SunSpec Alliance

Open Solar Performance and Reliability (oSPARC) Implementer's Guide

SunSpec Alliance NREL Project Workgroup
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Version 1.0

ABSTRACT

This document describes how solar power plant owners can enable their plants to participate in the Open Solar Performance and Reliability Clearinghouse (oSPARC) program. oSPARC supports an initiative, funded by the U.S. Department of Energy and managed by the National Renewable Energy Laboratory, that is designed to bring low-cost capital into the solar market by enabling securitization of long-term solar energy purchase contracts.

Included in this document are sections describing best practices in solar performance monitoring (and how developers can prepare their plants for optimal performance risk assessment) and an overview of the oSPARC software system and its theory of operation. Target audiences for this document include solar project developers, software developers, and financial analysts.

CHANGE HISTORY

D-1:	Initial Draft
D-2:	Incorporate review feedback, straw man data proposal
D-3:	130311 review comments
D-4:	130318 review comments
D-5:	130325 review comments
D-6:	130401 review comments
D-7:	130408 review comments
D-8:	Additional introductory material, rename, oSPARC examples
D-9:	Document reorganization, edit, additional introductory material
Version 1.0:	Layout, additional references

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1 Introduction

In March 2013, the SunSpec Alliance was appointed by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) to develop the Open Solar Performance and Reliability Clearinghouse (oSPARC). oSPARC supports an NREL initiative called Solar Access to Public Capital (SAPC) and is designed to answer the question of how solar plants perform over the long term, thus enabling increased investment in the solar industry.

The oSPARC system, located at http://osparc.sunspec.org/, incorporates a cloud-based computing service platform and standardized communications protocols to connect participating solar plants. oSPARC will answer the performance and reliability question by receiving and aggregating daily performance statistics pertaining to yield, availability, and reliability. Solar and financial industry personnel will be able to query the oSPARC database to generate reports of performance and reliability index values for selected groups of power plants. Report data will be anonymized to honor consumer privacy laws.

oSPARC leverages SunSpec Alliance specifications and the SunSpec Alliance Best Practices In Solar Performance Monitoring guidelines incorporated in this document. Implementation of these best practices is fundamental to increasing information quality and investor confidence in the solar industry.

This document is divided into three sections:

- General information about the Solar Access to Public Capital project and its relationship to oSPARC.
- Best Practices in Solar Performance Monitoring. This section is primarily intended for solar PV project developers and describes how to design and instrument solar PV plants for optimal performance risk assessment.
- oSPARC Design Overview and Theory of Operation. This section is primarily intended for risk assessment analysts and software developers of solar monitoring systems. Solar PV project developers also benefit by understanding how the information generated by solar power plants is used in investment risk assessment scenarios.

Additional information about oSPARC is available at www.sunspec.org/osparc/. If you would like to participate in this program, please contact Tom Tansy at tom@sunspec.org .

1.1 oSPARC Relationship To Solar Access to Public Capital

SAPC is a multi-year project managed by NREL that aims to facilitate and hasten the solar photovoltaic (PV) industry's access to public capital through securitized instruments and other investment vehicles. SAPC is driven by the SAPC working group, a collective that includes leading banks, rating agencies, solar industry suppliers, financial services organizations, and legal firms.

The SAPC working group has the goal of standardizing contracts and other documents relevant to the solar project development process in order to lower risk perception and due diligence requirements of investors, thus allowing project pooling and conversion into tradable securities. Experts at NREL have estimated that public capital vehicles (e.g. securitization) could lower the Levelized Cost of Energy (LCOE) of solar PV by 8% to 16%.

Financial ratings services firms have indicated that securitization—a financing technique that aggregates pools of assets, financial contracts, or loans, and through a structuring process transforms their future cash flows into a security—may be a viable option for developers that wish to monetize cash flows associated with solar leases and power purchase agreements (PPA's).

The primary risks of associated with solar securitization have been identified by the financial community. Risks include a lack of historical performance data, an inadequate operations and maintenance infrastructure, and ongoing downward pressure on solar system prices. The oSPARC database addresses the first of these risks by collecting and subsequently providing reliable historical performance information to the investment community.

Understanding the performance and reliability of solar assets is essential to the solar investment decision process. If the power plants underlying the tradable security are performing well, the security will also likely perform well. The converse is also likely true. Accordingly, the establishment of the oSPARC system will be a valuable contribution to the solar industry.

