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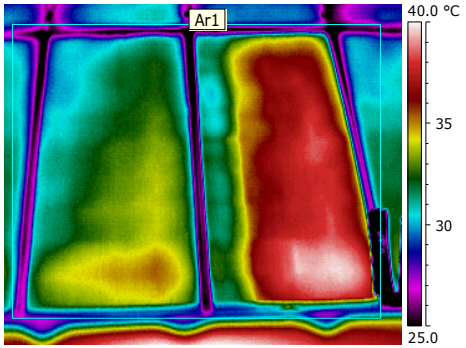

Availability and System Failure Modeling

Intersolar North America: Solar Asset Symposium

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Sandia National Laboratories
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U.S. DEPARTMENT OF ENERGY

SunShot U.S. Department of Energy

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Current Activities

- **PV Reliability Operations Model** – *A best practice for collecting operational data for reliability analysis*
  - Examples of Logistics Delays from existing data partners
  - Setting up Bill of Materials for new data partner
  - Analyzing raw performance and condition data from owner-operators – Activity starting this summer
- **System Advisor Model**
  - Energy production impacts due to failure modeling and O&M scheduling
  - Different ways to visualize DC and AC components
  - Using reliability data from our PVROM data partners, and any user with reliability data that wants to help test the beta version
- **Adding Reliability Elements to NREL O&M Cost Model**
  - Probabilistic failure elements to drive O&M planning decisions, e.g. financial exposure

Determining Logistics Delays

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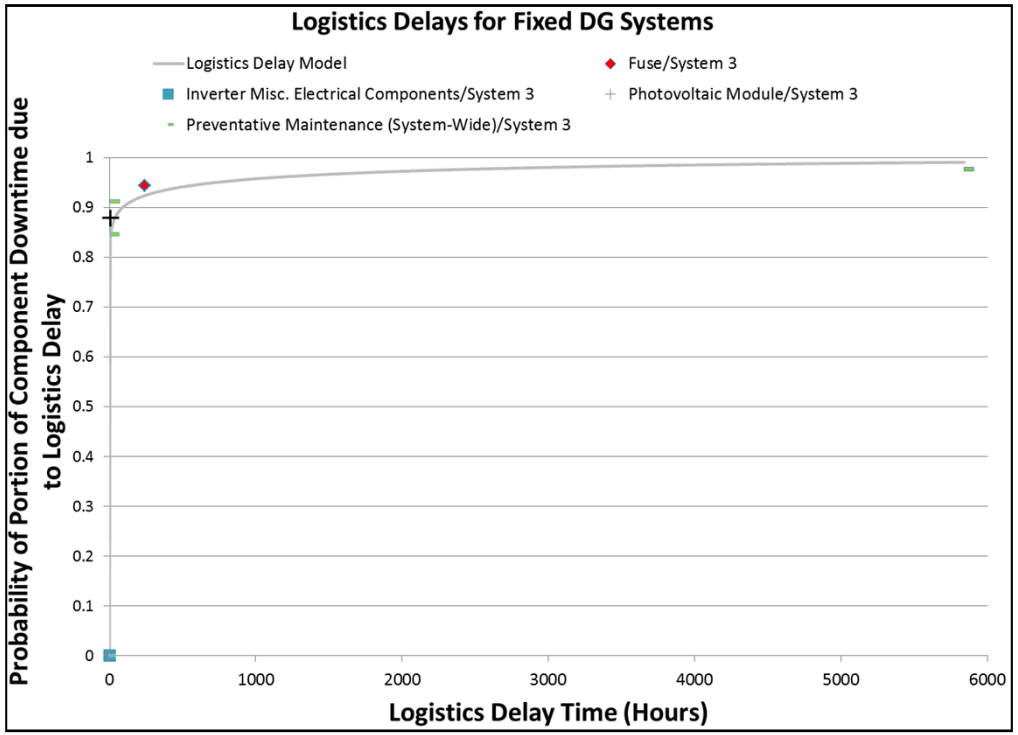
Fixed DG Sites in AZ

