AWS TRUEPOWER

RENEWABLE ENERGY SERVICES

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A RENEWABLE ENERGY

POWERHOUSE

Acquired by UL (2016), AWS Truepower is now apart of an even more extensive portfolio of renewable energy services.

As a trusted advisor we help mitigate risk and navigate complexity throughout the project lifecycle and across the supply chain.

AWS TRUEPOWER

100+

Country locations of UL renewable energy customers

55+

Years of combined experience in the renewable energy industry

Independent / Owner's Engineer on

450+

wind & solar projects*

*since 2012

ADVISED

90%

of the wind and solar industry's top **PROJECT DEVELOPERS** and **PLANT OWNERS**

500+ UL Renewable Energy Experts

200,000+ MW

Total renewable energy megawatts (MW) assessed

FORECAST PROVIDER for

60+ GW

of installed renewable energy projects

OFFICE LOCATIONS

UL OPERATES IN
140+
COUNTRIES

● Key Locations

MITIGATE RISK

Safety, reliability, and optimal performance are not a matter of chance.

Rely on engineering experts to provide you with transparent, high-quality solutions based on proven science that generate healthy returns.

NAVIGATE COMPLEXITY

Challenges in the earliest stages of development can impact project outcomes.

Trust that our experience, accessibility, and ability to provide reliable solutions will successfully guide you through the process.

UL PROVIDES SERVICES TO RENEWABLE PROJECTS ACROSS THEIR WHOLE LIFECYCLE

Software & Data

Project Development Support

Due Diligence & Bankability

Operational Asset Management

Grid Solutions

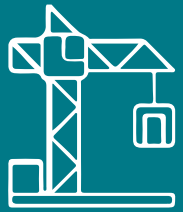
Certification

Testing & Inspection

Standards

Product System Evaluation

Research & Advanced Studies

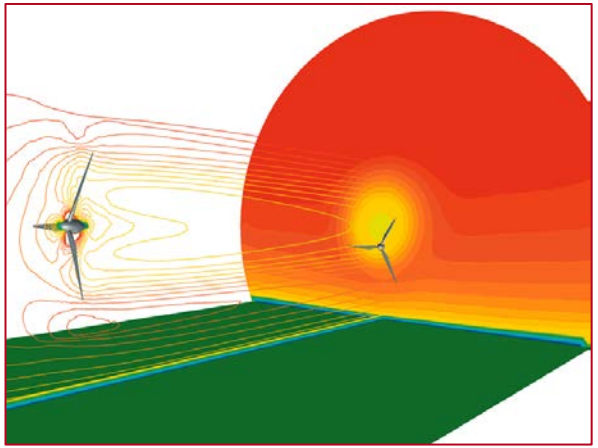


PROJECT DEVELOPMENT SUPPORT

Navigate project complexities in the earliest stages of development.

- Site Screening & Feasibility
- Long-Term Resource Assessment Studies
- On-site Solar and Wind Data Collection
- Conceptual Project Design/Drawings
- Energy Production Estimates
- Technology Selection & Suitability
- Permitting & Environmental Assessment
- On-Site Inspection and Construction Services

LONGTERM ENERGY ASSESSMENTS



- On-site solar and wind resource data collection and quality control
- Preconstruction energy assessments
- Design optimization and loss assessment
- Fleet analysis to support the acquisition of individual assets and portfolios

