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Regional Test Center Operations Manual

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Abstract

The U.S. DOE Regional Test Center for Solar Technologies program was established to validate photovoltaic (PV) technologies installed in a range of different climates. The program is funded by the Energy Department's SunShot Initiative. The initiative seeks to make solar energy cost competitive with other forms of electricity by the end of the decade. Sandia National Laboratory currently manages four different sites across the country. The National Renewable Energy Laboratory manages a fifth site in Colorado. The entire PV portfolio currently includes 20 industry partners and almost 500 kW of installed systems. The program follows a defined process that outlines tasks, milestones, agreements, and deliverables. The process is broken out into four main parts: 1) planning and design, 2) installation, 3) operations, and 4) decommissioning. This operations manual defines the various elements of each part.

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TABLES

NOMENCLATURE

AC	Alternating Current
DAQ	Data Acquisition Systems
DC	Direct Current
DOE	Department of Energy
IEC	International Electrochemical Commission
MOU	Memorandum of Understanding
NDA	Non-Disclosure Agreement
O&M	Operations and Maintenance
PV	Photovoltaic
RTC	Regional Test Center
SNL	Sandia National Laboratories

1 REGIONAL TEST CENTER DESCRIPTION

The U.S. DOE Regional Test Center (RTC) for Solar Technologies program was established to validate photovoltaic (PV) technologies installed in a range of different climates. The program is funded by the Energy Department's SunShot Initiative. The initiative seeks to make solar energy cost competitive with other forms of electricity by the end of the decade. Sandia National Laboratories (SNL) currently manages five different sites across the country. The sites include:

1) Albuquerque, New Mexico
2) Golden, Colorado
3) Williston, Vermont
4) Cocoa, Florida
5) Henderson, Nevada

As of 2016, the entire program has almost 500 kW of solar PV systems from 12 industry partners. The centers were designed to help U.S. industry partners improve their technologies and carve out an advantage in the PV marketplace. Partners selected through a proposal process use their own equipment and contribute cost-share for the testing and analysis services.

1.1 Types of Systems

The program provides system data for several cutting-edge solar cells and module systems including:

- High-efficiency c-SI PV solar cells and modules
- Module and submodule power electronics
- Bifacial modules that allow light to enter from both sides
- Thin-film PV technologies
- Module coatings for antireflection and self-cleaning
- Solar resource assessment technology

1.2 Organization Structure

Sandia National Laboratories manages the RTC program and four of the five sites. The National Renewable Energy Laboratory (NREL) manages the Colorado site. Each site has a lead that oversees local operations.

Program Management (SNL Team)
Role: The program management provides general oversight for the entire RTC program

Responsibilities:
- Planning & Design
- Operations oversight
- Data storage
- Data analysis

Site Leads (SNL & NREL Staff/Site Landowners)
Role: The site leads oversee individual RTC locations.

Responsibilities:
- Planning review & edits
- Installation management & oversight
- Operations & maintenance
- Data collection oversight

1.3 Program Steps

The RTC program follows a defined process that outlines tasks, milestones, agreements, and deliverables. The process is broken up into four main parts: 1) planning and design, 2) installation, 3) operations, and 4) decommissioning.

Table 1 Program planning, design, and installation elements outline

<table>
<tr><td>Planning & Design</td><td>Planning
Contract Agreements
Memorandum of Understanding (MOU)
Validation Plan
Define partner roles
Define system design requirements
List objectives
Operations & Maintenance (O&M) requirements
Commissioning & Decommissioning
Design
Preliminary Design
Final Design
As-Built Design</td></tr>
<tr><td>Installation</td><td>Construction
Site Prep
Foundation & Racking
Modules
Inverters & Enclosures
Connections
Electrical
Monitoring system
Commissioning
Visual Inspection
Sensor Calibration
Commission
Verification Report
Data Collection
Data Communications
Data Storage</td></tr>
</table>

Table 2 Program operations and decommissioning outline

Operations	**Operations & Maintenance** • Inspections • Sensor cleaning • Repair & replacement **Data Collection & Storage** • Local data collection (site data acquisition systems) • Data quality assurance • Data transmission (remote to central storage) • Data storage **Data Analysis** • Individual site performance analysis • Analysis reports
Decommissioning	**Plan** • Comply with MOU • Schedule **Construction** • Disassemble • Pack & Ship • Repurpose **Report** • Record actions

2 PLANNING & DESIGN

The planning and design of RTC systems is a critical step to solidify agreements, assign roles, validate objectives, and specify construction material and specifications. This stage engages the partners and develops action items for each stakeholder.

2.1 Planning

The establishment of plans for the RTC program has two main components. First, the management team works with the partner(s) to establish necessary contracts required to perform the work. The second step is to create a validation plan. The work plan defines roles and establishes short and long term objectives.

2.1.1 Contract Documents

The two main contracts to be processed during this planning stage is the Memorandum of Understanding (MOU) and the non-disclosure agreement (NDA). The MOU is a non-binding agreement that establishes a working relationship between the industrial partner and Sandia National Laboratories. The NDA is a binding agreement that places restrictions on the collected performance data. In most cases, the data cannot be shared publicly without written consent from the partner.

