describe. This white paper relies on a detailed understanding of the following distinctions, which are essential to keep in mind when calculating, evaluating, or comparing availability. This section discusses terms used to describe three areas:

- **Scope of analysis:**
  - System availability
  - Turbine availability
  - Balance of plant (BoP) availability
- **Contractual versus technical** availability
- **Calculation methods from operating data:**
  - Time-based:
    - Full-time definitions
    - Wind-in-limits definition
  - Production-based

Refer also to Section 4 for a discussion of the following related terms:

- Loss factor
- Model year
- Nominal availability

2.1 Scope of analysis: turbine versus system availability

System availability: If the primary interest is in understanding a wind plant's total power production, then a System availability is used, and all downtime may be counted as unavailable. System availability counts all downtime against availability, regardless of cause. It describes the ability of the wind farm as a whole to generate power given appropriate weather and grid conditions. Other names for this term are Project, Total, or sometimes Commercial availability. It may or may not include non-generating time due to curtailment or grid outage.

Turbine availability: On the other hand, if the turbine technology itself is being evaluated, then downtime related to other factors such as the balance of plant may be removed from the calculation. Any downtime due to non-turbine causes such as balance of plant or grid outages are removed from the numerator (and possibly the denominator) of the availability fraction.

These calculations consider only downtime that is attributable to the reliability of the turbine itself. Depending on the purpose of the availability definition, Turbine availability may include faults, maintenance, delayed maintenance due to impeded access, lightning, and cable unwrapping.

This white paper focuses primarily on Turbine availability, though the principles apply to System availability, as well as other metrics such as **BoP availability**, which describes the reliability of the wind plant's components other than the turbine such as the electrical collection system and substation, and **Grid availability**, for the presence of the grid.

2.2 Contractual versus Technical availability

Contractual availability: The Contractual availability is a metric negotiated in a turbine supply agreement (TSA) or operations and maintenance service agreement for a given project. The project's performance goals are measured with this metric and the value should be tracked precisely by the project's supervisory control and data acquisition (SCADA) system. Manufacturer- or owner-reported availability values such as those in monthly operating reports are likely to be of this form.

Contractual availability definitions typically have certain "carve-outs" or allowances[1] that serve an important purpose in the context of that contract but are not necessarily appropriate as a careful measure of turbine performance, or for comparison between projects and between turbine models. Contractual availability values often cannot be used directly as energy loss factor, and must be converted to a Technical availability value before use.

Technical availability: In contrast, Technical or Effective turbine availabilities seek to describe the technology's performance without special allowances and with uniform treatment of system states. Specifically, turbines are expected to generate power when site conditions are within specified operating ranges. This form of availability does not provide carve-outs for maintenance or other negotiated provisions, and is based strictly on a calculation of time in operation or energy produced. Technical availability is a more accurate measure of technology performance and provides a common basis for comparison across the industry.

[1] Downtime that is excluded from the availability calculation, such as an allowed 40 hours per year for scheduled maintenance, when the turbines are not generating but are flagged by the OEM as "available".

2.3 Calculating availability of operating projects

There are a number of methods to calculate availability given a set of operational SCADA data.

2.3.1 Time-based versus Production-based availability

Availability may be calculated as a ratio of two time values or as a ratio of energy values. While the former may be simpler computationally, the latter is a better representation of the energy losses, if the energy values can be accurately calculated.

Time-based availability: The calculation of availability based on a ratio of times does not consider the wind speed variation over time and so may not capture the added importance of a turbine's availability during high wind periods. Time-based definitions are easier to calculate given the data typically available from an operating wind project. Two types of time-based definitions are discussed in Section 2.3.2.

Time-based calculations take a form such as:

$$\text{Time-based availability} = \frac{\text{Time available (in hours)}}{\text{Total time in consideration (in hours)}} \qquad \text{(i)}$$

Production-based availability: It is common for turbines to have lower availabilities during high-wind periods than during low-wind periods: high winds imply higher production and higher loads, which in many cases may increase the number of faults and downtime. Additionally, if a project is able to confine a given turbine's maintenance and repair time to low-wind hours, that turbine will produce more energy than another with the same total number of down-hours but which suffered faults particularly during windy times. For these reasons, a careful review of project operational reliability often considers an energy-weighted or Production-based[2] availability. In contrast to Time-based availability, a production-based calculation considers the energy made as a fraction of the amount that would ideally be expected based on actual wind speeds and site conditions:

$$\text{Production-based availability} = \frac{\text{Energy actually produced (in kWh)}}{\text{Energy potentially expected (in kWh)}} \qquad \text{(ii)}$$

In practice, Production-based availability is more difficult to compute because of the added requirements for data and calculation; further, they require that the amount of energy that could have been produced had the turbine been operating be estimated. Production-based availability clearly carries an important distinction related to turbine reliability; these values may differ from time-based availabilities by up to 2% depending on the definitions being used.