Our Clients:
Developers
Investors
Utilities

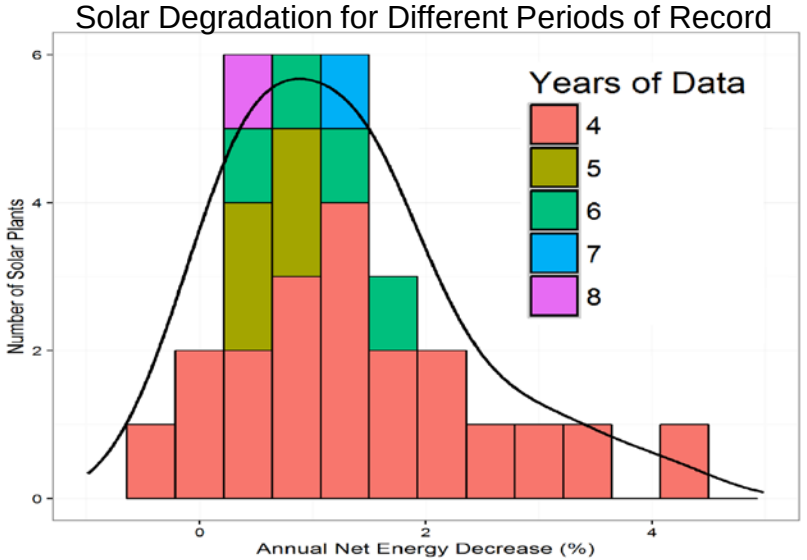
Investor / Lenders' Engineer on 450 Wind and Solar projects since 2012

ASSET MANAGEMENT

Manage expectations of operational plants and identify opportunities for performance improvement.

- Operational Energy Assessments
- Performance Analysis and Optimization
- SCADA Data Review and Reporting
- Extreme Conditions Analysis
- Root Cause Analysis
- Monthly Resource and Energy Reporting
- O&M Review and Optimization
- Grid Curtailment Analysis
- Verification of Loss Factors
- Portfolio Benefit Analysis

OPERATIONAL SERVICES



Performance Optimization:

- Equipment inspections
- SCADA analysis
- Systemic failure analysis review
- Degradation studies

Performance Assessments:

- Operational Energy Production Reports
- Portfolio Assessments
- Repowering Reports

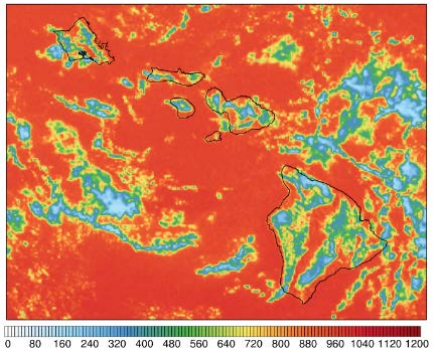
UL has assessed 100+ solar projects since 2013

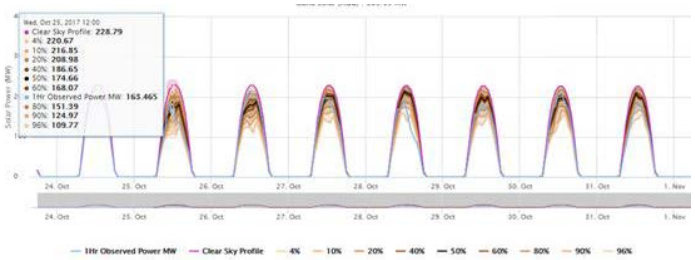
GRID SOLUTIONS

Understand renewable energy variability and the impact of weather-driven events.

- Real-Time Renewable Forecasting
- Grid Management & Planning Services
- Atmospheric Modeling & Applied Research
- Operational impacts on grid stability over multiple timescales
- Temporal and spatial impacts of solar and wind on the grid
- High Frequency data analysis
- Curtailment and Coincidence studies

FORECASTING AND MANAGING ENERGY INTEGRATION





- **Satellite data converted to power**
- **Informed models using measured sensor data**
- **Development of tools to provide visibility for real-time system operations**
- **High frequency power data over multiple timescales (seconds, minutes, hours)**
- **Integrated wind and solar generation studies**
- **Characterization of rare, but significant meteorological events that affect production**

Our Clients:
Utilities
ISOs
Owners/Operators
Non-Profit & Academia
Industry Research Centers

