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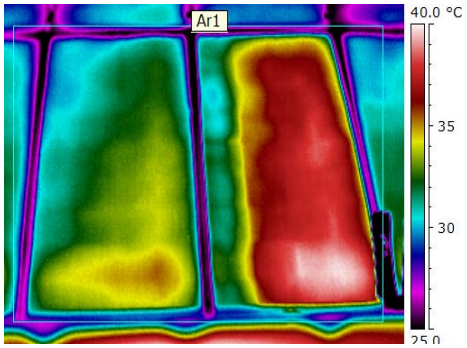

Integration of PV-RPM into the System Advisor Model (SAM)

8th PV Performance Modeling and Monitoring Workshop

May 9, 2017

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National Renewable Energy Laboratory

U.S. DEPARTMENT OF ENERGY

SunShot U.S. Department of Energy

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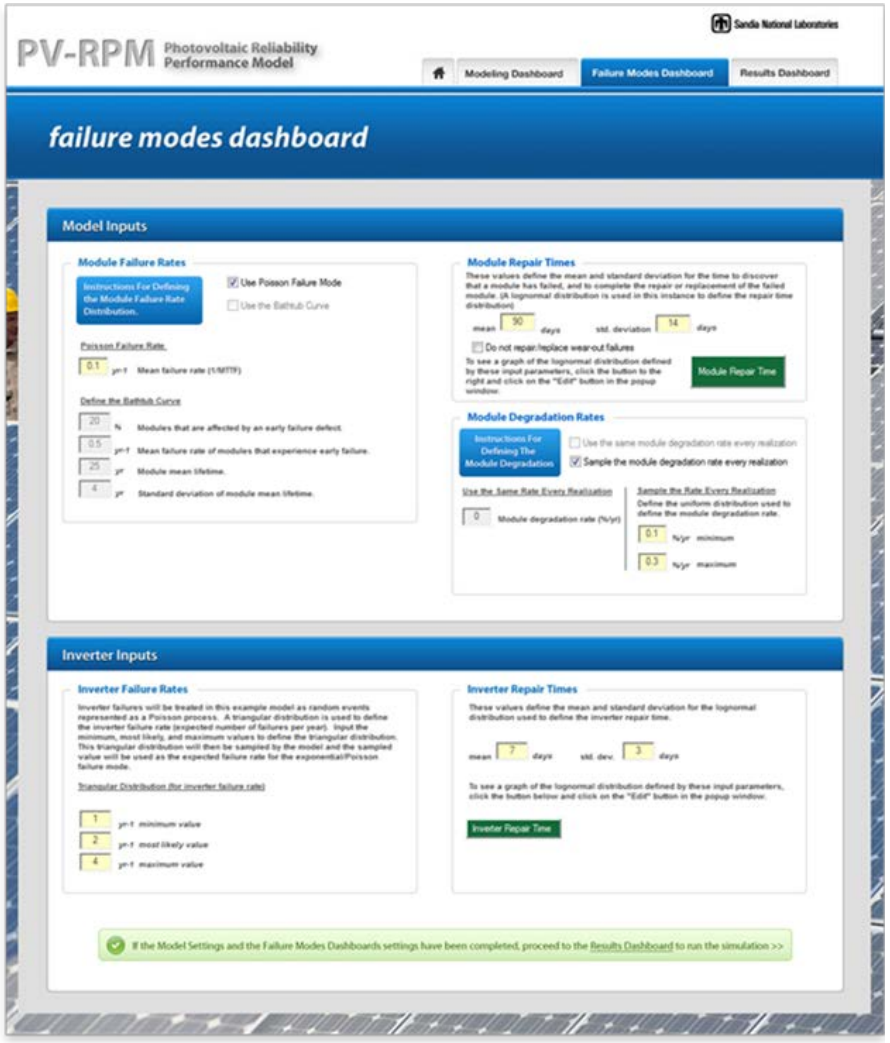
Acknowledgements

- DOE SunShot Photovoltaics Program and Soft Costs Program (through NREL) for providing funding
- Renee Gooding from SNL for data analysis
- Data partners

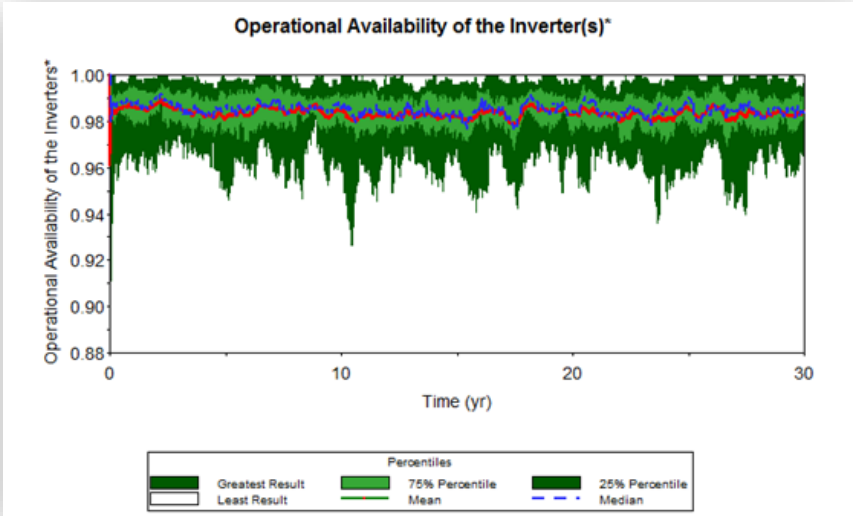
Outline

- What is the PV Reliability Performance Model (PV-RPM)? Why is this important?
- Benefits of integrating into SAM
- Features
- Data Analysis and Results
  - Both older and newer system components
- Next Steps

What is the PV Reliability Performance Model?



- Developed by SNL in 2010 as a proof-of-concept to evaluate PV performance impacts from probabilistic 'events' (faults/failures) impacting modules and inverters



- Goldsim player platform – limited evaluation capabilities (system configuration and failure mode types)

Why include reliability in a PV performance model?

