PV System "Availability" as a Reliability Metric – Improving Standards, Contract Language and Performance Models

Geoffrey T. Klise[1], Roger Hill[2], Andy Walker[3], Aron Dobos[3], Janine Freeman[3]

[1]Sandia National Laboratories, Albuquerque, NM, 87185, USA
[2]13809 Indian School Rd. NE, Albuquerque, NM, 87112, USA
[3]National Renewable Energy Laboratory, Golden, CO, 80401, USA

***Abstract* — The use of the term "availability" to describe a photovoltaic (PV) system and power plant has been fraught with confusion for many years. A term that is meant to describe equipment operational status is often omitted, misapplied or inaccurately combined with PV performance metrics due to attempts to measure performance and reliability through the lens of traditional power plant language. This paper discusses three areas where current research in standards, contract language and performance modeling is improving the way availability is used with regards to photovoltaic systems and power plants.**

I. Introduction

The "availability" of an electrical energy generating technology is a term that is used to describe its operational status, which is generally a reflection of component and system reliability (uptime, downtime and condition states). IEEE 762-2006 "Standard Definitions for Use in Reporting Electric Generating unit Reliability, Availability and Productivity" [1] defines availability as "…the fraction of time in which a unit is capable of providing service and accounts for outage frequency and duration," and that "Reliability in this standard encompasses measures of the ability of generating units to perform their intended function" (which is inherently a 'probability of success' that energy will be created). This standard, however, was developed for traditional power plants, as evidenced by a recent effort by the North American Reliability Corporation (NERC) to suggest "new terms and definitions for wind turbine generation" due to the intermittent nature of the fuel source [2].

Photovoltaic (PV) plants rely on irradiance as their fuel source and do not have clear guiding documents for expressing availability states. The inherent variability of PV (if not supplemented with some type of energy storage technology) as well as it being a 'new' electrical generating technology now working along-side the utility portfolio of conventional power plants, requires a new focus for understanding its variability and long-term reliability as compared to other energy generating technologies.

This paper discusses best practices and standards efforts underway to address the availability of PV plants, contract language and improvements in PV performance models for expressing the probabilistic results of different reliability states. When PV generating technologies represent a larger share of electrical generation, reliability concerns can be adequately addressed through a common understanding of terms and definitions unique to PV. To provide a recent example of the different ways availability is used, one only needs to look at papers presented at PVSC 42, where availability is described as an energy metric (an "effective availability") as a function of equipment outage [3], and as a reliability metric describing equipment operational state [4]. These differences stem from the macro vs. micro view of a fleet vs. a system, however there is nothing similar that each paper draws upon as a basis for describing availability.

II. Contract Language Improvement

One area where availability language can differ greatly is in an operations & maintenance (O&M) contract. A review of what is termed an "availability guarantee" within O&M contracts reveals multiple definitions, some of which are equipment and time-based, others energy-based, and some a mix of both. What is important in asset management contracts is the way equipment is maintained, and who is responsible for repair or replacement over the plant's lifetime. Availability can also be specific to the individual components and/or subsystems within a plant. For example, there may be a contractual requirement for one service provider to maintain a given availability for the tracking system and a separate provider contract addressing uptime of the inverter [5].

Time-based data on the PV plant's component operational states (raw availability, which includes unavailability of all forms) can also be utilized for calculating the contractual availability, which can have multiple exclusions that provide a different result than accounting for all outages, regardless of cause [6]. Examples include: down-time due to grid interaction (grid outage or shutdown to avoid grid instabilities); anticipated shutdowns for preventative O&M; or delays in repair beyond the service provider's control such as extreme weather or Force Majeure.

The way reliability, and ultimately availability can be better understood, and then improved is to structure data collection for reliability analysis, one of which, for example, allows for analysis using a commercial reliability tool [7]. While calculating the raw availability using methods to set up data for reliability engineering analysis, annual contractual availability can also be determined using the same dataset.

