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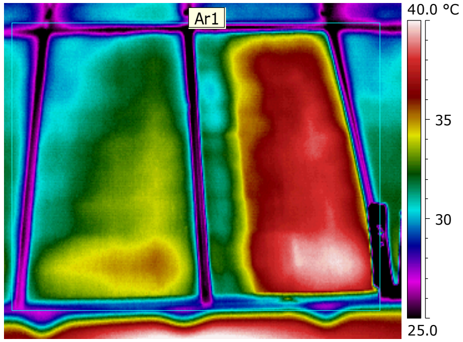

Sandia National Laboratories Photovoltaic and Grid Integration Dept. Capabilities

UVIG Solar O&M Roundtable
San Antonio, TX

Geoffrey T. Klise

October 2, 2014

U.S. DEPARTMENT OF ENERGY

SunShot U.S. Department of Energy

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Capabilities

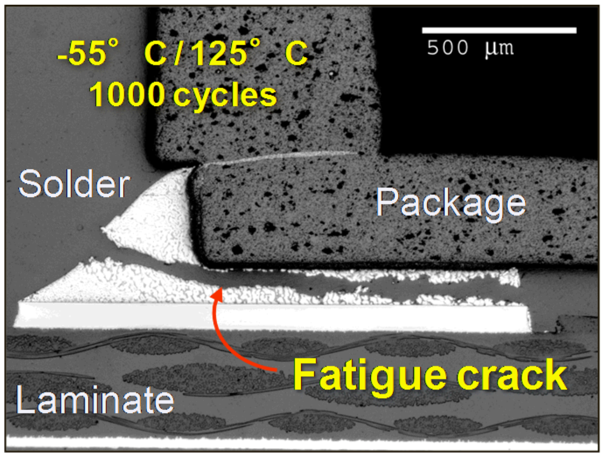
- O&M and Reliability
- Grid Integration
- Technology Validation
- *Facilities*
  - Photovoltaic Systems Evaluation Laboratory (PSEL)
  - Distributed Energy Test Laboratory (DETL)
  - Regional Test Centers (New)
    - New Mexico (at PSEL)
    - Vermont
    - Nevada
    - Florida
    - Colorado

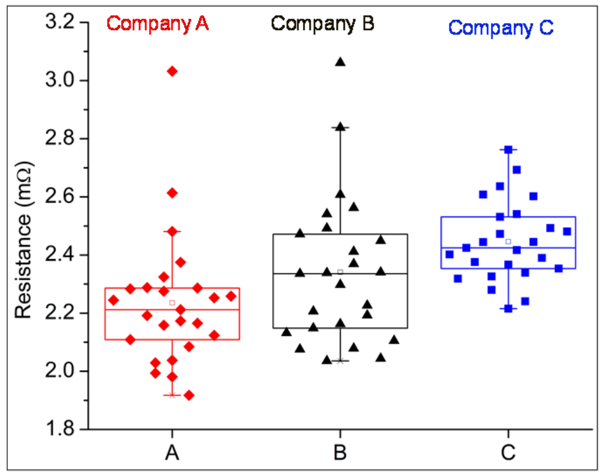
Sandia PV Reliability Program

Sandia National Laboratories

PV reliability program spans the spectrum from materials to systems

Focus on Balance of Systems (BOS)