2.1.2 Work Plan

The work plan provides a statement of work for each of the stakeholders. The plan defines the roles and expectations for the RTC partner, SNL management, and site leads. The plan includes the technical objectives, system description, and system installation requirements. It also describes the type of monitoring system, analysis methods, and operations and maintenance general procedures.

2.2 Design

The intent of the design stage is to describe the system layout, racking design, module configuration, electrical component sizing and specifications, and grid connection requirements. The system layout and specification are defined explicitly in construction drawings produced by the SNL management team. The monitoring system configuration design defines the need for low voltage power, data communication wiring, and the type of sensors as shown in Section 9. The construction documents are reviewed multiple times by the management and site leads as described in Section 2.2.1.

2.2.1 System Design

The electrical design should ensure that the PV system design and feasibility estimates are made using reliable data. The system must be designed in accordance to state and local building and safety requirements. The design should consider accurate site data such as existing electrical equipment, shade structures, etc. proper application of all codes included National Electric Code (NEC), International Fire Code (IFC), etc. Appropriate level of detail in the design drawings such that the installation team encounters a minimum number of unknown obstacles onsite. The necessary information for design reviews, permits, and approvals should include:

- Site Plan
- Racking plan

- Electrical Diagram (1- or 3-line)
- Electrical system details
- Equipment data sheets

2.2.2 Design Review Process

During the system design phase, there are three types of reviews:

1. Preliminary Design Review
2. Final Design Review
3. As-Built Review

The purpose of each review is to ensure that all contributory factors, reasonable design options, and all pertinent codes and standards have been considered. Additionally, the design must meet the partner specific requirements outlined in the Validation Plan (Section 2.1.2).

2.2.2.1 Preliminary Design Review

The preliminary design review includes a two-step process: 1) develop design documents and 2) critique of the documents. The solar PV system design considers necessary codes, standards, site constrains, and partner requirements. The design documents include:

- G1 – General Information
- G2 – Module Information
- G3 – String Calculations
- E1 – Electrical (one line diagram)
- R1 – Array Racking
- D1 – Data Acquisition (DAQ)
- D2 – DAQ: Logger Enclosure
- D3 – DAQ: DC Monitoring
- D4 – DAQ: Thermocouple Enclosure
- Specification sheet for modules and inverters

The design documents are provided to the design review team members for a detailed evaluation. The team members, consisting of the technical site lead, program manager, DAQ technical staff, electrical technical staff, and solar system technologist, review the design documents individually and as a team. The outcome of the review stage is to discuss and document the following:

- General design review comments
- Site specific requirements

2.2.2.2 Final Design Review

The final design review focuses on the site-specific requirements. At this point, the design documents have been updated to address the comments from the preliminary review. During the final review stage the design documents will be extended to include:

- S1 – Site Information
- E2 – Electrical: AC Calculations

- E3 – Electrical: DC Calculations
- R2 – Array Stringing
- R3 – Enclosure Locations

The final review of the documents is conducted by the same team members as described in preliminary design review (Section 2.2.1.1). Each of the team members must approve the drawings before the design can be finalized. Disputes are decided by the program manager. Then, once the drawings are updated the system is ready for submission at a local permitting office (if necessary) and then construction can proceed.

3 INSTALLATION

The installation process includes construction activities, data collection set up, and system commissioning. The intent of the construction activity is to assemble the PV system based on the final design construction drawings and specifications. The installation process also includes the set-up, calibration, and testing of the data collection system. The last step in the installation process is to commission the PV system based on a system inspection and an analysis of initial performance data.

3.1 Construction

The construction activity is scheduled based on the design document requirements, specific site constraints, and local permitting rules. The site lead will procure the construction personnel and monitor activity to ensure that safety protocols are followed and that milestones are met in a timely manner. The process typically begins with site preparation that could involve surveys and earth moving equipment. Once the site is leveled, the foundation can be installed according to the design. The racking can then be constructed on top of the foundations and the models can be installed. These initial steps can be skipped if existing racking will be used for the system. The installation of the racking structure is followed by the installation of the inverters, enclosures, conduit, and wiring. The electrical and monitoring system connections can then be terminated. Finally, once the equipment is installed and the grid connection is confirmed, a system inspection is performed by a qualified inspector. Following a successful inspection, the system can be turned on and begin to produce power.

3.1.1 Contractor Qualifications

The contractor is responsible for on-site system installation based on the intended design, equipment specifications, and local authority having jurisdiction requirements. The contractor hiring process and qualifications for each partner will be defined in the work plan (Section 2.1.2). Each partner will establish a contractor with a reputable company that meets the minimum qualifications outlined in this document. This includes work history, financial transparency, health and safety, insurance, and applicable trade licenses.

3.1.2 Contractor Best Practices

The construction activity shall be conducted based on scheduling and quality assurance best practices to ensure on-time delivery of well-functioning system. The contractor shall install equipment that matches the design and industry standards, acquire necessary permitting and inspections, follow system construction standards for PV systems, and meet all interconnection standards and requirements.

