New Best-Practices Guide for Photovoltaic System Operations and Maintenance

As solar photovoltaic (PV) systems have continued their transition from niche applications into large, mature markets in the United States, their potential as financial investments has risen accordingly. Mainstream investors, however, need to feel confident about the risk and return of solar photovoltaic (PV) systems before committing funds. A major influence on risk and return for PV is operations and maintenance (O&M)—but O&M practices and costs vary widely across the United States, making these variables difficult for investors to predict. To address this barrier to continued PV investment, the PV O&M Working Group has developed a new best-practices guide for PV O&M.

The guide encourages high-quality PV system deployment and operation that improves lifetime project performance and energy production. Optimizing and standardizing PV O&M can: increase efficiency and energy delivery; decrease costs and downtime; extend system lifetime; ensure safety; enhance system appearance; and satisfy the requirements of financing and warranties.

The best-practices guide offers information and recommendations aimed at increasing the effectiveness of O&M services, reducing O&M costs, improving the transparency of PV assets for investors and rating agencies, providing an industry framework for quality management, and reducing transaction costs. Checklists throughout the guide help users take concrete steps to improve their O&M practices. The guide is most relevant to fleets of third-party-owned, grid-connected PV systems—in rooftop and ground-mounted configurations—for residential, commercial, industrial, and utility-scale applications.

This fact sheet summarizes important topics covered in the PV O&M best-practices guide. A link to the complete guide is provided on the last page of this fact sheet.

Various strategies can discourage birds from soiling PV systems, such as narrowing the gaps between panels where nests are built, sealing the space between roof and panels with bird netting, and scaring birds off using a plastic owl or falcon with a swiveling head. *Photo by Andy Walker, NREL*

About the PV O&M Working Group

The PV O&M Working Group consists of solar developers, financiers, law firms, rating agencies, accounting and engineering firms, and O&M service and technology providers engaged in solar deployment, and is facilitated by experts from the National Renewable Energy Laboratory (NREL), Sandia National Laboratories, and SunSpec Alliance. The group is supported by the U.S. Department of Energy's SunShot Initiative.

Effects of PV System Design, Installation Site, and Environment

The best-practices guide discusses how O&M requirements and costs depend on the type and configuration of PV system, details of the system site, and environmental conditions. For example, best practices in wire management can reduce O&M issues such as rodent gnawing, pinched wires, wire movement, tension on wires, and UV-degradation. Inverter considerations depend on the type of inverter (micro-, string, or central) and include preventive maintenance schedules and making the right decisions between replacing versus repairing inverters. For rooftop systems, both PV and roof O&M must be considered, and steps should be taken to maintain any existing roof warranties. In addition, effective O&M plans consider site-specific environmental conditions—such as extreme weather and the intensity and sources of panel soiling—as well as the costs and benefits of mitigating the associated problems. Site issues such as water drainage and type of ground cover make some O&M measures site-specific.Road access through the ground-mounted array field must be maintained.

System Performance and O&M Plans

The PV O&M lifecycle begins with planning and system design, and it ends with provision for decommissioning or disposal or recycling of the system. PV O&M planning should consider the full performance period of the system, which is considered to be the asset life—typically about 25 years—even though ownership may change multiple times during that period. A system owner is likely to seek a performance contract where a specified performance indicator, such as megawatt-hours of energy delivered per year, is guaranteed over that period. Performance indicators that account for changes in weather, force majeure, and anticipated degradation are recommended. In addition to discussing performance indicators, the best-practices guide covers the development and use of O&M plans, document management and record keeping, PV plant operations, preventive and corrective maintenance, PV module degradation rates, and treatment of PV systems at the end of their performance periods.