In most cases, DNV GL finds that the Production-based availability calculations give results that are statistically equivalent to wind-in-limits (WIL) time-based calculations, which are discussed in the next section; where production-based calculations are not feasible, using the WIL definition rather than full-time definitions allows DNV GL to minimize this discrepancy.

[2] Also referred to as energy-based availability

2.3.2 Time-based availability: "Wind-in-limits" versus "Full-period"

Full-period definitions: Availability is often calculated as the ratio of hours deemed available as a fraction of the full period, such as the month or the year; in this method, the full period is in the denominator, e.g., 365x24=8,760 hours/year:

$$\text{Full-period availability} = \frac{\text{Number of hours available}}{\text{8,760 hours/year}} \qquad \text{(iii)}$$

Wind-in-limits definition: In contrast, a WIL form of calculation only considers the availability during times when the wind and temperature are within the turbine's operating limits, and the grid and BoP are available:

$$\text{Wind-in-limits availability} = \frac{\text{Number of hours generating kW}}{\text{Number of hours that the wind is between cut-in and cut-out}^{3}} \qquad \text{(iv)}$$

DNV GL uses historical availability data analysis to inform projections of availability into the future for use as loss factors in energy estimates. For these loss factor purposes, a Production-based availability analysis would be the most accurate; however, given the limited information often at disposal, Production-based availabilities may be difficult to calculate from project data, and so it is often more practical to calculate a Time-based availability. DNV GL has found that the WIL form of availability tends to closely approximate Production-based availabilities. The WIL definition allows "available" time to more carefully and meaningfully represent the time actually producing power, when a full Production-based calculation is impractical. For this reason, WIL availabilities are preferable to a Full-period definition for use in informing loss factors; DNV GL's full-fleet availability audits use a WIL calculation.

3 THE FORM OF AVAILABILITY DEFINITIONS

3.1 Generic framework

This section offers a framework for evaluating all types and definitions of availability.

For any definition of availability, one begins by categorizing states as "Ready," "Unavailable," or "Neglected" and then assigning every unit of time[4] so that they are all placed into one of these three bins – call them R, U, and N.

Then all definitions of availability take this form:

$$\textbf{Availability} = \frac{\mathbf{R}}{\mathbf{R + U}} \qquad \text{(v)}$$

[3] For short-hand, we refer to this as wind-in-limits, though it also requires that the ambient temperature is within specifications, and the grid and BoP are available. A more complete though unwieldy term could be "conditions-within-specifications".
[4] For time-based definitions, these units are typically 10-minute periods. For production-based definitions, they may be one-hour periods.

For Time-based availability calculations, the full study period (e.g., the year) will be accounted for by these three categories, so we can say:

$$\textbf{Period} = \textbf{Ready} + \textbf{Unavailable} + \textbf{Neglected} = \textbf{R} + \textbf{U} + \textbf{N} \tag{vi}$$

where "Period" is the full number of hours in the period under consideration; for instance, for a year that is not a leap year,

$$\textbf{Period} = \textbf{365*24} = \textbf{8,760 hours} \tag{vii}$$

A little algebraic manipulation allows this to be written as:

$$\textbf{Availability} = \frac{\textbf{R}}{\textbf{Period} - \textbf{N}} \tag{viii}$$

This formula can be used to describe all time-based definitions of availability and is a convenient basis for the discussion of the specific availability definitions below. For convenience, the rest of this section uses the time-based example, but the method is equivalent for production-based definitions.

3.2 Assignment and prioritization of states

All states must be assigned a priority because states are by nature non-exclusive; that is, two or more states may be in effect simultaneously. For instance, suppose that a given turbine is not producing power between 2:00 p.m. and 3:00 p.m. for several reasons – it is inoperative because of a fault (a "fault" state), and the wind is below cut-in ("calm" state), and the turbine cannot be reached for repair due to a snowstorm ("suspended" state). In this case, which single state should be assigned for this period? From the owner's point of view, the fault takes precedence over calm and suspended states, so in this example, the turbine must be listed as faulted.