Hawaiian Electric
Maui Electric
Hawai‘i Electric Light

WIND AND SOLAR ENERGY ASSESSMENT AND OPERATIONAL PERFORMANCE METRICS

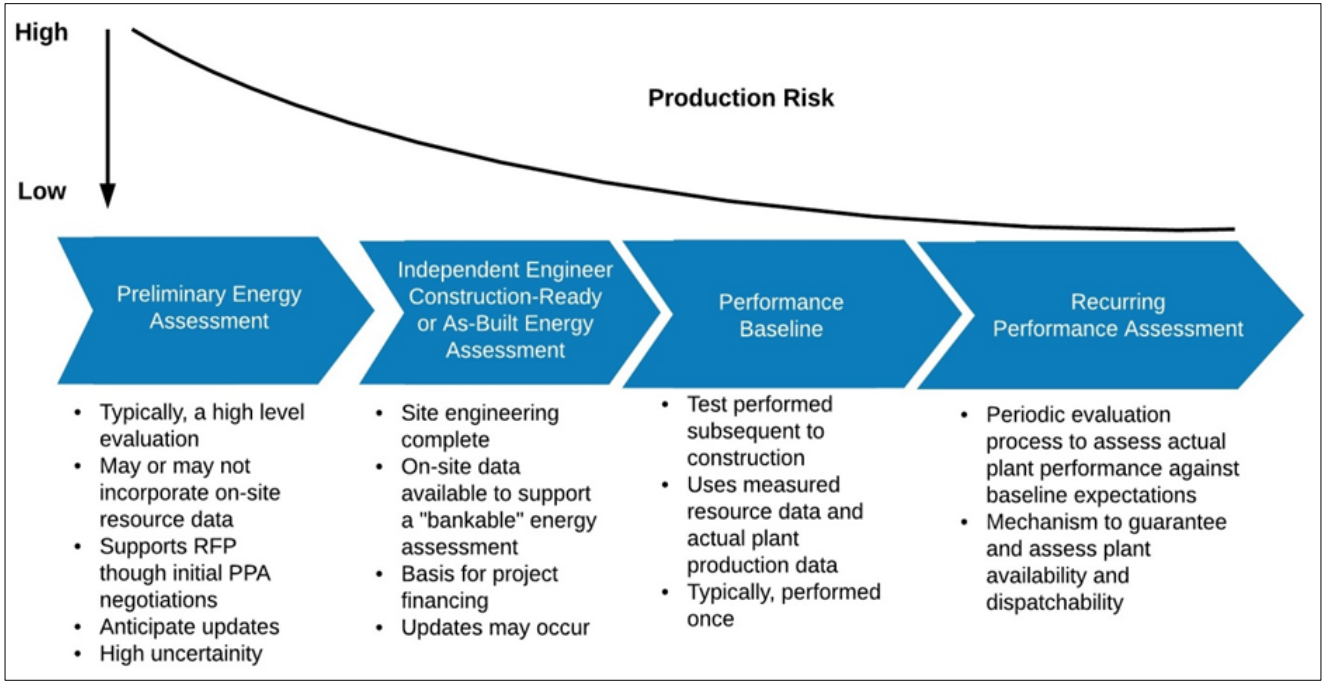
Version 1.0 / 11.06.17

TABLE OF CONTENTS

INTRODUCTION AND GOALS

- Background: Fixed payment Power Purchase Agreement (PPA) structure for utility-scale (Wind + Solar) renewable energy projects.
- Objectives as defined by Hawaiian Electric:
  - Define conceptual evaluation methods for preconstruction energy assessment and operational performance assessment in support of this PPA structure.
    - Cover entire lifecycle of a PPA from initial bid → PPA expiration
    - Can be evaluated virtually irrespective of utility operating strategy
    - Incorporate existing industry standards and best practices
    - Focus on transparent, independently verifiable and efficient evaluation processes

PROJECT PERFORMANCE ASSESSMENT LIFECYCLE



STAGE 1: PRELIMINARY ENERGY ASSESSMENTS

- Definition
  - An assessment of the long term energy for a proposed renewable energy project, typically supplied by an Independent Power Producer (IPP) in support of a utility Request for Proposal (RFP).
- Goals and Objectives
  - Realistic bid of long term energy
  - Submission of sufficient input to independently validate the long-term (LT) energy estimates

