PV EVOLUTION LABS
ADVANCING SOLAR

Increasing Investor Confidence in PV Power Plants through Latent Defect Screening (LDS)

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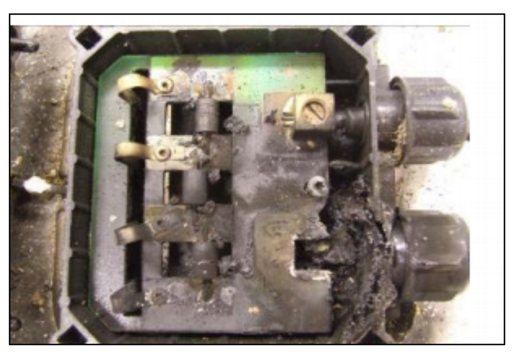
OVERVIEW

Solar power plant investors expect photovoltaic (PV) modules to safely and efficiently produce electricity for 25 years. International certification standards such as IEC are designed to evaluate new module designs for material and design flaws that contribute to product safety or performance issues. This initial certification testing is performed on ~10 panels and does not insure against defects caused by deviations in the manufacturing process. These defects affect between 0.1 and 10% of all installed panels and lead to increased performance degradation. Moreover, these defects are known as latent in that they typically manifest several years after installation. There is currently no certification analogous to IEC that insures against these latent defects. Knowledge of the exact quality of the PV panels installed at a given power plant provides opportunity for improved output predictability and investor confidence. In this poster we introduce the concept of latent defect screening (LDS) for PV modules. LDS involves the random sampling and accelerated life-testing of the PV panels to be used at the construction site. We find that for an additional testing cost of 1 penny per watt, we can be 85% sure that there are fewer than 2% defects at a 20 MW installation.

Latent Defects in the Field

A latent defect in a panel is unobservable at the factory gate but manifests in the field before the expiration of the warranty. These defects can cause a reduction in the power conversion efficiency beyond the manufacturer's spec, or can lead to a safety issues such as electric shocks or electrical fires.



There are many ways in which a panel can cease to function properly. Examples include solder-joint and junction-box degradation.

Latent defects lead to lost revenue:

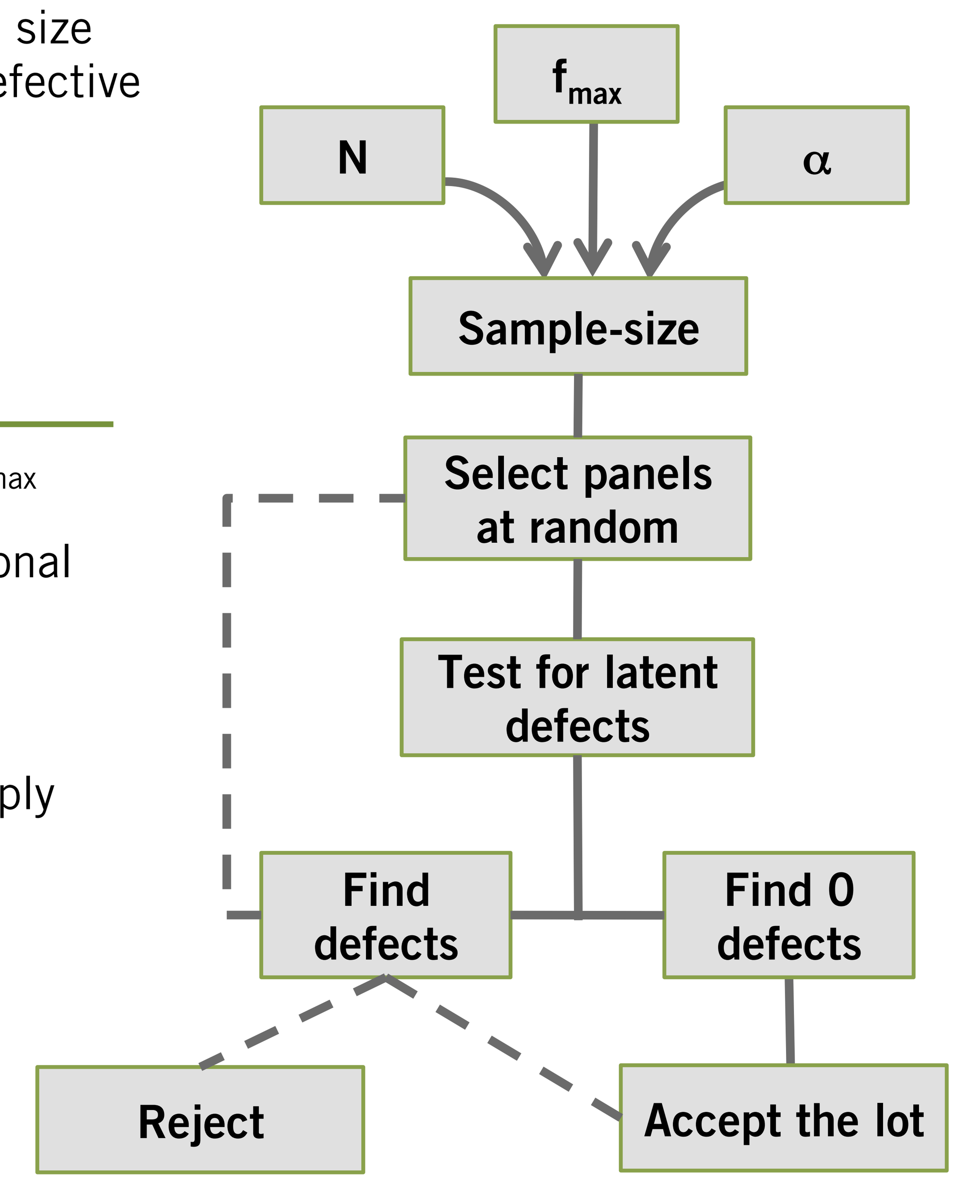
- »Reduced power production; it can take several months to detect the defect, verity the defect, and enact the warranty.
- »The costs associated with replacing the defective panel, including logistics, labor, and powering down a string of modules to make the replacement.
- »Increased O&M costs associated with panel inspections to find other defective units.