Solder Joint Degradation

Connector Reliability

Inverter Thermal Performance

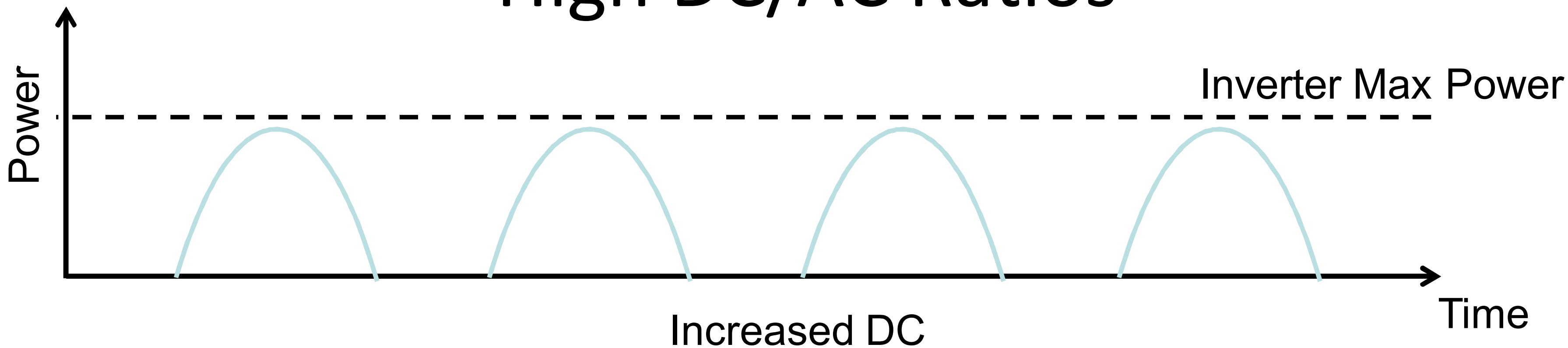
Advanced Inverter Function

Ground Fault
Arc Fault

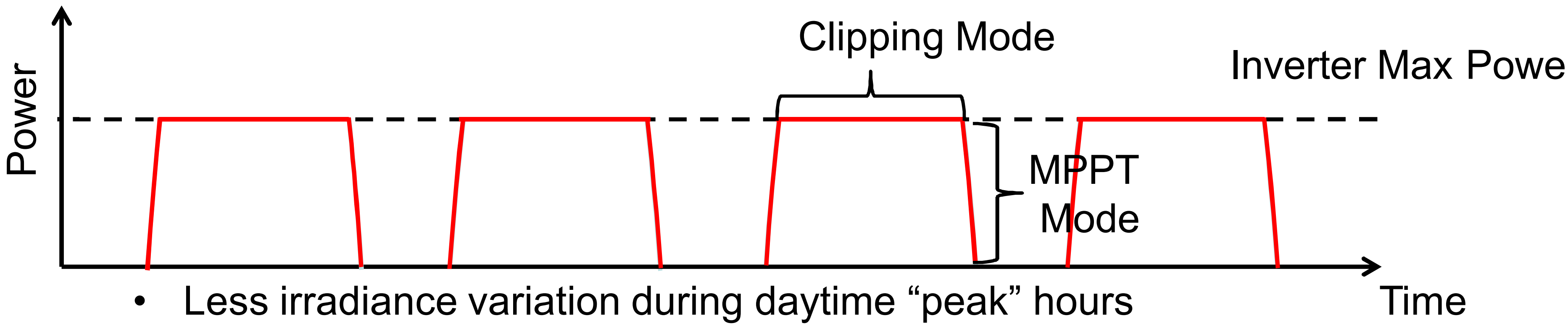
Materials — Components — Sub-system — System

