The Impact of PV Module Reliability on Plant Lifetimes Exceeding 25 Years

2013 PV Module Reliability Workshop

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NATIONAL SECURITY • ENERGY & ENVIRONMENT • HEALTH • CYBERSECURITY

Overview of Presentation

- Impact of potential induced degradation (PID)
- Correlation between early-life LTD rates and end-of-life failure rates

- Strategies for extending the life older plants
  - Diagnostics for detecting failed modules
  - Strategies for re-paneling PV plants
  - Performance and safety of re-paneled plants
  - Balance of system (BOS) equipment
  - Changes in O&M costs

Introduction to SAIC

- Since the 1980s we have worked with clients around the world to evaluate the viability of energy development
- We have advised clients on more than 1,000 power, infrastructure, and industrial projects in roughly 75 countries and territories
- Expertise in all conventional and renewable power technologies, including solar, hydro, wind, geothermal, and biofuels
- SAIC was ranked as the top independent engineering firm for renewable energy by the trade magazine *Infrastructure Journal*
- Our energy-focused consulting practice is backed by the full strength of SAIC – a diversified, 41,000-employee, Fortune 500 company

Role of the Independent Engineer (IE) in Project Finance

- Evaluate technical risks and mitigants
  - Pure technical risks (e.g., module performance and reliability)
  - Commercial risks from technical contracts (e.g., EPC, O&M)
- Review or develop projected operating results (performance, cost, etc.)
- Liaison between the sponsor and lenders/investors
  - A successful IE will be viewed by all parties as a trusted advisor, striking the right balance between the interests of all parties and showing how those interests are aligned %

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The IE's Interest in PV Module Reliability

- Fundamental questions all financial institutions are asking, directly or indirectly:
  - How much revenue will the project generate, and how much could that change year-to-year
    - Energy production and degradation, resource variability, uncertainty
  - How much will the project cost to operate
    - O&M costs including repair or <u>replacement of major equipment</u>
- Inverters can be repaired, modules can only be replaced
  - How many modules will need to be replaced and when? Why do we think so?
  - What if we can't find compatible modules?
    - Reshuffling of strings/blocks etc.

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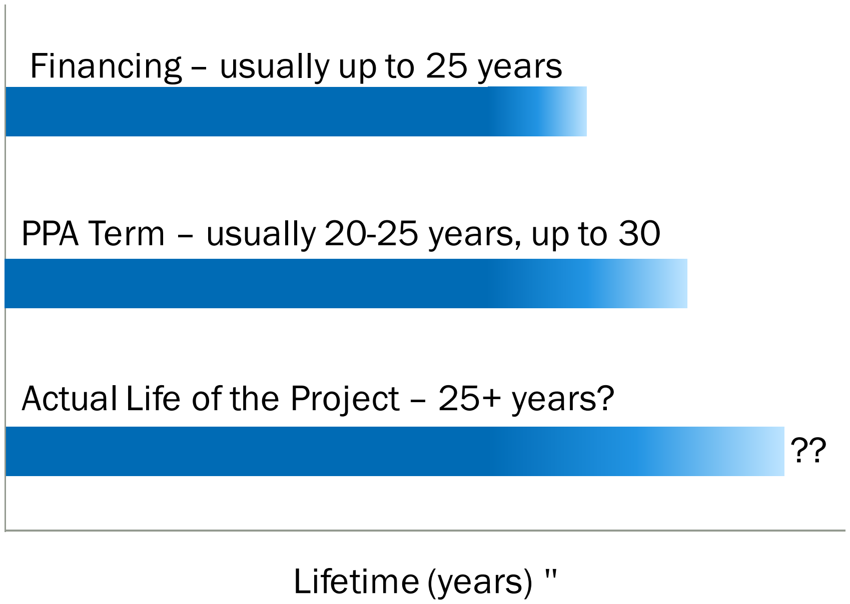
Push for > 25 year project "useful life"

- Several drivers
  - 25+ year term financing is rare, but not unheard of
  - Sale leaseback financing even for 25 years requires a "useful life" of > 25 years for IRS purposes
  - <u>Revenues from out years drive equity returns</u>
- What do we know?
  - PV modules won't spontaneously combust on Day 1 of Year 26
  - Project could/should have useful life beyond the warranty period, but modules <u>will</u> eventually start to fail at an increasing rate
- How do we consider this from the perspective of an investor?