3.1.2.1 Equipment Requirements

The system equipment must meet the minimum requirements defined by the design documents. At some sites, the equipment must meet UL, IEC, ASTM, and other standards. At other sites, non-listed equipment can be installed as long as site-specific procedures and inspections are followed. Each of the equipment specifications are defined as follows:

- Modules: Defined by RTC Partner in the Work Plan
- Inverters: Defined by final design construction documents

- Racking System: Defined by final design construction documents
- Monitoring: Defined by final design construction documents
- Electrical components:
    - IEC 62852 – UV exposure for connectors/cables
    - IEC 62790 – UV exposure for junction boxes
    - UL 1565 Wire Positioning devices
    - NEMA rated enclosures

3.1.2.2 Permitting and Inspections
The contractor is responsible for procuring all the necessary permit and approvals for the PV system construction and inspection.

3.1.2.3 System Construction
The installation shall be compliant with all state, utility, and local jurisdiction requirements. It must also comply with the manufacturers' installation requirements. This includes but not limited to:

- Required grounding and bonding
  Proper grounding will ensure that there is no hazardous voltage between exposed metal parts of the system and the Earth. Grounding and bonding must comply with applicable NEC code requirements.

- Ground-fault detection
  The ground-fault detection system must be installed properly and operational at the time of system start-up.

- Best practices labeling
  System labeling of PV systems is crucial for safety of operators, service personnel, emergency responders, and others. The system labeling must comply with applicable NEC specifications.

- Mounting System
  Module mounting systems must be capable of withstanding downward forces (modules, snow loads, etc.) and uplift (wind).

- PV Modules
  System installers shall be aware of specific mounting location stipulations for the module manufacture.

3.1.2.4 Interconnection
The completed PV system must be approved by the site lead and any local jurisdictions before it can be connected to the electric grid.

3.2 Data Collection
PV system monitoring is a critical tool that supports O&M activities. The RTC program also uses the data for detailed analysis of system performance. The data collection system connects

to electrical and environmental sensors that are installed at various locations on the array (see Appendix A for data types). The RTC systems include sensors that monitor both the DC and AC electricity. The DC voltage and current measurements are taken from a standardized monitoring system that uses voltage dividers, shunts, isolators, and a ICP-DAS© to collect data. The system has been standardized by SNL into a single box and is commonly referred to as the "Boilerplate" data collection system. While most RTC systems will use the "Boilerplate" system, exceptions are allowed as long as they are documented in the Validation Plan.

The data from the environmental and electrical ICP-DAS devices are collected at 5 second intervals using a Campbell Scientific© data logger. The Campbell Scientific© data logger processes the data and computes one minute averages. The one minute average data is then extracted from the data logger using a Campbell Scientific© software called Logger Net to produce data files. The data files are extracted each day, and stored on a local computer's hard drive. The data file is then transferred from the remote site to the host database using RepliWeb Managed File Transfer (RMFT).

3.3 System Calibration & Commissioning

Determining that the PV system is performing as designed requires a two-step process that includes: 1) calibration and 2) testing. It also includes the creation of a verification report that documents the state of the constructed system.

3.3.1 Calibration

The calibration of PV system sensors compares the measurement values with a calibration standard of known accuracy. The process ensures that the sensor data measured by the ICP-DAS© is accurate within a tolerance band. This process begins with controlled tests on a bench in the lab and ends with field tests.

3.3.1.1 Bench test

The indoor tests provide a precise tuning of the data collection system that calibrates the electrical devices to less than 0.3% of the known standard. The initial calibration shall be performed at SNL prior to deployment. After the systems are shipped to the remote sites the monitoring system calibration should be checked to ensure that the initial settings were maintained.

3.3.1.2 Field test

After the monitoring system has been installed in the field, qualified personnel must perform a calibration that sets the devices to measure values that are less than 0.5% of the known standard. The process includes the following actions:

1. Connect known voltage and current source to data collection device
2. Turn data collection system ON
3. Provide multiple voltage and current values to data collection system
4. Retrieve data and evaluate performance

3.3.2 Commissioning

The commissioning process is a critical part of a well-installed system. Commissioning provides a means to formalize quality control of installed PV systems. The process ensures that the system is safe and performing as designed. The RTC program implements a commissioning test process that complies with the IEC 62446 standard published in March 2009. The standard defines testing, inspection, and system verification procedures.

3.3.2.1 Inspection

The PV system shall be inspected prior to energizing the system. The inspection process includes the following categories:

- DC System
- Overvoltage and shock
- AC System
- Labeling and identification

3.3.2.2 Testing

The testing of the PV system shall be conducted in accordance with Electrical Safety in the Workplace standards. Technicians shall wear personal protective equipment and follow proper procedures and use appropriate tools. The process shall begin at the AC circuits first and then evaluate the DC circuit. The tests include the following activities:

- Test continuity of equipment grounding conductors and system grounding
- Test polarity of all DC cables
- Test open-circuit voltage
- Test short-circuit current
- Test functionality of major system components
- Test insulation resistance of DC circuit conductors

3.3.3 Verification Report

Once the PV system has been constructed the final review process must be conducted before it can be energized. This review includes two main steps:

1. Installation Acceptance Visual Inspection Form (Appendix B)
2. As-built drawing red-lines
3. Design document updates based on As-Built red-lines

The Installation Acceptance Visual Inspection Form is provided by the SNL management and provides a review of the installed power electronics, wires, PV modules, and racking systems. The inspector will also compare the constructed system with the design documents to provide a review of the as-built system. The inspector will red-line the final design documents and provide the edited drawings to the designer. The designer will then update the design documents to reflect what was constructed.