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- PV fleets are aging with different failure modes that vary by manufacturer, age and location, resulting in additional lifetime power and energy production uncertainty

Current Performance Model

- Energy and power output
- Maintenance/component repair intervals: No energy loss estimate
- Exceedance probabilities for solar resource variability
- Error estimates due to weather uncertainty and model inputs
- Single LCOE

Performance Model with Reliability Elements

- Probabilistic power and energy production, and losses
- Probabilistic estimates of *when* and *how many* events per component
- Additional uncertainty around component fault/failure impacts
- Probabilistic representation of LCOE

Benefits of Integrating into SAM

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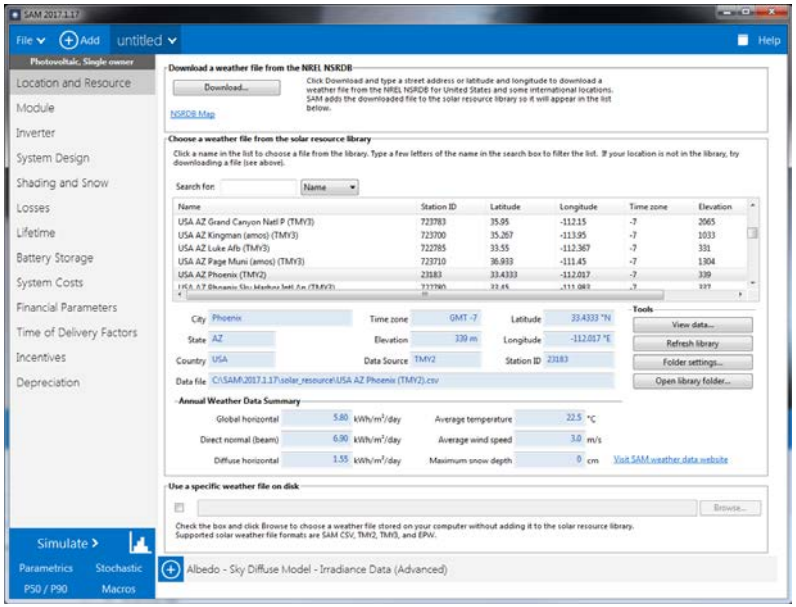
- More flexibility for different system design options
- SAM already has Monte Carlo – Latin Hypercube Sampling capability integrated from SNL Dakota software
- Open-source in LK script will allow for user customization. This could include developing failure modes for batteries, for example

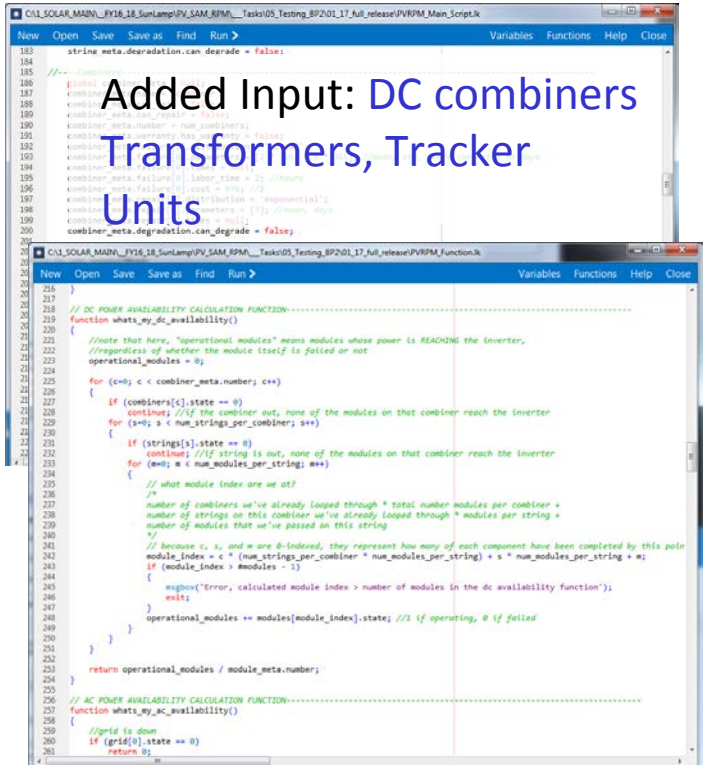
…and Challenges

- Bottom-up model only allows for 'even' and similar component configurations. Only 1 inverter type per site and same number of modules per dc combiner, for example
- Simulation time for larger architectures

SAM Implementation – LK Script



- Main Script
  Where distributions are defined
- Function Script
  Not modified by user



- System design window

Same as any other SAM model

- Components for analysis

Modules
Strings
DC Combiners
Inverters
AC Disconnects
Transformers
Grid Impacts
Trackers

