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Addressing Solar Photovoltaic Operations and Maintenance Challenges: A Survey of Current Knowledge and Practices

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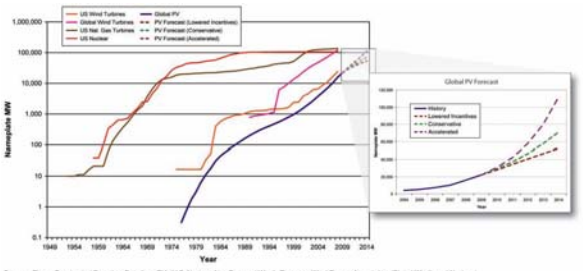
Abstract

Grid-connected solar PV systems are expected to proliferate over the coming decade and higher penetration levels will put a premium on achieving optimal performance and reliability. A few utilities and private companies have taken on the challenge and have advanced the state of the art of operating, maintaining and monitoring PV systems. This O&M experience is producing new industry knowledge, procedures and guidelines. Adoption by electric utilities and other PV system owners of current O&M practices and lessons learned distilled from experiences to date is expected to support and maintain planned increases in PV power.

Motivations for Greater Awareness of PV O&M

- Increasing PV into the utility portfolio
  - RPS compliance (16 "solar carve-outs")
  - Prospects of GHG emissions reduction legislation
  - Retiring fossil assets
- Growing utility PV asset ownership: Rate of return motivation: ~10 US utilities to invest >$3.7 billion and own/source ~1.2 GW



Cumulative Adoption Rates across Select Generation Technologies with Global PV Growth Forecast

PV O&M's Basic Elements and Strategies

Three major approaches exist in the marketplace today for handling PV O&M; each attempts to reduce costs while improving availability and increasing productivity.

- **Preventative maintenance:** Entails routine inspection and servicing of equipment to prevent breakdowns and unnecessary production losses.
- **Corrective or reactive maintenance:** Addresses equipment breakdowns after their occurrence; instituted to mitigate unplanned downtime.
- **Condition-based maintenance:** Uses real-time data to prioritize and optimize maintenance and resources.

O&M Costs

- Highly contextual: Budgeting an inherent compromise between the costs & benefits of maintaining asset availability and performance
- O&M is typically 1%-5% of system lifetime costs

System Size	$/kW	% of O&M Relative to "All In" Cost
1 MW and Less	$6/kW - $27/kW	<1% to 5%

Notes:
Figures represent a range of anecdotal data and comprise costs for handling O&M of distributed PV assets via utility in-house and outsourced approaches. Data largely indicates direct O&M costs and doesn't include variables such as roof leases and utility management oversight of labor.

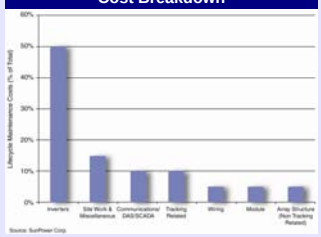
O&M Costs ($/kW-yr)	Fixed-Tilt c-Si	Fixed-Tilt CdTe	Fixed-Tilt a-Si	Tilted Single-Axis Tracking c-Si	Single-Axis Tracking c-Si
Scheduled Maintenance/Cleaning	$20	$25	$25	$30	$30
Unscheduled Maintenance	$2	$2	$2	$5	$5
Inverter Replacement Reserve	$10	$10	$10	$10	$10
Subtotal O&M	$32	$37	$37	$45	$45
Insurance, Property Taxes, Owner's Costs	$15	$15	$15	$15	$15
Total O&M	$47	$52	$52	$60	$60

Notes:
Fixed-Tilt c-Si defined as polycrystalline modules mounted at a fixed 30 degree tilt facing south. Fixed-Tilt CdTe defined as cadmium telluride modules mounted at a fixed 30 degree tilt facing south. Fixed-Tilt a-Si defined as amorphous silicon modules mounted at a fixed 30 degree tilt facing south. Tilted Axis Tracking c-Si defined as monocrystalline modules on a north-south axis tracker tilted south at 30 degrees with backtracking. Single Axis Tracking c-Si defined as monocrystalline modules on a north-south axis tracker with backtracking.

Isolating PV Plant Trouble Spots

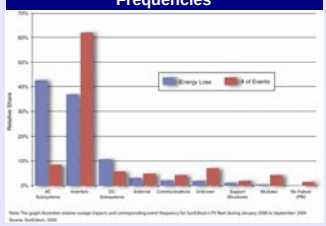
Though inverters are the main culprit for unplanned PV plant downtime, specific site and PV portfolio maintenance costs are impacted by the cost-benefit calculus of addressing, delaying, or ignoring outage and/or production-reducing events. Often, the make-up of events—their severity, frequency, and average O&M cost to repair—can determine an asset's relative value.

Solar PV Power Plant Maintenance Cost Breakdown

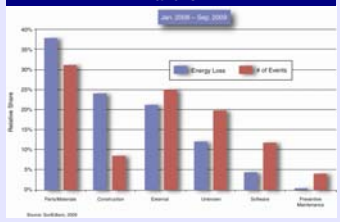


80/20 Rule: 80% Unrealized Production Due to 20% Total Outage Events

PV System Failure Areas and Relative Frequencies

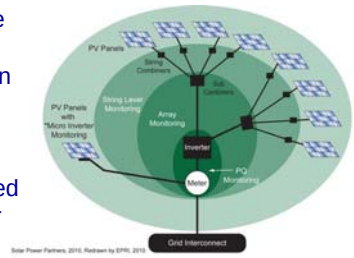


Root Causes of PV System Component Failure



Monitoring: Multiple Options for Information Collection

PV system monitoring capabilities have significantly advanced over the last decade and can now offer insights at an increasingly granular level. These application advances offer potentially huge benefits, especially given that the vast majority of PV plants are unmanned and remotely supervised. But like other aspects of O&M, choosing the appropriate monitoring level is system- and equipment-specific.



Pros & Cons of In-House vs. Outsourcing PV O&M

Utility In-House O&M	Turnkey/Third-Party O&M
Pros	
Better Visibility on Personnel/ Equipment Issues	Lower Upfront Costs, Greater Flexibility
Improved Quality Control	Lower Upfront Risk
Ability to Leverage Existing Utility Assets	Less Drain on Utility Labor Force
Workforce Training	Transitional O&M Option (3rd Party Trains and Hands O&M Responsibility to Utility in Negotiated Timeframe)
Institutionalization of PV O&M Process	
Cons	
Higher Upfront Costs (Adding Payroll can Bring Long Term Financial Concerns)	Less Control/Understanding of O&M Process
Increased Risk	Potential for Higher Back-End Costs (Based upon Equipment Selection and Level of Service)
Work Force Knowledge/Resource Ramp Up	Dependence on Outsourced Contractors

In-House vs. Outsource PV O&M

Each approach has varying levels of risk exposure, labor, upfront / backend costs, quality control, and knowledge capital. Most utilities embrace the outsource option, which typically runs 5-10 years, a few are venturing toward ownership, and others are taking a hybrid approach—the transitional O&M option.

Acknowledgements

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