4 OPERATIONS

The management of PV assets should be performed in a systematic process. The processes should include planning, operating, maintaining, upgrading, and replacing assets effectively with minimum risk and at the expected levels of service over the life cycle. An effective O&M program can enhance the likelihood that a system will perform at or above its projected production rate. Standardized practices and approach can help ensure that risks are mitigated and costs are minimized.

4.1 Preventive Maintenance

The intent of preventative maintenance is to maximizes system output, avoid expensive failures, and maximize the life of the PV system. Maintenance activities must balance the cost of scheduled maintenance with the cash flow through the life of the system. The protocols depend on system size, design, complexity, and the environment. A comprehensive list of these protocols is included in Appendix C

4.2 Corrective Maintenance

System outages or sub-system deficiencies result in lost or reduced electrical production. The need for repairs shall reported to the necessary stakeholders immediately. The corrective action shall be decided and implemented based on the established work plan (Section 2.1.2) procedures defined for the individual system. The types of services for corrective maintenance can include whole AC wiring, DC wiring, inverter, and repair as described in Appendix C.

4.3 Asset Management

The critical driver for the RTC program is not to maximize the generation of power. The intent is to test and evaluate a range of systems in different climate locations. Although the overall goal may be different than typical systems, the detailed management of the assets remains the same. Example activities are described in Appendix D, and in general the management requires the following:

1. Detailed data monitoring
2. Alarms
3. Material management
4. O&M Documentation

The detailed data monitoring provides performance and operations oversight. Each day the system data is monitored using PECOS (http://pecos.readthedocs.io/en/latest/installation.html) python scripts to evaluate data availability and compliance of rule based analytics. The performance and operations monitoring is an ongoing process that ensures that the system integrity is maintained. The management of materials and O&M documents is conducted in an as needed basis.

The material assets, that include electronics, modules, racking, etc., are managed by SNL staff. The management includes the documentation of material types, locations, and system names. This documentation begins during the installation phase when the material is purchased. The documentation is then updated based on the as-built review and when change orders are submitted and approved. The material change orders are typically submitted during maintenance activity when repairs and/or replacements are necessary. The change orders are submitted to the SNL staff for approval and processing.

4.4 Operations & Maintenance Provider

The O&M for each system is defined in the original work plan. Each site lead develops and executes a plan to provide the necessary O&M activities. The site lead shall engage an O&M provider(s) that can perform cleaning, inspections, and maintenance activities. The provider must meet minimal requirements defined by Sections 4.4.1 - 4.4.4 below.

4.4.1 Qualifications

The provider should have the necessary qualification to support the scope of work. For example, electrical work must be performed by individuals who have the following qualifications:

1. License electrical contractor
2. NABCEP PV installer certification
3. Experience with medium-voltage electrical systems
4. Experience with DC power systems
5. Familiarity with sections of the National Electric Code specific to PV (section 690)

4.5 Data Collection & Storage

Performance data collected from each system is initially stored on the system's datalogger and a local computer running at the site. Each night data is transferred to SNL and uploaded into a database. More information about the data transfer process is available in a separate report.[1]

4.6 Data Analysis

On intervals defined in the Validation Plan, a technical analysis report is generated by the RTC team to record the performance of each RTC system or set of systems across the various sites. These reports are shared with the partners and it is their decision on whether the reports are to be released publically or used internally.

More general analyses may be done that will compare the performance of many systems across the RTC sites. These reports will anonymize the data such that no individual RTC partner can be recognized in the results that are presented.

[1] Riley, D. M. and J. S. Stein (2016). The Regional Test Center Data Transfer System. Albuquerque, NM, Sandia National Laboratories. **SAND2016-9461**.

5 DECOMMISSIONING

Decommissioning of RTC systems may become necessary for a number of different reasons including the partner going out of business or deciding the partnership should end, the project is completed and no further monitoring of the systems are requested, or the RTC program scope is changed and a site must be removed from the network. In any case, the MOU with the partner should outline the roles and responsibilities for decommissioning.

When decommissioning is deemed necessary, a Decommissioning Plan will be created. This plan will define a schedule of activities, financial responsibilities, and ownership of equipment. In some cases, it might make sense for the partner to donate their equipment to the RTCs and allow the systems to remain operational and the performance data to be shared.

APPENDIX A SENSOR NOMENCLATURE

Table 3 Weather Sensor Nomenclature

Number	Name	Units	Description
1	TIMESTAMP	datetime	Time instance
2	RECORD	-	The record number of the output time
3	Global_Wm2_Avg	W/m^2	Average global horizontal irradiance
4	Direct_Wm2_Avg	W/m^2	Average direct normal irradiance
5	Diffuse_Wm2_Avg	W/m^2	Average horizontal diffuse irradiance
6	Pressure_mBar_Avg	mBar	
7	WS_ms_Mean	m/s	Average wind speed
8	Wdir_Mean	Degrees	Average wind direction in degrees eastward from north
9	Wdir_Std	Degrees	Standard deviation of the wind direction. Used to determine if the wind is blowing in a constant direction over the minute
10	WS_ms_Std	m/s	Standard deviation of the wind speed. Used to determine wind variability.
11	WS_ms_3sec_Max	m/s	Maximum 3 second average wind speed. Used to determine maximum wind gusts
12	WD_deg_SMM	Degrees	Sample max min
13	Temp_C_Avg	°C	Average ambient temperature
14	RH_pct_Avg	%	Average relative humidity
15	Panel_Temp_C_Avg	°C	Average temperature of the CR1000
16	Battery_V_Avg	Volts	Average battery voltage of the backup battery for the CR1000
17	ProcessTime_S_Max	Seconds	Maximum process time of the CR1000 to complete any scan of the instruments
18	Global_mV_Avg	mV	Average raw reading from the CMP22. Used in the calculation of the global horizontal irradiance
19	Rain_mm_Tot	mm	Totalized rainfall
20	Rain_mm_Daily	mm	Rainfall collected today (reset at midnight)
21	Temp_CMP22_C_Avg	°C	Average temperature of the CMP22.