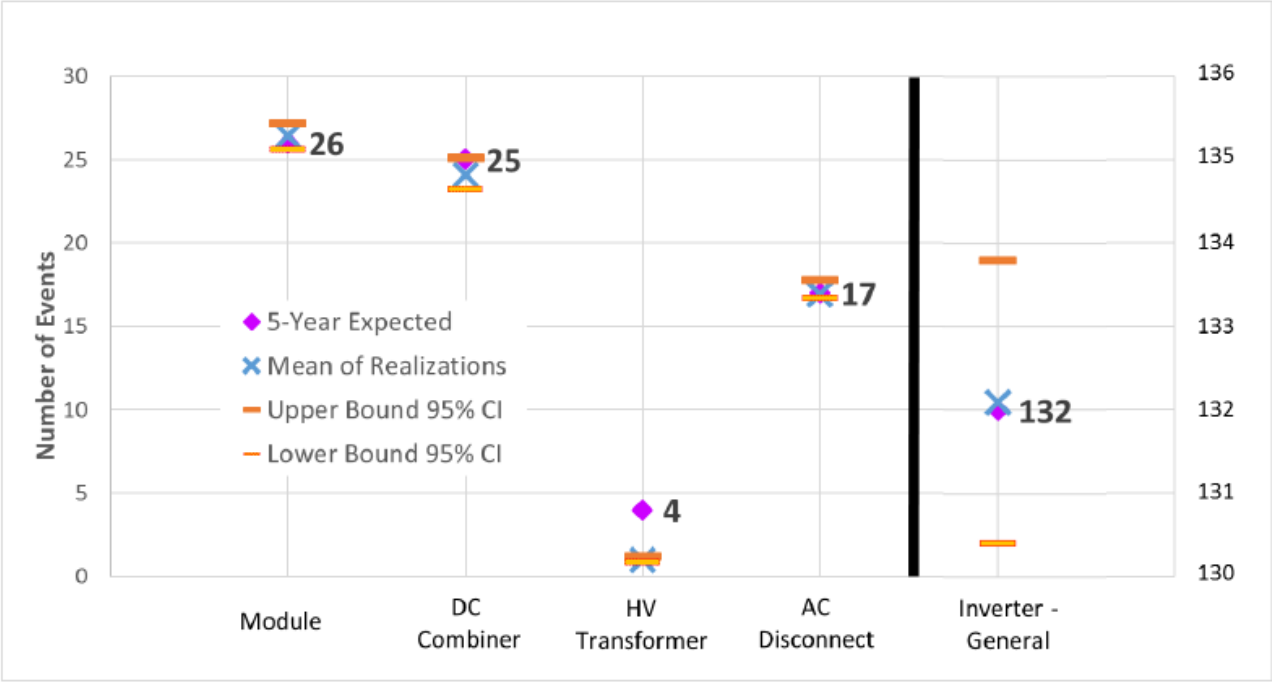
- Output File

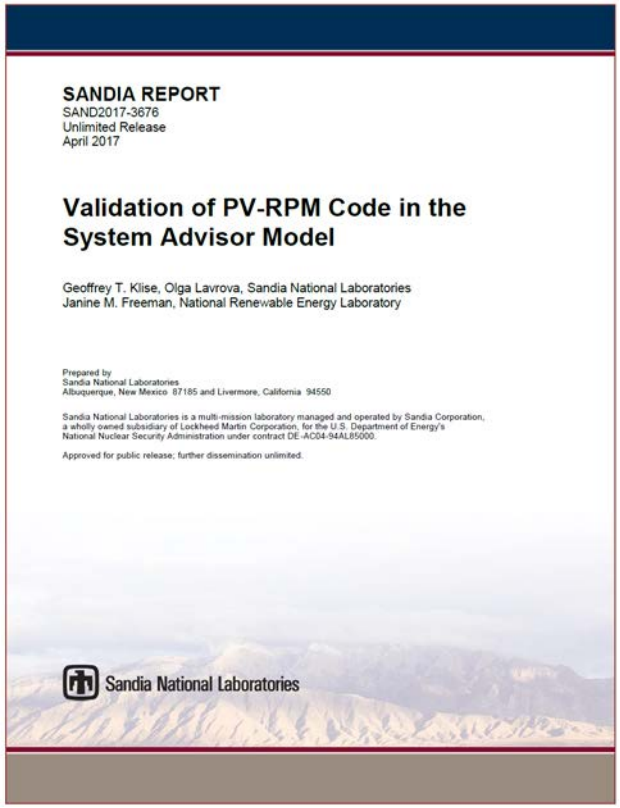
Power & energy loss, costs, labor hours, LCOE, failures per component. Time series and annual results, per realization

Event Validation – Existing Dataset

Details in recently published white paper

- Validated against proof-of-concept model results using same probability distributions (3.5 MW over 5-years)
- The mean of 100 SAM realizations revealed that for 4 out of 5 components, 95% of the sampled intervals contained the “5-year expected” value for Number of Events (Failures)
- This is not comparing against *actual*, just *expected* to evaluate how well models match

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Validation of PV-RPM Code in the System Advisor Model