This precedence ordering of states is part of an availability definition. The difference from one definition to another lies in the precedence of states and in the assignment of states to the three bins R, U and N.

3.3 Definitions of Turbine availability used by DNV GL

DNV GL formulates availability definitions in order to be compatible for several uses, including as a loss factor in pre-construction or operational energy production estimates, as a comparison across turbine technology, and as an indicator of wind project performance. In the last case, System availability is typically used, while in the former cases, the focus is usually on Turbine availability when possible[5].

Table 3-1 below delineates DNV GL's Turbine availability definition as used in energy assessments and turbine technology reviews. The definition is given by binning all major types of states and giving them a priority order. The table also compares it with how the states are commonly binned from other points of view. The states are listed in priority order: the first applicable state in the list must be assigned.

[5] For operational projects, it is not always feasible to extract Turbine availability from System availability.

Table 3-1 Comparison of three typical Turbine availability definitions, where Availability[1] = R / (8,760 – N)

Prioritized turbine states	Examples	DNV GL Technical "Wind-in-Limits" Availability: Owner's perspective (Energy loss factor)	Example Manufacturer's Availability: Manufacturer's perspective	Example Owner's "Operational" Availability: Owner's perspective
Out of wind or temperature specification	High or low winds, high or low temperature.	N (2)	--	--
Generating power		R (3)	--	--
Data unavailable		N or U (4)	N	N
Turbine-related stops	Scheduled maintenance	U	R	U
	All other repairs/maintenance Turbine faults Lightning 5 Cable untwist 5	U	U	U
Stops that the turbine is not responsible for	Grid or BoP outage 6 Blade icing Bat curtailment, etc.	N	R	N (possibly R for blade icing)
	Weather-impeded maintenance times	N (7)	R	U
Operative	Operating at or below design specifications (but not necessarily generating power)	-- (8)	R	R

1 All states are assigned one of these three categories: R: ready, U: unavailable, or N: neglected, for periods that are removed from consideration altogether. For any period considered, such as a month or a year, Period = R + U + N.

2 DNV GL uses the availability as a loss factor in energy assessment calculations. For this reason, only time between cut-in and cut-out is considered. All other time is removed from the denominator; that is, it is assigned to the category "N" in the general formula, Availability = R/ (Period – N).

3 In DNV GL's Wind-In-Limits definition, the only time considered "R" is time that the turbine is actually generating power.

4 Lack of data creates uncertainty. Periods with lost data may be calculated in any or all of three forms: as N, as U, or as both R and U in the same ratio as appears in the data. These calculations may be used to create a range of uncertainty.

5 DNV GL considers downtime due to lightning and cable unwinding to be unavailable. These may be placed elsewhere by others.

6 Note that this table focuses on *Turbine* availability. The owner may also be interested in windfarm availability in which case, for example, BoP outages would be classified as "U", etc.

7 DNV GL's energy assessments include another loss factor for faulted time during impeded access, and therefore this time does not need to be included in the turbine availability. However, during an operational data analysis, the data may not support this distinction and this non-generating time may get included in the turbine availability loss factor rather than the access loss factor. That is, this time may be called U during a data analysis, but it will only be included in one loss factor and will not be double-counted.

8 Some definitions may put an "Operative" state at the bottom of the priority, as a catch-all for lack of any known issues that are higher on the priority list. Instead, the WIL definition puts "Generating" and out of environmental specification at the top of the priority list. Notice those categories are not used in the other two definitions.

As discussed above, this WIL definition of availability can be summarized as follows:

$$\frac{\text{(Total time producing kW)}}{\text{(Total time the wind is between cut-in and cut-out, ambient temperatures are within specification, and there are no grid-out or BoP issues)}}$$

Some of the most significant differences between manufacturers' availability and DNV GL's fleet availability audits are:

