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Cooperative Utility PV Manual

Supplement:
Project Manager's PV Quick Start Guide

Prepared by:
National Rural Electric Cooperative Association
In partnership with SunShot, U.S. Department of Energy

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About this Series

Many co-ops are interested in solar PV, but only a few have deployed utility-scale (1 MW or more) systems because of industry gaps in standardized designs; cost-benefit analysis tools; assistance with finance, procurement, and permitting; and training and best practices for operations and maintenance.

NRECA's *Cooperative Utility PV Field Manual* is a three-volume series designed to support electric cooperatives as they explore and pursue utility-scale, utility-owned solar PV deployments. It is a product of the *Solar Utility Network Deployment Acceleration (*SUNDA) project, which is a four-year, multi-state 23-MW solar installation research project and collaboration among U.S. electric cooperatives, the National Rural Utilities Cooperative Finance Corporation (NRUCFC/CFC), Federated Rural Electric Insurance Exchange, PowerSecure Solar, and the National Rural Electric Cooperative Association (NRECA). The SUNDA project is funded in part by the U.S. Department of Energy's SunShot program, and its overarching goal is to address the barriers to utility-scale, utility-owned solar PV systems faced by co-ops. Participating cooperatives include:

Anza Electric Cooperative	Anza, CA
Brunswick Electric Membership Corporation	Shallotte, NC
CoServ Electric	Corinth, TX
Eau Claire Energy Cooperative	Fall Creek, WI
Great River Energy	Maple Grove, MN
Green Power Electric Membership Corporation/Oglethorpe	Tucker, GA
North Arkansas Electric Cooperative	Salem, AR
Oneida-Madison Electric Cooperative	Bouckville, NY
Owen Electric Cooperative	Owenton, KY
Pedernales Electric Cooperative	Johnson City, TX
Sandhills Utility Services	Fort Bragg, NC
Sussex Rural Electric Cooperative	Sussex, NJ
Tri-State G&T Association	Westminster, CO
Vermont Electric Cooperative	Johnson, VT

The standardized products for evaluation, implementation, and operation of utility-scale solar PV at co-ops are discussed in detail in this Cooperative Utility PV Field Manual:

- Volume I: Business Models and Financing Options for Utility-Scale Solar PV Installations
- Volume II: Planning, Design, Installation/Interconnection, and Commissioning
- Volume III: Operations, Maintenance, and Monitoring
- Supplement: Project Manager's PV Quick Start Guide

This document, the initial release of the Project Manager's PV Quick Start Guide, is a draft and should be treated as such. The document will continue to be modified throughout the project, based on lessons learned, and then re-released. The reasons for distributing it at this early stage are to (1) share available information so that co-ops can use it immediately and (2) collect feedback that can be incorporated to improve the usefulness of the end product.

Your Feedback Welcome

Because this is a draft, anyone who reads or uses this document is invited and encouraged to provide feedback:

What parts of the manual are most valuable/helpful?
What is not clear? Where are changes needed? What is missing?
What challenges or technical projects should NRECA be thinking about for the future?

NRECA is under no obligation to incorporate information based upon feedback received. Any modification made to this document shall be solely owned by NRECA. All comments, questions, and suggestions may be sent to SUNDA@nreca.coop.

Updated versions of all three PV Field Manual volumes plus this supplement are available at www.NRECA.coop/SUNDA. A final version will be posted no later than October 1, 2017.

Project Manager's PV Quick Start Guide

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1 Introduction

This *Project Manager's PV Quick Start Guide* provides information on the design, installation, operation, and maintenance of a 1-MW photovoltaic (PV) system. The system is based on a reference design developed by the SUNDA (Solar Utility Network Deployment Acceleration) project, a collaborative effort of the National Rural Electric Cooperative Association (NRECA) and the U.S. Department of Energy's SunShot program. The design can reduce engineering, design, and equipment procurement costs for a utility-scale PV system project.

This guide is intended for the cooperative project manager responsible for developing a utility-scale PV system and overseeing its details. Based on NRECA's *Cooperative Utility PV Field Manual*, it incorporates the experience of several cooperatives that have installed such systems as well as input from experts and consultants.

NRECA's Community Solar Playbook
Because a number of utility-scale PV systems are offered as community solar projects, NRECA is developing a Community Solar Playbook to help cooperative staff choose the best community solar business model and develop project implementation plans. Look for the playbook soon, and find additional resources at www.NRECA.coop/solar.

1.1 Scope and Purpose of the Guide

The *Project Manager's PV Quick Start Guide* addresses the major steps involved in planning and deploying a 1-MW (AC) PV system. It seeks to provide the cooperative project manager with the tools needed to ensure that those steps are carried out and all key activities are coordinated. The guide condenses Volumes II and III of NRECA's *Cooperative Utility PV Manual*, enabling the cooperative project manager to oversee and monitor the key steps in system deployment.

1.2 Organization of the Guide

This guide consists of seven sections. In addition to the Introduction, it includes the following: Planning, Site Selection and Permitting, System Design/Equipment Procurement, Site Preparation/Installation, Commissioning, and Operations and Maintenance. Each section is accompanied by a checklist.