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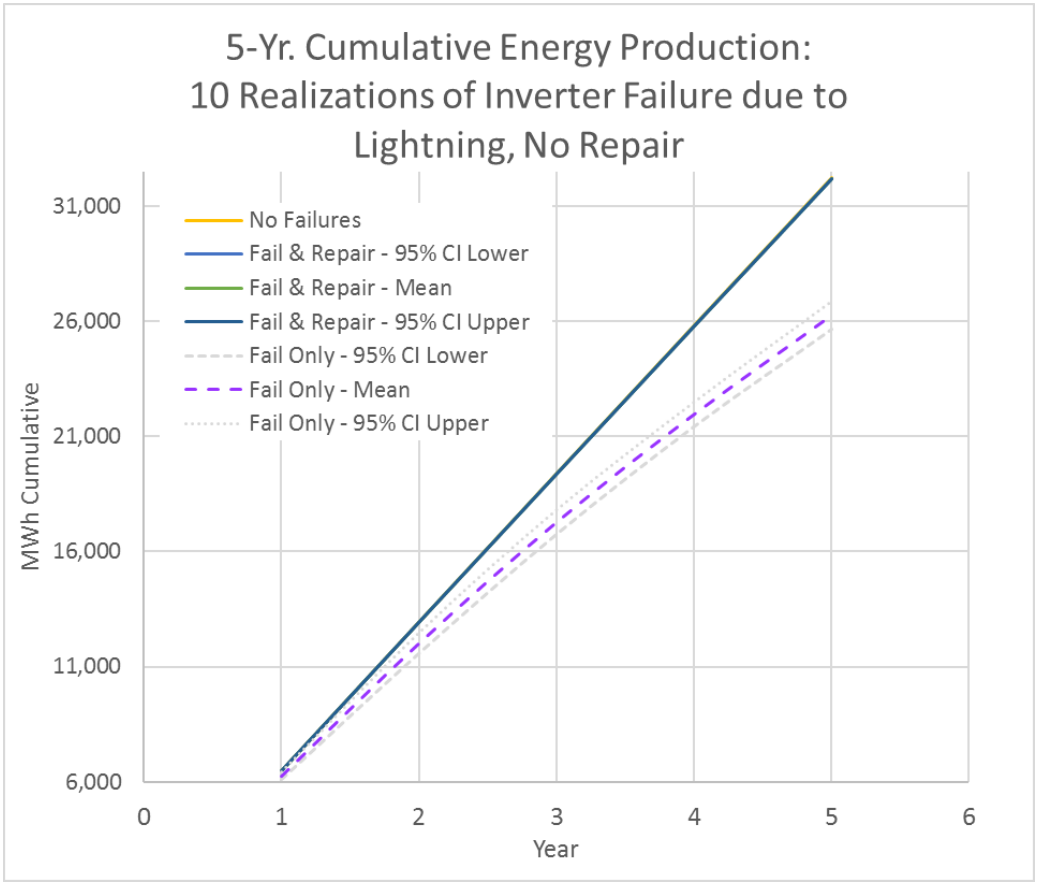
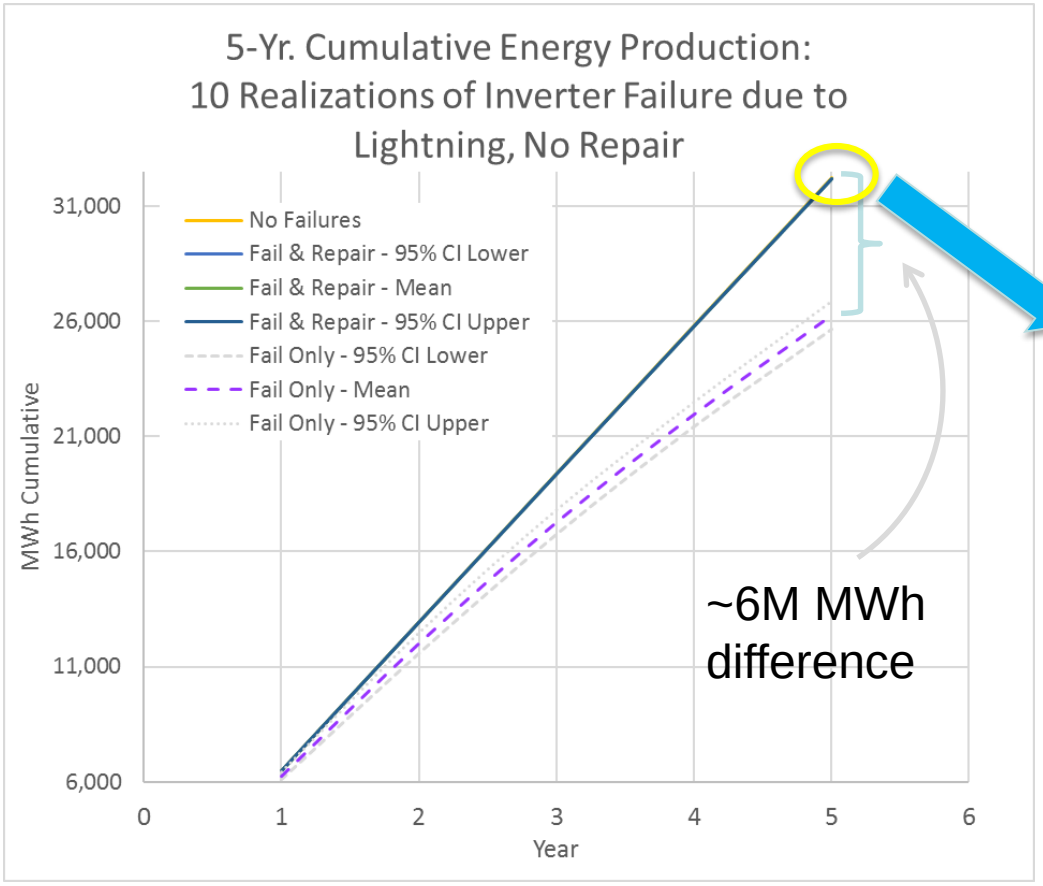
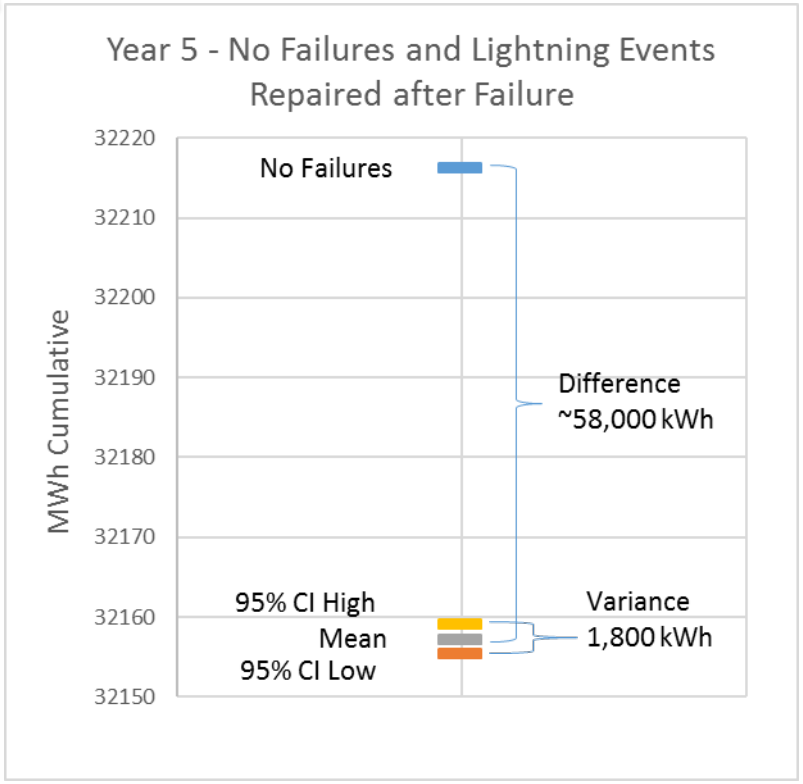
SAM Analysis – Existing Dataset



SAM Analysis – Existing Dataset



- Graph at bottom is the energy production range between No Failures & Fail and Repair



