PV Life Cycle Analysis
Managing PV Assets over an Uncertain Lifetime

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Agenda

- Background
  - Industry needs
  - Overview of EPRI project

- Research Findings
  - PV site surveys
  - Repowering and decommissioning guidance

- Conclusions and Next Steps
Background

Industry Needs

The Issue

- PV project lifetimes are not well-understood
- Factors that influence lifetimes have not been quantified
- Underperforming assets can be a burden to project owners
- Options and steps to restore power or decommission systems need to be defined
Background  
Overview of EPRI Project

The project provides guidance to PV system owners around assessing plant health—performance and safety issues—and determining best options for repowering and decommissioning.

Scope

1. Develop detailed methodology for PV site condition surveys
2. Conduct surveys of 30 PV systems
3. Develop processes for a) re-powering PV systems and b) decommissioning PV systems
4. Develop generic economic model to allow plant owners to compare repowering options
5. Research options for recycling and disposing of modules and other plant components

Results were packaged into a PV Life Cycle Analysis Manual, which provides guidance for owners and operators of PV systems.

EPRI Supplemental Project Stats:
- Schedule: 2013-2017
- $660k study funded by 6 utilities
- EPRI Report (3002008832) to be published late-Sept. 2016
Research Findings
PV Site Surveys
Background
Site Survey Methodology

- Visual Inspection
- Measurements
  - I-V curves
  - Bypass diode check
  - Infrared scanning
  - Power quality analysis
  - Shading analysis
## Research Findings
### Examples of Safety Failures

<table>
<thead>
<tr>
<th>Broken Module</th>
<th>Backsheet Delamination</th>
<th>Damaged Rack</th>
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<tbody>
<tr>
<td><img src="image1" alt="Broken Module" /></td>
<td><img src="image2" alt="Backsheet Delamination" /></td>
<td><img src="image3" alt="Damaged Rack" /></td>
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<table>
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<tr>
<th>Missing Lid</th>
<th>Backsheet Burns</th>
<th>Backsheet Cuts</th>
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<tbody>
<tr>
<td><img src="image4" alt="Missing Lid" /></td>
<td><img src="image5" alt="Backsheet Burns" /></td>
<td><img src="image6" alt="Backsheet Cuts" /></td>
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<table>
<thead>
<tr>
<th>Edge Delamination</th>
<th>Burnt Wire</th>
<th>Animal Bites</th>
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<tr>
<td><img src="image7" alt="Edge Delamination" /></td>
<td><img src="image8" alt="Burnt Wire" /></td>
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Research Findings

Example Site Survey Results: SolarTAC
Negative degradation rates, or performance gains, may be due to manufacturer underrating of modules, whereas positive values may indicate underrating.
Research Findings
Example Site Survey Results: SolarTAC Poly c-Si 1 System

System
- Size: 9.4 kWdc
- Modules: 33 (3 strings)
- Tilt: Latitude (20°)
- Installation: November 2010
- Status: Operational

Inverter
- Size: 10 kWac
- Quantity: 1
- Status: Operational

Example Results
One safety failure: failed diode
Average String Degradation: 0.31%/yr
Average Module Degradation: 0.03%/yr
Safety failure rate at the plant level = 162/2352 = 7%

- Hotspot issues leading to backsheet burn (37/2352)
- Ribbon-ribbon solder bond failure with backsheat burn (86/2352)
- Failed diode with no backsheet burn (26/2352)
- Hotspot issues with backsheat burn + Ribbon-ribbon solder bond with backsheet burn (1/2352)
- Backsheet Delamination (10/2352)
- Backsheet Delamination + Ribbon-ribbon solder bond failure (2/2352)
Research Findings

Summary of Module Distribution (all sites)

Degradation generally seems higher in the hotter climates (AZ and TX). Cool climates (NY) tend to have lower degradation, and CO systems fall in between.
Research Findings
Repowering and Decommissioning
Steps for PV System Owners and Utilities

1. Conduct site survey

2. Identify issues to be fixed
   - Safety
   - Performance
   - May include non-PV assets like roof repairs, infrastructure upgrades

3. Develop scope of work (perhaps for multiple options)
   - May include re-design
   - Can be reduced to time & materials (or sub-contracts)
   - Meet latest code for safety and performance
     - Authority Having Jurisdiction (AHJ) dependent
     - Grandfathering may apply
     - PV specific code changes: 2014 NEC for PV