Each checklist offers an option for noting the status of any given activity. This information—as well as any relevant photographs—should be included in the co-op's project documentation. Collecting and maintaining project documents is the responsibility of the cooperative, regardless of the party that provides the service.

1.3 Assumptions

This guide assumes that the cooperative's board has decided on the development of a utility-scale PV system—1 MW or larger—in the co-op's territory. It also assumes that the cooperative's goal is system ownership rather than a power purchase agreement (PPA). This guide specifically does not cover business cases for using the solar (i.e., adding to the generation mix, community solar), nor does it address financing options that may be available to the co-ops.

2 Planning

Planning for a utility-scale PV system is critical to the success of the project. The planning phase requires decisions on the system design and size, the use of external experts, equipment procurement considerations, and the documentation required for project implementation.

The activities discussed in this section do not necessarily need to be undertaken sequentially; some will occur simultaneously or overlap.

2.1 PV System Components

A utility-scale PV system includes several major components:

- Photovoltaic modules
- Mounting structures
- Wiring, combiner boxes, and other balance-of-system equipment
- DC-AC inverter(s)
- Interconnection transformer and switchgear
- Monitoring system

Mechanically, a PV array consists of PV modules mounted on steel and/or aluminum structures to provide rigidity and proper orientation. Arrays may be installed with a fixed tilt and azimuth (east-west orientation) or incorporate structures that track the sun, either on a single or dual axis. This document will deal exclusively with fixed-array systems, but many of the planning steps apply to trackers as well. The three most common foundation designs for ground-mounted, utility-scale systems are "driven pier," screw anchor, and self-ballasted racking.

Electrically, a PV array consists of building blocks of PV modules connected electrically in series strings to provide a proper input voltage. These are paralleled in "combiner boxes" to provide the desired electrical inputs to the inverter(s). One or more inverters convert DC power from the arrays to AC output power connected in parallel with, and synchronized to, the grid. The inverter AC output circuits are bussed together and run through a step-up medium-voltage transformer and protective switchgear for interconnection with the electric grid.

Monitoring is provided through three sources: the inverters, one or more revenue meters, and a meteorological data acquisition system (DAS).

- The inverters record both the DC inputs (sub-array voltage, current, and power) and AC output (voltage, current, power, frequency, and power factor), and report them either to a web browser or the cooperative's SCADA system. Inverters also record and display numerous error codes for fault conditions associated with problems in both the DC and AC circuits.
- The revenue-grade meters provide a single calibrated measurement of the system output (voltage, current, power, frequency, and power factor), which can be compared with the information provided by the individual inverters.

- The meteorological DAS measures solar irradiance, ambient and PV module temperature, and wind speed. This information can be used to calculate the expected performance of the array, which can be compared with actual system output.

Detailed information on PV system components is available in Volume II of NRECA's *Cooperative Utility PV Field Manual* at http://www.nreca.coop/wp-content/uploads/2015/02/NRECA-Cooperative-Utility-PV-Field-Manual-Vol-II-Final.pdf.

2.2 System Design/Size

The SUNDA 1-MW reference design includes a drawing sheet list, six site plans (layouts, trenching, and grounding), single-line diagrams, schedules, labels, partial plans for inverter pad, conduit details, and stringing plans for arrays. The 1-MW design can be accessed at http://www.nreca.coop/wp-content/uploads/2015/09/nreca_sunda_standard_design_1000kw_1000v_20150818.pdf.

The SUNDA design incorporates several criteria and attributes, including the following:

- 1.39 DC/AC ratio to optimize cost-effective energy production
- Maximum ground coverage ratio, expandable symmetric block
- Fixed, non-tracking design for cost-effective construction and low operation and maintenance (O&M) costs
- Optimized combiner box locations to reduce DC conductors
- Centrally located equipment pad to help reduce DC wiring cost
- Use of medium-voltage switch as site AC disconnect, reducing pad footprint
- Modular racking with integrated wire management and accessible height for rapid, simplified installation
- Electrical equipment pad designed to provide easy service access, minimize concrete, and optimize feeder stub-ups

The system size is based on the available site size and funding, but may also be constrained by the load on the feeder/substation. As a rule of thumb, the system size should not be larger than the minimum daytime load on a feeder/substation.[1] A co-op can use SCADA data to determine the largest size system it can build without backfeeding the transmission line. A "load flow planning" exercise should be done when decided on the initial size of the project, but may need to be revisited after a specific site is selected if there are changes to the proposed site / system size.