Event Validation – Newer Dataset

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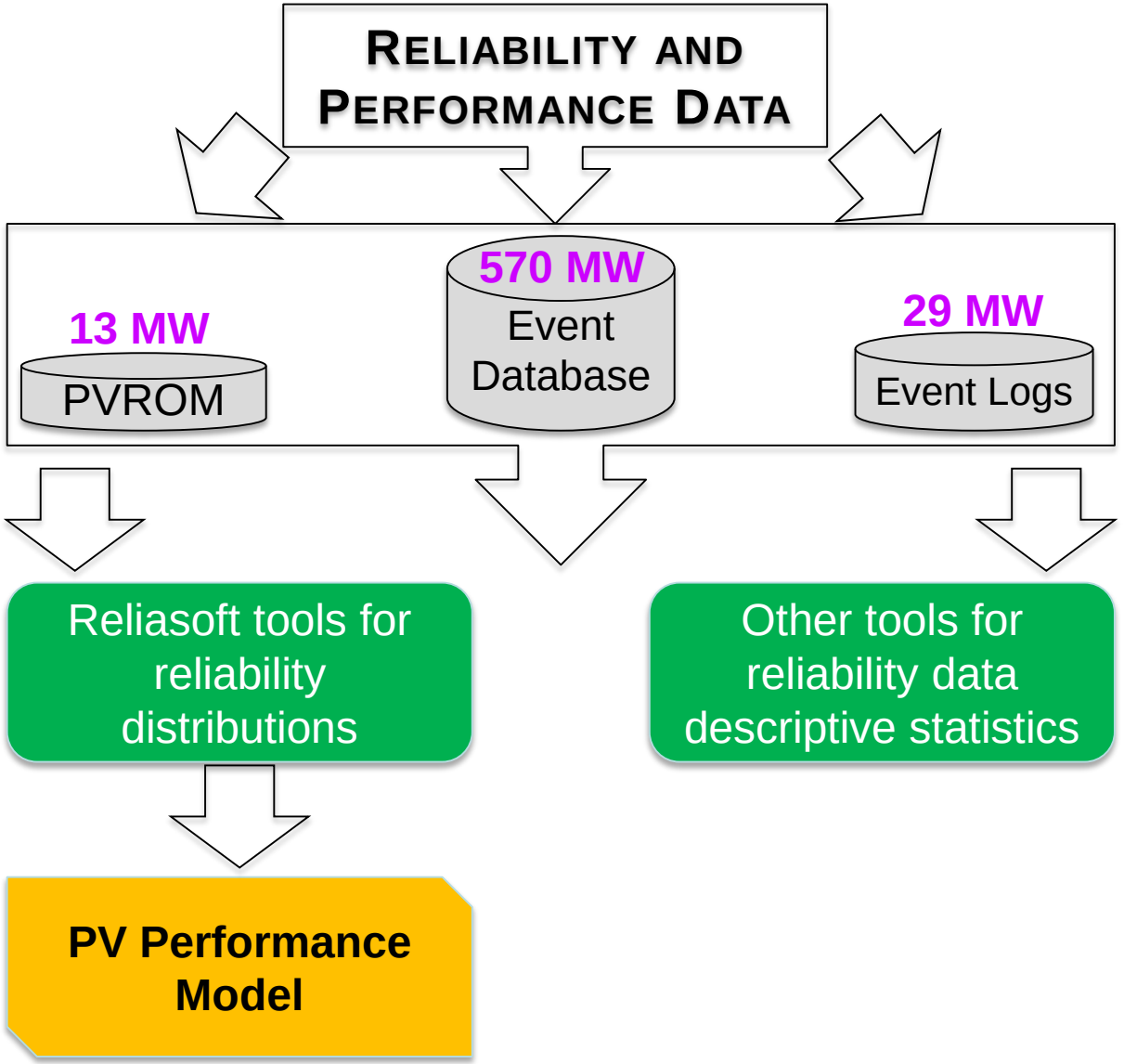
Raw Data Generation

