Utility/Lab Workshop on PV Technology and Systems

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PV O&M Best Practices

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EPRI Survey-Driven White Paper on PV O&M Best Practices

Survey Sample and Respondent Profile:

Utilities
- Arizona Public Service (APS)
- Austin Energy
- Detroit Edison
- Salt River Project (SRP)
- San Diego Gas & Electric (SDG&E)
- Southern California Edison (SCE)

Non-Utility Companies
- Draker Laboratories
- Florida Solar Energy Center
- Fat Spaniel Technologies
- Solar Power Partners
- Sun Edison
- SunPower Corp.
Cumulative Adoption Rates across Select Generation Technologies with Global PV Growth Forecast

The relevance of PV O&M is growing!
## Select Utility Solar PV Ownership Initiatives

<table>
<thead>
<tr>
<th>Utility</th>
<th>Investment ($M)</th>
<th>Initial Application Filing</th>
<th>Proposed Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona Public Service</td>
<td>$14.7</td>
<td>5/11/2009</td>
<td>1 MW utility-owned PV installed on residential/commercial customer rooftops; 0.5 MW stand-alone on utility-owned or leased property.</td>
</tr>
<tr>
<td>Duke</td>
<td>$50.0</td>
<td>6/6/2008</td>
<td>8 MW utility-owned roof-mounted PV (reduced from originally requested 16 MW).</td>
</tr>
<tr>
<td>Los Angeles Dept. of Water &amp; Power*</td>
<td>$1350.0</td>
<td>3/19/2009</td>
<td>400 MW of utility-owned PV to be installed on city-owned rooftops, reservoirs, and parking lots by 2014; Program status unclear.</td>
</tr>
<tr>
<td>National Grid</td>
<td>$31.1</td>
<td>4/23/2009</td>
<td>5 MW of PV to be installed on five company-owned, mostly brownfield sites in Massachusetts.</td>
</tr>
<tr>
<td>Northeast Utilities</td>
<td>$42.0</td>
<td>2/12/2009</td>
<td>6 MW to be installed on utility/customer property from 2009-12; targeting landfill, brownfield, commercial &amp; government buildings.</td>
</tr>
<tr>
<td>Pacific Gas &amp; Electric</td>
<td>$1,450.0</td>
<td>2/24/2009</td>
<td>250 MW utility-owned PV, plus 250 MW 3rd party-owned PV to be developed over five years starting in 2010.</td>
</tr>
<tr>
<td>Public Service Electric &amp; Gas</td>
<td>$773.0</td>
<td>2/10/2009</td>
<td>120 MW utility-owned PV to be deployed on utility poles/street lights, public schools, municipal and county-owned buildings, utility facilities/land.</td>
</tr>
<tr>
<td>San Diego Gas &amp; Electric</td>
<td>$250.0</td>
<td>7/11/2008</td>
<td>50 MW utility-owned tracking and thin-film PV, 27 MW 3rd party-owned to be installed in five years.</td>
</tr>
<tr>
<td>Southern California Edison</td>
<td>$875.0</td>
<td>3/27/2008</td>
<td>250 MW utility-owned ground- and rooftop-mounted PV to be installed in five years starting in 2008, plus 250 MW 3rd party-owned PV developed.</td>
</tr>
</tbody>
</table>

**Totals** | **$4,835.8** | | ~1.1 GW of utility-owned PV to be installed ~527 MW of 3rd party-owned PV to be installed for utility PV programs |

**Notes:**
*Estimated range in LADWP program cost is $1.1 to $1.6 billion without tax benefits; Program proposed as Measure B amendment on the municipal ballot was defeated 50.5% to 49.5% on 3/19/2009; Program status unclear.
## Major Elements of PV O&M

### Preventative Maintenance (PM)
- Panel cleaning (~1-2x/year or as needed)
- Vegetation management (~1-3x/year)
- Wildlife prevention (variable)
- Water drainage (variable)
- Retro-commissioning (1x/year)
- Upkeep of data acquisition and monitoring systems (e.g., electronics, sensors) (frequency: undetermined)
- Upkeep of power generation system (e.g., inverter servicing, BOS inspection, tracker maintenance (~1-2x/year)

PM’s value measured in system efficiency and system/component lifespan.

### Corrective maintenance
- On-site monitoring/mitigation
- Critical reactive repair
  - Address production losses
- Non-critical reactive repair
  - Address production degradation
- Warranty enforcement (as needed)

### Condition-based maintenance
- Active monitoring—remote and on-site options
- Warranty enforcement (planned)
- Equipment replacement (planned)
Major variables influencing extent and cost of PV O&M

- Site characteristics and environment
  - Systems size, type (e.g., roof mount, ground mount, tracker) and location
  - Number of distinct arrays, meters, inverters and ease of access
  - Availability of water
- Scope of O&M service and scale economies
- Desired level of monitoring capability
- Warranty terms and extent of equipment standardization
- On-site vs. off-site management
  - Can affect labor costs by 2-3x

Caption: FPL’s 10 MW Cape Kennedy PV Plant

European O&M costs 50-100% higher than US, given greater embrace and scope of O&M activities
Utility-Scale PV Power Plant O&M Cost Estimates: Typically ~1-2% of System Lifetime

### 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.

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### O&M Costs ($/kW-yr)

