Best Practices in Solar Performance Monitoring

Version 1.0

ABSTRACT

This document describes best practices in solar performance monitoring and how asset owners can prepare their plants for performance risk assessment (as required by investors). Target audiences for this document include solar project developers, asset owners, and investors.

CHANGE HISTORY

Version 1.0: Initial draft

LICENSE AGREEMENT

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1 Introduction

According to Dictionary.com, a best practice is defined as “a technique or methodology that, through experience and research, has reliably led to a desired or optimum result.” As such, best practices are used to define quality in particular fields of endeavor.

In the field of PV plant operations, quality is determined by a) the ratio of the amount of energy harvested to the potential amount of energy available for a particular plant and b) plant availability over time. Given this definition, the ability to accurately measure actual energy harvest and the solar energy available to that plant is of utmost importance.

By the same token, keeping the plant up and running at its peak operating point requires accurate performance measurements, the ability to easily pinpoint issues, and prompt repair of defects. Active plant monitoring is essential and the quality of the monitoring system itself is fundamental to the overall quality of the plant.

The quality of the monitoring system extends along multiple dimensions. In this document, the following aspects of quality are evaluated:

- Monitoring policy
    - Transparency of measurement protocols and procedures
    - Auditability of measurement protocols and procedures
    - Maintainability of hardware and software by a variety of service providers
    - Security of plants and fleets
- Equipment, sensors, and networks
    - Accuracy and reliability of sensors and instruments
    - Reliability of communication networks
    - Placement of sensors and instruments
    - Depth of the instrumentation
    - Frequency of inspection and calibration
    - Depth of telemetry
- Software
    - Ability of systems to share information with stakeholders
    - Ability to ensure “operational continuity” (backup & restore)
    - Support third-party access for custom application development
    - Security of software and applications

The following chapters discuss each of these points and make recommendations to solar performance monitoring system implementers regarding best practices for data collection, reporting, and analysis.

2 Monitoring Policy

2.1 Transparency of measurement protocols and procedures

The benefits of adopting open standards for information and communication are well established. As it relates to the quality of the solar monitoring system, open standards are applied at four levels:

1. Device communication and plant sensor readings.
2. Data collection and storage at the plant.
3. Information transmission from the plant to the information data store.
4. Information access to the data store from applications.

While high quality monitoring systems can be built with proprietary methods that encourage lock-in to a single vendor, a standard information model used across all four levels ensures high fidelity and eliminates poor or inconsistent mappings from one model to another. A standard information model allows systems to be compared to one another, independent of monitoring vendor.

Standardized information encoding and methods of transfer enable interoperability with multiple vendors and eases the development of custom applications. Use of open standards reduces supply-chain risk associated with vendor default or lost favor by allowing for plug-compatible replacement of equipment and services.

Recommended Best Practice

- Use open standards for information and data communication throughout the plant. The SunSpec Alliance standard information models, combined with standard transport protocols such as Modbus, Ethernet, WiFi, and Zigbee (radio) are recommended.
- Longer term, support information models as defined in IEC 61850 and/or Smart Energy Profile 2.0. SunSpec standards are harmonized with both of these technologies.

2.2 Auditability of measurement protocols and procedures

Since a significant amount of revenue may be tied to solar plant performance, the temptation to overstate production and underreport problems exists. The possibility of an independent third-party audit to reveal misreporting greatly mitigates such temptation and increases the confidence of all parties in the integrity of the information. Use of a public and open standard increases the level of transparency in that the information is more readily vetted in a standard format.

Recommended Best Practice

- Use information standards that are openly available for review to ensure auditability.

- Request a written statement from the Data Custodian regarding how information models and communications can be audited.
- Avoid proprietary protocols (i.e. “closed” and not able to be reviewed independently) when possible.

2.3 Maintainability by a wide array of service providers

Solar power plants are long-lived assets that are expected to remain in service for 20 years or more. Given that the [average life of a company in the S&P 500 has dropped to 15 years recently], and that the life expectancy of typical monitoring or applications companies (which are usually not as established as those in the S&P 500) is considerably less, it is a risky proposition to make bets on single companies with proprietary solutions.