Data Collection & Storage

Data Analysis

Data Application and Further Analysis



Event Validation – Newer Dataset

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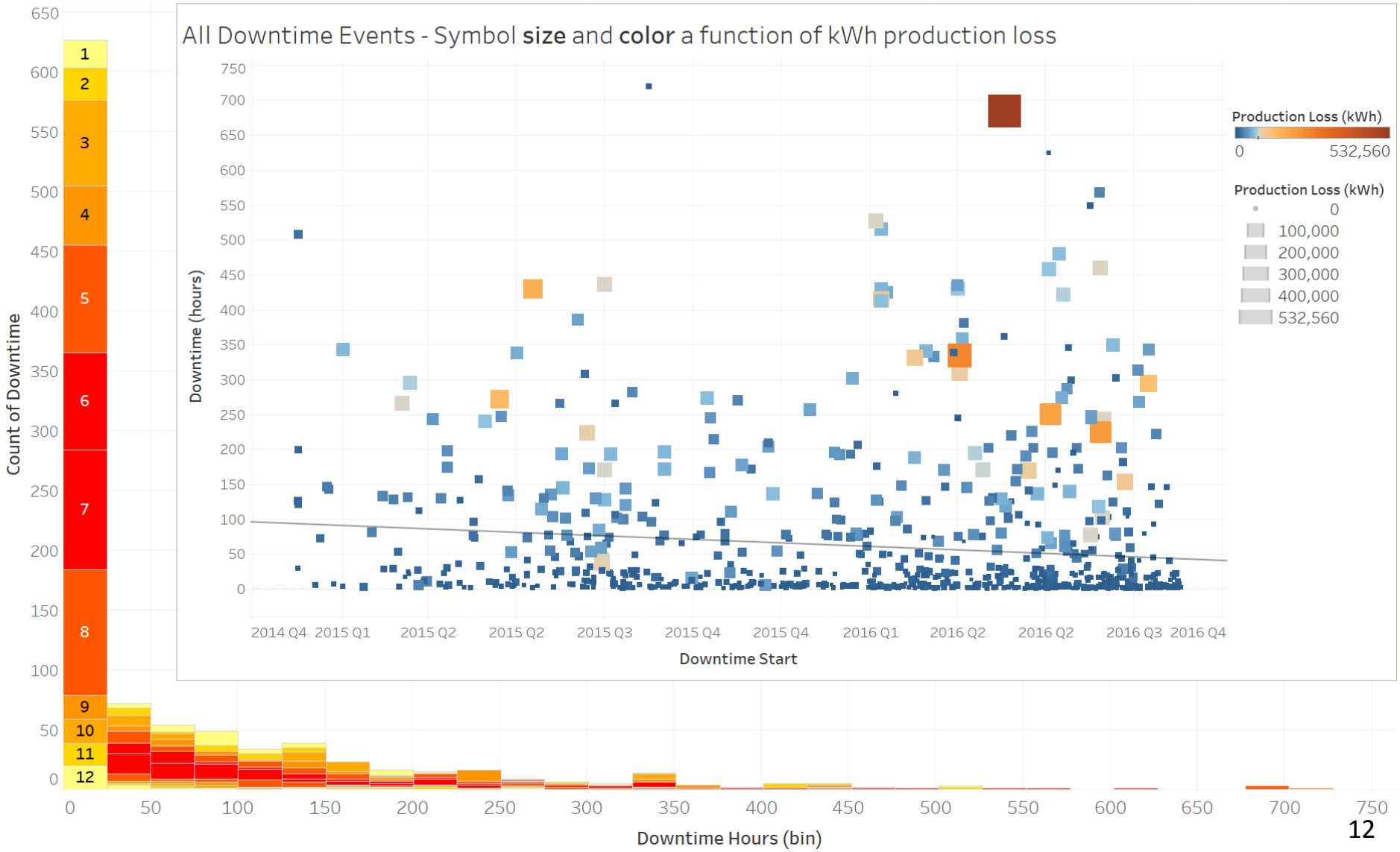
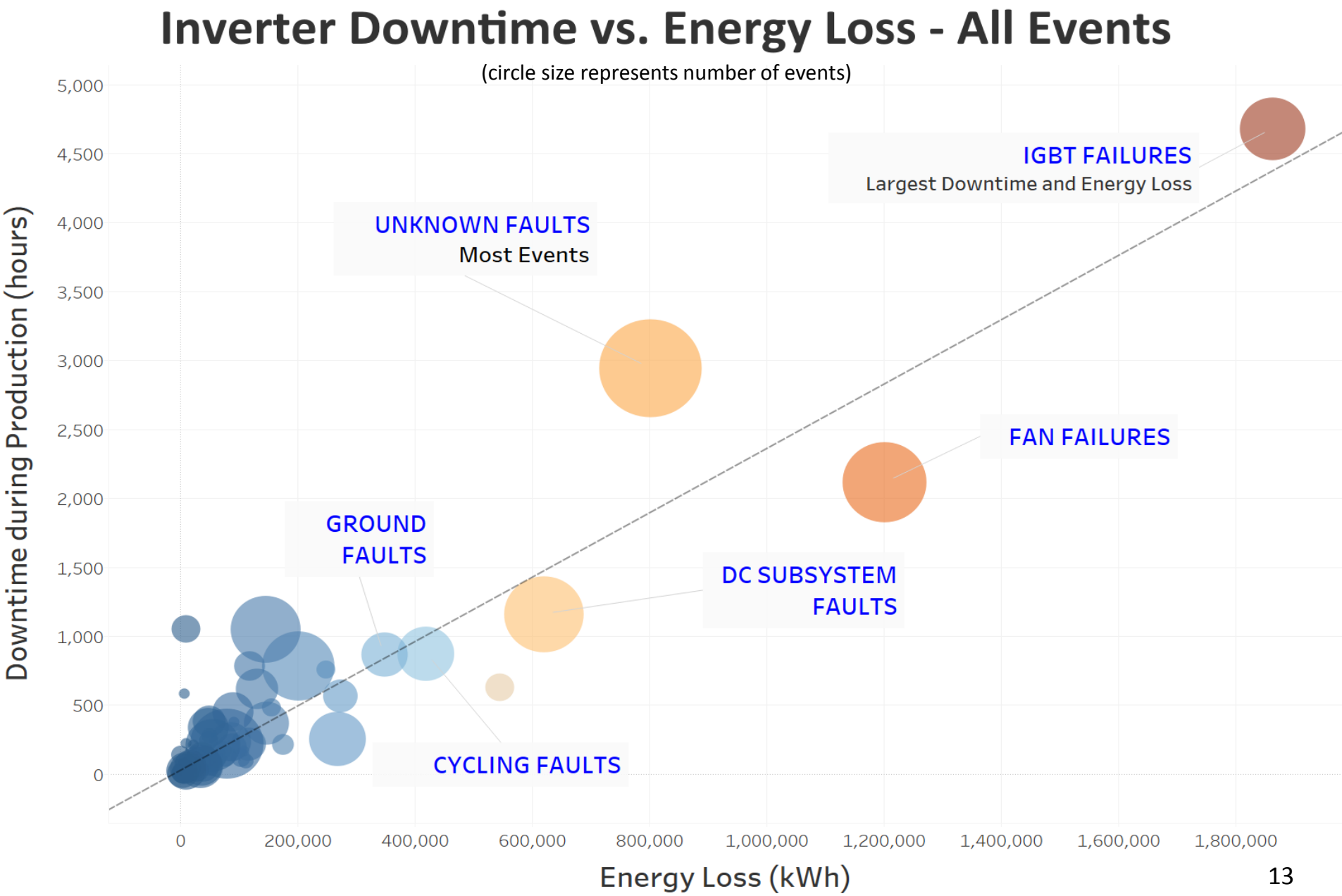
All Inverter Downtime - Frequency and Trend

Distribution of Downtime Events - Red colors represent **peak production months**