1. **"Wind-in-limits":** DNV GL removes all wind-out-of-limits time from the calculation, i.e., low and high wind periods are put in the "N" bin, in order to approximate a loss factor in the calculation of energy production. This category is given the highest priority; this is equivalent to saying that DNV GL only considers availability during times when the wind is within limits. Turbine manufacturers and many owners do not remove this time – manufacturers consider it "R" and owners may consider it "U". Both typically place it lower in the priority list. This characteristic often accounts for a large portion of the deviation of manufacturer's availability figures from DNV GL's values.
2. **Grid & BoP:** When comparing turbine technologies, DNV GL removes from consideration periods of grid and BoP outages. That is, DNV GL classifies grid outage time as "N", whereas turbine manufacturers appropriately would consider it "Available" – which is appropriate from their viewpoint. This is a good example of how the point of view affects the form taken by this calculation.
3. **Maintenance:** Scheduled maintenance is usually listed in contracts as "Ready" by manufacturers, because from their point of view, scheduled turbine maintenance is a required activity that doesn't reflect poorly on the machine reliability, and therefore it is normal to specify a number of expected hours for these routine tasks. Owners and DNV GL list the time as "Unavailable" because they are non-generating times attributable to the turbine.
4. **Lightning:** For the purposes of comparing and evaluating turbine technologies, DNV GL considers lightning-caused outages to be Unavailable, because some turbine types are better able to continue operating through lightning strikes than others.
5. **Icing:** DNV GL treats icing outages differently at this time, because most turbines shut down during severe icing. Therefore, DNV GL classifies icing outages as "N", removing this state from consideration. If anti-icing systems were to become more common and some turbines could significantly reduce icing downtime, icing could be handled similarly to lightning.

   Blade icing not only causes outages; before shutting a turbine down, it may cause a reduction in power output by disrupting the blade's aerodynamics. These two effects of icing are distinct and are not "double-counted" in DNV GL energy calculations. Availability as a metric is not intended to account for changes in performance, which would typically be addressed in a separate metric. Since icing-related downtime is removed from consideration ("N"), energy production losses due to icing are not accounted for in DNV GL's Turbine availability figures; instead, they would generally be accounted for as part of a separate energy loss factor (Environmental Losses) along with any reduced aerodynamic performance.
6. **Force majeure:** Force majeure terms are contractually defined and vary widely. With the exception of lightning, DNV GL generally considers force majeure periods to be in the "N" category.

7. **Access:** Turbine manufacturers often consider as "R" or "N" any time the turbine is down due to lack of access during a turbine fault or owner-requested shut-down. In most cases DNV GL classifies it as "N" because energy assessments include a separate loss factor for site access. During an operating data analysis, lack of information may cause this be counted instead as "U".
8. **Incomplete data:** The treatment of lost data time varies among definitions and can significantly affect the outcome. Periods with lost data may be calculated in any or all of three forms: as N, as U, or as both R and U in the same ratio as appears in the data. Note that using R and U in the same overall proportions may not be a valid assumption, since data are more likely to be lost during some form of outage. DNV GL typically uses two of these calculations to create a range of uncertainty.

3.4 Other definitions of availability used in the industry

DNV GL's use of WIL availability definition is essentially compatible with industry-standard definitions; however, the mandatory minimum data recorded under these general standards may not be sufficient for a careful calculation of the WIL availability value, and some review may be necessary to confirm if additional data could be required. In particular, the WIL definition must be able to distinguish environmental "U" states such as icing and lightning, from these "N" states: high and low winds, high and low temperatures. In contrast, industry definitions may group these into one environmental category. If the minimum industry classifications are used without some optional detail, other turbine or windfarm records must then be used to distinguish icing and lightning from times when the wind or temperature is out of specification.

3.4.1 IEC 61400-26

The International Electrotechnical Commission (IEC) issued a Technical Standard TS 61400-26-1 called "Time-based availability for wind turbines". The standard seeks to systematize the reporting of wind turbine states such as those listed in the "examples" column of Table 3-1 above. While it defines states, it does not seek to standardize the availability definitions themselves, although two typical examples are offered; these examples are shown in Table 3-1.

DNV GL's Turbine availability definition is largely compatible with the current TS 61400-26-1; however, a careful characterization of "wind-in-limits" time may occasionally require additional information, depending on how the TS is applied. The standard allows that many types of down-time be recorded as "Out of environmental specification", including high and low[6] winds, high and low temperatures, lightning, and icing; these states can thus not necessarily be distinguished based on minimally TS-compliant data only. In the TS, the "wind-in-limits" periods which constitute DNV GL's denominator may still have to be determined through nacelle anemometer records, temperature records, and other sources, which is DNV GL's standard practice.

The TS also includes a "Technical Standby" state, which includes both "U" states (e.g., cable untwist, pitch testing, de-icing periods) and "N" states (warm-up periods after cold), and the TS does not require that information about the nature of the technical standby be recorded. These are unlikely to amount to a large amount of time, and so in most cases, this ambiguity is not of significant concern.