The SUNDA 1-MW reference design can be adapted as a 500-kW system by using half of the design. It can also serve as a template for larger systems by simply replicating the 1-MW building blocks, mirroring as necessary to interconnect wiring up to about 5MW. There are also designs for 0.25MW and 0.5MW for smaller systems, as well as a string inverter design, which can all be found at:

[1] FERC Order 792, available at: https://www.ferc.gov/whats-new/comm-meet/2013/112113/E-1.pdf.

https://www.dropbox.com/home/SUNDA%20Internal/Engineering%20Team/Template%20Design/Reference%20Drawing%20Sets/Schneider%20Inverter%20packages

2.3 Division of Labor

Many cooperatives will choose to rely on outside resources for some, if not all, of the work needed to deploy a utility-scale PV system. It is not uncommon to break the engineering, procurement, and construction (EPC) work into multiple contracts.
Options include the following:

- *Turnkey:* Use an EPC firm, which is responsible for delivering a complete facility
- *Piecemeal:* Use one or more companies to handle various project activities (e.g., site work, engineering, installation) while performing other activities (e.g., procurement, O&M) in house
- *In house:* Use in-house resources for all aspects of project deployment while using external firms for specialized functions, such as system engineering or land surveying

Each co-op should identify the project activities it can do itself and those requiring an outside firm or expert. Some cooperatives may want to act as a project's general contractor, hiring various subcontractors for engineering, site preparation, and installation services. Some generation and transmission (G&T) co-ops or their members may have an engineering subsidiary that could handle certain project tasks. The balance between in-house and contracted services may change after the first project, when the process and technical details are better understood by the co-op engineering staff.

Co-ops should ensure that all such responsibilities are spelled out clearly and that each party understands its role. It is the responsibility of the co-op project manager to provide oversight and coordination. Although it is possible to change the division of labor partway through the project, this will likely result in added costs and delays.

Through its National Discounts Program, NRECA offers member cooperatives pre-negotiated discounts for EPC firms (see https://www.nreca.coop/what-we-do/bts/renewable-distributed-energy/sunda-project/).

2.4 Equipment Procurement Considerations

As part of its decision making on the division of labor, a co-op may want to consider who will select and procure the system components. Some co-ops choose to select and purchase the equipment themselves, whereas others have turned the task over to an EPC firm or other outside contractor. Co-ops should be aware that EPCs typically make a good portion of their fees on the markup of the materials which often runs about 10%. The co-op may be able to achieve some savings by purchasing equipment directly from the manufacturer or through the NRECA National Discounts Program.

The SUNDA reference design, which is fairly typical of systems in this size range, includes the following:

- 4,560 x 305Wp crystalline PV modules
- Driven-pier fixed-tilt support structure
- 10 x 24 string disconnect combiner boxes
- 2 x 4 pole 350A DC switches
- 2 x 500 kW, 100VDC inverters with 420 VAC output
- 1 x AC circuit breaker unit with 2 x 1,000A 3-pole circuit breakers, 1 x 15A 3-pole circuit breaker, 1 x 200A main circuit breaker, integrated step-down transformer for site AC loads
- 1 x medium-voltage transformer, typically 380-420V Wye [2]to 12.47kV YGRND liquid cooled, with fuses on primary side
- Photovoltaic production monitoring equipment and meteorological station (DAS)
- Photovoltaic production meter
- 15-kV pad-mounted fused switch
- Coordinated pole-mounted switch
- 6 x grounding rods
- Meteorological and performance monitoring system

When designing a monitoring system, this may include a combination of vendor-supplied monitoring, environmental monitoring and utility-SCADA monitoring. It is critical to develop the SCADA mapping early in order to determine exactly what additional monitoring, if any, is needed.

2.5 Documentation Needed

Co-ops should develop a detailed list of all of the documents needed during the planning, permitting, installation, commissioning, and O&M phases of a PV project. These documents may include most or all of the following:

- Site survey study results
- Site permits
- System design and equipment specifications
- Electrical and mechanical drawings—e.g., schematics of connections through to the inverter, single-line drawings showing anticipated cable routes, grid connections requirements
- SCADA mapping
- Site layout and equipment locations (including mounting frame and inverter locations)
- Civil plan (including access roads, water retention basins, storm water runoff)

[2] Many utility scale inverters have an AC output which is based on the inverter design and not the interconnection voltage. In the case of a connect to medium voltage distribution system, the inverter output can either be run through a custom transformer directly to the distribution voltage, or it can be run through a custom transformer to 480V and then a standard distribution transformer, which may serve more than one PV inverter.

- Environmental compliance plans (NEPA and others) may be required in some areas.[3]
- Installation and commissioning procedures
- QA/QC plan (responsibilities, documents control, construction process control, inspections and testing for in-process and completed work, recording of quality information
- O&M procedures
- Site-specific safety procedures
- Contracts for all external contractors, including EPC and other consultants
- Project schedule
- Insurance policies

2.6 Planning Checklist

This checklist will help to ensure that all key issues involved in planning a utility-scale PV project have been addressed.