STAGE 1: PRELIMINARY ENERGY ASSESSMENTS

- High Level Inputs
  - Wind + Solar
    - Rated AC capacity
    - Resource data
      - Wind: on-site meteorological masts
      - Solar: on-site monitoring stations and/or satellite derived
    - Plant / Collection system design, locations of installed equipment
    - Equipment manufacturer(s) / model(s) and associated conversion efficiency of resource → energy
  - Wind Only
    - Turbine hub height, warranted power curve
  - Solar Only
    - Rated DC capacity, module surface tilt / orientation, pitch / row spacing, string sizing

STAGE 1: PRELIMINARY ENERGY ASSESSMENTS

- High Level Methodology
  - Begin with on-site measured or satellite-derived resource:
    - spatially extrapolated to the collector plane of all points on site where equipment exists.
    - temporally extrapolated to the LT annual resource.
  - The comingled array effects of the equipment on the available resource are quantified:
    - Wind: Wake Losses
    - Solar: Row-to-Row Shading
  - LT Resource → LT gross energy of the plant's generating systems using modeling techniques or software (e.g Openwind or PVSYST).
  - LT gross energy → LT Net energy based on modelled losses (availability, electrical, environmental, performance). Time-dependent losses (i.e. degradation) are modeled over the lifetime of the PPA.
  - Uncertainties in LT net energy over the lifetime of the PPA based on the measurements, modeling, and energy-weighted resource variability are quantified.

STAGE 1: PRELIMINARY ENERGY ASSESSMENTS

- Key Considerations
  - Uncertainty in energy associated with models and model inputs can be significant.
  - Plant design may still change at this stage.
  - Energy assessment at this stage may not have been performed by a qualified IE.
  - Additional on-site resource data may still need to measured to capture seasonal influences or unseen spatial complexity.

<u>Long term energy of a proposed plant at this stage will likely still be subject to refinement and more rigorous independent validation.</u>

STAGE 2: IE CONSTRUCTION READY OR AS-BUILT ENERGY ASSESSMENTS

- Definition
  - Typically referred to as “bankable” energy assessments prepared by an IE using the finalized construction or as-built designs of renewable projects.
- Goals and Objectives
  - Indicative of the final or as-built plant design.
  - Provide the most accurate estimate of the LT energy possible from existing data
  - Performed by an IE
  - Where able, uses 1-year or more of on-site resource measurements.

STAGE 2: IE CONSTRUCTION READY OR AS-BUILT ENERGY ASSESSMENTS

- High Level Inputs
  - Same as for preliminary assessment, however these are representative of the most up-to-date resource data and the final or as-built plant design.
- Methodology
  - Identical to preliminary assessment, however this assessment is performed by a third party and is sufficiently rigorous for project financing.
- Key Considerations
  - Analysis is typically more rigorous, and is done independently of the parties involved in a financial transaction.
  - Analysis methods are clearly defined outputs are sufficiently granularity for use in modeling energy / revenue.

<u>Long term energy of a proposed plant at this stage is still subject to many modeling assumptions.</u>

STAGE 3: PERFORMANCE BASELINE

- Definition
  - An assessment of energy based on actual measured production and losses from an operational renewable energy plant.
- Goals and Objectives
  - Verify and/or quantify variance in the LT net energy potential established in the preconstruction IE report using observed operational data from the plant.

STAGE 3: PERFORMANCE BASELINE

- Methods of Assessing Operational Performance:
  - Wind + Solar: Operational Energy Production Report (OEPR)
  - Wind Only: Wind Turbine Generator Power Performance Test (not discussed)
  - Solar Only: Acceptance Test