Table 4 Electrical Sensor Nomenclature

Number	Name	Units	Description
1	TIMESTAMP	datetime	Time instance
2	RECORD	-	The record number of the output time
3	ModTemp[]_Avg	°C	Mean temperature recorded on back of module []. Thermocouples are attached to multiple modules, the [] represents module number
4	String[]_Avg	Amps	Mean DC current from string []. The PV array can have multiple strings, the [] represents the string number.
5	SystemVdc_Avg	Volts	Mean DC system voltage
6	SystemIdc_Avg	Amps	Mean DC system current
7	POAIrrad1_Avg	W/m^2	Mean plane of array irradiance from a broadband pyranometer
8	RefMod1Temp_Avg	°C	
9	RefMod1Irrad_Avg	W/m^2	
10	LocalAmbientTemp_Avg	°C	Mean ambient air temperature
11	VoltageDividerTemp_Avg	°C	Mean temperature of the system voltage divider housing
12	RefCell1Irrad_Avg	W/m^2	Mean irradiance provide by the cleaned plan of array reference cell
13	RefCell1Temp_Avg	°C	Mean temperature of the cleaned plane of array reference cell.
14	RefCell1R_Avg	mV	Mean measurement of the clean plane of array reference cell's irradiance signal.
15	ReffCell2Irrad_Avg	W/m^2	Mean irradiance provided by the soiled plane of array reference cell
16	RefCell2Temp_Avg	°C	Mean temperature of the soiled plane of array silicon reference cell
17	RefCell2R_Avg	mV	Mean measurement of the clean plane of array reference cell's irradiance signal.
18	ICP7019_[]CJCTemp_Avg	°C	Mean cold junction compensator temperature of the ICP-DAS M-7019R data acquisition device

Table 5 Electrical Sensor Nomenclature (continued)

Number	Name	Units	Description
19	ACV_Avg	Volts	Mean RMS AC voltage at the inverter output.
20	ACI_Avg	Amps	Mean RMS AC current at the inverter output.
21	ACW_Avg	Watts	Mean real AC power at the inverter output.
22	ACVAR_Avg	VAR	Mean reactive AC power at the inverter output.
23	ACPowerFactor_Avg	-	Mean AC power factor at the inverter output
24	ACFrequency_Avg	Hz	Mean frequency of the AC voltage at the inverter output

APPENDIX B VISUAL INSPECTION FORM SAMPLE

Note: Do not use this appendix for the form. Please contact SNL for form template.

Project Details		
RTC Site		
RTC Address		
RTC Site: GPS Coordinates		
Site Address		
RTC Site Contact		
Site Contact		
Site Contact Phone		
Site Contact Email		
Site Visit Date for Visual		
Designed by		
Company Name		
Address		
City, State, ZIP		
Contact		
Contact Phone		
Contact Email		
Installed by		
Company Name		
Address		
City, State, ZIP		
Contact		
Contact Phone		
Contact Email		
Inspected by		
Company Name		
Address		
City, State, ZIP		
Contact		
Contact Phone		
Contact Email		
Installation Details		
Date of Installation Completion		
Site Solar Noon (date of testing)		
Installed by Licensed Electrician?	Yes ☐	No ☐
System Design Drawings?	Yes ☐	No ☐

Item	Design Specified	Installed	Verification Initials
Total System Size [STC DC]			
PV Module Make / Model(s)			
PV Module Power [STC DC]			
PV Modules per String			
Strings per System			
Number of Systems			
Inverter(s) Make / Model			
Total Number of Inverters			
Racking Manufacturer			
Combiner Box Make / Model			
Maximum Number of Poles			
Total Number of Combiners			

Item	Manufacturer	Model #	Serial #	Fuse Rating	Rated Voltage	Rated Current
Combiner Box						
Junction Box (2)						
DC Disconnect (1)						
DC Disconnect (2)						
AC Disconnect (2)						
Inverter (1)						

System Design Summary and Field Verification:

Enter values from the design document and check after verifying in the field.

	Array to Junction Box	✓	Junction Box to Combiner	✓	Combiner to Disconnect	✓	Circuits Combined	✓	Disconnect to Inverter	✓	Inverter to Disconnect	✓	Disconnect to Panel	✓
Wire Size		☐		☐		☐		☐		☐		☐		☐
Wire Type		☐		☐		☐		☐		☐		☐		☐
Grd Cond Size		☐		☐		☐		☐		☐		☐		☐
Grd Cond Type		☐		☐		☐		☐		☐		☐		☐
Conduit Size		☐		☐		☐		☐		☐		☐		☐
Conduit Type		☐		☐		☐		☐		☐		☐		☐
OCPD Rating		☐		☐		☐		☐		☐		☐		☐
OCPD Type		☐		☐		☐		☐		☐		☐		☐

Checklist Items:

Review each item and place a check mark (✓) in the right-hand column if the item is complete/correct. If the item needs attention, however, write “Note” in the right-hand column. Please provide details for all Notes in the **Notes & Comments** section, located below the checklist.

