



Solar Access to Public Capital Working Group
Best Practices in

Commercial and Industrial (C&I) PV System Installation



NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
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Best Practices in Commercial and Industrial (C&I) Solar Photovoltaic System Installation

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The attached Best Practices in Commercial and Industrial (C&I) Photovoltaic (PV) System Installation Guide was developed through an industry-organizing process convened by the National Renewable Energy Laboratory (NREL). The process was open to a wide array of industry members to get a broad range of perspectives. The document represents the result of long discussions and negotiations on a variety of topic areas of interest to the participating stakeholders. The document does not reflect NREL's or the U.S. Department of Energy's endorsement of any activity or group of activities. Rather, the document is designed to provide a reasonable protocol associated with photovoltaics (PV) system installation supported by the industry stakeholder process in order to mitigate risks and improve PV asset energy and cash flow production reliability.

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List of Acronyms

AC	alternating current
AHJ	authority having jurisdiction
ASCE	American Society of Civil Engineers
API	application programming interface
BOS	balance of system
C&I	commercial and industrial
CA	commissioning authority
CGL	commercial general liability (insurance)
CX	commissioning
DC	direct current
EC	electrical contractor
EG	equipment grounding
E&O	errors and omissions (insurance)
EOR	engineer of record
EPC	engineering, procurement, and construction
EPRI	Electric Power Research Institute
FIV	field inspection verification
GFDI	ground fault detection and interruption
GFP	ground fault protection
IBTS	Institute for Building Technology and Safety
I-V	current-voltage (curve)
ICC	International Code Council
IEC	International Electrotechnical Commission
IFC	International Fire Code
IP	Ingress Protection (rating)
IREC	Interstate Renewable Energy Council
ISO	International Organization for Standardization
JHA	job hazard analysis
LPS	lightning protection system
MFL	maximum foreseeable loss
MW	megawatt
NABCEP	North American Board of Certified Energy Practitioners
NEMA	National Electrical Manufacturers Association
NEC	National Electrical Code
NERC	North American Electric Reliability Corporation
NLE	normal loss expected
O&M	operations and maintenance
OE	owner's engineer
OSHA	Occupational Safety and Health Administration
P.E.	professional engineer
PID	potential-induced degradation
PML	probably maximum loss
PPA	power purchase agreement
PPE	personal protective equipment

PV	photovoltaic
QA	quality assurance
QC	quality control
RCD	residual current device
SAPC	Solar Access to Public Capital
TCIR	total case incident rate
TOU	time-of-use (rates)
TPO	third-party owned system
TSRF	total solar resource fraction
UL	UL was formerly known as Underwriters Laboratories
UV	ultraviolet
V	volt

Table of Contents

1	Introduction.....	1
1.1	Solar Access to Public Capital	1
1.2	Purpose	1
1.3	How to Use This Document	2
1.4	Guide Overview	2
1.5	Definition of Roles	2
1.5.1	Owner	2
1.5.2	Developer	2
1.5.3	EPC Contractor	2
2	Qualifications.....	4
2.1	EPC Contractor General Qualifications	4
2.1.1	Trade Licenses.....	4
2.1.2	Work History.....	4
2.1.3	Financial Solvency	4
2.1.4	Health and Safety	4
2.1.5	Insurance	5
2.1.6	EPC Bonding Capacity (Performance Security)	6
2.1.7	EPC Engineer Insurance.....	6
2.1.8	Defined Quality Management Plan.....	6
2.2	EPC Contractor Personnel Qualifications	7
2.2.1	EPC Engineer Qualifications	7
2.2.2	EPC Project Manager Qualifications	7
2.2.3	EPC Installer Site Supervisor Qualifications	8
2.3	Operator/O&M Provider Qualifications.....	8
2.4	Engineer of Record Qualifications	8
2.5	Developer Qualifications.....	9
3	Project Design Best Practices.....	10
3.1	Usage Data and Estimate of Utility Cost Savings	10
3.2	Site Data	11
3.2.1	Site Information.....	11
3.2.2	Structural Information.....	11
3.2.3	Roof Information (if applicable)	11
3.2.4	Electrical Information	12
3.2.5	Potential Locations for New Equipment	13
3.3	Production Estimate	13
3.3.1	Estimating Tools	13
3.3.2	Modeling Tools	13
3.3.3	Solar Resource/Weather Data Sources.....	14
3.3.4	Performance Guarantees	14
3.4	System Design.....	14
3.4.1	Project Planset.....	15
3.4.2	Module Support Structure	16
3.4.3	DC System Design	17
3.4.4	AC System Design	17
3.5	Equipment Requirements	17
3.5.1	Photovoltaic Modules.....	17
3.5.2	Inverters.....	18
3.5.3	Racking Systems	18
3.5.4	Monitoring.....	19

3.5.5	Electrical Components	19
3.6	Permitting and Inspections	19
4	Installation Best Practices	20
4.1	Equipment Best Practices	20
4.1.1	PV Modules	20
4.1.2	Mounting Systems	20
4.2	Workmanship Best Practices	21
4.2.1	System Grounding and Bonding	21
4.2.2	DC Ground-Fault Protection (DCGFP)	22
4.2.3	DC Arc-Fault Circuit Protection (DCAFP)	22
4.2.4	Rapid Shutdown of PV Systems on Buildings	22
4.2.5	Marking (Labeling) Best Practices	22
4.2.6	Mechanical Components	23
4.2.7	Systems with Module-Level Power Electronics	23
4.3	System Documentation	24
4.3.1	Required Site Data Points	24
4.3.2	Required System Design Data	24
4.3.3	As-Built Photograph Inventory	25
4.3.4	EPC Submittal Information	25
4.4	Third-Party Inspection and Verification	26
4.4.1	Field Inspection Verification	26
4.4.2	Third-Party Inspector Qualifications	27
4.4.3	Scoring System	27
4.5	Interconnection	28
5	O&M Best Practices	30
5.1	Solar PV Operations, Maintenance, and Monitoring (OM&M)	30
5.2	PV System Warranty	31
5.3	Solar PV System Commissioning	31
6	References and Resources	33
	Appendix. References to Codes, Standards, and Guidelines	36

1 Introduction

1.1 Solar Access to Public Capital

The following Best Practices in Commercial and Industrial (C&I) PV System Installation Guide is one of several work products developed by the Solar Access to Public Capital (SAPC) working group. SAPC worked from 2012 to 2015 to open capital market investment for PV systems. Capital market investment includes debt and equity securities procured by pension funds, family offices, endowment funds, and other large managers of investment. These sources of institutional investments allow for the industry to access the lowest cost of capital financing.

SAPC membership included over 480 leading solar developers, financiers and capital managers, law firms, rating agencies, accounting and engineering firms, and other stakeholders engaged in solar asset deployment.¹ SAPC activities were directed toward foundational elements necessary to pool project cash flows into tradable securities:

- Standardization of power purchase, lease and loan contracts for residential and commercial end customers
- Development of performance and credit data sets to facilitate investor due diligence activities
- Engagement of rating agencies to comprehend their risk perception of the solar asset class
- Development of best practice documents for photovoltaic (PV) system installation and operations and maintenance (O&M) protocols to encourage high-quality system deployment and operation that may improve lifetime project performance and energy production.

1.2 Purpose

This Best Practices in C&I PV System Installation Guide is the second of a series of guides designed to standardize and improve solar asset transparency for investors and rating agencies, provide an industry framework for quality management, and reduce transaction costs in the solar asset securitization process. The Best Practices in C&I PV System Installation Guide is intended to outline the minimum requirements for commercial and industrial solar project developments. Adherence to the guide is voluntary. Providers that adhere to the guide are responsible for self-certifying that they have fulfilled the guide requirements. Investors and rating agencies should verify compliance.

The first in the series, *SAPC Best Practices in PV System Installation*, was published in March 2015 and addresses best practices in the installation of residential PV systems (Doyle et al. 2015).

¹ SAPC was funded by the U.S. Department of Energy during a three-year period that concluded on September 30, 2015.