Contractual availability is typically calculated at the inverter, but other locations can be used to measure sub-system, combiner and re-combiner boxes, string, or module-level availability, depending on instrumentation detail or data availability. This would be done if the PV plant owner or operator is interested in tracking a specific component in more detail, and has highly reliable monitoring equipment to capture that component's operational state. A classification system for collecting component level detail with associated levels of granularity is proposed in Table 1[6].

TABLE 1
CLASSIFICATION SYSTEM FOR DATA TO SUPPORT AVAILABILITY CALCULATIONS

Data Area/System Class	**A**	**B**	**C**
Data Granularity	**High**	**Medium**	**Low**
Components measured and potentially subject to availability calculation	Inverter, combiners (ac, dc), disconnects, modules, transformer, DAS, SCADA	Inverter, combiners (dc), disconnects, DAS	Inverter
Necessary Instrumentation	DAS, SCADA, inverter POA irradiance, Utility grade meter	DAS, SCADA, inverter, irradiance	DAS, inverter
Timestep	1 to 15 minutes	15 minutes	15 minutes
External Grid Events	Grid outage, curtailment, grid support	Grid outage, curtailment	Grid outage

PV plants that employ high dc to ac ratios can potentially allow a larger share of dc components to be non-operational than compared to systems with similar ac output but lower dc to ac ratio. Contracts with these plants would benefit from having greater data monitoring and/or analysis capabilities on the dc side to 1) help capture issues that could be covered by warranties, 2) provide more component capability data to assess reliability and availability impacts of operating in these states, e.g., tracking replaceable inverter parts for reliability analysis, and 3) provide greater clarity to O&M providers on responsibilities and exclusions for availability guarantees. For example, an availability guarantee for a high dc to ac ratio plant would have clear exclusions against outages that are not actively being serviced, though both parties are aware of the issue. As energy production is not being impacted due to operating at a high dc to ac ratio, the repair to the equipment experiencing an outage could be held off until a scheduled preventative maintenance check and the loss of availability would not be counted against the O&M provider.

PV plants with energy storage are an important topic as their availability 'time window' can look similar to conventional power plants. Availability guarantees will need to adapt to meet the schedule of when the energy storage will be utilized for advanced grid functionality or providing energy to meet peak demand periods. For example, the availability guarantee could have an additional energy storage device 'availability' that aims to ensure that the battery bank is actively charging within specified ranges and able to meet peak load demands as a function of battery charge capacity from the current-day irradiance profile. The availability guarantee will also need to anticipate exclusions for providing grid services that may include curtailment or reactive power support that may be a part of future interconnection agreements. For example, grid curtailment events are typically excluded from existing availability guarantees and not counted against the operator or maintenance provider, however new inverter functionality that results in greater grid interactivity may result in less energy production. These additional services may or may not have a 'value' depending on utility requirements, and a well written availability guarantee would ensure that energy lost due to these possibly competing events is not counted against the O&M provider availability guarantee.

PV trackers can be found in availability guarantees, with separate language that assigns damages based on an availability threshold. Damages may also be determined from energy production losses based on the uptime of the tracker. If a tracker goes out, it can still produce energy in an off-track position, however those losses can be difficult to quantify without accurate performance models that can replicate the tracker behavior or algorithms that can quickly back-out energy production losses due to tracker outages in a specific part of the field. Like inverter manufacturers, some tracker manufacturers offer extended warranties to protect against outages. This is a case where having a separation between energy production losses in a performance guarantee and tracker availability losses in a separate availability guarantee would reduce uncertainty around energy losses when multiple factors beyond equipment capability may be contributing to that loss.