Number of Sites	**41**
Total Nameplate Power (MW)	**1.26**
Total Modules	**7,857**
Total Inverters	**47**
Total Line Items	**9,160**
Total Incidences	**36**
Observation Time (months)	**46**

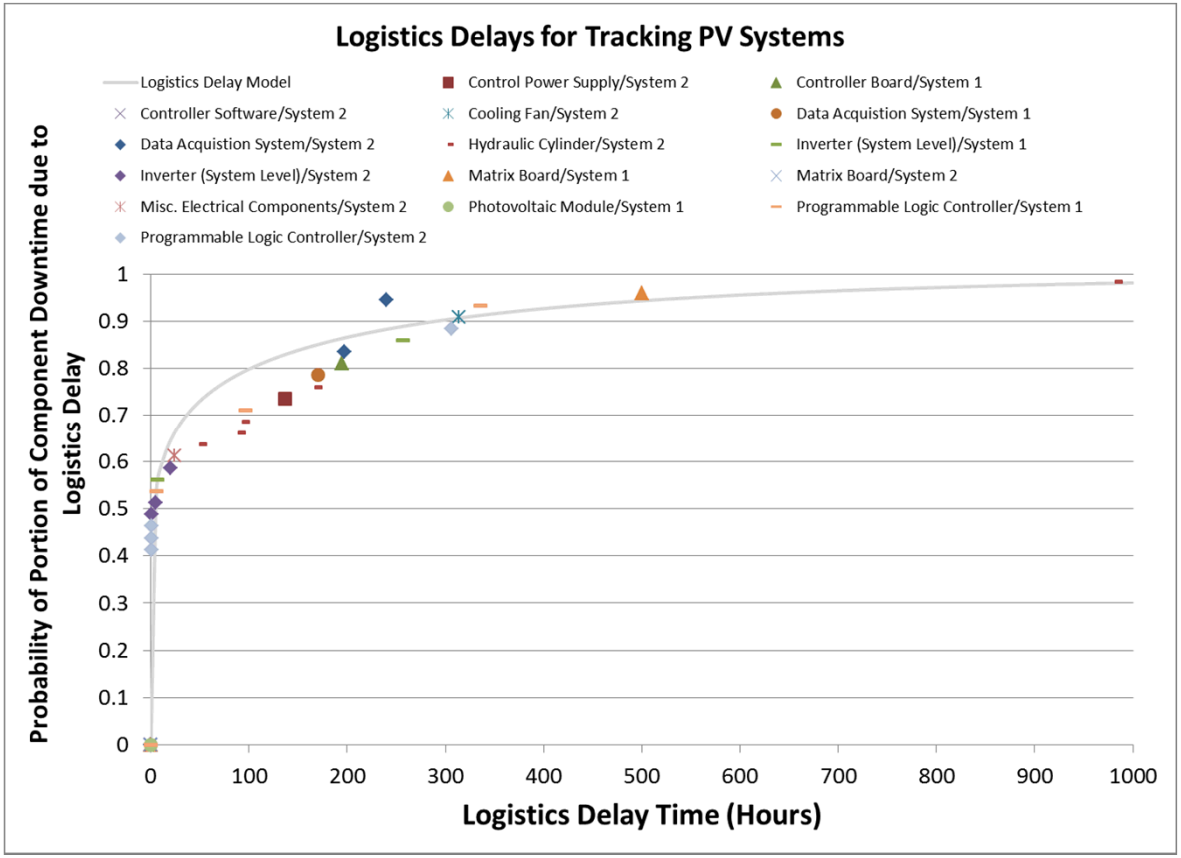


Item	Observation / Action
1. Plant Site	
a. General Cleanliness	dust
b. Animal Activity	cobwebs present
c. Vegetation	weeds ok
2. Solar Modules	
a. Inspect for Damaged Modules	ok
b. Module Cleanliness (Surface)	heavy dust
c. Inspect Wiring (Module)	ok
d. Inspect Wiring (Security)	replaced some zip-ties
3. Solar Module Support	
a. Inspect for Structural Integrity	ok
b. Inspect Bolted Connections	ok
c. Inspect Wiring (Security)	need some loop clamps
d. Concrete/Substructure Connections	ok
4. Combiner Enclosures	
a. Inspect wiring connections	ok
b. Check for Blown Fuses	PV07 blown; Array combiner 2 of 2; second fuse holder from top
c. Voc/Isc Test of Source Circuits	See Table 1 (not shown here)
5. DC/AC Disconnect Switches	
a. Inspect wiring connections	ok
b. Visual inspection of wiring	ok
c. Visual inspection of connections/Torque connections	ok, not torqued
6. Inverters	
a. General inspection/cleaning	intake screens cleaned
b. Connection and Wiring	ok, not torqued