1.3 How to Use This Document

This document is best viewed on a computer or tablet in order to take full advantage of the embedded, clickable hyperlinks that lead to further information and additional resources. Each hyperlink is fully cited in section 6, References and Resources. Relevant definitions used in this document are listed in the Appendix.

1.4 Guide Overview

There is no one-size-fits-all solar deployment strategy. Firms have unique value propositions, customer acquisition strategies, distribution channels, and technical specifications. The framework for the guide includes:

1. Developer qualifications
2. Engineering, procurement, and construction (EPC) qualifications
3. Design best practices
4. Installation best practices
5. O&M/Operator best practices.

1.5 Definition of Roles

1.5.1 Owner

In the C&I PV sector, development of third-party-owned (TPO) systems typically includes a turnkey solar energy supply agreement for a host client, also known as the energy off-taker. The “Owner” is identified as the long-term owner of the project, and may typically be a special purpose entity comprised of the Developer, the Investor, or both.

1.5.2 Developer

The Developer is responsible for facilitating the planning and construction of the PV project, including site selection, design, solar resource and energy production estimation, permits, utility interconnection, construction, and commissioning. The Developer might only act as an originator or project broker and not play an active role once the project construction commences.

The primary objective of the Developer is to create financeable PV projects with sound investment return and performance upside. Developers have found success in third-party leasing and power purchase agreement (PPA) models, backed with traditional sources of debt and equity financing. As the financing landscape evolves, these third-party ownership models are strong candidates for new sources of financing such as asset securitization.

Investors seek diversification of underlying assets, as well as predictable and profitable operations, low credit risk, and project transparency.

1.5.3 Engineering, Procurement, and Construction Contractor

The Developer or Owner typically contracts with a primary entity known as an engineering, procurement, and construction (EPC) Contractor for turnkey EPC services. The EPC Contractor may use internal design and construction resources, or may subcontract some of these services; for example, the EPC Contractor may subcontract installation to an electrical contractor (EC).

The EPC Contractor can have an important impact on the quality of the asset in terms of system safety, performance, and durability. As such, the legal agreement between the Developer or Owner and the EPC Contractor is a critical component of project risk for investors.

2 Qualifications

2.1 EPC Contractor General Qualifications

The EPC Contractor's performance and financial capabilities to successfully complete its obligations under contract are of key importance. The EPC Contractor should meet minimum general requirements and minimum personnel qualifications as set forth below.

2.1.1 Trade Licenses

The EPC Contractor should have all professional and trade licenses required by the applicable state and local authorities having jurisdiction (AHJ). Required solar PV licenses can be found through the Interstate Renewable Energy Council's (IREC) [Solar Licensing Database](#) (IREC 2014).

2.1.2 Work History

The EPC Contractor should have a successful track record of design and construction of similar type and scale projects, completed on time and on budget. The EPC Contractor should demonstrate this experience through:

- At least 3 years company work experience in design, engineering and installation of commercial scale solar PV systems

2.1.3 Financial Solvency

The EPC Contractor should have the financial resources to successfully complete projects and to meet all warranty obligations. EPC Contractors shall provide documentation related to the financial solvency of the company. The documents should be kept on file by the financing company. Sample documents include:

- Audited financial statements
- Bank references
- Supplier references

The purpose of these references is to demonstrate that the EPC Contractor is/was not in financial distress at the time of project development and installation. Financial distress could have a negative impact on the level of system quality.

2.1.4 Health and Safety

The EPC Contractor should have and maintain a health and safety manual that establishes appropriate rules and procedures concerning workplace safety, including rules related to: reporting health and safety problems, injuries, and unsafe conditions; risk assessment; and first aid and emergency response.

Some examples of typical rules and procedures include:

- Contractor Site Supervisor has completed a minimum of Occupational Safety and Health Administration (OSHA) 30-hour Construction Industry training, and all site personnel have completed a minimum of OSHA 10-hour Construction Industry training.

- Additional training should be supplemented to provide sufficient knowledge for installers to identify hazards, provide corrective actions, and prevent reoccurrence specific to solar PV systems.
- All site personnel must be equipped with complete personal protective equipment (PPE) and trained on any specific hazards associated with their jobs.
- Contractor Site Supervisor has completed a job hazard analysis (JHA).
- Contractor Site Supervisor has completed a job site orientation with all workers onsite.

The Contractor must maintain an OSHA total case incident rate (TCIR) of 5.00 or less or a similar rate based on a substantially equivalent, accepted measure used to report workplace injuries.

2.1.5 Insurance

An EPC Contractor must maintain appropriate levels of insurance relative to project scale, complexity, and associated risk. An insurance engineer and underwriter should be engaged to evaluate a design or installation and to negotiate the following parameters: normal loss expected (NLE), which determines the dollar amount of the deductible without an insurance claim; probable maximum loss (PML), which determines the premium paid on a policy; and maximum foreseeable loss (MFL), which sets limits on coverage. Coverage should include:

- Commercial general liability (CGL) insurance (\$1,000,000 per occurrence, \$2,000,000 aggregate)
- CGL umbrella policy
- Professional liability insurance, also known as errors and omissions (E&O) insurance
- Property insurance (builder's risk), written on an "all-risks" structure and replacement cost basis; alternatively, this may be covered under the Developer's coverage, depending on the specific arrangement between parties
- Commercial vehicle insurance (\$1,000,000 per occurrence)
- Workers compensation insurance (\$1,000,000 each accident, each employee)
- Business interruption insurance, which covers lost revenue due to downtime caused by covered event
- Inland marine insurance, which insures against loss of equipment not on the property premises
- Insurance policies should name the developer or owner and any intermediaries as additional insured(s) and certificate holder(s). Legal agreements between the Developer/Owner and EPC Contractor should require additional insured specification.

2.1.6 EPC Bonding Capacity (Performance Security)

Surety Bonds

Surety bonds, or performance bonds, are typically provided by an insurance company (surety or guarantor) to back the performance of the EPC Contractor and ensure that the construction project is completed even if the EPC contractor goes bankrupt. Surety bonds are a means to protect the contract counterparty, in this case the Developer, if the EPC Contractor is unable to fulfill its contractual requirements.

Payment Bonds

Payment bonds are insurance that ensures that subcontractors get paid even if the EPC contractor goes bankrupt, and thus there are no mechanic's liens against the facility upon completion.

2.1.7 EPC Engineer Insurance

Insurance requirements for project engineers should be relative to the scale and scope of the project, but should include at least:

- Professional liability (E&O) insurance
- Commercial general liability insurance
- Commercial vehicle insurance
- Workers compensation insurance
- Insurance policies should name the Developer/Owner and any intermediaries as additional insured(s) and certificate holder(s).

2.1.8 Defined Quality Management Plan

The EPC Contractor shall have a quality management plan that includes all elements of the company's customer service policy and other quality assurance practices. The plan should be distributed to all company employees and contain a Quality Manual, as defined by International Organization for Standardization (ISO) 9001:2008, which includes documented statements of a quality policy and quality objectives. A Quality Management Plan should include:

- System equipment specifications
- System equipment testing
- Inspection protocol/inspector qualification
- Design best practices
- Installation guidelines with explicit quality standards
- Safety policies
- System commissioning

- Upstream and downstream quality assurance (QA) activities with explicitly defined corrective action protocols.

2.2 EPC Contractor Personnel Qualifications

2.2.1 EPC Engineer Qualifications

The electrical and structural design of a PV system is the fundamental determinant in system safety and performance. The design process will include selection and application of major components, including modules and inverters, as well as balance of system (BOS) specifications, such as mounting system, combiner boxes, disconnects, conductors size/type, raceways, grounding & bonding specifications, arc-fault detection and interruption (AFDI), rapid shutdown, monitoring equipment and communications as well as other critical system components and features. EPC design must comply with all local codes and utility requirements, as well as meet performance expectations of the Provider and Off-taker.

At minimum, EPC engineer qualifications for electrical and structural design should include:

- Professional Engineer, licensed in the state where project is located. The P.E. should be qualified in the relevant specific discipline (electrical power, electrical controls, structural, environmental, mechanical, etc.).