Capacitor, IGBT, WBG

Future of Inverter Reliability
High DC/AC Ratios

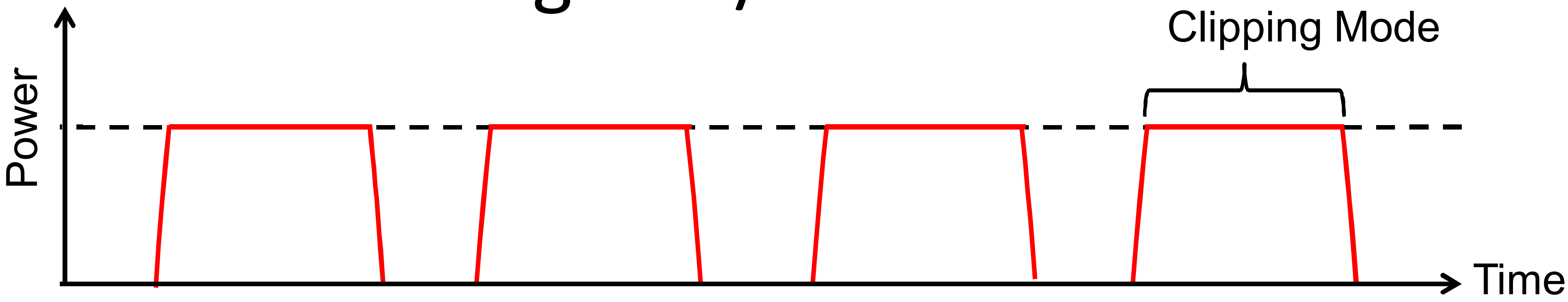


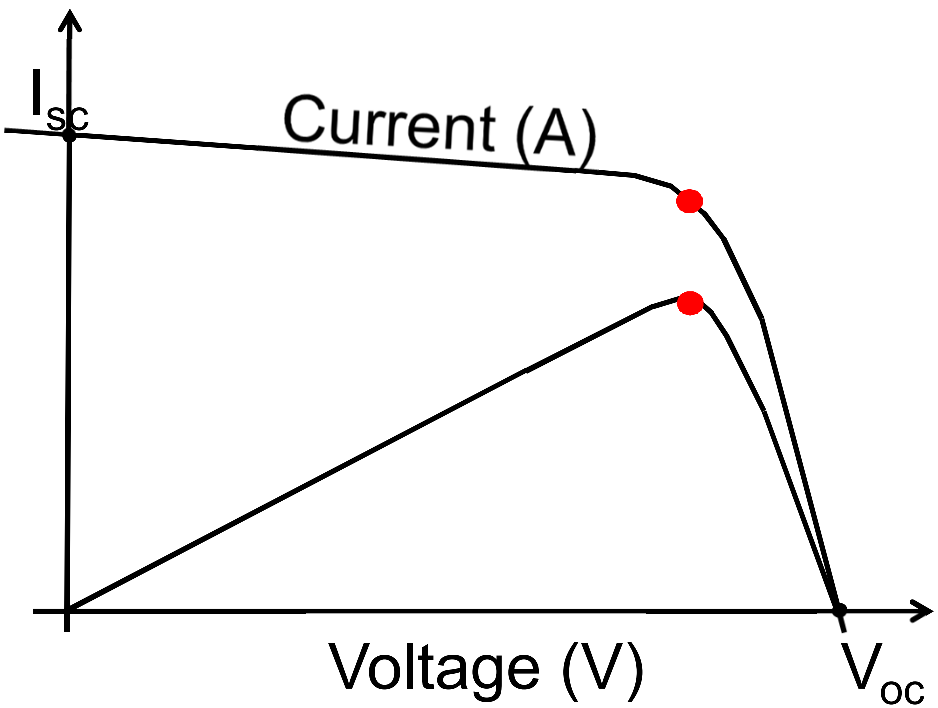
Increased DC



- Less irradiance variation during daytime "peak" hours
- Power output profile looks more like base generation

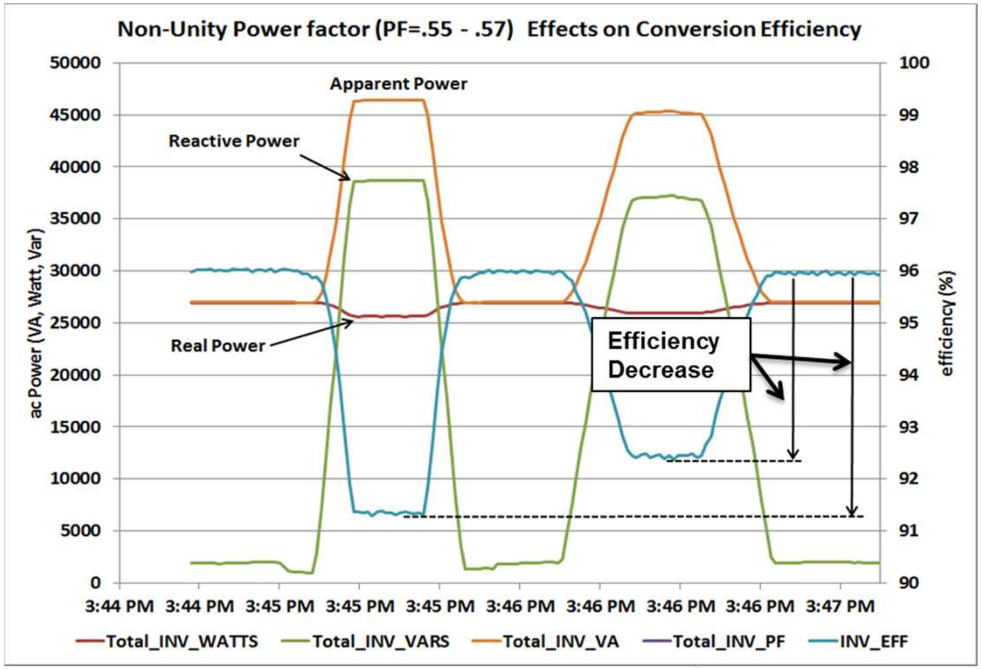
Future of Inverter Reliability
High DC/AC Ratios