c. Testing	no 5 minute delay after AC disconnect opened

Determining Logistics Delays

Tracking DG Sites in AZ

Number of Sites	**2**
Total Nameplate Power (MW)	**1.75**
Total Modules	**8,100**
Total Inverters	**33**
Total Line Items	**3,041**
Total Incidences	**26**
Observation Time (months)	**16**



- Helps group how different failures are responded to through maintenance activities
- When tied to energy losses and costs to cure, O&M plans can be modified

East Coast Fixed PV System

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6 MW: 3 Inverters, 20,000+ modules

- Unknown Fault Codes
- Internal inverter wiring issues
- Most down-time due to internal inverter faults

	operational days
2015	37
2016	125

Availability (time-based)		
Inverter A	**Inverter B**	**Inverter C**
84%	49%	8%
90%	91%	86%
1160	1050	925
	515	

Generation (MWh)

Lost Generation (MWh)

New Analysis: Currently Setting up Bill of Materials to match as-built and part level hierarchy. 3 levels being considered.

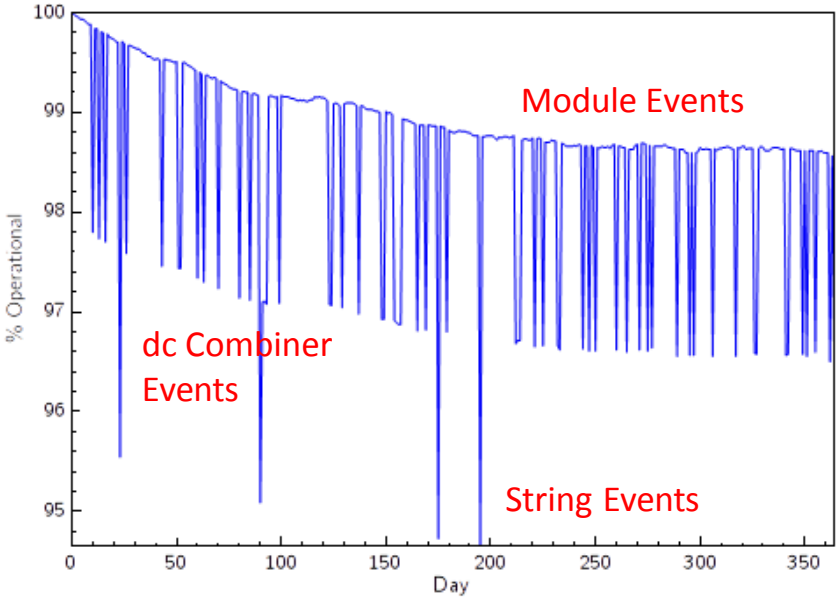
- Data partner interested in tracking inverter level items as shown in hierarchy
- Certain inverter electrical components will be grouped, but not all