Planning Checklist

Activity		Yes/No	Note (in documentation)	Photo
	System Components Review PV system components			
	System Design/Size			
	Review 1-MW template design criteria and attributes			
	Perform load flow planning study to determine effect of proposed system on local feeder(s). This may help determ[ine] maximum size of system			
	Adapt system size if necessary			
	Division of Labor			
	Choose contracting strategy: turnkey; piecemeal; in house			
	Equipment Procurement Considerations			
	Determine who is responsible for selecting and procuring system equipment			
	Documentation Needed			
	Develop list of all documents that will be needed over course of the project, including the following:			
	Site survey study results			
	Site permits			

[3] These are typically done after a specific site is selected but are included here to show a complete design set,

	System design and equipment specifications			
	Electrical and mechanical drawings			
	Site layout and equipment locations			
	Installation and commissioning procedures			
	Quality assurance/quality control plan			
	O&M procedures			
	Site-specific safety procedures			
	Contracts for all external contractors			
	Project schedule			
	Insurance policies			

3 Site Selection and Permitting

3.1 Preliminary Site Considerations

A 1-MW-AC PV system typically requires six to ten acres, depending on such factors as parcel shape, latitude, slope, and shading.

When identifying site options, co-ops should consider such factors as the solar resource, access (roads and driveways), proximity to a feeder, substation loads, community visibility, and structural loads.

3.2 Site Selection

Steps in the site selection process include the following:

- Identify suitable sites
- Determine ownership of land
- Identify current land use
- Ask the authority having jurisdiction (AHJ) about land use restrictions and permitting requirements
- Assess solar resource (primarily shading issues)
- Identify topographic characteristics
- Assess grid connection and substation load
- Determine availability of water supply if panel cleaning will be needed.
- Assess potential access routes to site
- Complete geotechnical survey to determine load-bearing properties of the soil and pullout parameters for driven-pier structures

In selecting a site, a co-op should consider several issues, such as the following:

- Does the site require major work—e.g., removal of buildings, trees?
- Is the site in a special taxation category that limits development?

- Is the land unincorporated?
- Is the land prime agricultural land?
- Are the project boundaries well defined?
- Will residents in the area be supportive or antagonistic to the project?
- Is a wall or living screen—trees, brush—around the system required by the AHJ?
- Are there any post-installation landscaping or aesthetic requirements?

A co-op may be well advised to employ a land broker or other expert to help assess the site options and select a site. For details, see NRECA's white paper, *Solar Project Land Acquisition and Permitting: A Case Study of Four Cooperatives Participating in the Solar Utility Network Deployment Acceleration Project*, available at: http://www.nreca.coop/wp-content/uploads/2014/09/sunda_whitepaper_on_land_permitting_and_acquisition__7_5_15.pdf.

Co-ops considering Rural Utility Service (RUS) financing should note that the service can be helpful with site selection. To make the best use of RUS assistance, its staff should be involved early in the process.

3.3 Site Acquisition/Permitting Schedule

If a co-op does not own the selected site, it may want to use a land broker or other expert to assist in buying the land. Co-ops should develop a timeline for buying the land and acquiring all necessary permits. Typical time requirements are as follows:

- Land acquisition: three to nine months
- Permitting: one to three months
- Obtaining special-use permits and re-zoning land (if necessary): two to four months

If a co-op owns the land or has access to it, the lead times may be shorter. In other cases, special considerations may extend the permitting time considerably. (Permitting can take two to three years in some cases!) It can be helpful to meet with the relevant AHJ to identify the supporting documentation that will be required when the co-op submits a permitting application.

3.4 Permitting Requirements

As part of the permitting process the detailed final drawing package/building plans will need to be submitted. Because the 1-MW reference design is not site specific, it must be adapted to the selected site. Site-specific factors affecting the design include maximum number of modules per string (based on minimum site temperatures and module voltage ratings), climate conditions (such as wind and snow loads), row spacing (based on latitude and array tilt), land contours, and shading. Site-specific modifications typically require 80–120 hours of engineering time. If an outside engineering firm is designing the PV system, it can use the SUNDA reference system drawing package for general guidance.

Beyond the drawing package, permitting a site involves a number of considerations. Among them are the following:

- Survey of the land: elevation, grade, ground water management
- Fire code compliance[4]
- Compliance with zoning, land use regulations
- Geotechnical study
- Soil studies—e.g., disturbance, sedimentation, and erosion control
- Environmental studies—e.g., wetlands, endangered and threatened species
- Archeological study
- Security—e.g., fencing, lights, cameras
- Tree shading, vegetation control
- Conditional use permit (which may require environmental quality compliance studies)
- Federal Aviation Administration (FAA) ocular impact study (required for federally regulated airport properties)

Co-ops should review the PV system design after permitting, double checking any changes which may have been required as a result of the permitting process. This is also an excellent time to begin the process of securing insurance for the new PV site.

3.5 Site Selection and Permitting Checklist

Site Selection/Permitting Checklist

Activity		Yes/No	Note (in documentation)	Photo
x				
	Preliminary Site Considerations			
	Verify acreage of potential PV parcel			
	Consider other site factors, such as the solar resource, access, proximity to a feeder, substation loads, community visibility, and structural loads			
	Site Selection			
	Identify suitable sites			
	Determine land ownership			
	Identify Authority Having Jurisdiction (AHJ)			
	Identify current land use			
	Ask relevant AHJ about land use restrictions and permitting requirements			
	Assess solar resource (primarily shading issues)			
	Identify topographic characteristics, including load-bearing properties of soil			
	Assess grid connection and substation load			
	Determine availability of water supply for panel cleaning			

[4] In addition to code compliance, co-ops will want to inform the local fire departs of the system and potentially even provide limited training since local fire departments may not be familiar with modern utility-scale PV systems.