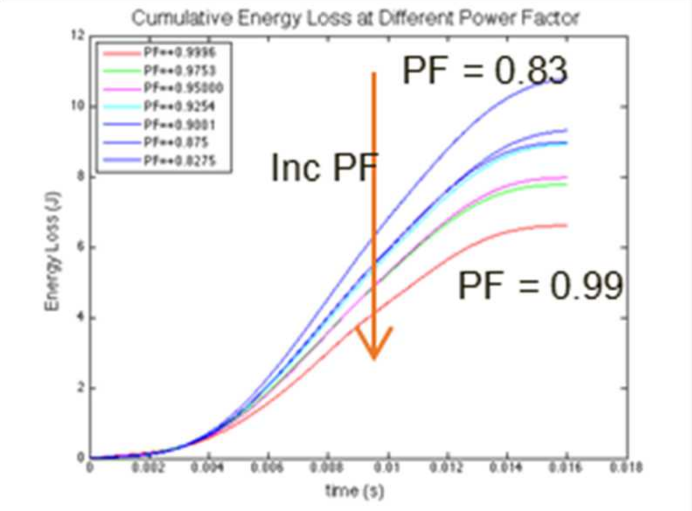




- DC/AC Ratios have been climbing in new PV installations (~125%)
- High DC/AC Ratios can be very challenging inverter reliability environments
- Inverter at maximum power, high voltage state for many hours during the day
- Lifetimes will become shorter due to high power/high voltage environments

System Level Reliability Research



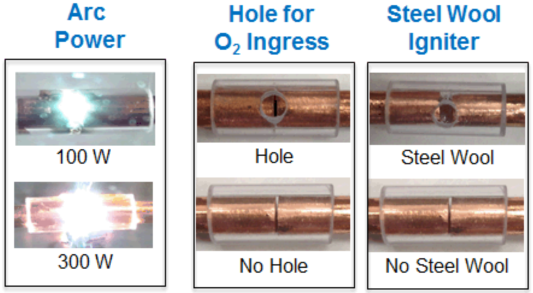


- System level measurements of advanced inverter functionality show that **operation at non-unity power factor** *decreases the real efficiency of the inverter*

- The decreased efficiency results in higher internal heating, accelerating component degradation and overall system aging

Arc-Fault Prediction Modelling

- Development of a Transient 2D FEA PV Arc-Fault Model capable of predicting electrical-thermal performance thresholds for Arc-Fault trip thresholds
- Model validation with experimental studies has been confirmed for various materials and geometries



*[1] Current UL1699B Standard

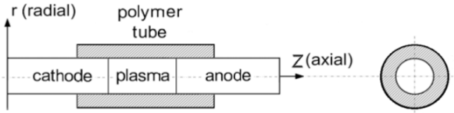
Selected Fundamental Modelling

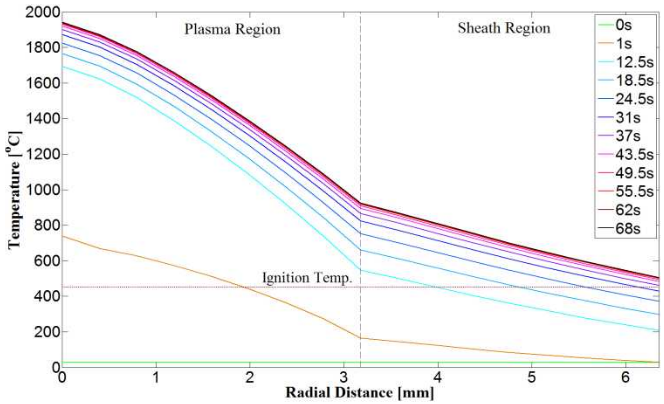
$$\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+\dot{Q}_{Plasma}=\rho C_p\frac{\partial T}{\partial t}$$