Additional qualifications of the design engineer should be strongly considered because direct current (DC) power systems, and in particular PV power plants, are quite different than other alternating current (AC) electrical systems. Such additional qualifications may include one or all of the following:

- North American Board of Certified Energy Practitioners (NABCEP) PV Installation Professional Certification
- UL Photovoltaic System Installation Certification
- Training by an instructor in PV system design including National Electrical Code (NEC) 690 and 705 and International Fire Code (IFC) 605
- Prior experience and successful track record in PV system design.

2.2.2 EPC Project Manager Qualifications

Technical Experience

- Bachelor of Science in engineering or other degree with relevant industry experience
- Commercial or utility construction experience
- Solar PV experience on commercial, industrial, or utility-scale projects
- Knowledge of construction and electrical codes
- Experience with electrical systems and wiring.

Management Experience

- Project management training

- Project Management Institute project management professional (PMP) certification or similar
- Project management experience on large-scale projects.

2.2.3 EPC Installer Site Supervisor Qualifications

Most electricians work on AC building systems, and even a master electrician may be unfamiliar with DC-based PV systems. PV-specific qualifications include:

- Licensed electrical contractor
- NABCEP PV Installation Professional Certification
- UL Photovoltaic (PV) System Installation Certification
- Experience with medium-voltage electrical systems
- Experience with DC power systems
- Familiarity with sections of the [National Electric Code](#) specific to PV (section 690).

2.3 Operator/O&M Provider Qualifications

Same as EPC installer site supervisor qualifications, plus:

- Certification by the North American Energy Reliability Corporation (NERC) (necessary for positions that affect the power grid).

For more details about Operator and O&M provider qualifications, please refer to Keating et al. (2015).

2.4 Engineer of Record Qualifications

The Engineer of Record (EOR) is responsible for stamping and approving the system planset. The EOR should be a Licensed Professional Engineer (P.E.). Approval of a specific planset is indicated with a unique stamp (including license number and signature) from the P.E. Note that typically, P.E. licenses do not specify a specialty (e.g., electrical, structural, mechanical, civil), and it is up to the engineer to only stamp projects that are within their realm of expertise.

The following engineering disciplines (from National Council of Examiners for Engineering and Surveying P.E. exam types) are typically required for PV system design (some overlap and not all may be required depending on system type):

- Civil: Construction
- Civil: Geotechnical
- Civil: Structural
- Civil: Water Resources and Environmental
- Control Systems

- Electrical and Computer: Electrical and Electronics
- Electrical and Computer: Power
- Environmental
- Fire Protection
- Mechanical: Mechanical Systems and Materials
- Software.

Different AHJs have different P.E. requirements, such as not requiring a P.E. stamp at all or requiring multiple P.E. approvals for the various disciplines relevant to the project.

2.5 Developer Qualifications

Developers seeking these sources of capital must meet investor expectations. While not an exact science, certain general characteristics of developer qualifications should be strongly considered. These considerations include:

- A proven track record of capabilities and successful projects similar in type and size
- Creditworthy off-takers
- Strong company financials/low bankruptcy risk
- Strong advisory team, with industry-specific expertise (legal, financial, technical, etc.)
- Proficiency and standardization in procurement, construction and O&M contracts, off-take agreements, permitting and technical requirements, quality assurance/quality control (QA/QC) protocols, and other aspects of PV development.

Developers are expected to carry adequate insurance coverage with levels of coverage commensurate with investor requirements, type and scale of development.

Additional types of coverage and policies may also be required. Coverage may be extended to cover contractors under these policies, contractors may carry their own policies, or both.

3 Project Design Best Practices

3.1 Usage Data and Estimate of Utility Cost Savings

The EPC Contractor is responsible for analyzing the customer's utility bills from the start of the contract and through at least one prior year, including electrical usage and current rate structure. It is vital that usage and rate structure data is included in the system design to ensure that the customer receives a system that is well suited to that particular situation in order to maximize the system's economic impact. Utility bill analysis may be contracted out by the EPC Contractor.

Measuring the savings associated with the energy delivery of an RE system with accuracy requires estimating the annual utility bills based on the details of the utility rate structure, with and without the output of the PV system.

There are many different types of utility rate structures involving combinations of the following features:

- **Energy (c/kWh):** The output of a PV generator varies with conditions, but monthly or annual energy delivery is more predictable and reliable. This is the feature of the rate schedule in which most of the benefits of the PV delivery will accrue under net metering. Every kWh of net-metered PV delivery will reduce this part of the utility bill according to the energy rate (c/kWh).
- **Demand (\$/kW/month):** Typically, demand charges are calculated as the 15-minute period of each month in which electricity consumption peaked. PV systems are able to reduce demand only when the system is producing during peak demand periods. Many commercial buildings have their peak load in the afternoon due to cooling loads, and many of these cooling loads are exacerbated by solar heat gain, so there is a coincidence of peak demand and solar output for many types of buildings in many climates. But it is possible that there will be some peaking demand period when the solar is not contributing and a new demand charge is determined. A rule of thumb is that solar can save demand equivalent to about 10% of its rated capacity- so a 1 MW PV system might be expected to save an average of 100 kW in demand.
- **Demand ratchet:** This 10% rule of thumb would not apply if there is a demand ratchet, which bases demand charges on a historic (usually annual) demand peak (kW) rather than the measured peak in a month. Now it becomes much more likely that there will be some 15 minute demand period in the preceding year when the solar is not contributing. So a demand ratchet generally results in little or no demand savings for a PV system driven by the intermittent solar resource.
- **Time-of-use (TOU) rates:** Time of use rates are meant to discourage energy use during the day with higher rates when system loads are highest, and incentivize energy use at night with lower rates when loads are lower. PV is generally favored by this type of rate structure because they offset the most expensive power during the afternoon.
- **Seasonal rates:** Many utilities have different rates for summer and winter months. PV produces additional cost savings for customers whose summer rates are higher than winter rates.

- Fixed customer charges and other riders: Fixed charges such as customer charges, metering and billing charges, or other fixed charges are not reduced by delivery of energy from a PV system, so they tend to reduce the average value (c/kWh) of the RE energy delivered in terms of utility cost savings.

To accurately estimate the utility cost savings, the EPC contractor must analyze time-series data of the estimated PV generation and load, and use the rate schedule to calculate monthly bills with and without PV generation. This calculation must be performed for every hour of the year and is generally accomplished using specialized software, such as the [System Advisor Model \(SAM\)](#), which can automatically download the appropriate rate schedule from the [Utility Rate Database \(URDB\)](#). The URDB contains more than 38,000 rate schedules from over 3,740 utility companies.

3.2 Site Data

C&I PV systems can be complex and require an extensive amount of site-specific information to be gathered early in the design process. If possible, the full structural and electrical plansets should be procured when mounting on an existing building. For ground mounts a detailed site survey should be performed including soils analysis and proposed utility interconnection location.

Relevant information from the following list should be noted on the construction plans submitted for permit application. Site data to be recorded includes:

3.2.1 Site Information

- Property and building dimensions
- Details of any existing easements, restrictions or open permits
- Photos of building from a variety of angles.

3.2.2 Structural Information (if applicable)

- Local design wind speed and source of information (e.g., ASCE 7, local AHJ)
- Local ground snow load and source of information (e.g., ASCE 7, local AHJ)
- Design roof snow load (indicate any snow load reductions)
- Roof support system type (e.g., metal truss, wood laminate joist/beam) and dimensions
- Support member spans and spacings
- Lumber species and grade (indicate whether identified in field or assumed)
- Photos of all components of the roof support system.