III. AVAILABILITY AND STANDARDS

A. Availability Information Model

In the standards area, an effort is underway to develop an availability information model that customizes existing IEC

Technical Specifications (TS) in Wind for PV power station (plant) use. Overall, the goal is to provide descriptions of quantitative numerical PV plant performance metrics which can then be used to develop statistical distributions of failures and failure rates, fault times, restoration times, and related effects on the plant O&M functions, which are useful for ongoing plant performance assessment. This information model [8] is currently being developed as an IEC Technical Specification: IEC/TS 63019 – "Photovoltaic (PV) Systems – Availability for PV Power Stations," which defines both time-based and production-based metrics used to convey the different states of availability/unavailability for a PV plant and how those can impact energy production and performance. This TS formalizes the different operational states for PV and is based in part on previous work done for the wind industry. External users of this information model (based on their interest in the energy production) may include retail utilities, grid system operators and power market organizations. Internal users (on the asset management side) may include project developers, designers, specifiers, financiers, insurers, policy makers, maintenance providers, operators and owners. The intention of this TS is to define a common basis for exchange of information on availability indicators between these parties.

This is achieved by providing an information model specifying how power plant time designations shall be split into information categories. The information model defines the terms and the basis for how to allocate time for reporting availability indicators, or more precisely, unavailability indicators. The station condition and/or energy of a PV power plant will take such conditions and environmental and other site aspects into account for reporting. Environmental aspects include solar irradiance and other weather conditions at the site. System operating constraints which might affect energy production need to be included in the energy calculus and reporting.

Table 2 shows the relationships between time allocations, measured energy production, and how these compare with expected energy. The state categories include: Full performance, partial performance, technical set points/standby, out-of-environmental specification, requested shutdown, out-of-electrical specification, scheduled maintenance, planned corrective actions, forced outage, and suspended operational situations. Some additional detail is as follows:

- **Measured Time –** The measured time is for any outage of any component. Hours are tracked and separately referenced as to what part of the plant was affected and any up-stream or downstream impacts of that outage.
- **Measured Production** – Reported as the plant's production, in MWh, for example. Full Production is when there are no failures or outages, or portions of unavailability. Partial Production would be when one inverter is down out of 10, for example, and measured production from those 9 is reported.
- **Expected Production** – Values here are what was expected from a performance model or adjustments from a pro forma. The Technical Setpoints/Standby require greater fidelity as they include clipped inverters, storage, power factors required by the grid, etc., which are not necessarily tied to expected production but other services, some which can lead to lost production.
- **Lost Production** – Category where over or underestimated production is recorded. For example, a forced outage is attributed to the specific component, where the partial production is then determined along with the overall lost production for that time period.

TABLE II

DATA RELATIONSHIP BETWEEN CATEGORIES ON A TIME AND PRODUCTION BASIS

Time and Production Data										
Major Time Categories	Full Production	Partial Production	Technical Setpoints / Standby	Out of Environmental Specification	Requested Shutdown	Out of Electrical Specification	Scheduled Maintenance	Planned Corrective Actions	Forced Outage	Suspended
Measured Time (units)										
Measured Production	*Production Reporting*									
Expected Production	*Performance Modeling (expected)*									
Lost Production										

Once the durations of unavailability events are observed or directed, the duration of these events will be logged by the impact on the affected systems, and guidance will be provided on techniques to measure the affected components availability metric and energy consequence. The metered production and estimated lost energy production can therefore be compared to expected energy values as governed by IEC 61724, as well as any additional plant deratings or adjustments that have been defined as expected occurrences made or other allowances stated for the expected losses in the state categories. The TS is to be harmonized with IEC 61724 as it includes approaches defining expected energy using performance modeling.

One complication inherent in this is that some designed functions of PV power plants may include features that might constrain or compete with full power operation. An interesting example is storage which diverts energy on a time basis for alternate use or delivery. The storage subsystem would not impact the availability of a more typical grid connected PV plant. But due to the competing use of energy, an energy balance may be needed for differing functions (i.e. charge/discharge), and this would be accounted for in the set point category. Similarly, the new TS could accommodate metrics for plants with utility-related operational constraints like energy feed-in limits under certain voltage conditions on distributions lines, or contractual limitations on energy delivery that gets implemented through clipped inverter operations. Performance models (or pro forma budgets) for such plants should also include those complications for calculating plant performance expectations as a basis for comparison.

As described earlier, the use of a contractual availability guarantee has been controversial for the stated reasons. This TS will provide a tool for inclusion and exclusions clearly stated for contractual use through clearly defined categories and comparisons to produced and expected energy during times of outages.