$$\dot{Q}_{Plasma}=jE-U(T)$$

$$F=j_iV_i+j_e\left(\phi_w+\frac{2k_bT}{e}\right)$$

$$j_{rich}=\xi T^2 e^{\frac{-\phi e}{k_bT}}$$





Arc Power [W]	Arc Duration Time [sec.] 0.20	0.40	0.63	0.83	1.15	1.50	2.00	4.00	6.00	8.00	10.00
100	25.79	27.03	33.06	41.94	61.23	86.90	128.03	297.40	425.27	499.96	538.53
300	25.91	28.87	40.87	58.66	98.42	153.16	242.46	556.19	694.35	743.50	760.65
500	26.05	30.78	49.15	76.87	140.46	229.68	372.76	754.14	861.42	890.81	898.93
650	26.13	32.00	54.49	88.81	168.60	280.93	455.90	846.23	936.74	958.79	964.23
900	26.27	33.99	63.38	108.97	216.57	367.08	584.86	961.27	1031.54	1046.20	1049.29
1200	26.44	36.37	74.23	133.93	276.20	470.04	719.73	1062.64	1116.78	1126.49	1128.25

Material Under Non-Destructive State
Material Undergoing Melting
Material Undergoing Fire Ignition

UL 1699B AFCI Maximum Trip Time
T_{melt} = 155°C
$T_{ignition}$ = 450°C

Improve PV System Reliability, by:

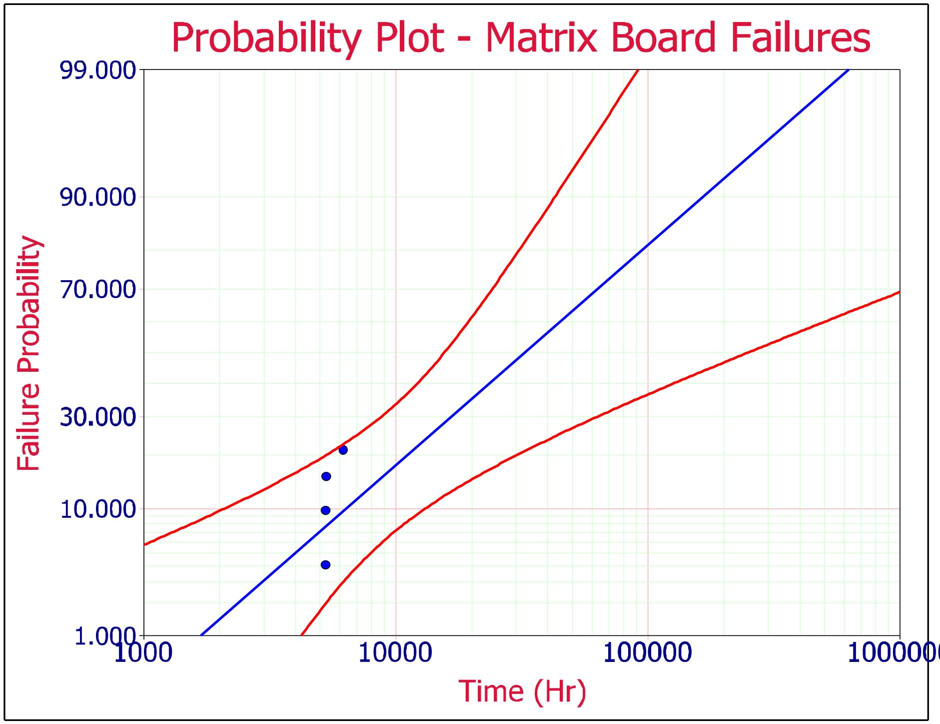
Developing PV Reliability Operations Maintenance (PVROM) *process* into a Best Practice

- Failure Reporting, Analysis, and Corrective Action (FRACAS) methodology
- Reveals reliability improvement or decline over time
- Relies on industry participation (data) to demonstrate value