	Assess potential access routes to site			
	Complete geotechnical survey • Does the site require major work—e.g., removal of buildings, trees? • Is the site in a special taxation category that limits development? • Is the land unincorporated? • Are the project boundaries well defined? • Is a wall or living screen—trees, brush—around the system required by the AHJ? • Will residents in the area support the project? • Are there any post-installation landscaping or aesthetic requirements?			
	Site Acquisition/Permitting Schedule			
	Develop timeline for land acquisition, permitting			
	Secure property insurance			
	Permitting Requirements			
	Survey of land: elevation, grade, ground water management			
	Fire code compliance			
	Compliance with zoning, land use regulations			
	Geotechnical study			
	Soil studies (disturbance, sedimentation, erosion control)			
	Environmental studies (wetland, endangered and threatened species)			
	Archeological study			
	Security system (fencing, lights, cameras)			
	Tree shading, vegetation control			
	Conditional use permit			
	FAA ocular impact study			

4 System Design/Equipment Procurement

4.1 Division of Labor Review

Co-ops should review their decisions on the division of labor for the project and determine whether any changes are needed before signing all relevant contracts.

4.2 Energy Output Estimation

Co-ops will need to decide whether they want their PV system to produce maximum power or be used for peak distribution system load matching. This decision will determine such factors as array tilt and azimuth angle (east-west orientation).

4.2.1 Array Tilt

In the northern hemisphere, a PV array oriented close to due south and at or near latitude will generate annual maximum energy. The angle is not critical for most locations. A tilt of as much as +/- 30 degrees from optimal typically reduces the annual energy output by less than 10 percent.

In addition, the greater the array tilt angle, the greater the distance needed between rows to prevent one row from shading the modules of the next row. For this reason, modules are usually mounted between 5 and 10 degrees shallower than local latitude and specified to the nearest 5 degrees. This also tends to skew the total annual system production slightly toward the summer months.

The SUNDA template design assumes a site in North Carolina (35 degrees latitude) and uses a fixed 25-degree tilt. The array tilt (and row spacing) will need to be adjusted for other locations, usually only to the nearest 5 degrees. It is important to note that a minimum tilt of about 10 degrees is needed to ensure that rain will flow off the modules without creating a sediment buildup on the bottom lip of the modules.

In northern locations, the ability to shed snow can be more important than optimal row spacing or optimal energy output; thus, a steeper than optimum tilt sometimes is sometimes selected. In far northern climates, steep tilts and high ground clearance to avoid snow buildup may require custom support structure which can add significantly to the cost of the system.

4.2.2 Azimuth Angle

Whereas most arrays are oriented close to due south (typically within +/- 30 degrees) to maximize energy output, other orientations may be optimal in some cases. Orienting arrays toward the west will reduce overall output but produce more energy during the afternoon, when it may match peak demand, depending on the co-op's demand profile. The value of this tradeoff depends on factors such as peak demand charges and time-of-use rates from the transmission company.

It is important to note that lower tilt angles mean less loss in performance with changes in azimuth.

4.2.3 Tracking

The annual energy output of a given size of PV array can be significantly increased by using systems which move the arrays during the day to keep them aimed at the sun. The two main variants of tracking include:

- single axis tracking, typically on a north-south axis (this is fairly common)
- dual axis tracking (this is rare outside of high-concentration systems)

Tracking can add up to 30% additional energy over a year, but this must be balanced with the additional costs for the tracking equipment, maintenance required for the tracking equipment and degraded system production when the tracking system, following Murphy's Law, eventually fails pointed the wrong direction!

4.2.4 Array Height

The structure should be designed such that the area under the array can be kept clear of vegetation and other obstructions. A starting point is to have the front edge of the array be a minimum of 24 inches above ground level, to allow for low vegetation growth and mowing. Some systems can be as low as six inches from the ground if the site includes methods to prevent vegetation growth.

In areas with high snowfall, the array typically is raised to allow snow to slide off the panels and not build up on the ground to a point where it shades the arrays. Northern latitudes could require as much as six-foot ground clearance.

4.2.5 Shading

Output from a module, and the string of which it is part, will decrease dramatically as a result of any shading. For this reason, it is critical to ensure that arrays are free of shading for the majority of daylight hours. Array shading can be caused by nearby trees, fences, buildings, and other obstructions. Arrays may be mounted at higher elevations to minimize shading from such obstructions. If the obstructions cannot be removed, arrays need to be offset from them.

Shading also can be caused by rows of modules that are too close to each other. Inter-row shading is a significant issue. Arrays at steeper tilts cast longer shadows, which require increased spacing between rows and thus more land area for a given system size. To avoid shading and minimize land use, arrays typically are tilted at shallower angles than true optimum, with the theoretical lost energy output being countered by reduced shading and increased land density.