Recommended Best Practice

- Use standards-compliant hardware and software solutions that are well understood and supported by competing service providers.
- Ask suppliers to provide written statements about which companies can provide back-up service solutions. This protects against losses in the event a vendor retreats from the business, is acquired by a company less eager to maintain proprietary solutions, or goes out of business.
- Solutions for which there are published interface specifications and open source software interfaces provide the best protection from product obsolescence and non-support.

3 Equipment, Sensor, and Network Considerations

3.1 Accuracy and reliability of sensors and instruments

No system is perfect and there is always a level of uncertainty when performing measurements. Establishing acceptable tolerances for measurement accuracy is necessary to assess the overall quality of the monitoring system. The system input and system output are the most critical to measure accurately to determine the system performance.

For a PV plant, the input is the amount of sunlight energy hitting the plane of the PV array (POA). Sunlight is most accurately measured by a pyranometer located near the array. The output is the AC electric energy and is measured by an AC meter. Since this measurement is what the power generator ultimately gets paid for, it needs to be highly accurate (±0.5%). Measurements internal to the inverter are less accurate (typically ±5%) and therefore more uncertain.

Data quality limits shall be established based on the known characteristics of each recorded parameter. Limits should include upper and lower bounds on the value range as well as limits on the maximum change between consecutive readings. A Data Quality Index (Q) is associated with the telemetry stream that indicates the percentage of valid samples relative to missing or invalid samples, and speaks to the quality of the data collection process itself.

Recommended Best Practice

- A high accuracy "Revenue Grade" AC meter on the combined output of the plant with uncertainty of ±0.5% is required for plants >100kW in size and is highly recommended for all plants. A revenue grade meter is typically required for all plants where third-party financing is involved.
- For smaller plants, typically residential or commercial rooftop systems of <100kW in size, inverter-direct monitoring (no external AC meter) with an uncertainty of ±5% is acceptable to some financial institutions—but increased uncertainty usually means a less favorable assessment of performance risk. For more information regarding meter accuracy, please see the ANSI C12 standard published by the American National Standards Institute.
- Onsite environmental sensors that measure irradiance and temperature are required for plants of >100kW. An irradiance sensor for each array in the plane-of-array with an uncertainty <±5% and a single irradiance sensor in the global horizontal reference are recommended.
- Each array should have a back-of-module temperature sensor with an uncertainty of ±1°C. An ambient temperature sensor with an uncertainty of ±1°C for the plant is also required.
- For plants where onsite environmental sensing equipment is not practical (i.e. most residential plants), irradiance and ambient temperature measurements should be supplied by a nearby weather station or estimated from satellite data. Irradiance measurements may only be accurate to <±25% and temperature measurements to ±5°C, which increases uncertainty but is currently acceptable in the residential setting.

3.2 Reliability of communication networks

The monitoring system is wholly reliant on the ability to collect information from the field instrumentation and transmit that information over a communication network to application servers. If a device is not reporting, it is very difficult to distinguish a component or plant failure from a communication network failure. Incomplete data can lead to false conclusions and lost revenue. Missing data samples reflect negatively in the Data Quality Index. Reliance on a shared communication network raise availability and security issues that result in lost or incorrect data, disrupted service, unneeded service calls, and lost revenue.

Recommended Best Practice

- A dedicated network connection such as a cellular, dedicated broadband backhaul, or virtual private network is required for plants of >100KW. For smaller plants, where it is not practical to implement a dedicated network connection, a shared network connection may be used but raises the service risk profile considerably. Where possible, a dedicated network connection is highly recommended.

- Onsite data storage is required to prevent data loss during communication network outages. The amount of storage needed depends on the expected mean-time-to-repair should an outage occur. An amount of storage that is equal to two times your highest recorded communications outage is recommended. Best results are seen where three months of storage is installed. Six months of storage is recommended.
- Standard data encryption techniques should be employed to protect the confidentiality and integrity of the data in transit over wide area networks. For example, the SunSpec Alliance Logger Upload protocol specifies the use of Transport Layer Security standards (e.g. https, SSL) for data transmission over the Internet Protocol (IP) based networks.

3.3 Placement of sensors and instruments

Placement of the AC utility meter fis dictated by the requirements of the utility. For all other sensors, placement is left to the discretion of the installer.