1.2 oSPARC Relationship to SunSpec Standards

oSPARC is based upon SunSpec Alliance standards and related communication prototcols. For more information on SunSpec Alliance specifications and to download them free of charge, go to http://www.sunspec.org/specifications/.

While the oSPARC project embraces all SunSpec Alliance specifications, it relies on one in particular—the **SunSpec Plant Extract Document**—to enable its objective of providing access to the widest possible array of data providers and application builders.

Version 1 of the **SunSpec Plant Extract Document** specification was designed to satisfy the requirements of the Bulk Data Transfer application. As such, it enables access to a superset of information required for financial risk assessment, but at the cost of increased bandwidth, storage requirements and security concerns.

Version 2 of the **SunSpec Plant Extract Document** specification expands the scope of version 1 to support the additional uses cases for financial oversight.

1.3 oSPARC Development Status

The oSPARC system is currently in development and partial deployment. As of May 2013, Data Custodians are able to post daily production reports to the oSPARC service manually or by way of a web service interface at http://osparc.sunspec.org.

SunSpec is actively engaging with Data Custodians to allow daily performance metrics to be imported and stored. Early end-user access to the oSPARC system for querying and reporting will be provided in Q4 2013. The system will be fully operational in Q1 2014.

If you would like to connect your power plants to the oSPARC system, please contact tom@sunspec.org. He can provide you with further instructions and the credentials required to post daily production and reliability data to the oSPARC system.

2 Best Practices in Solar Performance Monitoring

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 examining the ratio of the amount of energy harvested to the potential amount of energy available for a particular plant. 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 section, 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 sub-sections discuss each of these points and make recommendations to solar performance monitoring system implementers regarding best practices for data collection and reporting.

2.1 Monitoring Policy

2.1.1 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.

2.1.2 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.

2.1.3 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.

2.2 Equipment, Sensor, and Network Considerations

2.2.1 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.

2.2.2 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.

2.2.3 Placement of sensors and instruments

Placement of the meter for plants of all sizes is 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.

2.2.4 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.

2.2.5 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.

2.2.6 Depth of telemetry

The 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.

2.3 Software Monitoring System Considerations

2.3.1 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. The oSPARC service adds one more constituent to this list. 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.

2.3.2 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.

2.3.3 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.

3 oSPARC Theory of Operation

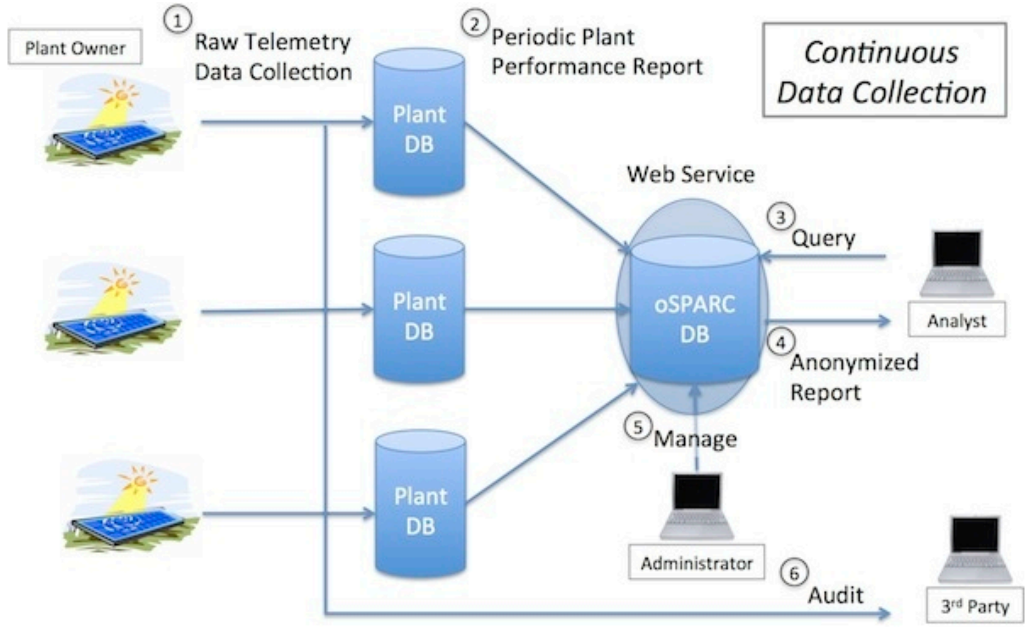
The oSPARC system incorporates three key concepts that serve as a foundation for the system as a whole:

1. **Best practices** to optimize the quality of PV monitoring. Using these best practices, the collection of raw telemetry can support a broad range of applications such as bulk data transfer, financial reporting, and regulatory compliance. Raw telemetry is delivered to a primary data custodian and optionally sent to third-party custodians and custom application providers.