A shading analysis will identify any obstructions and estimate their impact on energy output. This can be done using software, such as Helios 3D by Schletter. Other tools / software programs can be used, but the important point is that shading can cause significant system performance degradation so it should be addressed in the design stage. While initial shading is easily addressed, a good system analysis should account for growth of shading over the projected life of the system. For example, a mature forest will probably not create additional shading, but planting of young trees to "visually hide" the system may end up causing problems in later years.

4.2.6 Thermal Considerations

Operating temperatures of PV arrays are strongly dependent on the mounting system design and air flow around the array. Higher operating temperatures reduce array voltage, power output, and energy production. Rack-mounted arrays have the greater passive cooling and lower operating temperatures than roof mounted design due to maximizing air flow around arrays and lower thermal reflectance of soil versus a rooftop.

4.2.7 AC-DC Ratio

The DC (array) rating for a PV system typically is significantly higher than the AC (inverter) rating because the array itself will rarely produce full nameplate output, primarily because it operates at higher temperatures than those used to calculate the nameplate ratings. Current design practice calls for the ratio between DC-kWp and AC-kW to be in the range of 1.3–1.5. In the event that the array produces more energy than the inverter can process, some of the potential energy from the array will be "clipped." The SUNDA template design uses a DC-AC ratio of 1.39; first-year clipping is typically around 2 percent of possible energy. However, as output of the array degrades over the life of the system, this clipping factor is reduced and eventually eliminated.

It is important to verify that the selected inverter(s) can safely manage the proposed DC input.

4.2.8 Calculation of System Energy Production

Co-ops can estimate the energy production of a PV system using the *SUNDA Solar Costing & Financing Screening Tool* (available at: https://www.dropbox.com/s/piyh2qc806c7ab2/SUNDA%20Solar%20Costing%20%20Financing%20Screening%20Tool%20-%20released.xlsm?dl=0)
which includes cost estimates and financing options. This toolis based on PVWatts, an online calculator developed by the National Renewable Energy Laboratory (available at: http://pvwatts.nrel.gov/ The calculator estimates monthly and annual electricity production using an hour-by-hour simulation over a typical one-year period, based on historical solar radiation and climate data. A number of derating factors are considered in estimating the AC production, based on a given size PV array and site conditions. Accurate estimates of these factors are required to produce verifiable results. Output from a system will vary on a daily, monthly, and annual basis.

Other tools to calculate the energy production of an array include the following:

- *System Advisory Model*, which combines PVWatts with economic analysis to provide a more detailed look at system performance (available at: https://sam.nrel.gov/)

- *PVsyst*, a commercial stand-alone software package that provides a deeper level of analysis and design tools than PVWatts (available at: http://www.pvsyst.com/en/)
- HelioScope by Folsom Labs, a commercial web-based software service that provides a deeper level of analysis and design tools than PVWatts (available at: http://www.folsomlabs.com/)

It is important to note that these performance projections are based on historical solar irradiance and temperature data, which means they will not directly apply to any given year and may also change over the life of the project due to long-term variations in weather patterns. In addition, the electrical output of a PV array will gradually degrade over the life of a system. Current estimates of the degradation rate vary between 0.5 percent and 0.8 percent per year.

4.2.9 Daily, Monthly, and Annual Variability

Co-ops should also consider the impact of clouding and seasonal variations, which can result in daily, monthly, and annual variability in PV output.

4.3 Equipment Selection/Procurement

Some co-ops may choose to select and procure the components for a PV system themselves, whereas others will turn procurement over to an EPC firm or other outside consultant. In either case, co-ops can take advantage of pre-negotiated discounts on modules, inverters, and racking systems offered by NRECA's National Discount Program (NDP) through the SUNDA project (see https://www.nreca.coop/what-we-do/bts/renewable-distributed-energy/sunda-project/). NRECA currently is in the process of developing an EPC RFP guide.

Delivery times for large orders of PV modules, inverters, and other equipment have grown more variable due to the large increase in the number of systems being designed and installed. The delivery time for modules had grown to an average of six months because of the impending end of the investment tax credit (ITC). Since the ITC has been extended for five years this time is expected to drop somewhat. See Technology Advisory Solar ITC and Wind PTC Extension; https://www.cooperative.com/interest-areas/crn/research-topics/documents/tech_advisory_itc_extension_january_2016.pdf

The lead time for structures is typically six to twelve weeks; inverters may take slightly longer, depending on the options ordered. Custom transformers are becoming more readily available, but may still take 18 weeks or more for delivery. The project manager should verify projected delivery times with the major equipment manufacturers and place orders to coordinate that the equipment arrives on site at the proper time.