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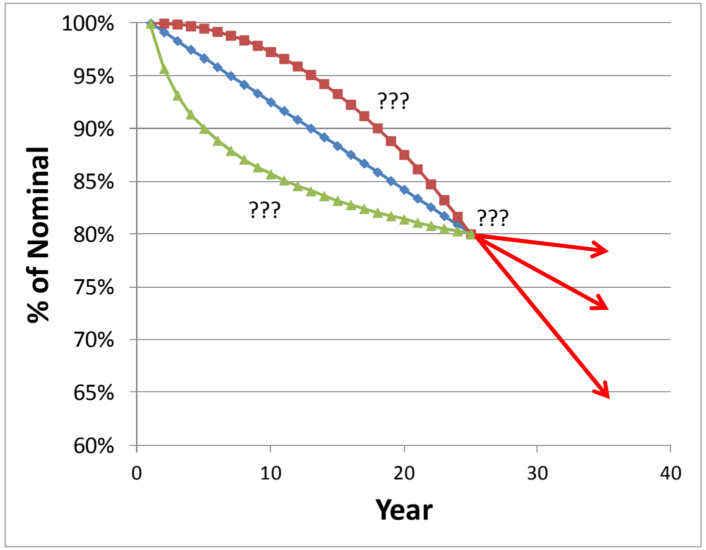
PV Module Life and Long-Term Degradation: Summary of Current Knowledge and Issues

How long will PV modules operate reliably?
What constitutes “failure”?

Useful Life of Modern PV Modules

- Useful life of 25 years supported by accelerated life tests (ALT) of modules, materials tests and field survival of pre-1990 modules
- Little consensus on life beyond 25 years
- Limited field data on multi-decade degradation rates
  – Do degradation rates continue linearly, level off or accelerate?



- What causes end-of-life?
  - Early life failures largely due to poor manufacturing; may not relate to end-of-life failure mechanisms
  - Do old modules just fade away, or do sudden failure mechanisms dominate?
  - Can we identify potential end-of-life failure mechanisms that are simply due to age?
    - Package breakdown, followed by corrosion

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Multi-Decade Rates of Long Term Degradation

are inconclusive on key issues:

- Rate of LTD (% per year)
- Linearity of LTD rates over time
  - Do LTD rates accelerate or do modules stabilize?
- Influence of climate on LTD rates
- Applicability of data from old modules to current production

Impact of potential induced degradation (PID)

- Reversible PID
  - Certain PID effects can be reversed if the % proper mitigation is implemented %
  - No impact to LTD?
- Non-reversible PID
  - Na+ diffusion from glass to cell
  - Contribution to LTD?

Courtesy of Department of Energy / National Renewable Energy Laboratory

Courtesy of DOE/NREL

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Strategies for Extending the Life of Older PV Plants

What Options Will be Available to Plant Owners %
for Extending Plant Life Well Beyond 25 Years? %

What Defines a “Failed” PV Module?

In this context, module failure is defined in <u>business</u> terms, not purely <u>technical</u> terms

foundations and racking)

- That leaves PV modules as the *de facto* component that limits useful life
- “Failed” modules then are those <u>that produce so little power that it is uneconomical to continue to operate the plant</u>, if all modules performed equally poorly
  - Whether this occurs through a catastrophic component or material failure or ongoing long-term degradation (LTD) is not essential

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Safety Concerns as a Failure Mode

- Can safety issues cause a plant to be uneconomical to continue operation, even though power production is unaffected?
- Potentially yes. For example:
  - O&M costs may increase due to an increase in the hazard level workers are exposed to %
  - Insurance costs may increase, or insurance may be refused
  - Payments related to injured workers
- Are there any scenarios where hazard could increase simply due to module aging?
  - Back sheet deterioration, breaking down voltage isolation
  - Failure of junction box means of attachment, exposing live conductors
  - Breakdown of insulation on module pigtails
- Safety concerns will likely increase with higher DC voltages becoming more common

Safety concerns can cause or contribute to ongoing operations becoming uneconomical

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Diagnostics for Detecting Failed Modules

- Low cost, effective diagnostics will be required
- Options: spot tests or mining operating data
  - Mining operating data likely lowest cost, but also likely requires "smart" combiners (or module-level data from optimizers or micro-inverters)
  - Alternative may be spot measurements of current, voltage or full IV-trace inside combiner boxes
  - Test for activated bypass diodes? IR imaging?
  - Plant-wide IR imaging of modules (fly over)
  - Other tests?