[6] The TS's "calm" state is an optional sub-state of "out-of-environmental specification".

In 2014, the IEC issued the second part of its availability technical standard, TS 61400-26-2 called "Production-based availability for wind turbines". Like the first part, it seeks to unambiguously describe how data about wind turbine states should be recorded, by adding a method to record both the energy that is actually generated, and the energy that could potentially have been generated for a turbine that is generating less than its expected output. Lost production is thus estimated and a Production-based availability may be calculated. As in part 1, the details of the "out of environmental specification" states are not specified, and the "calm winds" sub-state is still optional. The third part, TS 61400-26-3: Availability for wind power stations, does not affect the potential ambiguity of environmental and technical standby downtime either.

3.4.2 NERC GADS

In Canada and the United States, North American Electric Reliability Corporation (NERC) requires the reporting of detailed data on the amount of time spent in various wind turbine states. Under this Generating Availability Data System (GADS) data standard, non-generating time due to icing, temperature, and lightning are all recorded with separate codes. The GADS Outage Classification Guidelines in Appendix H carefully considers the complexity of categorizing downtime during specific environmental conditions:

> Weather events are often difficult to categorize. When labelling an outage as FO[7], determine what equipment caused the failure. For example, if a turbine has an anemometer with a heater to prevent icing, but it ices up anyway, then the heater failed and the outage would be FO–Control System. If lightning were to strike a blade with lightning protection and cause damage, then the protection system failed, and the outage would be FO-Rotor. Consideration must be taken into account for circumstances that exceed the protection system design limit.

Figure 3-1 from the GADS reporting instructions shows the correlation between its categorization of states and those of Institute of Electrical and Electronics Engineers (IEEE) 762 and IEC 61400-26.

[7] FO: Forced Outage, i.e. "N"