2. **A periodic plant report** from the plant monitoring system of key plant measurements, supported by the oSPARC Web Service. The plant report format, known as oSPARC Plant Information Profile (PIP), is based upon the SunSpec Plant Extract Document specification. This format is designed to meet the information needs of the financial community. Periodic plant reports are delivered to the oSPARC database by the Data Custodians and underpin the derivation of Key Performance Indicators (KPI's).

3. **A query and report system** to determine fleet performance. This system aggregates plant measurements in the database and produces reports for users (typically financial analysts) that are anonymized to protect the identity of consumers related to power plants. Users query the system using descriptive terms to generate a report of KPI's for plants meeting the search criteria. For example, a query may request performance data for plants less than 10KW in size, located in a four state area, owned by particular fleet operators.

The diagram below illustrates these concepts.



3.1 oSPARC Plant Information Profile

The oSPARC Plant Information Profile (PIP) describes the subset of the SunSpec Plant Extract Document (PED) used by the oSPARC application. Each plant is required to provide descriptive "meta data" that uniquely identifies it (e.g. name, location, owner, etc.) and allows for comparison with other plants.

Additional plant level measurements are provided to give a top-level view of plant performance without needing to delve into the individual equipment measurements. The details and format of the PED are found in the SunSpec Alliance Specification Plant Extract Document v2 located in the appendix. Elements of the Plant Information Profile are described here.

3.2 Plant Meta Data

3.2.1 Plant Description

The Plant Description is captured during the design, construction, and commissioning of the plant. The plant information includes a summary description of the plant design, the equipment used, plus the participant organizations and/or individuals.

UUID	**U**niversally **U**nique **ID**entifier of the plant. This string value distinguishes this plant from all others. The UUID is created and assigned when the plant is provisioned in the oSPARC database.
Name	Common name of the plant.
Location	Physical location of the plant, including the **Postal Code**, **Timezone**, and **Longitude/Latitude**.

Participants	Entities participating in plant including the Project Originator**,** Data Custodian, Utility, Offtaker, O&M Provider, EPC, Owner, Lender, Loan Servicer, Designer, and Project Developer.
Activation Date	The date the plant was put into commercial operation and began delivering energy to the Offtaker.
Array Info	Characteristics of each array including the DC Rating, Panel Area (m^2), and number of planes of arrays.
Plant Design	Design attributes of the plant including plant type (residential, commercial, industrial), inverter type (central, string, micro), mounting type (fixed, horizontal, tilted, azimuth, dual, mixed),DC optimization type (none, string, module), weather source type (onsite, local, satellite, model, mixed), and design model (PVsyst, SAM, other).

3.2.2 Plant Equipment Information

Plant Equipment information provides manufacturer, model, and key ratings for standard PV plant equipment.

Module Info	For each Manufacturer/Model: $W_{dc\ stc}$ rating, Area Area (m^2), temperature coefficient, total number of modules.
AC Meter Info	For each Manufacturer/Model: Uncertainty, total number of meters.
Inverter Info	For each Manufacturer/Model: kW_{ac} rating, total number of inverters.
Combiner Info	For each Manufacturer/Model: $W_{dc\ stc}$ rating, total number of combiners.
Sensor Info	For each Manufacturer/Model: Irradiance Sensor class (thermopile, reference cell), uncertainty & orientation (ghi / dni / poa), Temperature, other environmental.
Monitoring Info	Primary Data Custodian vendor name, logger hardware/ software name, field bus type, wide area network type (cellular, shared broadband, dedicated).

3.2.3 Plant Ratings

Plant Ratings provides the stated output capacity of the plant as determined by the design model.

installedDCCapacity	Combined total DC Watt rating of all arrays under standard test conditions (DCWstc).
installedACCapacity	Combined total AC Watt rating of all inverters (kWcapacity).
nominalPowerRating	Nominal AC power rating of the plant (kWp).

3.3 Time Series Data

3.3.1 Plant Measurements

The Plant Measurements are measured values from the AC meter at the point of common coupling.

WH	Lifetime ac energy generated from PV.
W	AC real power output (AVG).

3.3.2 Array Measurements

The Array Measurements are measured values taken from the environmental system and DC meters located within the array.