STAGE 3: PERFORMANCE BASELINE

OPERATIONAL ENERGY PRODUCTION REPORT

Project Data

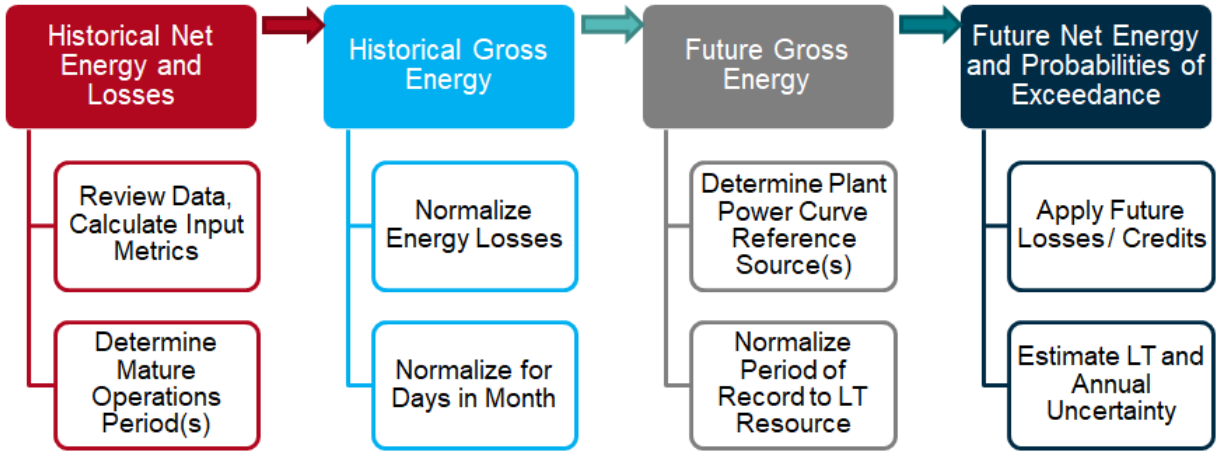
- Revenue meter – project energy generated
- Operational reports (typically monthly)
- On-site meteorological measurements
- Plant design specs
- Energy Loss Accounting
  - Availability
  - Undispatched Energy
  - Balance of Plant
  - Electrical
  - Environmental (**bird/bat, icing, wind sector management**, **shading, soiling**)

Reference Data

- Data Types
  - Wind Speed
  - Wind Direction
  - Temperature
  - Pressure
  - RH%
  - Precipitation
  - **Irradiance (GHI, DNI, DHI, POA)**
- Data Sources
  - Reanalysis: MERRA-2 / ERA-Interim
  - Surface Station Networks (ASOS, AWOS, RAWS, ISH)
  - WRF model simulations
  - **Satellite models (CPR, SolarGIS)**

STAGE 3: PERFORMANCE BASELINE OPERATIONAL ENERGY PRODUCTION REPORT

High Level Methodology



STAGE 3: PERFORMANCE BASELINE OPERATIONAL ENERGY PRODUCTION REPORT

- Key Considerations
  - OEPR typically has substantially lower uncertainty than a preconstruction report
    - Most metrics are measured instead of modeled.
  - Accurate accounting by the plant operator of the amount and categories of lost energy is key, particularly the amount of energy that was not dispatched by the utility.
  - Calibrated Baseline of future net energy potential. However, it does not hold IPP accountable for changes in future performance through the lifetime of a PPA.

STAGE 3: PERFORMANCE BASELINE

SOLAR ACCEPTANCE TEST

- Definition / Goals and Objectives
  - An assessment of a plant output metric(s) subsequent to or coincident with initial plant operations which tests whether or not the plant can meet expectations of capacity and/or performance.
- High Level Inputs
  - Performance targets during designated testing period
  - Quantified weather conditions (irradiance, temperature, time of day) for valid test data collected.
  - Measurement instrumentation information
  - Plant production at the point of interconnect
  - Availability of components (used for filtering)
  - Minimum threshold of valid data that needs to be collected

