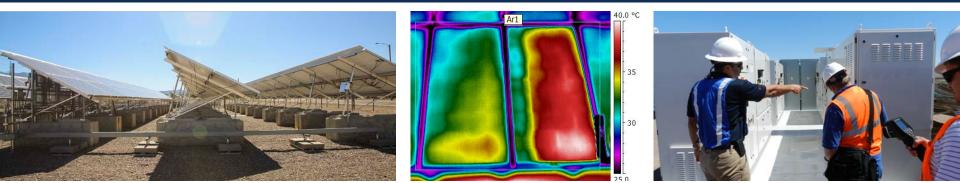


Exceptional service in the national interest



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

8th PV Performance Modeling and Monitoring Workshop May 9, 2017

Geoffrey T. Klise, Olga Lavrova

Sandia National Laboratories

Janine Freeman

National Renewable Energy Laboratory

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.





Acknowledgements



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

Outline

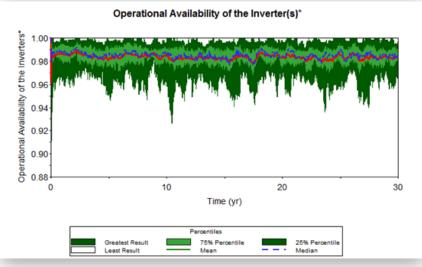


- What is the PV Reliability Performance Model (PV-RPM)? Why is this important?
- Benefits of integrating into SAM
- Features
- Data Analysis and Results
 - Both older and newer system components
- Next Steps

What is the PV Reliability Performance Model?

ilure modes dashboard					
Aodel Inputs					
Module Failure Rates Module Failure Rates Immunolity	Model Reparations Berry address backback, due to densite the organization of the table to the state of the densite to densite the organization of the state of the densite to densite the organization of the densite to dens				
nverter inputs					
Inverter Fallers Rates Inverter Fallers will be treaded in this exceptire model as random events represented as a Physics process. A Phanagular distribution is used to define minimum, next level, and maximum values is before the treaged of this budint is strongular distribution will then be sampled to the exponential Physics tables will be as the excepted faller rate for the exponential Physics tables will be as the excepted faller rate for the exponential Physics tables and the excepted fallers rate for the exponential Physics tables will be added for the excepted fallers tables and the excepted fallers tables	Inverter Repair Times These values define the mean and standard deviation for the topermut distribution used to define the inverter repair time. mean 7 , drys with deviation 3 , drys To see a graph of the topermut distribution defined by these input parameters, static the function below and shall on the "Edd" botton in the plops worker.				
p=1 minimum value p=1 minimum value p=1 maximum value The Model Settions and the Falues Modes Dashboards settions	Sweder Figure Tele				

Developed by SNL in 2010 as a proofof-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?