G_{poai}	Irradiance in the plane of the array (AVG).
H_{poai}	Lifetime irradiation over the plane of the array.
Tmp_{bom}	Back of module temperature (AVG).
DCW	DC power output (AVG).
DCWH	Lifetime DC energy generated from array.

3.3.3 Additional Plant Environmental Measurements

The Additional Plant Environmental Measurements are measured values taken from the environmental system.

G_{ghi}	Global Horizontal Irradiance reference (AVG).
Tmp_{amb}	Ambient Temperature (AVG).
WndSpd	Wind Speed (AVG).
Pres	Pressure (AVG).
RH	Relative Humidity (AVG).

3.3.4 Additional Plant Electrical Measurements

The Additional Plant Electrical Measurements are measured values taken from the DC and AC meters.

DCV	DC Voltage.
DCA	DC Current.
V	AC Voltage.
A	AC Current.
Hz	AC Frequency.
PF	Power Factor.

3.3.5 Facility Net Energy Measurements

The Facility Net Energy Measurements are measured values taken from AC meters located at the point of load.

WH_l	Lifetime ac energy exported to facility loads.
WH_x	Lifetime ac energy exported to grid.
WH_i	Lifetime ac energy imported from grid.
WH_c	Lifetime ac energy charged to storage.
WH_d	Lifetime ac energy discharged from storage.
WH_p	Lifetime ac energy imported to PV (parasitic losses).

3.3.6 Derived Data

Derived Data is calculated by combining measured values and rating values generated by system design models. Derived Data is used in the calculation of Key Performance Indicators (KPIs).

System Derate Factor	K_{Derate}	$kWp\ /\ kW_{dc\ stc}$
Temperature Correction	K_{temp}	$[1 + \mu (Tmp_{cell} - 25)]$
Expected DC Power	P_{dc}	$kW_{dc\ stc} * (G_{poai}/1000) * K_{temp}$
Expected AC Real Power	P_{ac}	$P_{dc} * K_{Derate}$

3.4 Plant Availability and Status

3.4.1 Availability States

Availability States indicate the operational readiness of the plant to generate power. Not all periods without generation are related to operational failures or lost generation. The availability state changes of the plant are recorded and reported.

Operating	Connected and generating power.
Islanded	Disconnected and generating power for local loads.
Standby	Includes starting up, shutting down, test mode.
Env	Environmental conditions are out of specification (i.e. not enough sunlight to generate power).
Grid	The grid interconnection is out of specification (i.e. voltage or frequency violations caused the plant to trip off).
Shutdown	Operator requested shutdown for maintenance, testing, or other purposes.
Forced	Outage due to plant failure.

Emergency Shutdown due to force majeure. Extraordinary event beyond the control of the operators.

3.4.2 Fault Information

Fault Information is the number of fault events reported by equipment installed in the plant and the time stamps of the oldest active fault for each device.

Inverter Number of active inverter faults, timestamp of oldest active.

Module Number of active module faults, timestamp of oldest active.

Meter Number of active meter faults, timestamp of oldest active.

Sensor Number of active sensor faults, timestamp of oldest active.

Comm Number of active communication faults, timestamp of oldest active.

Other Number of active other faults, timestamp of oldest active.

3.5 oSPARC Web Service

The oSPARC Web service is the interface through which the Data Custodian (i.e. the operator of the monitoring system) transfers daily plant performance and reliability reports for each plant under management. Plants can be setup to report manually or through a machine-to-machine process.

The oSPARC Web Service provides three functions:

1. Data Custodian registration

   A Data Custodian registers with the oSPARC Web service and receives a login/password. The login/password is used for subsequent operations. Registration requires a valid email address.

2. Initial plant setup and UUID generation

   A Data Custodian authenticates to the service, provides Meta Data describing a plant, and receives a universally unique identifier (UUID) for the plant. The UUID is used in the plant reporting process. This step may be performed through a Web user interface.

3. Upload periodic plant report

   A Data Custodian authenticates to the Web service, references the UUID for a plant, and uploads a periodic plant report containing hourly time-series plant performance data. Hourly values should be uploaded daily for the previous day or when available.

3.5.1 oSPARC Web Service Details

The Web service URL is http://osparc.sunspec.org/ and is currently set to receive periodic plant reports. It uses the HTTP / POST method over SSL and basic authentication. The Data Custodian login/password is used to authenticate.

The POST body contains an XML document conformant to the SunSpec Plant Extract Document schema. See sample documents in the appendix.