Protocols and procedures for environmental sensor placement in solar power plants are surprisingly rare. This has led to even greater measurement and production uncertainty than would be implied by sensor accuracy.

Recommended Best Practice

- For plants of 10 MW or larger, one environmental station should be installed per 10 MW (60 acres) of array area. Sensors should be placed in areas without shade. If wind sensing is included, take care not to block or deflect normal wind patterns. Back of module temperature sensor placement is recommended at a rate of one sensor per 1MW of module capacity, with the sensors distributed across the array proportionately.
- For plants of <10 MW, one environmental station is sufficient. The ratio of one back-of-module temperature sensor per 1 MW of module capacity is recommended.

3.4 Depth of the instrumentation

While accurate measurement of the energy output by the plant is necessary to recognize revenue, in-depth instrumentation throughout the plant can increase uptime by pinpointing failures and providing predictive indications of maintenance needs. Measurement of the solar irradiation input is essential to determine the plant efficiency relative to its potential.

In general, more instrumentation throughout the plant increases the quantity of information available for analysis, and thereby drives efficiency and quality by identifying under-performing components over time.

For critical measurement points, redundant measurements increase the reliability of the system by helping to isolate sensor errors from actual plant defects. For example, a pyranometer measurement can be correlated with a nearby pyranometer or satellite approximation. If the measurements are not close enough to each other, it is probable that one of the measurements is the result of a sensor error. Triple Modular Redundancy (TMR) can be used to determine which single sensor is the culprit.

Redundancy also ensures that all critical measurement can be captured even when instruments are repaired or returned to the factory for calibration.

Recommended Best Practice

- DC measurements of energy and power production are needed to aid in fault detection, efficiency calculations, and degradation analysis. Array or string level measurements may be provided by the inverter or by independent DC meters in string combiners.
- Additional environmental measurements of humidity, pressure, rainfall, and wind speed are useful for determining more accurate assessment of performance, maintenance, and local forecasting.
- For smaller (residential) systems, use of satellite-generated information or nearby environmental stations and instruments is sufficient though less certain.

3.5 Frequency of inspection and calibration

Monitoring systems require regular inspection and calibration to ensure quality as part of the plant maintenance regime. For example, soiling of the pyranometer will lead to inaccurate assessment of available solar resource and, by extension, plant performance.

The manufacturer's specifications will indicate the required frequency of calibration and expected lifetime of the device. Preventative maintenance has been shown to lower the probability of unplanned outages and thereby greatly improve plant uptime and performance.

Recommended Best Practice

- Institute commissioning of data acquisition and monitoring systems at time of installation. Implement annual inspection and retro-commissioning to ensure accuracy of measurements. Highly accurate instruments may require more frequent checking. This recommendation applies to systems of all sizes.
- The typical expected life of data acquisition and monitoring equipment is one to ten years, with an average of five years. Replacement is recommended at 80% of the expected component lifetime.

3.6 Depth of telemetry

SunSpec information model standards identify "mandatory" elements that must be supported by all devices of a given type. Many "optional" elements are also defined that, when provided, give additional insight into component performance. Many devices expose internal alarm conditions that indicate abnormal operation or pending failures. Capturing and analysis of detailed telemetry leads to deeper insight into individual component performance and failure rates.

Short interval sample data can provide more precise estimations over larger periods of time. A 15-minute sample rate (four samples per hour) is the minimum recommended while a 1-minute sample rate or less is recommended for parameters that vary directly with irradiance. These base samples may then be averaged or otherwise aggregated over larger time periods – hourly, daily, etc.

Shorter interval sampling results in more data to transmit over wide area networks. Historically, the high cost of cellular data plans discouraged short interval sampling, but these costs have shrunk dramatically recently. Consult with your cellular data provider to determine communications costs.

Recommended Best Practice

- A minimum sample interval of 15 minutes is required for all plants. Shorter interval sampling down to one minute is recommended to further reduce uncertainty when calculating facility energy offsets.
- Inclusion of additional AC metering points (for facility load and net energy usage) is required to determine overall value of PV production.
- Record and track plant availability and equipment failures to aid in cost tracking and lost production estimations.