Item #	Description	“✓” or “Note”
	PV Modules	
1.	No cracked or broken glass on the modules	
2.	No signs of delaminating or water infiltration on modules	
3.	No broken, damaged or discolored module cells	
	PV Array	
4.	Array tilt is ______ degrees (+/- 1 deg.)	
5.	Module wattage is as shown on drawings.	
6.	Layout of modules is as depicted on the Array Plan.	
7.	Racking components are attached per racking manufacturer’s drawings.	

8.	Racking components are tight and secure.	
9.	Modules are securely attached to the racking system.	
10.	Module and string homerun wiring is secured to racking.	
11.	All modules and racking system are grounded.	
	DC Wiring	
12.	DC conduits & wire ways are properly installed and supported.	
13.	All DC components are rated for continuous operation at DC, at the maximum possible DC system voltage, and at the maximum possible DC fault current.	
14.	Protection by use of Class II or equivalent insulation is adopted on the DC side.	
15.	PV string cables, PV array cables, and PV DC main cables have been selected and installed so as to minimize the risk of ground faults and short circuits.	
16.	Wiring systems have been selected and installed to withstand the expected external influences such as wind, temperature, ice formation, and solar radiation.	
17.	For unfused strings: verify that the module reverse current rating is greater than the possible reverse current. Also verify that the string cables are sized to accommodate the maximum combined fault current from parallel strings.	
18.	For fused strings: verify that the string over-current protective devices are fitted and correctly specified to local codes or to the manufacturer's instructions for protection of PV modules.	
19.	Verify that a DC switch disconnect is installed to the DC side of the inverter.	
20.	If blocking diodes are installed, verify that their reverse voltage rating is at least 2 x Voc (at STC) of the PV string in which they are installed.	
21.	Wiring and conduit sizes are as shown on drawings.	
22.	Connectors on homerun cabling are installed correctly.	
23.	Homerun wiring is color-coded correctly and labeled as shown on drawings.	
24.	All wiring is terminated correctly.	
25.	All wiring is secure within terminals.	
26.	All conduits are sealed from moisture ingress.	

AC System		
27.	A means of isolating the inverter has been installed on the AC side.	
28.	All isolation and switching devices have been connected such that PV installation is wired to the "load" side and the public supply to the "source" side.	
29.	The inverter operational parameters have been programmed to local regulations.	
Protection Against Overvoltage/Electrical Shock		
30.	Verification of type B RCD were: RCD is installed and the PV inverter is without at least simple separation between the AC side and the DC side.	
31.	To minimize voltages induced by lightning, the area of all wiring loops has been kept as small as possible.	
32.	(Where required by local codes) Array frame and/or module frame protective grounding conductors have been correctly installed and are connected to ground. Where protective grounding and/or equipotential bonding conductors are installed, they are parallel to, and bundled with, the DC cables.	
Labeling and Identification		
33.	All circuits, protective devices, switches, and terminals are suitably labeled.	
34.	All DC junctions boxes (PV generator and PV array boxes) carry a warning label indicating that active parts inside the boxes are fed from a PV array and may still be live after isolation from the PV inverter and public supply.	
35.	The main AC isolating switch is clearly labeled.	
36.	Dual supply warning labels are installed at the point of interconnection.	
37.	A single line wiring diagram is displayed on-site.	
38.	Inverter protection settings and installer details are displayed on-site.	
39.	Emergency shutdown procedures are displayed on-site.	
40.	All signs and labels are suitably affixed and durable.	
Monitoring and Inverter		
41.	Enclosures are properly installed and supported.	
42.	Enclosures are labeled per the drawings.	

43.	All cabling is terminated and labeled correctly.	
44.	DC Fuses are sized as indicated on the drawings.	

Notes & Comments *Detail all Notes below.* *Preface each Note with its corresponding Item #. List notes in numerical order.*	
Item #	Comment
NOTE: All identified issues were corrected by ___________________________ while on-site.	