3.2.3 Roof Information (if applicable)

- Dimensions, including the depth and height of any parapet walls
- Locally required minimum roof setback dimensions (from 2012 IFC or local AHJ)

- Age and type of roof covering (e.g., thermoplastic polyolefin², built-up asphalt, torch-down). To avoid unnecessary cost to the EPC or the building owner, the roof covering should have sufficient life remaining such that re-roofing is unlikely to be needed during the contract term.
- Roof construction (e.g., mechanically attached, partly adhered, fully adhered)
- Decking type and dimension (e.g., ¾” OSB, 8” reinforced concrete, corrugated metal)
- Roof condition (roof covering, decking, and roof framing)
- Existing equipment locations and drainage path
- Existing roof warranty (manufacturer and installer) information and original roofer of record
- Safety or liability considerations such as skylights, pipes, and other trip or fall hazards
- Photos of the entire roof, with close-ups of features, equipment, and existing damage.

3.2.4 Grade Information (if applicable)

- Soil analysis
- Environmental impact study
- Topical graphical information
- Ground cover information
- Location of all easements, underground utilities, or other features that could impact system design or installation
- Photographs of site conditions
- Identification of outstanding easements or non-disturbance agreements.

3.2.5 Electrical Information

- Service type and size (e.g., 208/120 V or 480/277 V; wye or delta configuration; location of ground connection)
- Main service panel details (e.g., make and model, main breaker and busbar ratings, available breaker spaces)
- Location of other electrical equipment (e.g., sub-panels, transformers, disconnects, gutters)
- Photos of all electrical equipment
- Utility meter location.

² Thermoplastic polyolefin is also known as TPO.

3.2.6 Potential Locations for New Equipment

- Inverter(s)/transformer(s)
- Conduit runs/wire trays/gutters
- PV modules
- Disconnects
- Monitoring equipment.

3.3 Production Estimate

There are multiple tools for estimating PV system production, with more options becoming available every year. The key features for a tool include accurate weather data, shading functionality, adjustable system derate factors, component hardware selection, and monthly energy production estimates.

It is important to use the same production model for initial design, ongoing performance monitoring and metric reporting, so that the design model can be a baseline for comparison to operating results.

3.3.1 Estimating Tools

Popular tools for production estimates are estimating algorithms like PVWatts or more complex simulating software like PVsyst, PV Complete, Aurora, Helioscope or Energy Pariscope. NREL's System Advisor Model includes the PVWatts v1 algorithm.

3.3.2 Modeling Tools

Sophisticated modeling software, such as PV Syst, PV Sol, Aurora SIM, and PV SAM, should be used to estimate C&I system performance. Software tools should have accuracy validation from an independent third party such as NREL, DNV GL, or Black and Veatch. The software should include:

- Module-level performance simulation showing the current-voltage (I-V) curve at module level
- Real equipment electrical characteristics for modules, inverters, and power optimizers (unlike PVWatts, for example)
- Ability to include multiple types of inverters (micro versus string) as well as module-level DC optimization
- A wire-loss calculator used to model wire losses in long distances
- Specific losses should be calculated based on real system design, for example, DC to AC derates, conductor sizes, and other factors as applicable (as opposed to a general loss factor)
- A soiling/snow study of the local region could be taken before the production is modeled to improve the accuracy of including these losses.

3.3.3 Solar Resource/Weather Data Sources

The EPC Contractor shall perform an onsite analysis or remote shade analysis for each project using a Solmetric Suneye, Solar Pathfinder, or similar industry-accepted measurement tool. For each unique array tilt, orientation, or module type used, the EPC Contractor shall evaluate, at a minimum, the corners of each array, and possibly more if the array is large enough where a shade obstacle could impact the center without impacting the corners of the array. For each portion of the array, the EPC Contractor will calculate a total solar resource fraction (TSRF) and provide a calculated TSRF for the overall array. This will be done by weighting each portion's TSRF by its proportional capacity to the entire array as stipulated by the resource measurement tool manufacturer.

Weather data sources for all design estimates shall be one of the following:

- Meteonorm synthetic data sets
- NREL typical meteorological years (TMY) data sets: TMY2, TMY3
- White Box Technologies CZ2010 data set for California
- NREL 40-km gridded data set for United States
- Clean Power Research 10 km gridded data set.

In lieu of an onsite shade analysis, it may be acceptable to perform the analyses remotely with tools that incorporate aerial photography and satellite imaging techniques. Examples include:

- Aurora SIM
- Solar Census
- Helioscope.

For large projects, the project developer can install weather monitoring equipment at the site; however a minimum of one year of monitoring should be completed. Even this, however, could provide inaccurate information in terms of “typical” weather.

3.3.4 Performance Guarantees

EPC Contractors or third-party designers may provide a performance guarantee of some form to the Provider. The modeling methods, tools, and estimates used must be agreed upon, results acceptable to both parties, and results clearly stated in the contract. If there are material design changes during construction (such as updated module performance), the original models may need to be adjusted accordingly and should be investigated. Using a performance guarantee standard, such as IEC 61724 Photovoltaic System Performance Monitoring, can help eliminate subjective estimates.

3.4 System Design

EPC Contractors should ensure that system design and feasibility estimates are made using reliable data. NABCEP's [Resource Guide](#) addresses many of the key factors and current industry best practices regarding PV system design and can be used as a resource. Below are brief

summaries of major design topics, with references to existing documentation, which provides further detail.

The EPC Contractor is responsible for the PV system design, although outsourcing system design is acceptable provided the details of the design are confirmed on site. Key factors of PV system design include:

- Accordance with all state and local (AHJ) building and safety requirements
- Accuracy of collected site data, including roof dimensions and slope, grade conditions, existing electrical equipment locations, and shade analysis
- Proper implementation of all applicable codes, such as NEC, IFC, and IBC
- Consideration of customer priorities, including aesthetics, power production maximization, equipment manufacturer preferences, and equipment location preferences
- Appropriate level of detail in the design drawings such that the installation team encounters a minimum number of unknown obstacles onsite
- Designer proficiency with implemented software (e.g., PV Syst, Helioscope, CAD)
- P.E. approval as required.

3.4.1 Project Planset

The project planset—also known as design drawings—should have a sufficient level of detail to address any questions that the AHJ may have during the permitting process and any questions that the installation crew may have during construction. A robust and detailed planset can be considered a very important indicator of construction quality and consistency on a PV project. An example of the level of detail to expect for a MW-scale PV system planset follows.

General	<ul style="list-style-type: none"> • Contact information for all project stakeholders (including designer, client, profession engineer of record, project manager, electrician, and construction manager) • Site location, including a map showing system location and surrounding area • System details (including system capacity [kW], module type(s), inverter type(s), support structure type(s), and number of strings and sub-arrays) • List of the codes and standards applicable to the project (such as relevant NEC version, state-specific codes, AHJ-specific guidelines, building codes, seismic codes, historical codes, and safety standards) • Version control documentation and revision history • Table of contents • General Notes section outlining project responsibilities, processes, procedures, requirements and expectations • Torque specifications and requirements • Abbreviations and symbols legend • Location of key system components, such as PV arrays, equipment pads, walkways, interconnection location • Staging and access plan for modules and equipment • Tree removal, lighting, grading, and erosion control plans (as applicable).
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Structural	<ul style="list-style-type: none"> • Notes section detailing specific design criteria (such as maximum and minimum design temperatures, wind speed data, exposure category, seismic data, concrete specifications, steel specifications, and welding specifications) • Structural layout including array support structure locations and anchor points • Roof-mounted systems: <ul style="list-style-type: none"> ○ Roof loading details (e.g., design wind speed, design snow load) ○ Roofing system elevation drawing (including roof type and flashing/attachment) ○ Installation detail for mounting system stand-off and roof penetration ○ Roof framing details and design checks (e.g., span tables or calculations), loads associated with PV system including ballast weight. Consider both distributed loads after system is installed and also point loads when equipment is staged on the roof prior to installation, in particular concentrated loads such as heavy inverters • Ground-mounted systems: <ul style="list-style-type: none"> ○ Soils analysis ○ Environmental impact study ○ Fencing layout and details ○ Trenching and underground construction plan (where applicable) ○ Foundation details showing how the mounting structure is secured in place • Carport systems: <ul style="list-style-type: none"> ○ Bollard locations and installation details ○ Foundation details showing how the carport structure is secured in place ○ Lighting plan • Tracking systems: <ul style="list-style-type: none"> ○ Tracking system mechanical details.
Electrical	<ul style="list-style-type: none"> • Electrical Notes section outlining equipment requirements, approved wiring methods, grounding requirements, and general electrical installation guidelines • 1-line and 3-line diagrams • Conduit and wiring schedule • Inverter and BOS elevation drawings and riser diagrams • Plan views of all electrical equipment locations • String diagrams • Construction detail drawings showing how every electrical part and piece of equipment on the project is to be installed • Grounding details • Required labels, including location-specific electrical values • Monitoring system wiring diagram.
Equipment	Equipment data sheets for all equipment including modules, inverters, mounting systems, enclosures, monitoring equipment, and any other equipment to be installed.