STAGE 3: PERFORMANCE BASELINE

SOLAR ACCEPTANCE TEST

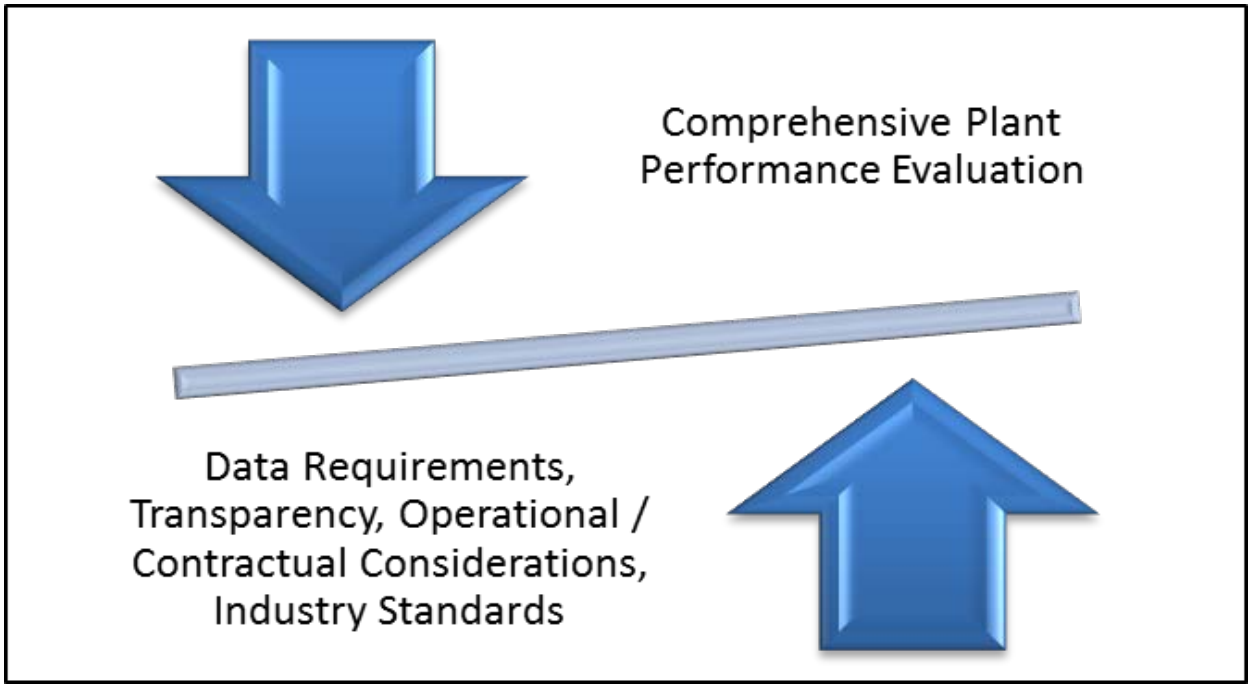
- Methodology
  - Typically defined as either a capacity test or a performance ratio (PR) test.
  - Filtered for valid test conditions (irradiance, availability, designated test period).
  - Minimum thresholds for data completeness must be achieved prior to test completion.
  - Pass / Fail is determined based on the comparison of observed vs. target minus test uncertainty.
- Key Considerations
  - Acceptance tests are indicative of initial plant performance under filtered, or ideal conditions. While this does validate some aspects of plant performance, not a sufficient metric for evaluating all aspects of plant performance throughout the lifetime of a PPA. Additional assessment is necessary.

STAGE 4: RECURRING PERFORMANCE ASSESSMENT

- Definition
  - Evaluation of a performance metric(s) on a periodic basis throughout the lifetime of a PPA which assesses a plant's ability to achieve an agreed upon level of performance, ideally tied to the preconstruction IE report and/or performance baseline.
- Goals and Objectives
  - Incentivize the operator to maintain plant operational performance through the lifetime of the PPA.
  - Agreed upon threshold should be consistent with assumptions of performance defined Stages 1-3.
- Methods Discussed
  - Wind + Solar: Availability Guarantee
    - Wind: Production-based
    - Solar: Time-based
  - Solar Only: Performance Guarantee