- Plant setup request
- Meta-data update
- Time series data upload

3.6 oSPARC User Query

End users query oSPARC via web interface using Plant Information Profile attributes to select power plants meeting the query criteria. Core performance analytics for the plant set are calculated for the requested time period and aggregated into a result set for user analysis. Personal and consumer information is removed from the result set.

3.6.1 Query Parameters

Date Range – The time window for the report. The default date range is last year, and the minimum range is a day.

Plant Location – The zip code or region of plants to include in the report. The zip code can be a single zip code or a collection of zip codes. A region is a pre-determined collection of zip codes, e.g. State, County, City, Service Territory, or Metropolitan Statistical Area (MSA).

Plant Size Range – The range of plant sizes to include in the report . The user defines a set of standard ranges, e.g., <10kW, 10 – 100, 100-1MW, >1MW. The system supports an arbitrary range.

Equipment Type – The type of equipment to filter on for the selected plants in the report. Filter by type {Inverter, Module, Meter, etc.} , by Manufacturer, and/or by Model (optional).

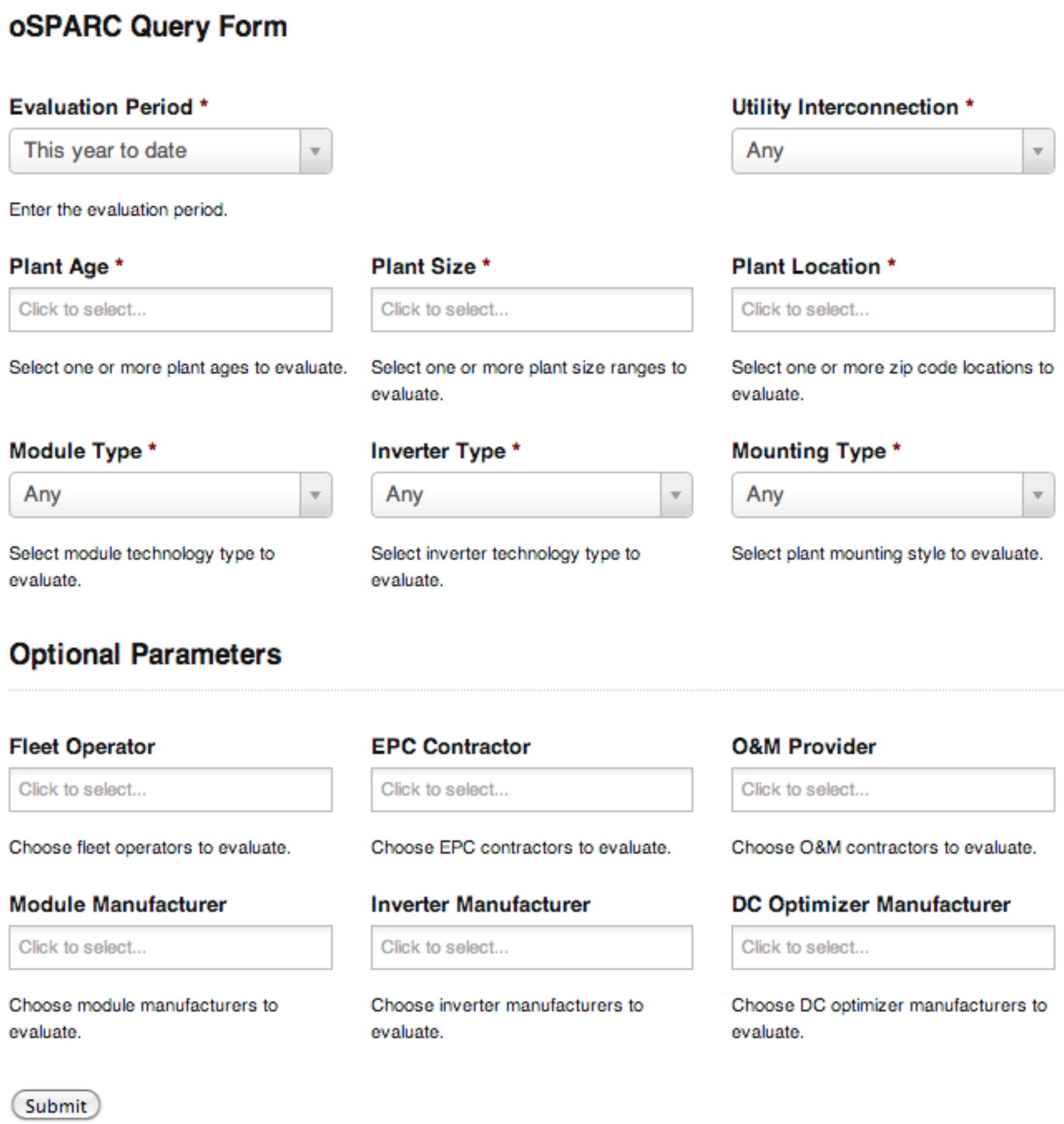
Participants – Filter on plants with particular "Participants" as defined in Plant Meta Data.