 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



- 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



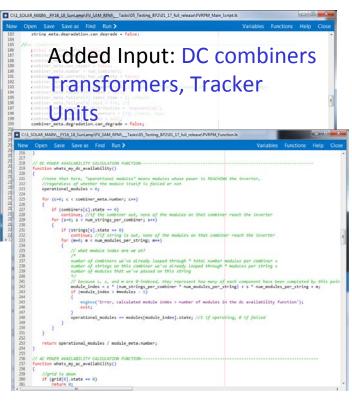
Photovoltaic, Single owner	- Download a weather file from t	he NREL NSRDB							
Location and Resource	Download	Click Download and type a str weather file from the NREL NS	eet address or labits RDB for United Stat						
Module	NSECE Map	SAM adds the downloaded file to the solar resource ibrary so it will appear in the list below.							Main Scri
Inverter	Choose a weather file from the	solar resource library						-	IVIAIN SCH
System Design	Click a name in the list to choose downloading a file (see above).	a file from the library. Type a few l	etters of the name i	in the search box to	filter the list. If y	our location is not	in the library, try		
shading and Snow	Search for:	Name 👻							Where
osses	Name		Station ID	Latitude	Longitude	Time zone	Elevation	3	vviiere
	USA AZ Grand Canyon Natl P		723783	35.95	-112.15	-7	2965		
ifetime	USA AZ Kingman (amos) (TM)	3)	723700	35.267	-113.95	-7	1033		
lattery Storage	USA AZ Luke Afb (TMY3) USA AZ Page Muni (amos) (Th	N.C.	722785 723710	33.55 36.933	-112.367 -111.45	-7	331 1304		distributions
	USA AZ Phoenix (TMV2)	((3))	23183	31,4133	-112.017	.7	339		aistributions
System Costs	11CA A7 Oknamic Shu Markov In	(An (TMV2)	777780	22.45	.111 082	.7	127		
Inancial Parameters	5					Tools	1		are defined
	City Phoenix	Time zone	GMT-7	Latitude	33,4333 "N		ew data		ule uejiileu
lime of Delivery Factors	State AZ	Elevation	339 m	Longitude	-112.017 °E	Re	resh library		2
incentives	Country USA	Data Source	TMY2	Station ID	23183	Folder settings			
Depreciation	Data file CASAM 2017.1.17 iso	ar_resource\USA AZ Phoenia (TM	V2).esv			Open	library folder		
	-Annual Weather Data Summ	iry				-			Eunction
	Global horizontal	5.80 kWh/m ² /day	Average terri	perature	22.5 °C				Function
	Direct normal (beam)	6.90 kWh/m²/day	Average win	nd speed	3.0 m/s				
	Diffuse horizontal	1.55 kWh/m ¹ /day	Maximum sno	w depth	0 cm	Visit SAM wite the	, data website		\sim \cdot \cdot
	Use a specific weather file on d	sk							Script
							Erowse		
Simulate >	Check the box and dick Browse Supported solar weather file for	to choose a weather file stored on nats are SAM CSV, TMr2, TMr3, and	your computer with s EPW.	hout adding it to th	ne solar resource li	ibrary.			Not modifiea
Parametrics Stochastic	Albedo - Sky Diffuse M	odel - Irradiance Data (Ad							NOT MODITIED

- System design window Same as any other SAM model
- Components for analysis

Modules Strings **DC Combiners** Inverters

AC Disconnects **Transformers Grid Impacts** Trackers

by user



Output File

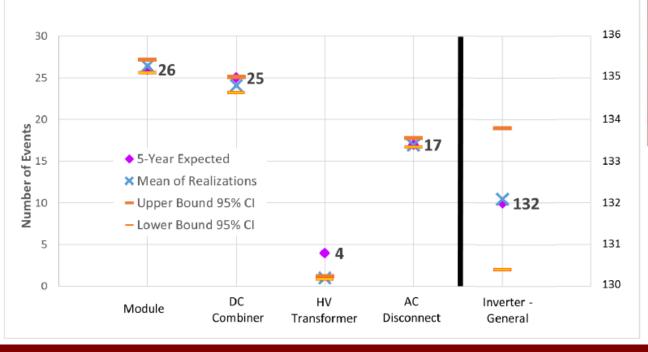
Power & energy loss, costs, labor hours, LCOE, failures per component. Time series and annual results, per realization

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



SANDIA REPORT SAND2017-3676 Unlimited Release April 2017

Validation of PV-RPM Code in the System Advisor Model

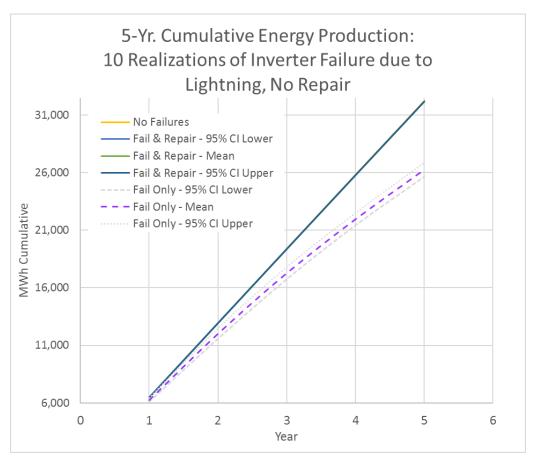
Geoffrey T. Klise, Olga Lavrova, Sandia National Laboratories Janine M. Freeman, National Renewable Energy Laboratory

Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholy owned subaidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE -ACO4-94AL85000. Accessed for public release: further dissemination unimited.