Inspector Name	
Inspector Signature	
Date	

Inspector Name	
Inspector Signature	
Date	

APPENDIX C PREVENTATIVE MAINTENANCE

Table 6 Preventative maintenance sample activities

Activity Area	Component	Description	Interval	Provider
Cleaning	PV Module General	Clean PV modules with water or mild dishwashing detergent. Do not use brushes, any types of solvents, abrasives, or harsh detergents.	Dependent on environment	Module cleaner
Cleaning	PV Module	Snow removal	Dependent on environment	Module cleaner
Cleaning	PV Module	Dust	Dependent on environment	Module cleaner
Inspection	AC Wiring	Inspect electrical boxes for corrosion or intrusion of water or insects. Seal boxes if required	Annual	Electrician
Inspection	AC Wiring	Check position of disconnect switches and breakers	Annual	Electrician
Inspection	AC Wiring	Exercise operation of all protection devices.	Annual	Electrician
Inspection	AC Wiring	AC disconnect box inspection	Annual	Electrician
Inspection	DC Wiring	Scan combiner boxes with infrared camera to identify loose or broken connections	Annual	Journeyman Electrician
Inspection	DC Wiring	Inspect cabling for signs of cracks, defects, pulling out of connection, overheating, arcing, short or open circuits, and ground faults	Annual	Electrician
Inspection	DC Wiring	Check proper position of DC disconnect switches	Annual	Electrician
Inspection	Combiner Boxes and DC Wiring	Check fuses and electrical connections. Check for water incursion and corrosion damage. Use infrared camera for identifying loose connections.	Annual	Electrician
Inspection	DC Wiring	Look for any signs of intrusion by pests such as insects and rodents	Annual	Inspection
Inspection	Inverter	Observe instantaneous operations indicators on the faceplate of the inverter to ensure that the amount of power generated is typical of the conditions	Monthly	Inspection

Table 7 Preventative maintenance sample activities (cont.)

Activity Area	Component	Description	Interval	Provider
Inspection	Monitoring	Spot-check monitoring instruments with hand-held instruments to ensure that they are operational and within specifications	Annual	PV Module/Array Specialist
Inspection	PV Array	Test open circuit voltage of series strings of modules	Annual	Journeyman Electrician
Inspection	PV Array	Check all hardware for signs of corrosion, and remove rust and repaint if necessary	Annual	Mechanical Technician
Inspection	PV Array	Walk through each row of the PV array and check the PV modules for any damage. Report any damage to rack and damaged modules for warranty replacement. Note location and serial number of questionable modules.	Annual	PV Module/Array Specialist
Inspection	PV Array	Inspect ballasted, non-penetrating mounting system for abnormal movement	Annual	Mechanic
Inspection	PV Array	Determine if any new objects, such as vegetation growth, are causing shading of the array and move them if possible.	Annual	Tree Trimming
Inspection	PV Module	Use infrared camera to inspect for hot spots; bypass diode failure	Annual	PV Module/Array Specialist
Inspection	Transformer	Inspect transformer meter, oil and temperature gauges, include housing container, or concrete housing	Annual	Journeyman Electrician
Inspection	Controller	Check electrical connection and enclosure for tracking motor/controller	Annual	Electrician
Inspection	Motor	Check electrical connections	Annual	Electrician
Inspection	DC Wiring	Check grounding braids for wear	Annual	Electrician
Inspection	Transformer	Transformer/switchgear inspection	Annual	Electrician
Inspection	Tracker	Anemometer inspection	Annual	Inspector
Inspection	Tracker	Driveshaft torque check & visual inspection	Annual	Mechanical technician
Inspection	Tracker	Inclinometer inspection	Annual	Mechanical technician
Inspection	Tracker	Limit switch inspection	Annual	Mechanical technician

Table 8 Preventative maintenance sample activities (cont.)

Activity Area	Component	Description	Interval	Provider
Inspection	Tracker	Module table inspection	Annual	Mechanical technician
Inspection	Tracker	Screw jack inspection	Bi-annual	Mechanical technician
Inspection	Tracker	Slew gear torque check & wear inspection	Bi-annual	Mechanical technician
Inspection	Tracker	Torque inspection	Annual	Mechanical technician
Inspection	Tracker	Tracking controller inspection	Annual	Mechanical technician
Inspection	Tracker	Universal joint inspection, gears, gear boxes, bearings as required or documentation by manufacturer	Annual	Mechanical technician
Inspection	PV Module	PV module torque check & visual inspection	5 years	PV module/array specialist
Inspection	PV Module	Racking torque check and inspection	5 years	PV module/array specialist
Inspection	PV Module	Inspection: corrosion and encapsulate yellowing	Annual	PV module/array specialist
Inspection	PV Module	Galvanization inspection	Annual	PV module/array specialist

APPENDIX D CORRECTIVE MAINTENANCE

Table 9 Corrective maintenance sample activities

Activity Area	Component	Description	Interval	Provider
Emergency response	System	Dispatch contractor in response to alarms, alerts, or contact by others	As needed	Journeyman Electrician
Repair	AC Wiring	Replace invert AC fuse(s)	As needed	Electrician
Repair	AC Wiring	Replace protective devices	As needed	Electrician
Repair	AC Wiring	Replace broken/crushed AC wiring conduit and fittings	As needed	Electrician
Repair	AC Wiring	Repair line-to-line fault	As needed	Electrician
Repair	AC Wiring	Locate line-to-line fault	As needed	Electrician
Repair	DC Wiring	Replace failed fuses in combiner box	As needed	Electrician
Repair	DC Wiring	Replace MC Connectors between modules	As needed	Electrician
Repair	DC Wiring	Replace MC connector lead to combiner box	As needed	Electrician
Repair	DC Wiring	Re-route conduit	As needed	Electrician
Repair	DC Wiring	Replace broken/crushed Dc wiring conduit and fittings	As needed	Electrician
Repair	DC Wiring	Repair ground fault	As needed	Electrician
Repair	DC Wiring	Locate ground fault	As needed	Electrician
Repair	DC Wiring	Locate underground DC wiring as part of repairs to faults	As needed	Electrician
Repair	DC Wiring	Replace fuse(s) on DC source circuits to inverter	As needed	Electrician
Repair	DC Wiring	Seal leaking junction box	As needed	Electrician
Repair	Inverter	Replace fuse	As needed	Electrician
Repair	Inverter	Start/stop inverter (reboot to clear unknown error)	As needed	Electrician
Repair	Inverter	Replace inverter fan motor	As needed	Invert Specialist
Repair	Inverter	Replace inverter data acquisition card/board; diagnose with fault code	As needed	Invert Specialist
Repair	Inverter	Replace inverter control card (PWM signal, voltage, phase, frequency, shut-down); diagnose with fault code	As needed	Invert Specialist
Repair	Inverter	Replace IGBT driver card/board; diagnose with fault code	As needed	Invert Specialist