In regions prone to sliding snow and ice, developers should consider heavy snow-rated modules and snow guards in specific areas where people could be at risk of snow/ice shedding, such as roofs over building entries, parking lots, and walkways. Provide a safe place for snow sliding off the array to accumulate without shading the array.

3.4.2 Module Support Structure

Items to include in the design description:

- Anchoring method (e.g., ballasted, concrete piers, helical ground screws, driven piles)
- Racking material (steel, aluminum)

- Varying tolerances for variations in terrain
- Module attachment method (e.g., top clamps, bottom clamps, bolt through)
- Note that some locations may require non-penetrating racking (e.g., landfills)
- Grounding (e.g., integrated grounding, UL 2703, what parts of the rack need to be grounded).

3.4.3 DC System Design

Items to include in the design description:

- PV Module layout: Number of modules in series strings, series strings per combiner box, recombiner boxes, disconnects, overcurrent protection, ground fault protection, arc fault protection, and grounding
- Inverter architecture (monopolar vs. bipolar; 600 vs. 1000V)
- Inverter types (micro, sting, central)
- Inverter loading.

3.4.4 AC System Design

Items to include in the design description:

- Inverter AC output types
- AC disconnect means
- AC overcurrent protection
- Grounding
- Transformer (if needed based on inverter type)
- Interconnection location/method.

3.5 Equipment Requirements

PV systems are composed of a multitude of components, each of which has its own set of specifications and certifications. This section will identify the most common requirements for the fundamental types of PV system equipment.

3.5.1 Photovoltaic Modules

Baseline requirements:

- UL1703 – Flat-Plate Photovoltaic Modules and Panels
- International Electrotechnical Commission (IEC) 61215 or UL 61215 - Crystalline Silicon Terrestrial Photovoltaic (PV) Modules

- ❑ IEC 61646 or UL 61646 Thin-Film Terrestrial Photovoltaic (PV) Modules
- ❑ ASTM E2481-06 Standard Test Method for Hot Spot Protection Testing of Photovoltaic Modules
- ❑ Manufactured using an ISO-9001 quality management system
- ❑ Warranties for both “materials and work quality” and “production”
- ❑ Manufacturer is required to remain willing to participate in third-party audits if required by the EPC Contractor or capital provider.

It is recommended that modules that are resistant to potential-induced degradation (PID) be used for systems where transformerless inverters are used because these systems are ungrounded.

3.5.2 Inverters

For information on inverters, consult [UL 1741 Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources](#).

- ❑ [IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems](#)
- ❑ [IEEE 1547.1 Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems](#)
- ❑ Inverter installation requirements are governed by the NEC Articles 690 and 705. Article 705, Part II lists requirements of Utility Interactive Inverters including circuit sizing and over current protection
- ❑ NEC 690.10 lists requirements for standalone system inverters
- ❑ NEC 690.14 provides additional requirements including location of inverters in not-readily-accessible locations
- ❑ NEC 705.12(D) lists requirements for utility interactive inverters
- ❑ NEC 705.40 lists requirements of inverters for loss of primary source of power.

Arc fault protection is required for inverters in jurisdictions subject to NEC 2011 or beyond. It is noted that future requirements, such as those [under consideration in California](#) at the time of this writing, may include “smart inverter” capabilities, which allow for remote system shutoff and restart by the utilities. New provisions of IEEE 1547 facilitate grid integration issues by allowing, upon mutual consent of the system owner and the utility, for low voltage ride through, low frequency ride through, and non-unity power factor.

3.5.3 Racking Systems

See [UL 2703 Rack Mounting Systems and Clamping Devices for Flat-Plate Photovoltaic Modules and Panels](#) for installation criteria regarding rack mounting PV systems and clamping devices for flat-plate PV modules and panels that comply with UL 1703. UL 2703 is intended to address product safety concerns for electrical rack mounting systems and clamping devices

pertaining to ground and bonding paths, mechanical strength, and suitability of materials. This standard also addresses installation, materials, wind resistance, and fire classification.

International Code Council (ICC) Evaluation Services has published AC 428, Acceptance Criteria for Modular Framing Systems Used to Support Photovoltaic (PV) Modules. This publication was created to provide the criteria for evaluation of rooftop PV mounting systems for manufacturers seeking a product listing under ICC Evaluation Services. It includes structural design criteria that are useful for designing mounting systems:

- Ballasted racking
- Hybrid racking (ballast and anchors)
- Anchored racking.

3.5.4 Monitoring

A monitoring system with connectivity (99.5% uptime preferred) to the O&M provider is recommended to support revenue and O&M, including regular performance and availability alerts.

It is preferred that the monitoring system be application programming interface (API) compatible with SunSpec Alliance [Best Practices in Solar Performance Monitoring](#) guidelines. Data structures should conform to SunSpec Alliance's [SunSpec Plant Information Exchange](#) document to support compatibility of the system lifetime. One common standard for monitoring protocols is [IEC 61724 – Performance Monitoring](#).

3.5.5 Electrical Components

Additional electrical components such as junction boxes, combiner boxes and ancillary electrical equipment should be subject to the following criteria:

- IEC 62852 – ultraviolet (UV) exposure for connectors/cables
- IEC 62790 – UV exposure for junction boxes
- UL 1565 Wire Positioning Devices
- National Electrical Manufacturers Association (NEMA) or Ingress Protection (IP) ratings for electrical enclosures.

3.6 Permitting and Inspections

The EPC Contractor is responsible for procuring all necessary permits and approvals for PV system construction and inspection. Permitting processes vary based on the project capacity, requirements of the Owner, AHJ, and the utility.

4 Installation Best Practices

4.1 Equipment Best Practices

4.1.1 PV Modules

Regardless of construction type (e.g., metal-framed, frameless, building-integrated, “peel and stick”), care must be taken to comply with all manufacturer instructions concerning the transportation, storage, mounting, grounding, and connecting of the PV modules. Failure to do so could result in voiding of the module warranty, underproduction of the PV system over time, and increased shock- or fire-hazard risk. Important items to consider when installing the PV modules include:

- Awareness of any specific mounting location stipulations from the module manufacturer, which may or may not vary based on the potential wind load at the site or proximity to marine environment.
- Understanding of the different module mounting options, such as bolting the module frame to the mounting structure or clamping the frame with the appropriate hardware and compression force.
- Appropriate use of fall protection equipment is particularly important during array installation because PV modules tend to be large and unwieldy, presenting elevated risk for installer injury and to workers on the ground if any equipment is dropped. This risk is further exacerbated on steeper roofs.
- Knowledge of electrical safety protocols, such as ensuring that homerun conductors are not connected during installation to ensure the safety of any personnel wiring electrical equipment.

4.1.2 Mounting Systems

PV modules are typically attached to roofs via purpose-built metal (usually aluminum) mounting systems. Module mounting systems must be listed for the application and capable of withstanding the uplift (due to wind) and downward forces (e.g., snow load) that they could potentially be exposed to, based on the specific location of the installation. Important items to consider when installing the mounting system include:

- Appropriate weather sealing of all penetrations of the building envelope.
- I-codes guidelines on array setbacks (requirements vary based on roof design).
- Complying with local guidelines when navigating existing vents or equipment on the roof.
- Layout on roof should provide walkways for firefighter access including areas for laydown of equipment and places for people walking in opposite directions to pass each other.
- Understanding best practices for working with a given roof covering as per the [National Roofing Contractor’s Association Roofing Manual](#).