Production period	% Affected	Notes
1994-2002	0.13% annually	2 million modules in the field
2008	100% recall	All of 2008 production
2008-2009	4%	Loss of performance
early 2000's	10%	Junction box fires
early 2000's	~3.5%	Severe cell cracks
early 2000's	2.9%	Local heating from solder joint failure

Latent Defect Screening (LDS)

Test	Qualification	Timing	Volume
IEC/UL	Design/Materials	Prototypes	8 – 12 panels
LDS	Process	Lot-by-Lot	Statistically Significant

N = Installation size
f_{max} = Max % defective
= Confidence



FINDING A DEFECT

- »Calculate new f_{max}
- »Calculate additional sample-size for preferred f_{max}
- »Renegotiate supply agreements

TESTING

Thermal Cycling
Damp Heat
Humidity Freeze
UV
Dynamic Mechanical Testing
DH under bias

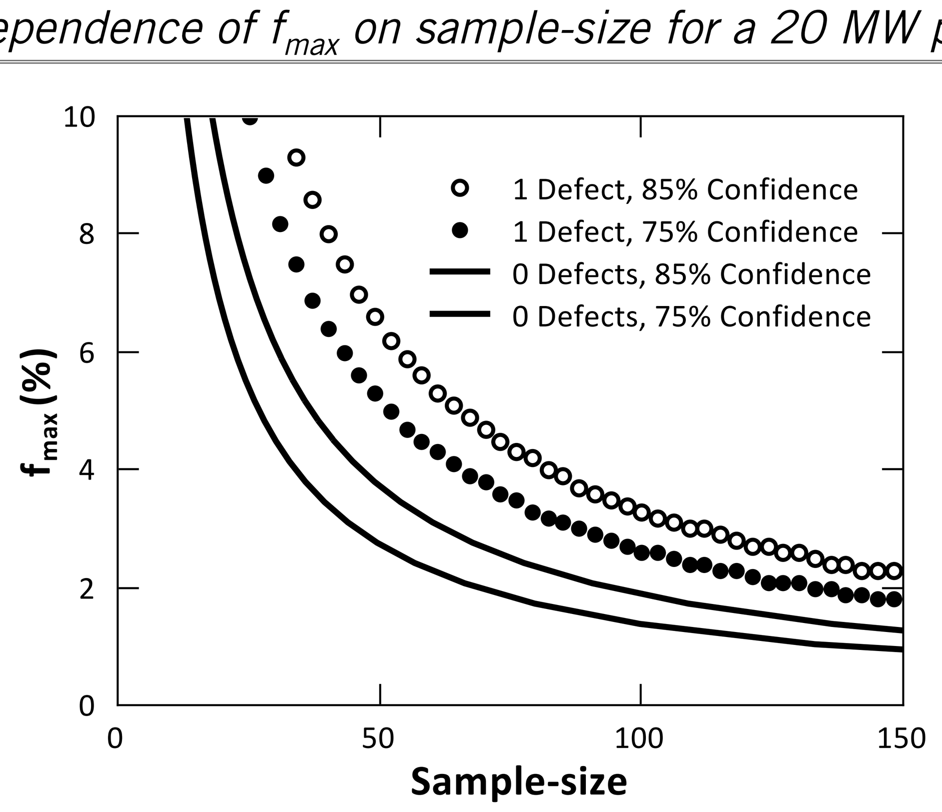
Statistics of f_{max} and Confidence

- » The confidence (α) around the max percent defective (f_{max}) is dependent on the installation-size (N) and the sample-size (n).
- » If no defects are encountered in testing, the relationship can be calculated using the hypergeometric distribution:

$$P(c=0 \mid n, f_{max}) = 1 - \alpha = \frac{\binom{N(1-f_{max})}{n} \cdot \binom{Nf_{max}}{0}}{\binom{N}{n}}$$