Hierarchy Order	Part Number	Part Description	Notes
1	PVSYS	Photovoltaic System-Top Level	No incidents would normally be written against this category. This for organization of the hierarchy of other parts. An incident could be written for events that affected the system in a broad sense.
2	ECON	System level electrical components	This would be a "basket" part that would capture cabling, connectors, fuses, etc., that are associated with the system as whole and not associated with some other part as specified in the hierarchy. Replacement of any specific items under this part would be
2	INV	Inverter	
3	COMMB	Communication Board	
3	CTRLBD	Control Board	
3	CTRLSW	Control Software	
3	FAN	Cooling Fan	
3	ICONSM	Inverter Consumables	Coolant and oil would be under this "part"
3	IECON	Inverter level electrical components	Miscanellous electronics like the capacitors, fuses, interconnect cables, etc.
3	IGBT	Isolated Gate Bi-Polar Transistor	
3	ISTACK	Inverter Stack Electronics	Need to determine if this should be broken out more.
2	DDS	DC Disconnect Switch	
2	DCCOMB	DC Combiner Box	
3	DCCFUS	DC Combiner Box Fuses	
3	DCCSW	DC Switch	
2	STRING	PV String	No incidents would normally be written against this category. This for organization of the hierarchy of other parts. A incident could be written for events that affected the an string in a broad sense.
3	MOD	PV Module	
3	MECON	PV Module Connectors, Cables, Miscellan	This would be a "basket" part that would capture cabling, connectors, fuses, etc., that are directly associated with PV Module under a PV

Modeling Reliability and Availability

- Integration of reliability algorithms into SAM is almost complete
- Years 2 and 3 will focus on model validation, beta testing and detailed documentation

The % of dc power available for inverter input

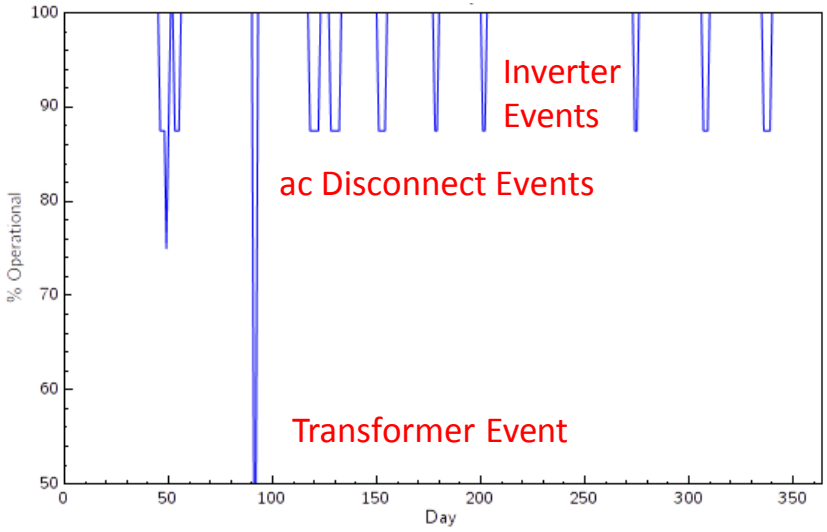


How can we better understand simulated reliability of the components?

1-year example of failures/events for 2 MW system with 8 inverters & 9,400 modules

- 379 modules fail and are not replaced
- 12 strings
- 66 dc combiner
- 7 inverter
- 4 ac disconnect
- 1 transformer