Courtesy of tenKsolar, Inc.

If re-paneling, detailed measurements are possible, once modules are removed.

Expected Performance of Older Arrays

- Examples in table show 5 cases; all have 20% power loss from "as new"
- All will produce same AC power
  - Inverter voltage thresholds may cause some differentiation
- On DC side LTD is primarily a loss of current; failure is primarily a loss of voltage
  - Therefore relatively easy to distinguish Case A from Case E
  - Less certainty in distinguishing among Cases B, C & D
- The real world is more complex than this example

Example cases of 20% power loss in a string of 20 modules

Header	Degradation	Failed Modules
Case A	20%	0
Case B	15%	1
Case C	10%	2
Case D	5%	3
Case E	0%	4

True ability to distinguish more readily comes from historical performance data. Each of these five cases could be readily differentiated from historical data trends.

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Potential Re-Paneling Strategies

Components Replaced	By Strings or Tables	By Inverters	New DC Field
PV modules	●	●	●
Module fasteners	○	●	●
String wiring	○	●	●
Combiner boxes	○	○	●
Racking		○	●
Foundations		○	●
Inverters		○	○
Underground cabling			○
	• Lowest cost • Requires similar modules • Large mismatch errors	• No mismatch • Permits updated electrical • Increased safety	• Required if foundation integrity suspect • Use of adjacent land?

● Replace ○ Optional

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Performance of Re-Paneled Plants

- Structural review of foundations and racking likely required before long-term re-use permissible

Courtesy of Department of Energy / National Renewable Energy Laboratory

Courtesy of DOE/NREL

O&M Costs

- How much will they rise, and when?
  - As IE we look for bottoms-up analysis, some thought behind what O&M expenses will increase and when/why
  - Lenders/investors will look for a robust project that can withstand some uncertainty around future O&M costs
- Is it worth it?
  - Post-PPA revenues are uncertain at best even if module performance/reliability is known
  - Difficult question for project developers/owners to answer

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Re-Paneling Conclusion

- We conclude that re-paneling will often include replacement of all above ground equipment in the DC field, with the possible exception of the foundations, because:
  - Modules may not be mechanically or electrically compatible, after two-plus decades of innovation
  - Old racking and fasteners may lack the integrity to last another 25+ years
  - Safety concerns may mandate the replacement of all wiring exposed to the weather
  - Concerns of lessened performance if only partial array replacement undertaken
- However, renewal may take place over 2 – 5 years, to spread costs and maintain revenue
  - Owners of larger portfolios may be able to plan staged renewals funded from operations, avoiding the need for capital investment
- Possible exceptions
  - Plant shutdown expected within a few years
    - Unable to extend property lease, unable to negotiate post-PPA power agreement, etc.
  - Future plants have more robust structural design when new, with all components except modules (and string wiring) designed for 50+ year useful life

Developers should <u>consider</u> designing foundations for very long life

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Areas for Further Discussion and Research

1. %What will the LTD rate of crystalline modules be in years 25 – 40?
2. %What mechanisms can cause sudden end-of-life?
   – Can we quantify seriousness via HALT?
3. %Do differences in the ability of new modules to withstand extended HALT provide a reliable indication of differences in useful life, or merely differences in early life failure rates?
4. Will safety concerns (e.g. environmental breakdown of dielectrics) play a bigger factor than degraded performance in decisions to continue operating older PV plants? %
5. %If cumulative heat exposure is a major contributor to LTD and/or sudden failures, will module useful life be:
   – Longest in locations with moderate insolation?
   – Somewhat shorter in locations with high insolation?
   – Shorter still in tracking systems?

Thank You

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