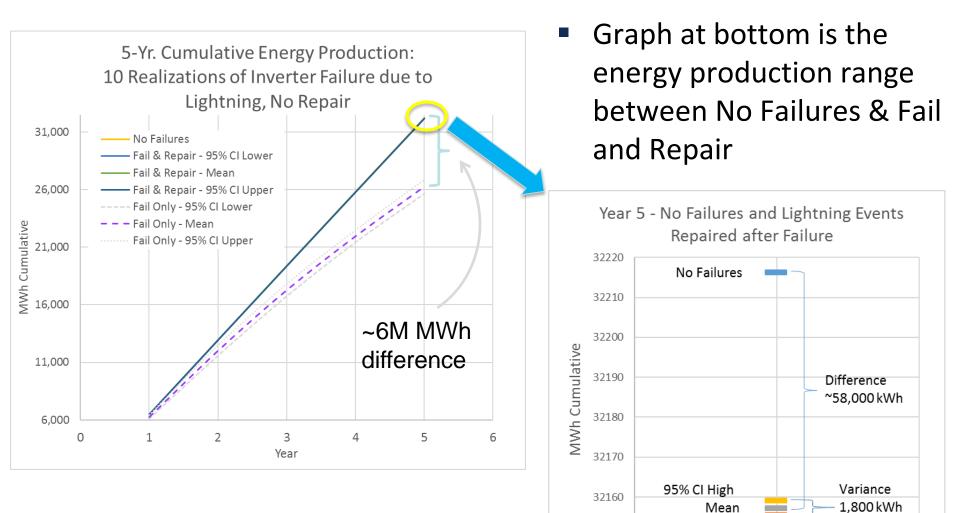
SAM Analysis – Existing Dataset



Sandia National Laboratories

SAM Analysis – Existing Dataset

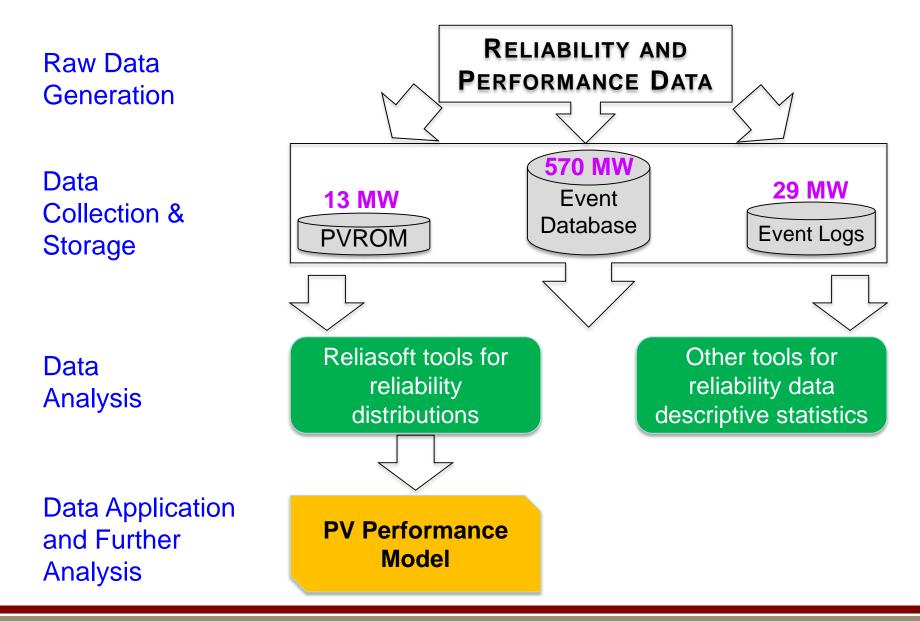