The % of ac power that can be delivered to the grid



Modeling Reliability and Availability

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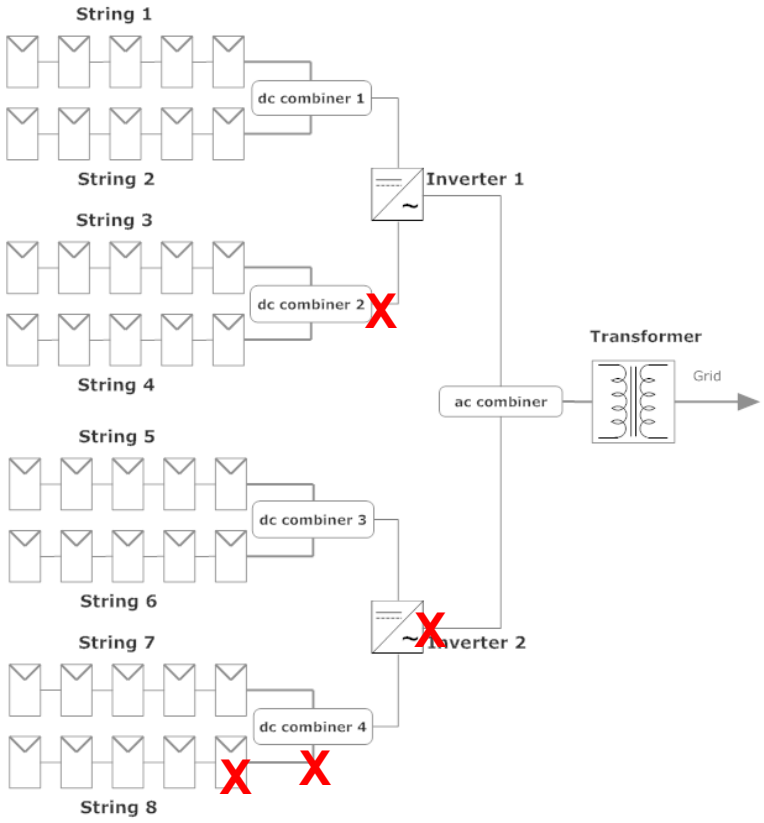
The SAM Reliability Module will have a feature to estimate component availability over simulation period

Component	Offline days (annually)	Component time-based availability
Modules	28.7	99.0
Strings	1.2	99.8
dc Combiners	12	95.0
Inverter	19.2	88.0
Transformer	0	100

$$A_{raw\_i} = 1 - \frac{DownTime_i}{TotalTime_i}$$

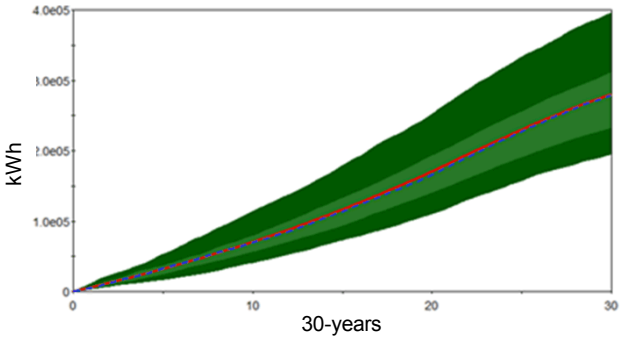
Klise and Balfour (2015) *A Best Practice for Developing Availability Guarantee Language in Photovoltaic (PV) O&M Agreements*

$$A_{raw\_sys} = \frac{\sum_{i=1}^{n} A_{raw\_i} \times NP_i}{\sum_{i=1}^{n} NP_i}$$



Estimates of energy production as a function of failure rates, including confidence intervals

Lifetime energy lost with 20 realizations



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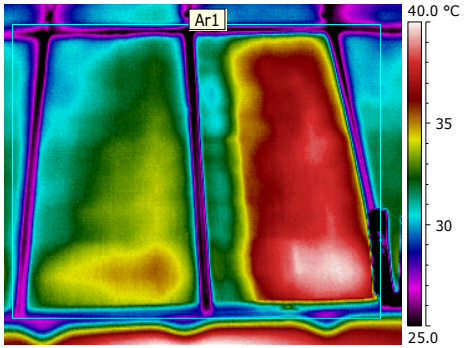

Thank You

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