<table>
<thead>
<tr>
<th></th>
<th>Fixed-Tilt c-Si</th>
<th>Fixed-Tilt CdTe</th>
<th>Fixed-Tilt a-Si</th>
<th>Tilted Single-Axis Tracking c-Si</th>
<th>Single-Axis Tracking c-Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduled Maintenance/Cleaning</td>
<td>$20</td>
<td>$25</td>
<td>$25</td>
<td>$30</td>
<td>$30</td>
</tr>
<tr>
<td>Unscheduled Maintenance</td>
<td>$2</td>
<td>$2</td>
<td>$2</td>
<td>$5</td>
<td>$5</td>
</tr>
<tr>
<td>Inverter Replacement Reserve</td>
<td>$10</td>
<td>$10</td>
<td>$10</td>
<td>$10</td>
<td>$10</td>
</tr>
<tr>
<td>Subtotal O&amp;M</td>
<td>$32</td>
<td>$37</td>
<td>$37</td>
<td>$45</td>
<td>$45</td>
</tr>
<tr>
<td>Insurance, Property Taxes, Owner’s Costs</td>
<td>$15</td>
<td>$15</td>
<td>$15</td>
<td>$15</td>
<td>$15</td>
</tr>
<tr>
<td>Total O&amp;M</td>
<td>$47</td>
<td>$52</td>
<td>$52</td>
<td>$60</td>
<td>$60</td>
</tr>
</tbody>
</table>

**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 20 degrees with backtracking. Single Axis Tracking c-Si defined as monocrystalline modules on a north-south axis tracker with backtracking.
Solar PV Power Plant Maintenance Cost Breakdown

Source: SunPower Corp.
The 80/20 Rule: 80% of Unrealized Production Due to 20% of Total Outage Events

Source: SunEdison
PV System Failure Areas and Relative Frequencies

Note: The graph illustrates relative outage impacts and corresponding event frequency for SunEdison’s PV fleet during January 2008 to September 2009.
Source: SunEdison, 2009
Root Causes of PV System Component Failure


Relative Share

Energy Loss

# of Events

Parts/Materials
Construction
External
Unknown
Software
Preventive Maintenance

Source: SunEdison, 2009
PV Monitoring Options Across the System

## In-Housing Versus Outsourcing PV O&M

<table>
<thead>
<tr>
<th>Utility In-Housing</th>
<th>Turnkey/Third-Party Outsourcing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
<td><strong>Pros</strong></td>
</tr>
<tr>
<td>• Better visibility on personnel/equipment issues</td>
<td>• Lower upfront costs and upfront risk</td>
</tr>
<tr>
<td>– Improved quality control</td>
<td>• Less drain on utility labor force</td>
</tr>
<tr>
<td>• Ability to leverage existing utility assets</td>
<td>• Transitional O&amp;M option</td>
</tr>
<tr>
<td>• Workforce training</td>
<td>– 3rd party trains and hands O&amp;M</td>
</tr>
<tr>
<td>• Institutionalization of PV O&amp;M process</td>
<td>responsibility to utility in negotiated</td>
</tr>
<tr>
<td></td>
<td>timeframe</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
<td><strong>Cons</strong></td>
</tr>
<tr>
<td>• Upfront costs</td>
<td>• Less control/understanding of O&amp;M</td>
</tr>
<tr>
<td>• Work force knowledge/resource ramp up</td>
<td>• Potential for higher back-end costs</td>
</tr>
<tr>
<td>– Utility perspective: Adding payroll = long term financial concerns</td>
<td>– Based upon equipment selection</td>
</tr>
<tr>
<td>• Increased risk</td>
<td>• Dependence on outsourced contractors</td>
</tr>
</tbody>
</table>

No consensus on cost-benefit of in-house vs. outsource options, but tradeoffs apparent.
Warranty Coverage: An Essential O&M Ingredient

- System warranties clearly outline responsibility for system repairs, between plant owner, plant manager/EPC, and integrator, including:
  - Repair response requirements – “critical” vs. “non-critical”
  - System performance thresholds

- Primary warranty scenarios (from the utility perspective):
  - **PPA**: Warranty terms embedded in the PPA and are the integrator’s responsibility for the duration of plant lifetime
  - **Ownership (outsource)**: Utility contracts out to EPC/turnkey provider who handles warranty enforcement (pass through) for negotiated time period
  - **Ownership (in-house)**: Utility responsible for warranty enforcement

Warranties are only as good as the companies that honor them!
Current workforce skill level mismatched w/reqts of successful PV asset O&M. 

- Significant training of utility and third-party personnel is necessary to improve the labor pool while insuring its safety.

**Third Party Services Providers**
- At minimum, federal OSHA rules followed any time personnel are in the field
- Industrial safety courses and formal training and qualification offered
  - How to handle fault and voltage protection
  - Working rules around skylights and angled roofs
  - Adherence to stringent fire codes

**Utilities**
- SCE developing in-house O&M standards
  - Staff perform annual retro commissioning
- Austin Energy maintains/distributes list of qualified contractors that are NABCEP certified
- Utilities and municipalities host annual or semi-annual workshops
  - John Wiles of NMSU and Bill Brooks of Brooks Engineering offer classes on new product developments and associated handling
Lessons Learned & Best Practices

30 best practices/lessons learned gathered from EPRI interview sample along 3 broad categories:
1) Preventative Maintenance; 2) Monitoring; 3) Warranty

- **Focus on design, engineering and the initial build of the PV plant.**
- **Institute continuous commissioning and continuous stress testing**
- **Two overriding factors driving O&M decision-making are system size and site distance from personnel.**
- **Identify core factors that determine the economic tradeoffs of monitoring resolution.**
- **Consider creating boilerplate contracts to clearly articulate the insurance requirements to O&M third parties**
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Albuquerque, New Mexico, USA
Together…Shaping the Future of Electricity