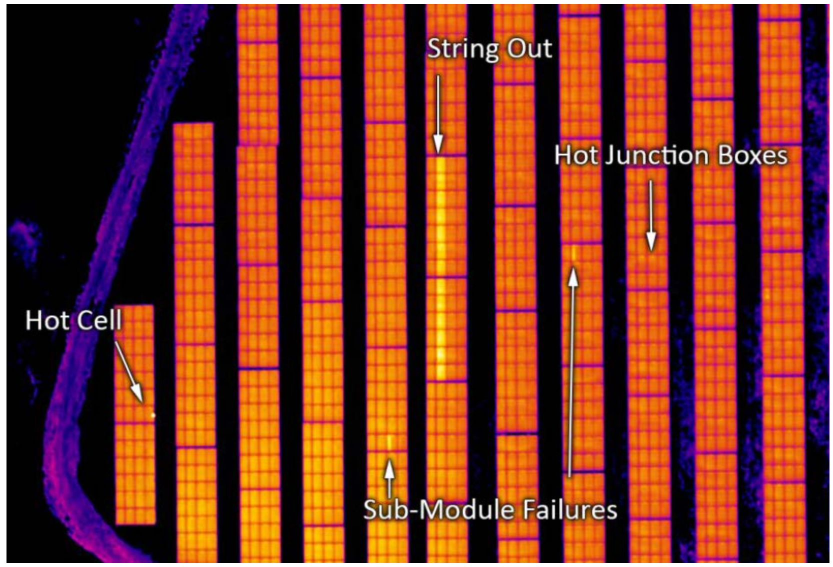
Qualifications and Responsibilities of O&M Providers

Personnel are critical to a PV O&M regime, and each type of service provider requires qualifications. The best-practices guide includes the service category, scope of work, typical salary, and qualifications for the full range of PV O&M personnel. The guide also covers important

Why Consider O&M Early in the Design Process?

With classroom grades, effective O&M can bring a PV system with a "D" grade up to a "C" or "B," but it is impossible to achieve an "A" unless O&M was considered during system design. Selection of reliable equipment is a big factor, as is proper site preparation and effective commissioning. Keep in mind, O&M might not be able to save a failing system if the problems are intrinsic to the design or products used.

Corrective maintenance to address failure in materials and workmanship, such as the failure of this module's encapsulant, are often covered by a product warranty—but it is important to comply with the preventative maintence requirements and conditions associated with such warranties when developing an O&M plan. *Photo by Andy Walker, NREL* details related to the financial solvency of O&M providers, worker health and safety, project insurance, and provision of backup O&M providers.



High-resolution, infrared aerial imaging can identify the location of failed strings, modules, and cells, reducing the cost and risks of manual circuit testing. *Image from Rob Andrews, Heliolytics Inc.*

System Monitoring

PV system monitoring helps operators create an "energy balance" that accounts for the amount of solar resource available, as well as the losses in each energy conversion process up to delivery at the point of interconnection. Monitoring is a powerful tool for understanding PV system performance, and it is fundamentally dependent on the quality of sensors and analytical models used. Best practices include optimizing use of on-site measurement of solar resources or satellite measurements. The approach to monitoring and associated cost depends on the revenue associated with the performance of the asset. In the best practices guide, three main areas of system monitoring are discussed: data presentation, quality of monitoring equipment, and transparency of measurement protocols and procedures.

O&M Supporting Systems and Implementation Strategies

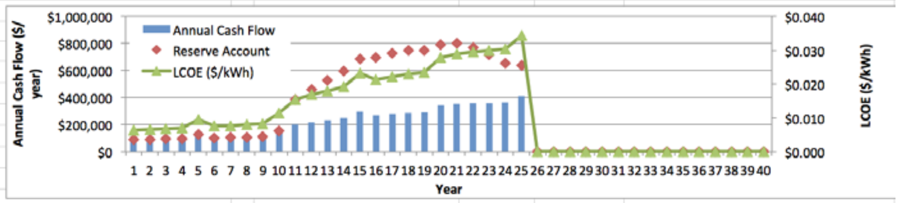
A section of the best-practices guide covers information technologies, O&M implementation strategies, and O&M contracts and performance guarantees.

- Information technologies: Considerations include the provision of secure, reliable storage and transmission of environmental and operations data, as well as software systems that enable rigorous management of O&M processes and costs. Data analytics have become powerful tools by reducing the cost and increasing the effectiveness of delivered O&M.
- Implementation strategies: O&M can be managed by the PV system's engineering, procurement, and construction company or installer, it can be performed in-house, or it can be outsourced to a specialized, third-party O&M provider. Often, a mix of these three strategies is chosen, depending on the age of the PV system, the provider's business model, system composition (e.g., commercial versus residential),

Key Recommendations for PV O&M

- Carefully plan and deliver PV O&M, rather than reacting on an as-needed basis.
- Track key performance indicators to enable continuous improvement, reduce O&M costs, and maximize performance.
- Establish a strategy to address unexpected expenses and reduce downtime due to failures—such as a line of credit, reserve account, or access to rapid-repair funds.
- Consider lifecycle issues during system design and equipment selection, such as ease of operations (including automation), preventive maintenance requirements, reliability and failure rates, and end-of-life issues like component recycling and hazardous material disposal.
- Take advantage of emerging technological developments such as software for data analytics, remote diagnostics, asset management, remote imaging, and module-level power electronics.