- ❑ Balancing customer aesthetics expectations with code requirements and airflow directives from the module or racking manufacturer.
- ❑ Assessment of the roof structure (usually via attic or crawl-space inspection) for lumber type, dimension, and condition.
- ❑ Assessment of the condition of the roof covering. If the roof covering will need replacement before the end of the expected PV system lifetime (20–25 years), the Project Owner should consider roof replacement prior to PV system installation.
- ❑ Using the appropriate size and type of fasteners for the application, and achieving the proper embedment in the substrate.
- ❑ Understanding the cause and effect of inter-row shading in tilted arrays and identifying when such shading may become an issue.
- ❑ Understanding of the span and cantilever limitations of the mounting system.

4.2 Work Quality Best Practices

4.2.1 System Grounding and Bonding

Proper grounding and bonding (or *earthing and continuity*) is a crucial safety element of an installed PV system. Grounding and bonding of PV systems is covered in NEC 690(V), along with many sections of Article 250. There are two forms of PV grounding: system grounding and equipment grounding.

An equipment grounding ‘network’ consists of equipment-grounding conductors, a grounding-electrode system, and a grounding-electrode conductor. The purpose of the equipment grounding (EG) system is to ensure there is no hazardous voltage between any exposed metal parts of a system and earth. If a system is properly “earthed,” a barefoot person standing on the ground and touching any exposed metal surface of the system will not experience an electrical shock.

All metallic equipment (both DC and AC) should be grounded per the requirements of the NEC and equipment manufacturer. This includes metal raceways, enclosures, mounting hardware, module frames, conduit fittings, metal fences, etc. If there is a lightning protection system (LPS) existing on a building, the electric engineer of record should make a determination as to whether, and how, to bond the array EG to the LPS main ground.

It is essential that a current-carrying conductor of a PV output circuit is bonded to ground at only one point, as per NEC Article 250 requirements.

PV strings with the fuse on the positive side are grounded on the negative side so that if the fuse blows the path to ground is not interrupted. In “bi-polar” systems the reverse will also be true: strings with the fuse on the negative side are grounded on the positive side. Article 690.35 of the NEC allows ungrounded PV systems of any voltage, if conditions are met, particularly ground-fault protection (see below). “Ungrounded” systems do not have a bonding connection between a current-carrying conductor of the PV output circuit and ground. They are becoming increasingly common due to lower equipment costs and higher efficiency. Note that the name refers only to

the fact that there is no “system ground” (i.e., grounded current-carrying conductor), but that all equipment grounding and bonding requirements do still apply.

4.2.2 DC Ground-Fault Protection (DCGFP)

All PV systems now incorporate DC ground-fault protection (GFP), as required by the NEC. The two types of GFP are 1) directly fused (reference grounded) or 2) differential “residual” current sensors. A third type of GFP is a combination of both, depending on the grounding application. For separated (isolated DC/AC) systems, a residual current device (RCD) is essential to measure the difference in polarity currents (leakage) because there is no singular fault path to earth to monitor. Grounded DC system inverters typically still use a fuse between the grounded pole and earth that blows when more than an amp or more flows through the common bond between them. Sometimes the fuse is paralleled with an RCD to signal the inverter when fault current is first sensed, in an attempt to disconnect the DC input as quickly as possible and possibly avert a blown fuse.

A particular hazard still exists for systems using inverters with the “directly fused” ground fault detection and interruption (GFDI) protection, which many inverters still incorporate (see Solar America Board for Codes and Standards’ [Solar ABC’s] [Ground Fault Detection Blind Spot](#) for details). The situation of having a blown (open) GFDI fuse, with no defined path for any fault current to earth, can have severe consequences for the safety of personnel, structures, and equipment. The industry is gradually moving away from fused ground fault detectors and toward differential RCDs that do not open the path to earth (as with “ungrounded” inverters).

4.2.3 DC Arc-Fault Circuit Protection (DCAFP)

Arc-fault circuit protection, which is now required by the 2014 NEC for all systems 80V_{DC} or more, should safely extinguish any series arcing faults resulting from a loose or broken connection in a PV source or output circuit. These devices open the faulted circuit at some point to interrupt arcing current across the faulty connection. Note that these devices do not detect or interrupt “parallel” arc-faults, which occur between two current-carrying wires or connections of opposite polarity. Arc fault detection and interruption is recommended even if not required by the AHJ due to the safety benefits.

4.2.4 Rapid Shutdown of PV Systems on Buildings

2014 NEC requires that all PV systems installed in or on buildings include a rapid shutdown function to. The DC section of a PV system can still be energized during an emergency, even if the inverter has been shut down. The rapid shutdown function protects first responders. For reference, a building is defined by NEC as a structure that stands alone or is adjacent to other structures but separated by a fire wall. This definition includes any structure, such as canopies, or even a pole, billboard, sign, or water tower.

4.2.5 Marking (Labeling) Best Practices

Strict conformance to system marking (or labeling) requirements of PV systems and their components is crucial for the safety of operators, service personnel, emergency responders and others. PV system general labeling requirements are covered in NEC 2014 690 Chapter VI, as well as specific accompanying requirements throughout Articles 690 and 705. All required and desired labeling language should be included in the design drawings.

Electrical equipment and components used in PV systems have markings identifying the manufacturer, size, type, ratings, hazard warnings, and other specifications. Equipment markings should never be removed, and all equipment markings must be durable for the environment in which the equipment is installed. Markings must be visible or easily accessible during and after installation.

Field-applied markings are required for certain components and for the inclusive PV system. These markings must be designed to withstand the environment in which they are installed (e.g., “UV rated” for outdoor labels) and permanently affixed to the respective equipment in a manner appropriate for the environment and compatible with the substrate materials. Field-applied markings are required on many types of equipment and components, including (but not limited to) conductors, connectors, conduits, disconnecting means, point of utility connection, as well as special markings for bi-polar arrays, ungrounded arrays, battery storage systems, standalone inverters providing a single 120-volt supply, and other marking as required by codes and local AHJ requirements.

One common mistake to avoid is to use combiner boxes that are labeled as negative ground in a bi-polar system in a location that is actually positive ground, or to re-label one that is supplied as negative ground to positive ground with labels or markers that are not permanent.

4.2.6 Mechanical Components

Though a PV system’s purpose is electrical in nature, it is very important that the components are mechanically installed in a manor appropriate for the local environment. This holds true for all types of installations, but is particularly important for rooftop installations due to the load forces they may be exposed to (e.g., wind and snow), and the potential damage to life or property that could occur if mechanical connections were to fail.

4.2.7 Systems with Module-Level Power Electronics

For future O&M purposes, the serial numbers of module-level power electronics (e.g., power optimizers, microinverters) should be mapped during installation (e.g., [Enphase installation guide](#)). There are numerous technology solutions to capturing equipment barcode information through mobile technology.

Additional resources:

- [International Building Code Section 1504](#)
- [PV Racking and Attachment Criteria for Effective Asphalt Shingle Roof System Integration](#)
- [A Guide to Photovoltaic \(PV\) System Design and Installation](#)
- [Field Inspection Guidelines for PV Systems](#)
- [Photovoltaic Power Systems, 2005 National Electric Code: Suggested Best Practices](#)
- [Southwest Technology Development Institute, Codes and Standards Resources](#)
- [NABCEP Photovoltaic \(PV\) Installer Resource Guide](#)

- [Best Practices for Solar Photovoltaic Installations – Renewable Energy Vermont Partnership Program](#)
- [IEC 62446 Commissioning Standard](#)
- [Green Job Hazards: Solar Energy](#)
- [Solar Construction Safety](#).

4.3 System Documentation

EPCs should store basic Project Owner and system information for the term of the initial customer agreement. Data naming methodology should follow the SunSpec [Data Dictionary](#).

Outlining the minimum documentation that should be provided for grid-tied PV systems will ensure transparency to investors of basic system components, information on design and installation, and O&M requirements. Additional data representing the consumer credit worthiness are not included in this list.