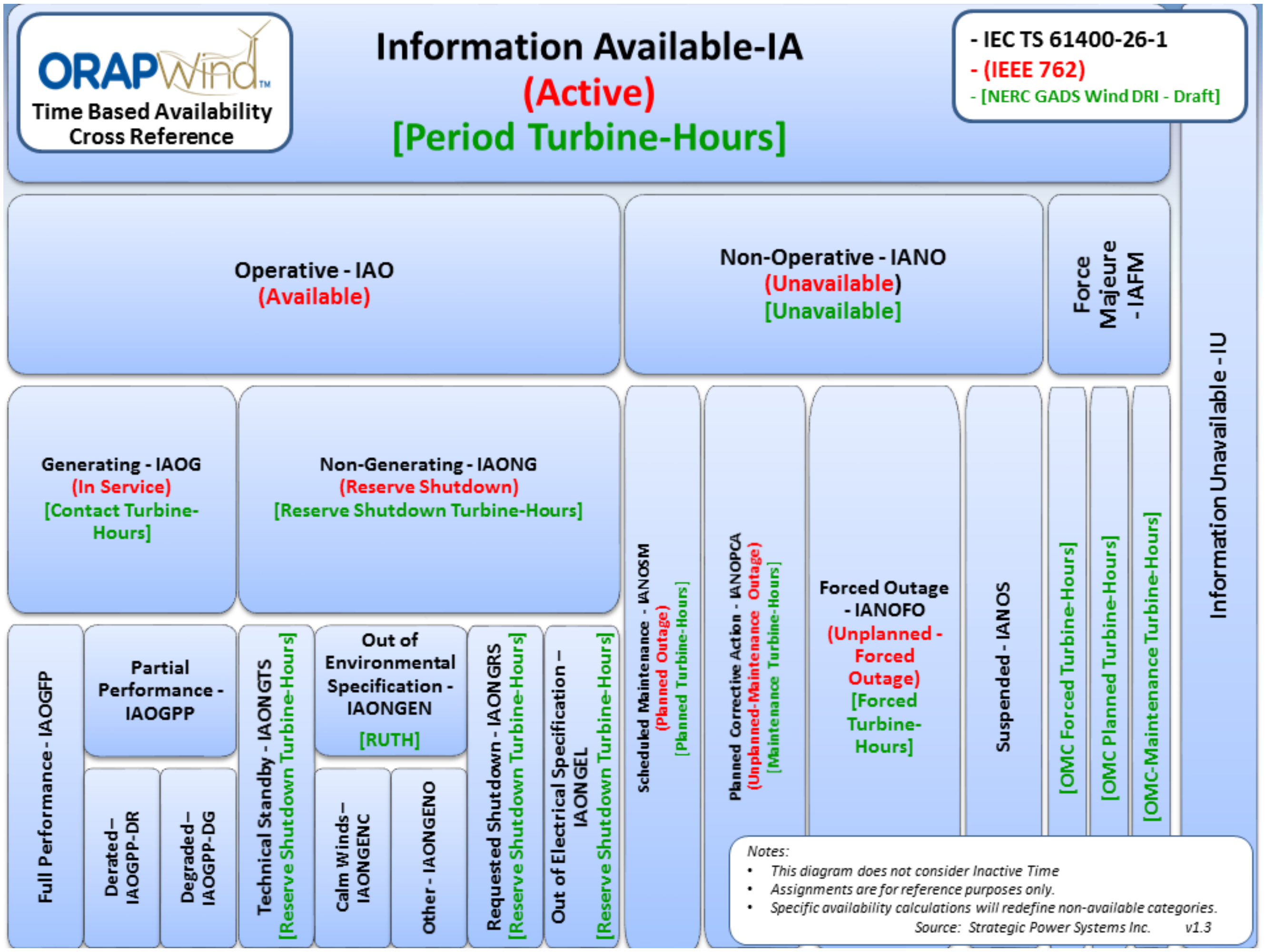

Figure 3-1 Cross reference of NERC, IEEE, and IEC states, from GADS instructions [3]

3.4.3 Other data standards

Some earlier data standards used for wind plants were developed referencing more general standards developed for electric power reliability reporting. For instance, the IEC's TS 61400-26 refers to IEEE's Standard 762 and the ISO's 3977-9 "Gas Turbines - Procurement - Part 9: Reliability, Availability, Maintainability And Safety". These older and more general standards do not conflict with wind-in-limits definitions, though they are likely to have the same or more limitations as those discussed earlier in this section.

4 DISCUSSION OF RELATED TERMS

4.1 Loss factors

In estimations of energy production, wind conditions and a turbine power curve are used to calculate a "gross energy output" in GWh/annum. This figure is multiplied by a series of loss factors to account for the many factors that reduce this ideal upper bound; typical loss factors include wake effects, electrical efficiencies, temperature shutdowns, curtailment, BoP availabilities, turbine performance, and Turbine availability. For this Turbine availability loss factor, DNV GL uses the turbine model's projected availability discussed in this white paper.

The availability loss factor, since it is multiplied by the gross energy output, must apply only to the turbine's performance during wind-in-limit times. The turbine's status during calm times is completely irrelevant; for instance, "availability" below cut-in speeds could vary arbitrarily without having any effect on the energy output of the turbine.

The most appropriate availability loss factor would be a Production-based availability calculation, which is implicitly "wind-in-limits", since by definition it does not include non-generating times in the numerator or non-windy times in the denominator. A Production-based availability can be difficult and sometimes impractical to calculate; however, DNV GL has found that the WIL availability is usually closely related to the Production-based availability. For this reason, DNV GL uses a WIL availability definition for the availability loss factor.

In contrast, the use of a "Full-period" definition of availability for a loss factor implicitly assumes that performance is the same whether the wind is in and out of limits; this is not typically the case.

4.2 Model year

A "model year" is the set of turbines installed in a given year in a given region. For instance, if commercial installation of the XYZ-2.4MW-100 turbine began in January 2010, the first "model year" includes all those turbines installed in 2010. DNV GL notes that the life-time average availability of a turbine's first model year is apt to be somewhat lower than the lifetime average of the same model's third model year. For this reason, DNV GL may project a slightly lower *long-term* availability for the first model year of a turbine design in a given region.

The idea that the first "model year" of a given turbine model has a lower life-time availability is not to be confused with the "ramp-up", which refers to the expectation that a turbine will have a lower availability during the first year of operation after commissioning. In other words, the distinction is drawn here between a given turbine's first operating year, and the full life of the first installations of a given turbine model.

4.3 Nominal availability

DNV GL reports the average availability projection for a project's operating years 2-5 as "nominal" availability. This term can be applied to any of the definition types discussed above, such as nominal Turbine availability or nominal System availability.

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Present uniform definitions of terms related to availability in wind projects for use by DNV GL Energy.

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