System Name	10 MW Ground Mount
Results	
Annualized O&M Costs ($/year)	$143,581
Annualized Unit O&M Costs ($/kW/year)	$14.36
Maximum Reserve Account	$800,840
Net Present Value O&M Costs (project life)	$2,043,656
Net Present Value (project life) per Wp	$0.204
NPV Annual O&M Cost per kWh	$0.013



Lifetime NPV by Service Type

Service	Avg. Cost/Yr	NPV (Life)	% of Total
Administrator	$43,424	$472,939	23%
Cleaner	$25,005	$272,345	13%
Inverter specialist	$71,551	$550,944	27%
Inspector	$26,850	$286,646	14%
Journeyman electrician	$17,358	$110,105	5%
PV module/array Specialist	$11,399	$86,393	4%
Network/IT	$186	$1,825	0%
Master electrician	$7,223	$53,383	3%
Mechanic	$1,706	$11,542	1%
Designer	$0	$0	0%
Pest control	$1,702	$18,536	1%
Roofing	$0	$0	0%
Structural engineer	$10	$69	0%
Mower/Trimmer	$16,424	$178,884	9%
Utilities locator	$6	$44	0%
Total	**$222,844**	**$2,043,656**	**100%**

Lifetime NPV by Component Type

Component	Avg. Cost/Yr	NPV (Life)	% of Total
AC wiring	$2,423	$22,299	1%
Asset Management	$40,082	$436,553	21%
Cleaning/Veg	$41,410	$451,019	22%
DC wiring	$15,265	$123,136	6%
Documents	$3,286	$35,784	2%
Electrical	$1,894	$20,351	1%
Inverter	$72,075	$555,708	27%
Mechanical	$5,607	$53,304	3%
Meter	$19	$205	0%
Monitoring	$72	$783	0%
PV Array	$12,517	$135,644	7%
PV module	$13,439	$72,798	4%
Roof	$0	$0	0%
Tracker	$7,960	$86,694	4%
Transformer	$6,795	$49,377	2%
(blank)	$0	$0	0%
Total	**$222,844**	**$2,043,656**	**100%**

The PV O&M cost model provides system- and condition-specific analysis for each year of the performance period. Shown are model results for a 10-megawatt ground-mounted PV system with tracking and central inverters, with pollen as an environmental condition. *Figure by Andy Walker, NREL*

fleet geographic density/distribution, and strengths of available in-house resources.

- Contracts and performance guarantees: Detailed contract terms are beyond the scope of the best practices guide, but the guide makes recommendations related to the relationship between O&M and contracted system performance guarantees.

PV O&M Cost Analysis

The best-practices guide also reports PV O&M cost estimates from various organizations, which are generally around 0.5% of system initial cost per year for large systems and 1% for small systems. The guide then recommends using the PV O&M Working Group's cost model to move beyond these generic estimates and perform detailed, customized analysis based on specific systems and conditions. Importantly, the model results reveal annual fluctuations in O&M cost based on scheduled intervals for preventive measures, failure distributions that increase with system age, warranty expiration, and inflation in the cost of materials and labor. Because of these factors, O&M costs can be much higher at the end of a performance period than at the beginning. Survey data on cost and backup services providers are being correlated with model test data to "calibrate" the cost model, which is currently available from NREL and SunSpec.org as an Excel spreadsheet. An online version by SunSpec Alliance is being used by beta-testers within the working group.

Download the Guide

NREL/Sandia/Sunspec Alliance SuNLaMP PV O&M Working Group. 2016. *Best Practices in Photovoltaic System Operations and Maintenance, 2nd Edition*. NREL/TP-7A40-67553. Golden, CO: National Renewable Energy Laboratory. *www.nrel.gov/docs/fy17osti/67553.pdf*.

Questions

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