If a co-op chooses to do all the procurement for its PV system, it will want to consider several issues, including the following:

- Financial stability of suppliers
- Material and labor warranties

- Coordination of equipment delivery
- Sourcing of "balance-of-system" equipment, such as wires, fuses/circuit breakers, and grounding rods

4.4 System Design/Equipment Procurement Checklist

System Design/Equipment Procurement Checklist

Activity		Yes/No	Note (in documentation)	Photo
x				
	Division of Labor Review			
	Review decision on division of labor, make any needed changes			
	Energy Output Estimation			
	Identify output goal: maximum power or peak matching			
	Array Tilt			
	Select array tilt angle based on PV system latitude, orientation and shading conditions			
	Azimuth Angle			
	Select orientation based on production goal—e.g., south, west			
	Determine azimuth angle optimal for site			
	Array Height			
	Determine height of array to minimize vegetation and other obstructions (e.g., snow accumulation)			
	Shading			
	Adjust array row spacing based on latitude			
	Evaluate extent of shading using commercially available tools (e.g., Helios 3D)			
	Identify options for eliminating obstructions or offset arrays			
	Thermal Considerations			
	Assess impact of mounting system on array operating temperatures			
	Identify options for maximizing air flow around arrays			
	AC-DC Ratio			
	Determine AC-DC ratio			

	System Energy Production			
	Estimate energy production of PV system using a tool			
	Conduct costing and economic analyses			
	Daily, Monthly, Annual Variability			
	Consider the impact of clouding and seasonal variations on annual variability in PV output			
	Impact of Permitting Process on Design			
	Review the PV system design during and after permitting			
	Equipment Selection/Procurement			
	Evaluate module suppliers (including those in NRECA's NDP)			
	Consider the following issues for PV component procurement			
	Financial stability of suppliers			
	Material and labor warranties			
	Coordination of equipment delivery			
	Sourcing of balance-of-system equipment			
	Site Design Modifications			
	Review system design to determine whether output estimation and site conditions require changes			

5 Site Preparation/Installation

5.1 Site Preparation

Site preparation includes general leveling of the land, improving access roads and drainage as necessary, and trimming specified vegetation. The perimeter fence usually can be installed when the site grading is completed.

Co-ops may want to rely on the services of several outside contractors for site preparation—including surveyors, civil engineers, security contractors, or earth moving companies.

5.2 Installation

Once the site is prepared, installing a 1-MW PV system typically takes approximately six weeks and involves both mechanical and electrical construction activities.

The mechanical activities include the following:

- Installing support foundation (pouring concrete pads or driving piles)
- Installing racking structures
- Installing conduits for wiring from combiner boxes to inverter DC switchgear
- Preparing inverter pad
- Installing grounding system for metal structure and inverter pad
- Installing modules on racking
- Installing combiner boxes on racking structures
- Installing weather/monitoring station to verify proper operation of system
- Installing inverter(s), lightning protection/surge arrestors, and associated DC and AC switchgear

The electrical activities include the following:

- Wiring modules into series strings and connecting to combiner boxes
- Running DC wires from combiner boxes to inverter DC switchgear
- Running DC wires from DC switchgear to inverter
- Connecting inverter(s) to interconnection transformer and associated switchgear
- Connecting structure and combiner boxes to grounding system
- Connecting inverter and associated equipment to grounding system and protection equipment
- Installing metering cabinet and associated telecommunications
- Connecting monitoring system to co-op's SCADA system
- Connecting system to electric grid

5.3 Documentation

It is important to document the installation project at all stages through photos, videos and even aerial documentation if that is permitted.

5.4 Site Preparation/Installation Checklist

(A more detailed site preparation and installation checklist is available at: http://www.nreca.coop/pv-manual-and-sunda-reference-designs/.)

Site Preparation/Installation Checklist

Activity		Yes/No	Note (in documentation)	Photo
x				
	Site Preparation			
	Level/grade the land			
	Improve access roads (if necessary)			
	Improve drainage (if necessary)			
	Trim vegetation (as needed)			
	Install perimeter fencing			
	Install site surveillance / security system			
	Mechanical Installation			
	Install support foundation			
	Install racking structures			
	Install conduits for wiring from combiner boxes to inverter DC switchgear			
	Prepare inverter pad			
	Install grounding system for metal structure and inverter pad			
	Install modules on racking			
	Install combiner boxes on racking structures			
	Install weather/monitoring station to verify proper operation of system			
	Install inverter(s), lightning protection/surge arrestors, and associated DC and AC switchgear			
	Electrical Installation			
	Wire modules into series strings and connect to combiner boxes			
	Run DC wires from combiner boxes to inverter DC switchgear			
	Run DC wires from DC switchgear to inverter			
	Connect inverter(s) to interconnection transformer and associated switchgear			
	Connect structure and combiner boxes to grounding system			

	Connect inverter and associated equipment to grounding system and protection equipment			
	Install metering cabinet and associated telecommunications			
	Connect monitoring system to co-op's SCADA system			
	Double check all connections and run all recommended manufacturers pre-energizing tests			
	Connect system to electric grid			

6 Commissioning

Commissioning verifies that installation has been completed satisfactorily and safely according to the plans and applicable codes.

Key steps in a commissioning procedure typically include the following:

- Completing final installation details
- Completing visual inspections
- Verifying compliance with NEC requirements
- Conducting electrical verification tests
- Verifying system functionality, including start-up, operations, shut-down, and emergency procedures
- Verifying that system power output and energy production meet performance expectations
- Completing system documentation, including changes for as-built drawings
- Conducting user orientation and training on system operation and safety
- Conducting hazard assessment and safety training

6.1 Final Inspection

A final checkout confirms that installation is complete before conducting any testing and beginning system operations. The checkout typically is performed by the installation contractor before the final inspection by the AHJ. With the exception of the PV arrays, all circuits should be de-energized whenever possible in preparation for system testing. In addition to a test of the system, component-by-component testing is recommended.