B. Performance Standards Using Availability

When considering PV performance, availability is not a part of existing test standards such as IEC 61724 or ASTM 2848 that both focus on energy metrics. That is beginning to change with an update to IEC 61724, where it is proposed to include an *energy* availability as a function of expected energy production, but for the energy test, also explicitly exclude unavailable time when components are not producing energy. As such, it is important that PV performance standards qualify their use of availability. Descriptive or modifying terms such as *energy* availability or *effective* availability help reduce confusion as they explain the energy "output" derived from that equipment state. These are substantially different from the time-based, equipment-specific *raw* availability used as a basis for contracts and the TS. Certain energy production metrics, whether predicted, expected or measured are not always directly correlated to the equipment state.

The information standard discussed in III.A. is being developed to further elaborate on reliability impacts to potential or actual energy production, where terms such as full and partial performance are a function of internal and external events that can impact energy production, but do not define energy production and output explicitly like a performance ratio or energy performance index would, but do include the determination of lost energy due to unavailability by category and production consequence. This is an important distinction and re-stated again as energy metric calculations in the upcoming revision of IEC 61724 exclude equipment downtime (unavailability) and operation in 'clipping' modes in order to accurately quantify the system's energy performance under normal operational conditions.

IV. AVAILABILITY IN PV PERFORMANCE MODELS

PV performance models currently define availability as a function of scheduled downtime, with no true representation of the probabilistic behavior of how components fault or fail and the downtime associated with repair or replacement. This simplistic representation neglects the true probability that a plant will operate at a desired availability level, and therefore performance and energy production estimates have additional error that is not quantified.

SNL developed a proof-of-concept PV reliability performance model (RPM) which adds that lifetime uncertainty to energy production using statistical distributions of component behavior [9]–[11]. These include both failure and restoration distributions that can be used for scenario analysis, which, for example can help optimize maintenance activities based on the probability of anticipated component failure. Although gathering reliability data to support models like this has proven to be challenging [12], this reliability-data collection framework now exists for industry to use [7].

The functionality of PV-RPM is currently being added to the NREL's System Advisor Model (SAM) to provide a feature for evaluating PV performance model estimates with reliability statistics. This new capability allows for improved availability estimates by sampling distributions of component events, faults and failures. This in turn will help better inform O&M contracts and their associated availability and performance guarantees, as well as production estimates and equipment component states used in the availability information model.

Reliability metrics have been added to the SAM model within the scripting environment. Current testing of the implementation has revealed that the reliability algorithms used in the proof-of-concept match well with how it is being implemented in SAM through a comparison of module failure rates and resulting energy loss. A new dc derate is being developed to account for the losses from applying the component reliability statistics on the dc side, such as modules and dc combiners. On the ac side, the existing derate will now include reliability statistics for inverter and transformer outages. By the end of the year, validation and testing by PV modeling experts will commence, along with development of case studies using real failure data, and a detailed user manual describing how to set up a reliability analysis in SAM.

V. Conclusion

These current efforts on best practices, standards development, and software improvements are supporting an improved understanding of availability and the reliability assumptions and calculations behind the metric.

Contract improvement work is focusing on the time-based aspect of availability to improve availability guarantee language with PV plants using high dc to ac ratios, energy storage and trackers. Technical Specifications are being developed on time and energy-based availability, with multiple definitions that can be used for a variety of stakeholders, i.e., reporting reliability states to transmission grid operators as well as system owners.

Key improvements to PV performance modeling software are underway which will allow performance estimates to be expressed with reliability impacts, along with improved availability estimates.

A goal of this work is to see the availability information model language specified in O&M contracts and availability guarantees. Accurate and standardized data collection on both the equipment and impacts to performance and energy production will then be necessary to support a reliability-focused performance model. When a plant's energy production is modeled with reliability, these inputs can then be validated with field-collected fault and failure data to improve model prediction results. Ultimately, improved estimates of PV performance and levelized cost of energy can be made with a greater focus on probabilistic events that will occur over the PV plant's lifetime.

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