4. Perform cost-benefit analysis
Repowering Guidance
2014 NEC Code With Legacy PV Plants

- The 2011 and 2014 NEC code cycles made significant changes to Article 690
  - Improved safety
  - Improved performance
- Allow ungrounded DC systems
- Require use of PV Wire not USE-2 for ungrounded systems
- Improved ground fault detection
- Require arc fault detection
- Rapid disconnects required for rooftop systems

The above changes significantly affect repowering legacy PV plants
For some legacy systems, to replace the inverter means:

- Switch to a transformerless inverter due to limited availability of isolated inverters and lack of manufacturer support/warranties
  - Unground the PV system, as required by the transformerless inverter
  - Replace all modules with products that have PV wire
  - Replace home runs and combined wires (no white wire)
- Restring to 1000 V to match inverter specifications
  - Replace combiner boxes to support positive and negative fusing
  - Replace disconnects to support positive and negative disconnecting means
- Relabel entire system

Replacing the inverter may cost almost as much as a new installation.
PV Plant Decommissioning

- Reasons for decommissioning include:
  - End of project life
  - Economic viability
  - Safety

- Decommissioning plans include steps to restore sites to their intended use:
  - Land and water use restoration
  - Salvage, recycling, and disposal of plant equipment
  - “Safe” disposal of all materials (although plans often don’t specify what to do or how to do it)
Decommissioning PV Plants
Balance of System

- Equipment removal, disposal, and recycling
  - Inverters and other electronic components – e-waste recycling
  - Module mounting structures – steel recycle, resale
  - Concrete – recycle
  - Electrical equipment – reuse or recycle
  - Wiring – copper recycling

- Equipment abandon in place
  - Underground conduit
  - Certain structures

- Equipment reuse
  - Infrastructure improvements – roads, fences, etc.
  - Substations, communication towers
  - Maintenance buildings
Decommissioning PV Plants

Modules

Recycling

- No federal, state, or local regulations require PV module recycling in the U.S.
- No 3rd party or public module recycling programs in the U.S., with the exception of limited manufacturer take-back programs
- Recycling technologies exist to extract/reuse ~80% of module material

Disposal

- PV modules are not classified as hazardous waste, but they contain hazardous materials
- Disposal options in U.S.
  - Modules that fail the Toxicity Characteristic Leaching Procedure (TCLP) must be disposed of in hazardous waste landfills
  - Long-term storage in storage containers may be best option until recycling becomes available

Module waste volumes are 0.1-0.6% of total e-waste today, but by 2050 panel waste may surge to over 10% of 2014 global e-waste levels*

*Source: IEA-PVPS Report: T12-06:2016 (June 2016)
Conclusions

- Interest in PV plant repowering and decommissioning is growing as PV plants age and experience performance and safety issues
- Module disposal is potentially a major issue
  - Some modules contain hazardous waste, but limited data available to verify which modules fail the Toxicity Characteristic Leaching Procedure (TCLP)
  - Some deployment estimates show that PV waste could equal 10% of today’s e-waste by 2050
  - Disposal in regular landfills not recommended in case modules break and toxic materials leach into the soil
- Regulatory environment
  - Europe regulates panel recycling, and Japan and Korea are establishing recycling programs
  - Currently no regulatory framework in U.S. and no public PV recycling facilities
Next Steps

Planned Work

- Deeper dive study on PV recycling feasibility in the U.S.
  - Regulatory environment
  - Feasibility of developing a comprehensive collection system
  - State of the art in PV recycling technology
  - Limited TCLP testing to determine module toxicity in landfill environment

Proposed Projects

- Comprehensive test and evaluation program to assess various factors that may influence TCLP outcomes
- Technical and cost considerations for the decommissioning and disposal of PV plants

More data is needed to clarify the extent to which module toxicity is a pervasive issue.
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Questions for potential discussion

- Who budgets for PV end-of-life costs?
  - Method and considerations in your cost calculation?
  - Is PV salvage value positive or negative? Anecdotal data?

- Has anyone repowered or decommissioned a plant?
  - Challenges and/or key questions during the process?
  - Chosen method of module and/or balance of plant disposal?
  - Compatibility of new vs. old equipment?

- Hazardous waste associated with PV plant disposal?
  - Aware of Toxicity Characteristic Leaching Procedure?
  - Usefulness to include on module or BOS spec sheet?

- Do you think the U.S. needs to regulate PV recycling?
  - What are the biggest challenges, e.g., economics / value of materials, collection?
  - Percentage of project developers opting to include recycling in the upfront purchase contract?