95% CI Low

32150

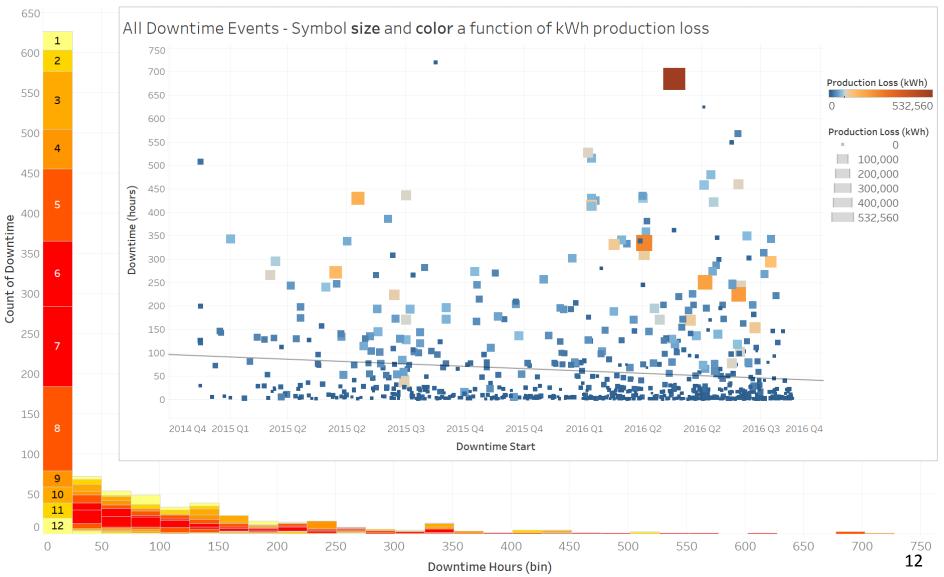






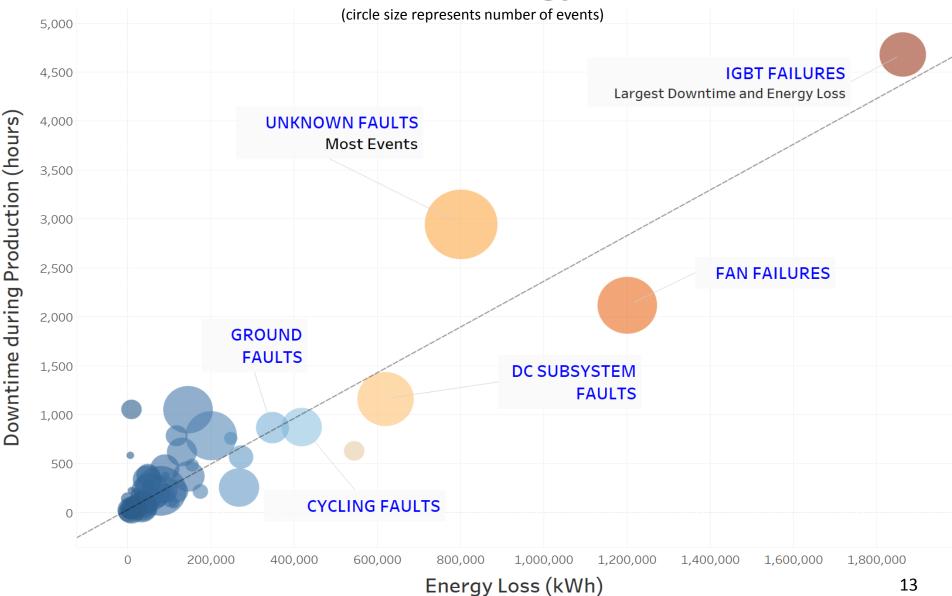
All Inverter Downtime - Frequency and Trend