4.3.1 Required Site Data Points

- Plant identifier
- Site owner name
- Site owner address
- Site owner city
- Site owner state
- Site owner zip code
- Site owner phone number
- Site owner email address
- Activation date
- Individual PV system boundaries for buildings that have more than one system.

4.3.2 Required System Design Data

- Design model
- Installed DC capacity
- Derate factor
- Nominal power rating
- Module manufacturer
- Module model

- Module units
- Inverter manufacturer
- Inverter model
- Inverter units
- Racking manufacturer(s)
- Racking model(s)
- Wiring layouts:
 - Wiring of modules into strings; strings into combiner boxes; combiner boxes into re-combiner boxes; disconnects; source circuits into inverter. Wiring layouts help personnel locate the origin of faults.

4.3.3 As-Built Photograph Inventory

The EPC Contractor shall maintain a photograph inventory of all active systems. Photographs may be captured through the installation EPC Contractor, third-party inspector, or in-house personnel. A photograph inventory allows the provider to have a strong understanding of onsite conditions and overall level of quality. A photograph inventory will reduce O&M costs. Photographs shall be stored through the life of the service contract and retrievable through Customer/Address query. Electronic capture and cataloguing of site information is preferred to ensure consistency and accuracy. Mandatory photographs include at least one onsite photo of each system component outlined in Table 1.

Table 1. Required System Photographs

Roof (array)	Balance of System
Site Address Confirmation	DC Disconnect location and interior
Overall Array	Inverter Location
Under Array	Inverter Nameplate
Array Horizon (shading)	AC Disconnect location and interior
Module Nameplate	Main service panel (cover open)
Conduit Runs and Support	Main service panel (cover closed)
Junction Box Locations	Connection to premise's grounding system
Junction Box Interior	Production meter
Wire Management	Monitoring system
Flashing of roof penetrations	Net meter
	Vegetation and other shading objects

4.3.4 EPC Submittal Information

Copies of additional key information should be provided to the system owner and stored through the duration of the service agreement.

4.3.4.1 Electrical Design

- Company name
- Company address
- Company phone number, email, website
- Contact person (contact name, address, phone number)
- Structural/mechanical design (if provided by mounting equipment manufacturer, list manufacturer information).

4.3.4.2 PV Installer (If more than one company, list for each and note company roles)

- Company name
- Company address
- Company phone number, email, website
- Contact person (contact name, address, phone number).

4.3.4.3 Electrical Design Documentation

At minimum, a one-line or three-line wiring diagram that includes:

- General specifications
- String diagram
- 3-line diagram
- Electrical details/inverter information
- Grounding/overvoltage protection
- Ac system specification
- Equipment data sheets
- Warranty information
- Installation manuals
- O&M manuals
- Test results/commissioning (Cx) data.

4.4 Third-Party Inspection and Verification

4.4.1 Field Inspection Verification

EPC Contractors should verify and measure installed asset quality through a continuous process of third-party field inspection verification (FIV) of the EPC Contractor's completed systems. For purposes of this document, a third-party inspector means any technically qualified entity that was

not directly involved in the installation or system design process. The third-party inspector can be part of the installation company (e.g., part of the O&M division) or an entirely separate entity. The FIV process includes onsite inspections of completed system installations to verify the systems have been installed to equipment manufacturer specifications, relevant codes, and installation best practices. This process is essential to the checks and balances of solar as an asset class.

- To ensure an objective process, the inspector(s) should be a third-party provider, not involved in the design or installation of the inspected system(s)
- Data collected by the FIV are subject to approval by the EPC Contractor and may be modified by the EPC Contractor upon review
- FIV results should be shared with the EPC Contractor for a continuous improvement process for installation quality.

4.4.2 Third-Party Inspector Qualifications

The third-party inspector should have at least one of the following professional certifications and have specific knowledge of solar PV design and installation.

- NABCEP Certified Installer
- UL Certified PV System Installer
- Licensed Professional Engineer
- Licensed Electrician
- ICC Certified Electrical Inspector and/or Plans Examiner
- Equivalent proprietary training programs.

All inspectors shall have a minimum OSHA 10-hour certification and applicable skills (climbing and carrying ladder, walking on roof surface, etc.) to perform an objective inspection.

4.4.3 Scoring System

The FIV will also result in a system quality scoring metric that can be used as a single quality assessment of the initial installation. The scoring system should numerically quantify the level of risks associated with the safety and performance of the system.

- Pass/Fail – For each inspection, a report shall be issued that summarizes the issues identified and provides the EPC Contractor with a list of deficiencies requiring corrective action. The report shall also include the overall QA score.
- Define System Components – The sample breakout includes inverter, models, conduit/junction box, AC disconnects, DC disconnects, PV system labeling, grounding/bonding, wire management, roof conditions, flashing, shading, and system layout.

4.5 Interconnection

Before a PV system is allowed to operate legally, the appropriate utility provider must approve the system for operation. Similar to PV permitting, PV interconnection requirements vary around the country but are generally based on one or a combination of the following major interconnection standards:

- FERC's Small Generator Interconnection Standards (SGIP)
- California's Rule 21
- IREC's Model Interconnection Standards
- The Mid-Atlantic Demand Resource Initiative procedures (MADRI).

The interconnection of a distributed generation system such as a PV system with the local utility depends upon state regulations and utility policies and practices. Interconnection guidelines and state- and utility-specific rules can usually be accessed by installers through utility websites. Contractual aspects of interconnection include fees, metering requirements, billing arrangements, and size restrictions on the system. Understanding the local utility's requirements is a very important process.

In addition, national and local codes have interconnection and system equipment and labeling requirements so that the system can be easily identified and/or shut off. For example, some states or utilities require an easily accessible external disconnect switch. The NEC governs how the output of a PV system can be connected to the utility in Article 705. The two relevant connections would be:

1. Supply side (similar to installing another service onsite and usually found on larger installations)
2. Load side (most commonly used for smaller systems and requires a dedicated circuit breaker or overcurrent device with the sum total of overcurrent devices supplying the busbar should not exceed 120% of the busbar rating for commercial applications as per 2014 NEC 705.12(D)(2)).

Before investing in a solar PV system, it is wise to apply for interconnection approval as early in the process as possible. This allows added costs or barriers to be factored into the decision to install at a particular location; it can impact decisions about system design. With PV market penetration increasing, there are emerging issues around the need for transformer or other equipment upgrades on local circuits and the question of who pays for this. In the case of non-residential systems, even more equipment and local circuit considerations may arise, making it unfeasible to install a system at a particular location or at the intended size. These factors can change the economics of a project and should be identified as early as possible.

Further details on interconnection requirements can be found on the [Database of State Incentives for Renewable Energy](#). Additional information on interconnection requirements can be found on the [Freeing the Grid](#) website.

- [IEEE 1547 Series of Interconnection Standards](#)

- NEC 690, 705.

5 O&M Best Practices

5.1 Solar PV Operations, Maintenance, and Monitoring (OM&M)

The ongoing operation, monitoring and maintenance of a solar PV generating system throughout its lifespan is absolutely critical to keeping the system running, achieving optimal performance and realizing the expected rate of return.

The OM&M requirements and plan need to be roughly defined during the design phase of the project so they can be adequately budgeted and included in the energy production and financial models. All instrumentation should be designed and installed as part of the larger PV system. Production models typically assume a system availability of at least 99% of daylight hours, which equals less than two days of total downtime during the year—including scheduled maintenance. Meeting these uptime requirements can be very difficult unless the system is properly designed and carefully operated, monitored, and maintained.

Solar PV operations, procedures, and maintenance best practices are still evolving and new tools are becoming available for improving the quality of maintenance inspections and testing. Monitoring systems also continue to advance and provide ever more detailed data on the system's operation and performance, some even down to the individual module level (as in optimizers and microinverters).