4 Software Monitoring System Considerations

4.1 Ability of systems to share information with stakeholders

Information collected by solar plant monitoring systems is typically shared with five to six stakeholders per power plant. Operations maintenance personnel, bank lenders, regulatory reporting authorities, equipment providers, and the general public (via web site or lobby kiosk) routinely demand access to monitored information. If access to the information in the monitoring system is difficult to access and administer, operations costs and the probability of lost revenue increase dramatically.

Recommended Best Practice

- Ask your monitoring service provider to confirm in writing that access to information can be provided easily and securely to all stakeholders.
- Make sure that user access to the monitoring system can be properly authenticated and authorized. For application-to-application information exchanges, make sure that the monitoring system provides a Web service interface implemented over http or https protocols.
- Implementation of the SunSpec Plant Extract Document specification by the monitoring system vendor ensures compatibility with the oSPARC system and is a good way to enable access by multiple applications and users.

4.2 Ability to ensure operational continuity

To ensure supply chain integrity and the ongoing operation of deployed solar assets, solar developers and asset owners have implemented a strategy of maintaining multiple alternative sources of supply for all component and sub-system types. This strategy protects the asset owner in cases where a vendor exhibits quality, availability, or pricing problems, or where the vendor exits the business.

Until very recently, solar monitoring systems have been proprietary in nature and tied to specific hardware components. As a result, the multi-source strategy described above has been unattainable. Many solar developers have faced the need to replace sensors and data acquisition equipment in operational solar power plants when their preferred monitoring company went bankrupt or otherwise exited the market. This process replacement process is often time consuming and has resulted in lost production reporting, sub-optimal plant operations, and lost revenue.

Recommended Best Practice

- Require that monitoring system providers confirm in writing that their systems have the ability to transfer all data stored to alternate monitoring systems. Ask vendors to demonstrate the system-to-system data transfer process and ensure that operational personnel understand how to affect such a transfer should it be required.
- Require that monitoring system providers demonstrate how to back up the data store for archiving or back up purposes. While Software-as-a-Service (SaaS) system providers often claim that backup services are provided "transparently" (meaning without customer involvement or oversight), this type of backup is insufficient to protect against vendor failure and is therefore unacceptable.
- Implementation of the SunSpec Plant Extract Document specification by the monitoring system vendor is a good way to enable off-site back up, operational continuity, and vendor independence.

4.3 Support third-party access for custom application development

As the sophistication of solar asset owners grows, the need to develop custom applications to address unique operational requirements arises. For example, entry into a new geographic market might introduce the requirement to send data to a new regulatory reporting agency. Energy off-takers, who might also be owners of the buildings hosting solar power plants, may request that solar plant data be continuously transferred to an Energy Management System (EMS) or similar software application.

The likelihood that solar monitoring systems will be required to integrate with other data processing systems increases exponentially as new plants are added to the fleet. As a result, solar monitoring providers must be able to provide access to the solar monitoring system via Application Programming Interface (API).

Recommended Best Practice

- Require that monitoring system providers confirm in writing that their systems contain an Application Programming Interface. Ask vendors to demonstrate this interface and state, in writing, which application programming languages are supported. Review API documentation to ensure robustness.
- API's that support Web services, including support for http and http protocols, are best because of the large pool software development talent that is knowledgeable of this technology and available at competitive wage rates.
- Implementation of the SunSpec Plant Extract Document specification by the monitoring system vendor within the API is a good way to enable consistent representation of plant data in each application.

5 Conclusion

By implementing best practices in solar performance monitoring, solar project developers can meet the requirements of investors, fleet managers, and grid operators while simultaneously decreasing capital- and operating costs.

Solar performance monitoring strategies that are based on standards--de facto, national, or international--yield performance results that are independently verifiable and supply chain management programs that are failsafe.

Solar assets are long lived. Evolving customer requirements and business opportunities will invariably lead to the need for new information-based application software. In this context, Application Programming Interfaces to monitoring software is a fundamental requirement.

Asset owners operating at scale, and who are considering accessing capital markets for downstream financing, are strongly advised to implement the practices describe here. Doing so will enable operational efficiency at scale while increasing investor confidence through increased accountability and transparency.