Table 10 Corrective maintenance sample activities (cont.)

Activity Area	Component	Description	Interval	Provider
Repair	Inverter	Replace maximum power point tracker card/board; diagnose with fault code	As needed	Invert Specialist
Repair	Inverter	Replace AC contactor in inverter	As needed	Invert Specialist
Repair	Inverter	Replace IGBT matrix in inverter	As needed	Invert Specialist
Repair	Inverter	Replace 24VDC power supply for inverter controls	As needed	Invert Specialist
Repair	Inverter	Replace DC contactor in inverter	As needed	Invert Specialist
Repair	Inverter	Replace surge protection in inverter	As needed	Invert Specialist
Repair	Inverter	Replace GFI components in inverter	As needed	Invert Specialist
Repair	Inverter	Replace capacitors in inverter	As needed	Invert Specialist
Repair	Inverter	Replace inductors (coils) in inverter	As needed	Invert Specialist
Repair	Inverter	Replace fuses internal to inverter	As needed	Invert Specialist
Repair	Inverter	Replace inverter relay/switch	As needed	Invert Specialist
Repair	Inverter	Replace overvoltage surge suppressors for inverter	As needed	Invert Specialist
Repair	Inverter	RE-install inverter control software	As needed	Invert Specialist
Repair	Inverter	Manual reset of arc-fault trip (NEC 690.11)	As needed	Invert Specialist
Repair	PV Array	Excavate and replace failed foundation element	As needed	Engineer
Repair	PV Array	Repair or replace rack parts damaged by corrosion or physical damage	As needed	PV Module/Array Specialist
Repair	PV module	Replace modules failing performance test after showing cracks in glazing, discoloration of metallic contacts, delamination or signs of water in	As needed	Electrician

Table 11 Corrective maintenance sample activities (cont.)

Activity Area	Component	Description	Interval	Provider
Repair	PV module	Repair cracking of PV module back sheet	As needed	PV Module/Array Specialist
Repair	PV module	Repair or replace damage to module frame	As needed	PV Module/Array Specialist
Repair	Tracker	Repair/replace tracker drive shaft	As needed	PV Module/Array Specialist
Repair	Tracker	Replace tracker drive bearing	As needed	Mechanical Technician
Repair	Tracker	Replace tracker mount bearing	As needed	Mechanical Technician
Repair	Tracker	Replace tracker motor controller	As needed	PV Module/Array Specialist
Repair	Tracker	Replace/upgrade tracker control software	As needed	PV Module/Array Specialist
Repair	Tracker	Replace tracking controller power supply fan filter	As needed	Mechanical Technician
Repair	Tracker	Replace hydraulic cylinder	As needed	Mechanical Technician
Repair	Transformer	Replace transformer	As needed	Electrician
Repair	Transformer	Re-tap transformer	As needed	Electrician
Repair	IT, DAQ, internet connections	Repair/Replace repair onsite IT, DAQ, internet connections	As needed	Electrician
Repair	Monitoring devices	Replace monitoring components at combiner boxes	As needed	IT
Repair	Environmental sensors	Repair/replacing environmental sensors	As needed	Electrician
Repair	Combiner boxes	Repairing/replacing combiner boxes (DC, AC side)	As needed	Electrician
Repair	Inverter	Replace inverter	As needed	Electrician
Repair	AC Wiring	Locate underground AC wiring	As needed	Utility

APPENDIX E ASSET MANAGEMENT

Table 10 Asset management sample activities

Activity Area	Component	Description	Interval	Provider
Management	Asset Management	Daily operation and performance monitoring	Ongoing	Office staff
Management	Asset Management	Monitor alarms and site specific alert parameters	Ongoing	Office staff
Management	Asset Management	Manage inventory of spare parts	As needed	Office staff
Management	Asset Management	Monitoring annual service package	Ongoing	Office staff
Management	Documents	Document all O&M activities in a workbook available to all service personnel	Ongoing	Office staff
Management	Documents	Confirm availability and take any measures to secure operating instructions, warranties and performance guarantees, and other project documents.	Monthly	Office staff
Management	Documents	Review O&M agreements and ensure that services are provided	As needed	Office staff
Management	Documents	Update record with preventative maintenance activities and track any problems or warranty issues and secure the record onsite	Ongoing	Office staff
Management	Documents	Meet the key site staff to continue awareness, question any issues, and report on findings	Annual	Office staff
Management	IT	Check central SCADA/network manager, include software IT and IT hardware updates as required	Annual	Office staff

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