The administrative effort required to keep track of warranty paperwork, recruit and contract with service providers and suppliers can be considerable and should be included in the initial planning. Similarly, reviewing performance information and plan O&M activities should be included as part of the OM&M plan. As outlined in the Electric Power Research Institute's (EPRI's) *Addressing Solar Photovoltaic Operations and Maintenance Challenges* (EPRI 2010), there are several different approaches and strategies for solar PV O&M, each attempting to reduce costs while improving availability and increasing productivity. The three major approaches identified are:

- Preventive maintenance (PM)
- Corrective/reactive maintenance (RM)
- Condition-based maintenance (CBM).

Depending on who is responsible for system maintenance, the value of productivity, accessibility to the site, and many other factors, any one (or even a combination) of these approaches may be appropriate. Every system must be evaluated and cost-benefit tradeoffs for the different approaches analyzed to determine how best to proceed.

In 2010, EPRI gathered anecdotal data for direct O&M costs for both in-house and outsourced approaches from several installers of systems of 1 MW and less. They ranged from \$6/kW to \$27/kW of rated capacity, and from <1% to 5% of the “all in” cost of the complete project.

Scheduled comprehensive maintenance visits are usually required at least annually, sometimes semi-annually, or even quarterly—particularly at sites that often need the modules cleaned or weeds pulled, etc., to prevent shading and lost solar production. And inverters, despite being solid state devices, may still have cooling systems with fans and filters that need periodic

cleaning and occasional replacement. Close monitoring of the AC output versus DC input of an inverter helps determine if there may be a problem, and it is possible for inverters to fault or even fail while still under warranty. Inverter manufacturers typically offer a range of extended warranties beyond the 10–12 year industry standard, which need to be carefully assessed for cost versus benefits by an experienced designer or installer.

Some of the newer maintenance test procedures that have been instituted recently due to the availability of proper test equipment are thermographic imaging of modules and individual string tests, including insulation resistance. Both of these tests can fairly quickly point out faults and trouble spots in a PV array that need attention. String testing data can also be compared from year to year to give an indication of the average degradation of module power to determine if the modules are still producing within their warranted power range (typically 80% of original rated capacity after 25 years).

5.2 PV System Warranty

Warranties for both work quality and products are an essential and integral component to the O&M program. Work quality warranties must clearly define what constitutes a required repair or replacement, whether it's critical or non-critical, who is responsible for equipment replacement, labor and shipping costs, and response timeliness.

Warranty coverages for modules and inverters usually have very clear terms and conditions for proper installation, operation and maintenance, and must be followed to the letter for the warranty to remain in effect. The detailed requirements of all equipment warranties must be understood and enforced by the commissioning authority during installation and final commissioning to assure full coverage is maintained.

5.3 Solar PV System Commissioning

The process of commissioning (Cx) PV systems has evolved into a comprehensive program that typically includes not only the EPC Contractor's testing and inspections by their Cx authority but often full oversight and QA of an entire project by an independent, third-party consultant. Commissioning is the link between the EPC contractor and the operator. Documentation of the system, array testing, and whole-system performance test (as applicable to commercial, industrial, and field systems) should be performed as defined in IEC 62446: Grid Connected Photovoltaic Systems-Minimum Requirements for System Documentation, Commissioning Tests, and Inspections (2009).

Ideally, Cx begins with the basis of design, continuing through construction and final acceptance testing, and sometimes beyond (retro-Cx, on-going Cx). It is best directed by an independent owner's engineer (OE), usually an experienced consultant who works directly for, and represents only the interests of, the owner. The OE typically oversees the EPC Contractor's Cx authority and plays an advisory role throughout the life of a project to assure a quality installation.

The cost for an OE to fully oversee and commission a PV project can vary between 2%–3% (or more) of the total project cost, depending on the specific application and complexity of the installation. It can be advantageous and preferable to spend more up front, to get the project

clearly defined and designed correctly, thus avoiding very costly and difficult mid-stream changes during procurement and construction.

The Cx process follows a general path of design review, construction inspections, start-up and acceptance (functional) testing, and final performance testing. The final Cx report should include all design reviews, issue logs, inspection and testing data, and the OM&M plan. Performance Guarantees, if any, shall be clearly defined along with the responsibility for on-going monitoring of the system and enforcement of the contract.

5.4 System Monitoring

[SunSpec PV Performance Metrics](#) and [IEC 61724](#) describe the basic data required for reporting standard PV performance metrics, including energy performance index and availability. The monitoring system used should be capable of collecting this information.

6 References and Resources

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Appendix. References to Codes, Standards, and Guidelines

The following references relevant codes and standards that are commonly adopted by the AHJ.

Relevant Codes

IBC - 2012 International Building Code

- 1503.2 Flashing
- 1507.2.9 Flashings
 - 1507.2.9.1 Base and cap flashing
- 1507.3.9 Flashing
- 1505.8 Photovoltaic systems
- 1507.17 Photovoltaic modules/shingles
 - 1507.17.1 Material standards
 - 1507.17.2 Attachment
 - 1507.17.3 Wind resistance
- 1509.7 Photovoltaic systems
 - 1509.7.1 Wind resistance
 - 1509.7.2 Fire classification
 - 1509.7.3 Installation
 - 1509.7.4 Photovoltaic panels and modules
- 1511.1 Solar photovoltaic panels/modules
 - 1511.1.1 Structural fire resistance

IRC - 2012 International Residential Code

- R903.2 Flashing
- R905.2.8.1 Base and cap flashing
- R905.2.8.4 Other flashing

R905.3.8 Flashing

R905.16 Photovoltaic modules/shingles

R905.16.1 Material standards

R905.16.2 Attachment

R905.16.3 Wind resistance

M2301.2 Installation

M2301.2.1 Access

M2301.2.2 Roof-mounted collectors

M2301.2.7 Roof and wall penetrations

M2301.3.1 Collectors

M2302.1 General

M2302.2 Requirements

M2302.2.1 Roof-mounted panels and modules

IFC - 2012 International Fire Code

[A] 105.7.13 Solar photovoltaic power systems.

605.11 Solar photovoltaic power systems

605.11.1 Marking.

605.11.1.1 Materials

605.11.1.2 Marking content

605.11.1.3 Main service disconnect

605.11.1.4 Location of marking

605.11.2 Locations of DC conductors

605.11.3 Access and pathways

605.11.3.1 Roof access points

605.11.3.2 Residential systems for one- and two-family dwellings

- 605.11.3.2.1 Residential buildings with hip roof layouts
- 605.11.3.2.2 Residential buildings with a single ridge
- 605.11.3.2.3 Residential buildings with roof hips and valleys
- 605.11.3.2.4 Residential building smoke ventilation
- 605.11.3.3 Other than residential buildings
 - 605.11.3.3.1 Access
 - 605.11.3.3.2 Pathways
 - 605.11.3.3.3 Smoke ventilation
- 605.11.4 Ground-mounted photovoltaic arrays.

NFPA 70 - National Electrical Code

Relevant Standards

ASCE 7: Minimum Design Loads for Buildings and Other Structures

ASCE 7 is the source of wind loads, snow loads, etc., and the calculation methods that develop the loads from tabled data.

2012 National Design Specification For Wood Construction

Many sections of the NDS are relevant for checking roof framing for the added loads from solar. Span tables are derived from values and formulas in the NDS.

UL 1703

UL 2703

UL 1741

Roofing Guidelines and Resources

PV Racking and Attachment Criteria for Effective Asphalt Shingle Roof System Integration: <http://roofingcenter.org/main/Initiatives/pv>

NRCA - 2010 National Roofing Contractor Association, Chapter 3: Guidelines Application to Steep-slope Roof Systems

3.9 PENETRATIONS

4.1 Rack-Mounted Photovoltaic Modules Flashings

ARMA - 2006 Asphalt Roofing Manufacturers Association, Chapter 10 Flashings, soil stacks and vent pipes

TRI - Tile Roofing Institute

<http://www.mca-tile.com/downloads/TRIGuide2010.pdf>

TRI ICC-Evaluation Report – ESR-2015P

http://www.icc-es.org/Reports/pdf_files/ESR-2015P.pdf.