Distribution of Downtime Events - Red colors represent peak production months



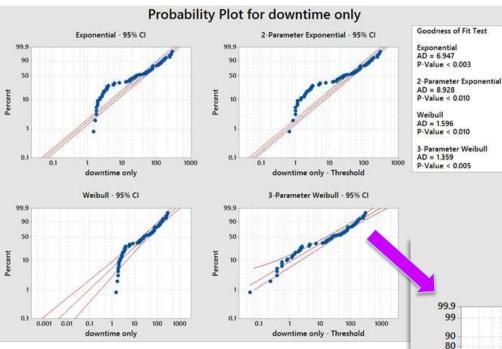


Inverter Downtime vs. Energy Loss - All Events



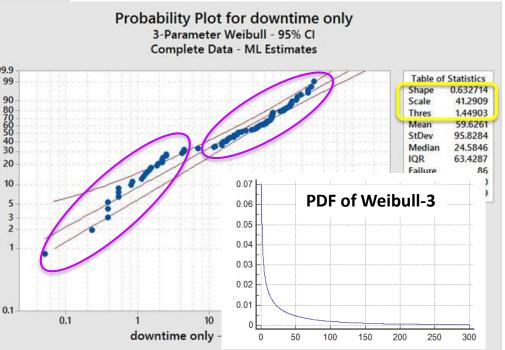
Percent





- 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

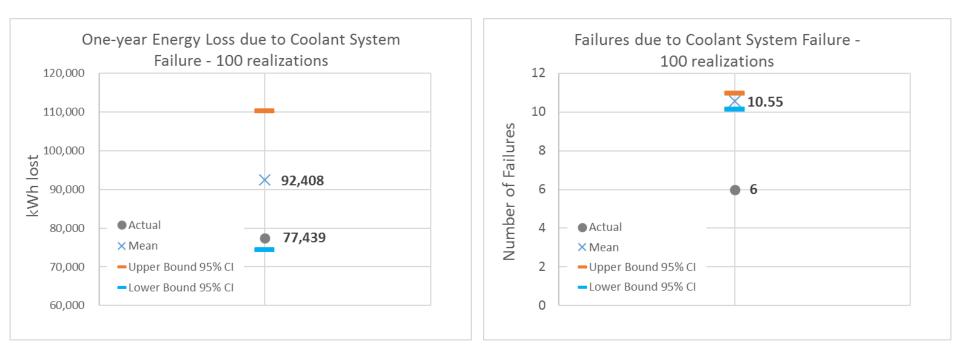
- Example showing ALL fan outage data across all sites
- Data fitting is done to find the distribution with a P-value and AD statistic that explains how well underlying data fits the selected distribution type



Failure and Energy Loss Validation



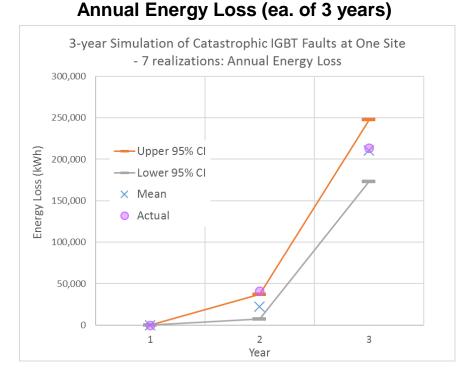
- Inverter dataset Coolant failures for one 24 MW system with 20 inverters (Impacts to 4)
- 1.2 years for analysis period. 1 year for model (can only model annually)
- 100 realizations
- Energy Loss: 95% of the sampled intervals contained the "actual" value for energy loss
- Failures: 5% of the sampled 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



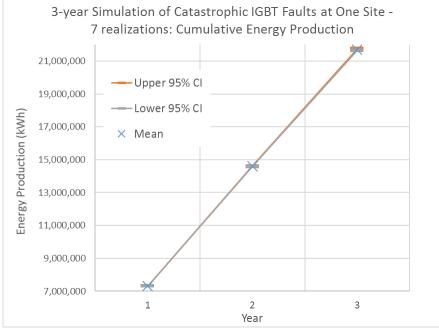
Failure and Energy Loss Validation



- 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



Cumulative Energy Production (3 years)



Difficult to see spread in first 3 years No data to compare "actual" energy production

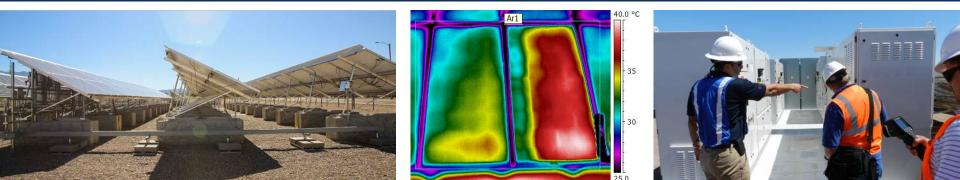
Next Steps



- 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)

Exceptional service in the national interest





Thank You

gklise@sandia.gov







Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.