Event Validation – Newer Dataset



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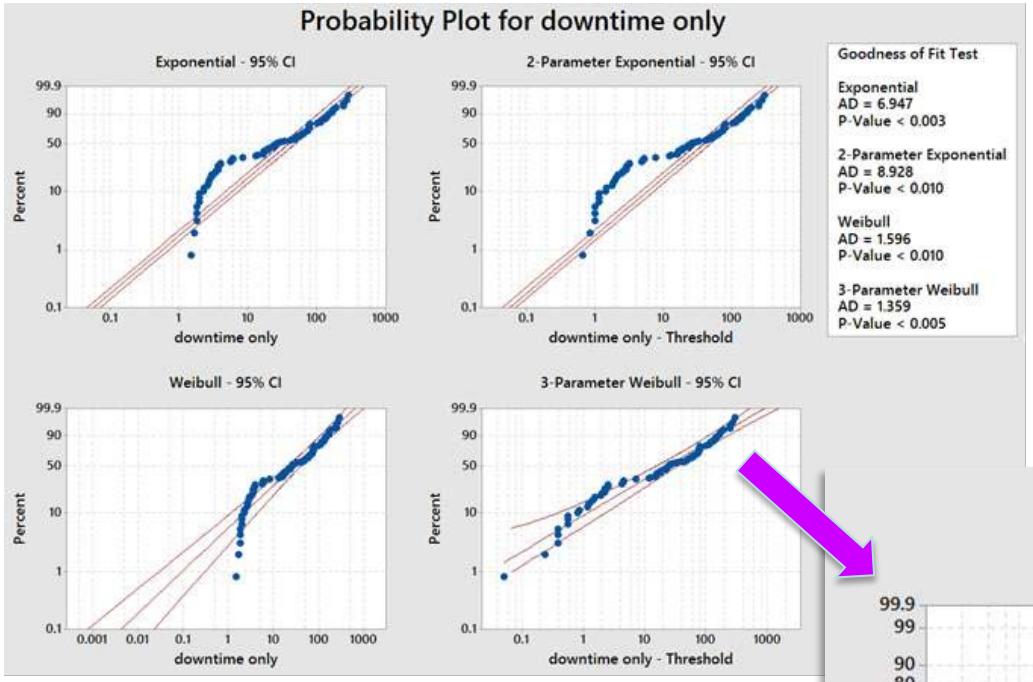
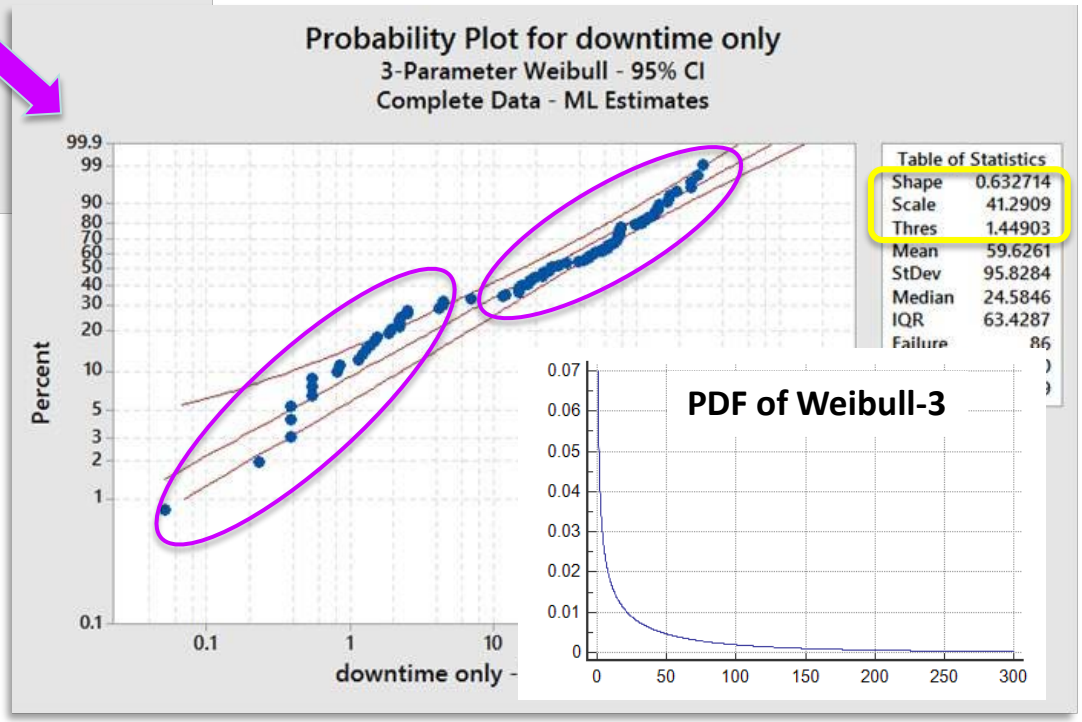


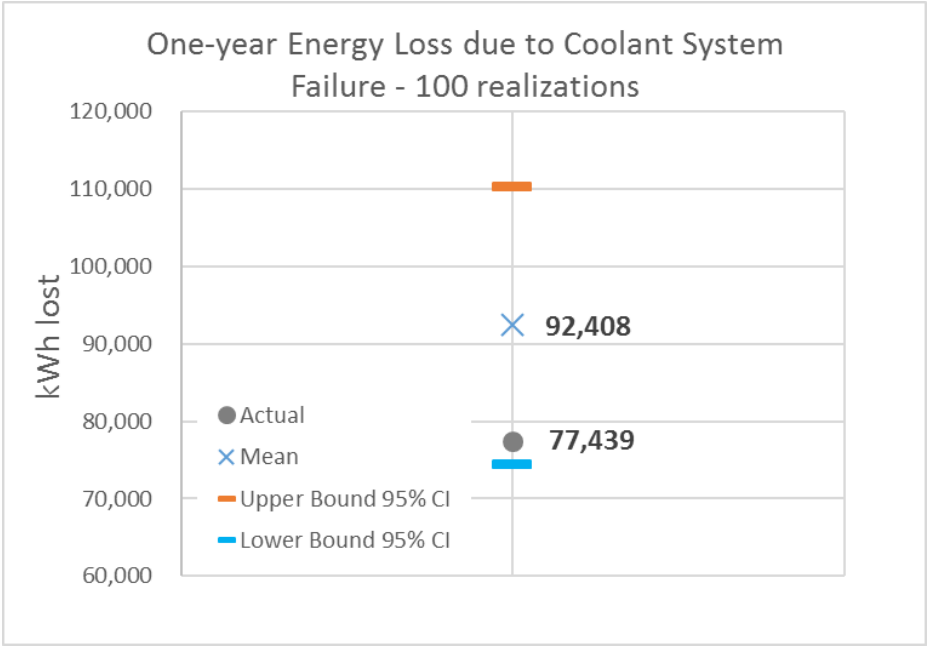
- Example showing ALL fan outage data across all sites
- Data fitting is done to find the distribution with a P-value and AD statistic that explains how well underlying data fits the selected distribution type

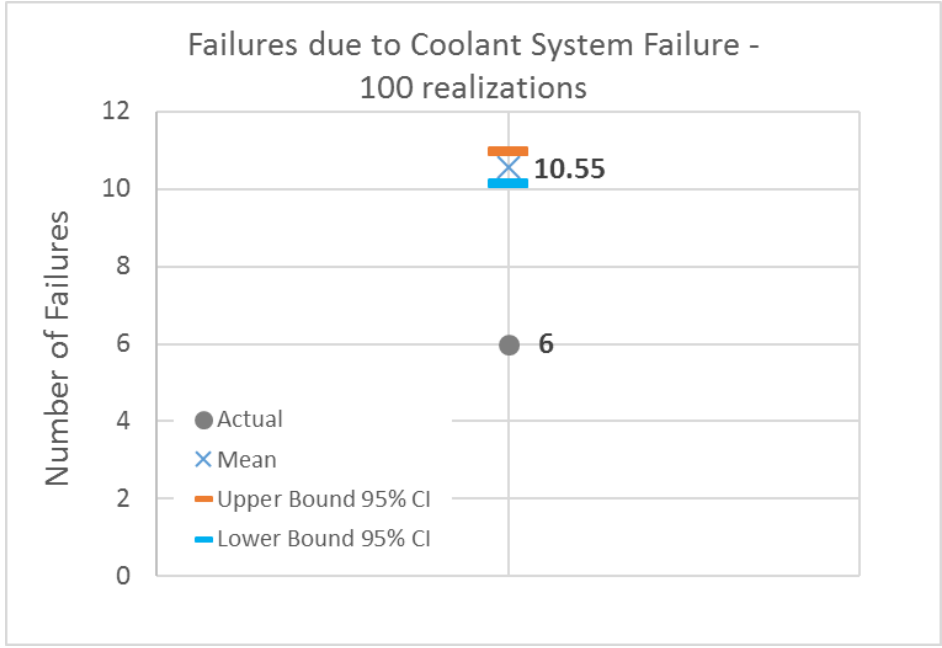


- Confidence intervals are narrower around the upper part of the distribution
- In this case, we have what appears to be a bi-modal distribution of data, owing to different downtime durations and likely, different failure modes