- » If a defect is encountered, the numerator is modified

Dependence of f_{max} on sample-size for a 20 MW plant

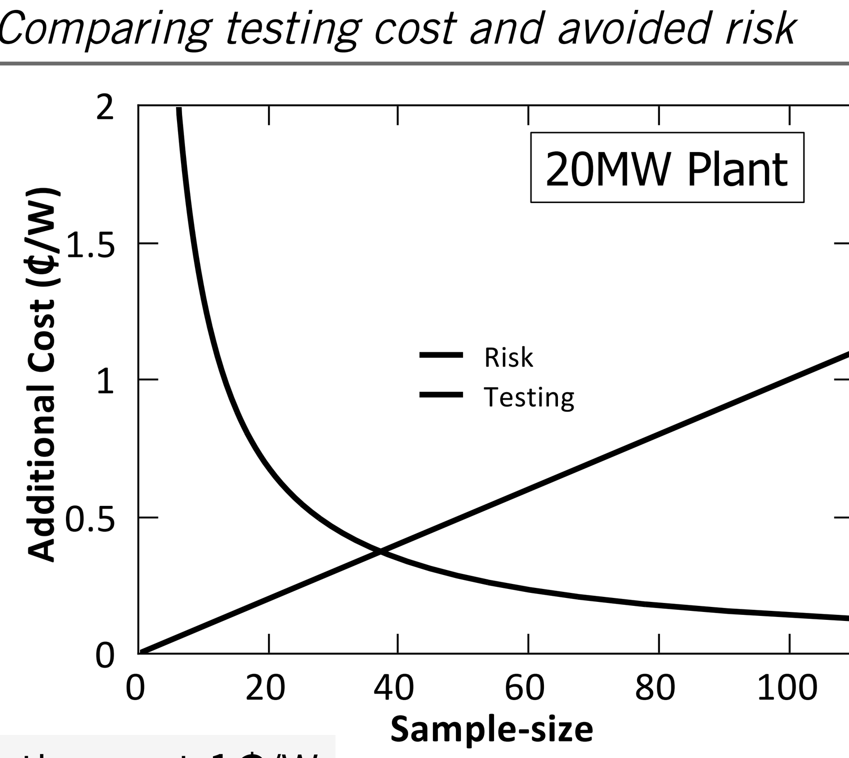


Confidence	f_{max}	f_{max}, C = 1	Sample-size
75%	1.5%	2.9%	90
75%	2.9%	5.5%	47
85%	2%	3.7%	90
85%	4%	6.9%	47

Financial Implications

- » The best way to judge the value of testing is to compare the testing cost versus the risk associated with f_{max} and confidence as a function of sample-size.
- » For simplicity, the cost of testing can be estimated at $2000/panel.
- » An accurate financial calculation is complicated and depends on replacement costs, insurance premiums, interest rates, etc. However, a simplified calculation based on avoided risk cost, $\$_{risk}$, can be estimated assuming a replacement cost , $\$_{repl}$ = $0.5/W as: $\$_{risk} = \$_{repl} \cdot f_{max} \cdot (1-\alpha)$

Comparing testing cost and avoided risk



Fixed testing cost 1₵/W

Confidence	Project Size	f_{max}	Sample-size,
75 %	1 MW	24 %	5
85 %	1 MW	31 %	5
75 %	20 MW	1.4 %	100
85 %	20 MW	1.8 %	100

Summary and Outlook

- » Certifications such as IEC and UL insure product design and materials, but do not guarantee against deviations in the manufacturing process that can lead to defects in the field. These defects can lead to reduced performance or safety risks.
- » Third party LDS increases the confidence in the quality of panels for a given installation to help maximize the return on investment through reduced risk.
- » Testing costs can be below 1₵/W for a financial risk below 0.2₵/W; actual benefits will be much higher.
- » This is becoming increasingly important as the market penetration of PV increases; especially considering the large number of module suppliers.

Questions for Discussion

- » How does prior knowledge of a manufacturer's quality affect the statistics? Is this valuable?
- » How will increasing the confidence affect insurance premiums, interest rates, debt-service coverage ratios, etc?
- » How will this affect approved vendor lists?

References

1. G. TamizhMani, "Testing the reliability and safety of photovoltaic modules: failure rates and temperature effects", PV-Tech (2010).
2. D. DeGraaf, R. Lacerda, Z. Campeau, "Degradation Mechanisms in Si Module Technologies Observed in the Field; Their Analysis and Statistics", presented at NREL 2001 Photovoltaic Module Reliability Workshop (2011).
3. "Utilizing Panel-Level Monitoring to Improve Project ROI", Alternative Energy Magazine (2012)