STAGE 4: RECURRING PERFORMANCE ASSESSMENT

Conceptual Plant Performance Guarantee Tradeoff



STAGE 4: RECURRING PERFORMANCE ASSESSMENT WIND AVAILABILITY GUARANTEE

- High Level inputs
  - Total time from all turbines within the period which correspond to states of operability, turbine or balance of plant (BOP) downtime, derate, grid-related derate / downtime, force majeure and periods of unavailable information.
  - Total Actual Production and Potential Production
    - Potential Production calculated from nacelle anemometer wind speed, ambient temperature and pressure.
- Methodology
  - Based on production-based availability calculation of Wind Power Systems (WPS) from IEC-61400-26-3 https://webstore.iec.ch/publication/25625

$$\text{Production-based Availability} = 1 - \frac{\text{Lost Production}}{\text{Actual Production} + \text{Lost Production}}$$

$$\text{Lost Production} = \text{Potential Production} - \text{Actual Production}$$

- Key Considerations
  - Categorization of state information from the plant is key to determining what energy loss is included / excluded from definition. Without a translation matrix, reproducibility will be difficult and calculation disputes are likely.

STAGE 4: RECURRING PERFORMANCE ASSESSMENT SOLAR PERFORMANCE GUARANTEE

- Definition:
  - Performance Ratio (PR): the ratio of the electricity generated to the electricity that would have been generated if the plant consistently converted sunlight to electricity at the level expected from the DC nameplate rating.
  - Relevant background material
    - IEC 61724-1: Photovoltaic System Performance – Part 1: Monitoring https://webstore.iec.ch/publication/33622
    - NREL: Weather-Corrected Performance Ratio: https://www.nrel.gov/docs/fy13osti/57991.pdf
- Goals and Objectives:
  - Define a metric that encompasses as many of the elements of PV plant performance as possible
    - Normalizes for the available resource (irradiance, temperature, soiling)
    - Filters out low irradiance, low availability and times when production is not fully dispatched
    - Accounts for an assumed level of module degradation over the life of the plant.

STAGE 4: RECURRING PERFORMANCE ASSESSMENT SOLAR PERFORMANCE GUARANTEE

- High Level Input
  - Guaranteed PR Target input:
    - IE preconstruction bankable energy assessment 8760 performance ratio
    - Also, results from the Acceptance Test can be used to adjust preconstruction expectation for actual plant operation.
  - Observed PR input (typically either high resolution samples or 15-minute aggregates):
    - Availability of equipment
    - Periods of force majeure or information unavailable
    - Average power or net energy at point of interconnect
    - Utility power set point (used in filtering)
    - Measured irradiance
    - Module temperature

STAGE 4: RECURRING PERFORMANCE ASSESSMENT SOLAR PERFORMANCE GUARANTEE

- Methodology
  - Key metric: $Operating\ Performance\ Ratio = PR_{OP} = PR_{wc} * f(degradation, soiling)$

    where: PR_{wc} = weather corrected performance ratio using mutually agreed upon reference source(s)

    $f(degradation, soiling)$ = correction based on contractually-assumed, modeled or measured levels of degradation and soiling

- Key Considerations
  - Accurate measurements of observed resource is critical to isolating variances in performance from expectations.
  - PR targets and weather corrected values use the same reference source(s) as resource inputs
  - Modeled vs. observed degradation rates will become important parameters as project age

STAGE 4: RECURRING PERFORMANCE ASSESSMENT SOLAR AVAILABILITY GUARANTEE

- High Level Inputs
    - Availability of equipment
    - Periods of force majeure or information unavailable
    - Utility power set point (used for filtering)
    - Measured irradiance
- Methodology
    - Nighttime hours, periods forced outage from the grid or force majeure as well for unavailable information, are excluded. All other times included.

$$Availability\ \% = 1 - \frac{Unavailable_{time}}{Available_{time} + Unavailable_{time}}$$

- Key Considerations
    - Availability guarantee can be used to supplement the performance guarantee.

ADDITIONAL INFORMATION

- An executive summary of the information presented here and a recording of this webinar will be made publicly available.
- Additional information on these topics and others can be found within the AWS Truepower Knowledge Center:
  - https://www.awstruepower.com/knowledge-center/