Failure and Energy Loss Validation

- Inverter dataset – Coolant failures for one 24 MW system with 20 inverters (Impacts to 4)
- 1.2 years for analysis period. 1 year for model (can only model annually)
- 100 realizations
- **Energy Loss:** 95% of the sampled intervals contained the "actual" value for energy loss
- **Failures:** 5% of the sampled intervals did not contain the "actual" value for number of failures
- Failure and repair distributions only had 6 sample points. Greater potential for results with sampled intervals outside of the 95% confidence interval
  - Longer dataset collection period will result in better distribution fit

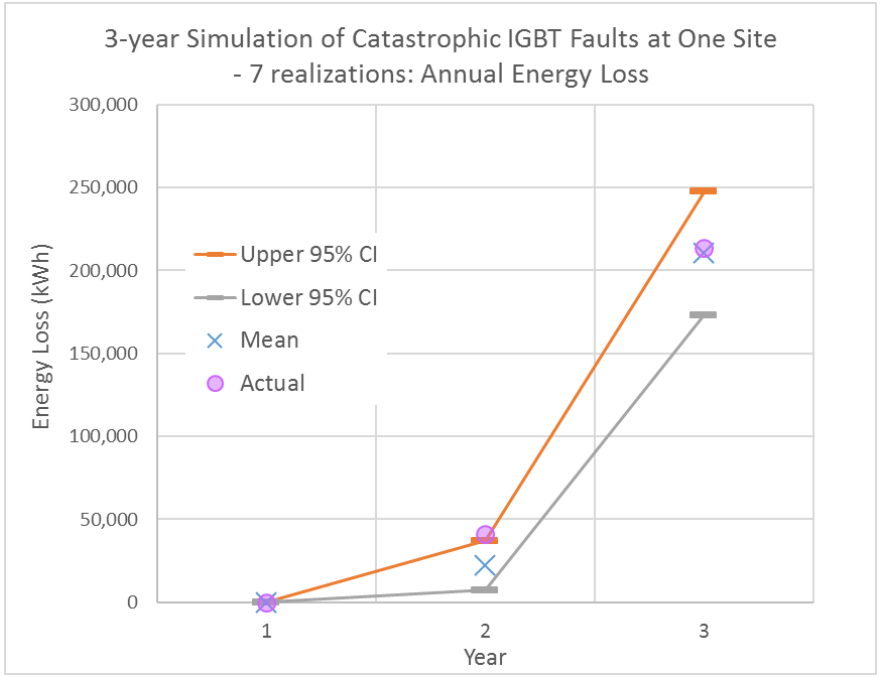




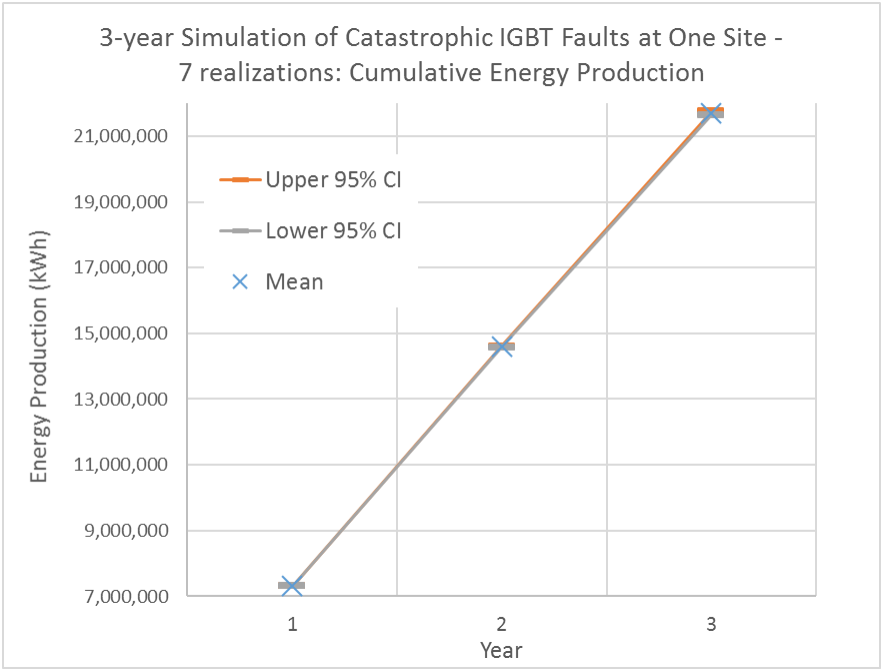
Failure and Energy Loss Validation

- Inverter dataset – IGBT failures for one 5 MW system with 8-500 kW inverters (impacts to 7)
- 2.8 years for analysis period. 3 years for model (can only model annually)
- 7 realizations
- **Energy Loss:** Year 2 –5% of the sampled intervals did not contain the "actual" value for energy loss. Year 3 – 95% of the sampled intervals did contain the "actual" value for energy loss
- **Failures:** Actual failures = 7, Mean of modeled failures = 8

Annual Energy Loss (ea. of 3 years)



Cumulative Energy Production (3 years)



Difficult to see spread in first 3 years

No data to compare "actual" energy production

Next Steps

- Beta review by industry
  - Looking for additional test users for new reliability feature within SAM. Beta version will be distributed to 33 volunteers late May
- Improving realization speed
- Incorporating beta test feedback
- User manual development
- Use case analysis (FY 18)

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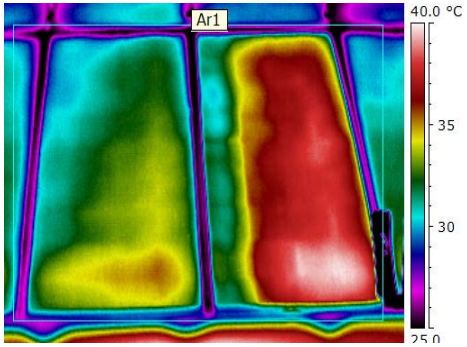

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