Design Elements – Filter on plants with particular design elements.

Plant Age – Filter on plants of a certain vintage.

Data Quality – Filter on plants with a minimum data quality index.

The figure below shows an early prototype of the oSPARC User Query Interface. This interface can also be accessed online at http://www.sunspec.org/osparc-query-interface/.



Example oSPARC Query Form

3.6.2 Query Results and Key Performance Indicators

Query results are generated by the oSPARC system and returned to the end user in the form of a downloadable Excel file that includes the Key Performance Indicators (KPI's) shown below.

These KPI's provide an aggregated and normalized view of the measurements of plant performance for plants selected by the query.

KPI's can be further combined to provide blended overall score or blended overall percentile ranking as needed by the user. The exact formulas for these blended scores are a work in process and will be determined by a consensus of oSPARC reviewers and users.

Here is the list of KPI's supported in Query Results:

Final Yield	Y_f	$WH / kW_{dc\ stc}$
Expected Yield	Y_e	H_{poa} / G_{stc}
Final Yield Compensated	$Y_{f\ tc}$	$WH / (kW_{dc\ stc} * K_{temp})$
Performance Ratio	PR	Y_f/Y_e
PR Compensated	PR_{tc}	$Y_{f\ tc}/Y_e$
DC Performance Ratio	PR_{dc}	DCW / P_{dc}
Power Performance Index	PPI	W / P_{ac}
Energy Performance Index	EPI	$WH / (P_{ac} * \Delta t)$
Availability Index	Avail	Normalized Availability
Health Index	Health	Ratio of active faults to equipment
Data Quality Index	Q_d	Ratio of missing and invalid data samples

3.7 oSPARC Output Report

The oSPARC Output Report provides a summary of the query parameter used to generate the report and a collection of statistics for each of the core performance analytics. The following is a Mock oSPARC report provided for review and comment.

Query	Parameter			
Report ID	cac22430-a486-11e2-9e96-0800200c9a66			
Report Date	2013-Apr-15			
Sample Size	1024			
Evaluation Period	YTD			
Interconnection	ANY			
Location	90566			
Age	< 5 years			
Size	<10kW			
Module Type	Poly			
Inverter Type	String			
Fleet Operator	ANY			
EPC Contractor	ANY			
O&M Provider	ANY			
Module Manufacturer	XYZinc			
Inverter Manufacturer	ABCinc			
DC Optimizer Manufacturer	NONE			
KPI	AVG	MIN	MAX	STDDEV
Final Yield				
Expected Yield				
Performance Ratio				
Compensated Performance Ratio				
DC Peformance Ratio				
AC Performance Ratio				
WH Performance Ratio				
Availability Index				
Health Index				
Data Quality Index				
oSPARC Index				
oSPARC Percentile				

3.8 Anonymization For Vendors and Plant Participants

While the concept of anonymization is most relevant to the oSPARC Output Report and is oriented on protecting consumer information, it is also relevant to the periodic plant **input** report and the vendor data represented therein.

Especially during the development stage of the oSPARC project, equipment vendors, EPC's, and other participants in solar plants may wish to conceal their identities until they can see what the data says about them. This is a reasonable concern that the oSPARC team is happy to accommodate.

At the vendor's request, parameters that identify vendors (shown in Plant Description and Plant Equipment Information) can be populated with the label "Other" to suppress vendor identification. This eliminates the possibility of user search queries specifying vendor names, but still allows power plants to be present in the database and referenced in anonymized and normalized search results.

If, after gaining experience with the oSPARC system, a vendor wishes to reveal its identity, this can be easily accommodated. We believe that the best vendors will be associated with the best performing power plants and will want to feature their brand names within search queries.

4 Next Steps

Thank you so much for reviewing this document and for your interest in the oSPARC system. If you are interested in configuring your power plants to report to the oSPARC system, and to take advantage of the financial advantages provided by the Solar Access to Public Capital initiative, please contact Tom Tansy at 831-227-1073 or send email to tom@sunspec.org.