6.2 Initial Testing

PV systems should be tested thoroughly at the time of commissioning and periodically over their lifetimes to ensure proper performance and safe operation. Baseline measurements at the time of system commissioning are compared to the system ratings and expectations for acceptance, and serve as a baseline for comparison with future measurements.

Common types of tests are the following:

- Continuity and resistance testing
- Polarity testing
- Voltage and current testing
- Insulation resistance testing
- Thermal imaging is an increasingly accessible tool which can help find problems both in the installation process and during commissioning. Thermal imaging should definitely be used to examine all switchgear and the inverter cabinet as well as combiner boxes. If problems appear, thermal imaging of selected PV subarrays / strings may also be informative.

6.3 System Functional Testing

Initial start-up of a PV system is conducted after all inspections and checks have been completed, with all outstanding items resolved.

Start-up procedures include the following:

- Installing overcurrent devices
- Closing DC and AC disconnects and turning on inverter
- Verifying output

System functional testing verifies proper system operation, including start-up, shut-down, and nominal operating conditions. These tests confirm that system operating parameters are within expected and nominal limits but are not intended to verify system ratings in accordance with specifications or warranty provisions. Additional detailed testing, using additional measurements and normalizing data, is required to verify performance with system ratings.

6.4 Commissioning Checklist

(A more detailed commissioning checklist is available at: http://www.nreca.coop/pv-manual-and-sunda-reference-designs/.)

Commissioning Checklist

Activity		Yes/No	Note (in documentation)	Photo
x				
	Commissioning Procedure—Key Steps			
	Complete final installation details			
	Complete visual inspections			
	Verify compliance with NEC requirements			
	Conduct electrical verification tests			
	Verify system functionality, including start-up, operations, shut-down, and emergency procedures			
	Verify that system power output and energy production meet performance expectations			
	Complete system documentation, including changes for as-built drawings			
	Conduct user orientation and training on system operation and safety			
	Conduct hazard assessment and safety training			
	Verify through thermal imaging that all cabinet connections are appropriately tightened.			
	Verify property insurance			
	Final Inspection			
	Installation contractors completes final checkout			

	AHJ completes final inspection			
	Initial Testing			
	Conduct continuity and resistance testing			
	Conduct polarity testing to verify correct polarity for PV DC circuits and proper terminations for DC utilization equipment			
	Conduct voltage and current testing			
	Conduct insulation resistance testing			
	System Functional Testing			
	Install overcurrent devices			
	Close DC/AC disconnects and turn on inverter			
	Verify output			

7 Operations and Maintenance

7.1 Output and Performance Verification

The party or parties responsible for O&M should confirm system availability and performance on a regular basis. System performance can be estimated using array sizing parameters and the specific meteorological data from the site. A mismatch of system output with predicted performance indicates some problem with the system. The problem can be further isolated by examining data from the inverter DC input circuits and then examining parameters at each of the system's combiner boxes.

There are monitoring platforms that can provide this service on an automated basis.

7.2 Project-Specific Maintenance Plan, Schedules, and Responsibilities

Maintenance activities include the following:

- Inspection of components and wiring systems
- Module cleaning
- Electrical tests, performance verification
- Visual inspections
- Thermal imaging of electrical cabinets and even PV subarrays if necessary
- Water infiltration
- Site erosion
- Calibrations
- Repairs
- Hazard assessment, safety training

Co-ops should review and verify responsibility for maintenance as identified during the project's planning stage. The PV system maintenance plan should include a schedule of routine or preventative maintenance.

In addition to preventative maintenance, co-ops need to be prepared to address events such as component failures, natural disasters, and any breaches in security that will require unscheduled maintenance.

Information on test equipment is available in NRECA's *Cooperative Utility PV Manual, Volume III: Operations, Maintenance and Monitoring*, available at: http://www.nreca.coop/wp-content/uploads/2015/02/NRECA-Cooperative-Utility-PV-Field-Manual-Volume-III-Final.pdf.

7.3 O&M Checklist

O&M Checklist

Activity		**Yes/No**	**Note (in documentation)**	**Photo**
x				
	Output and Performance Verification			
	Confirm system availability and performance on a regular basis			
	Match to predicted performance			
	Project-Specific Maintenance Plan, Schedules, and Responsibilities			
	Inspect components and wiring systems			
	Clean modules			
	Conduct electrical tests, performance verification			
	Conduct visual inspections			
	Perform thermal imaging			
	Inspect for water infiltration			
	Inspect for site erosion			
	Perform calibrations			
	Make repairs			
	Conduct hazard assessment, safety training			
	Create schedule of routine or preventative maintenance			
	Unscheduled Maintenance			
	Replace failed component(s)			
	Respond to emergencies or natural disasters			
	Respond to security breaches			

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