Facilitating working group to tackle topics on improving PV *system* reliability

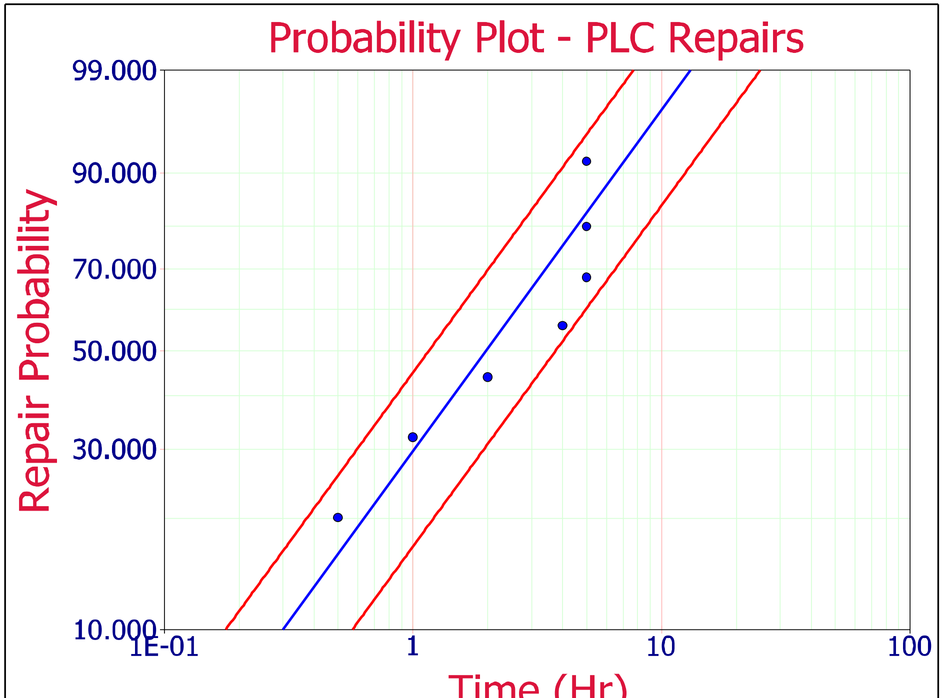
- O&M Practices and Standards – gaps analysis
- Key Performance Indicators – definitions and applications
- Availability states – Definitions and examples
- Preventative Maintenance

Prediction of O&M Performance

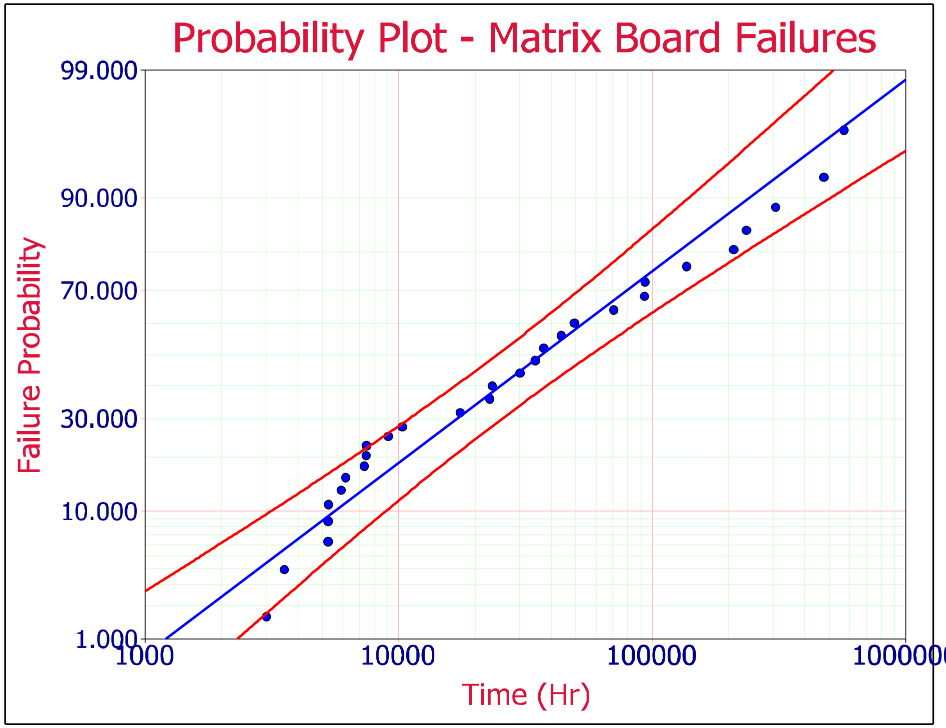


- Using the data from PVROM we can “fit” statistical models

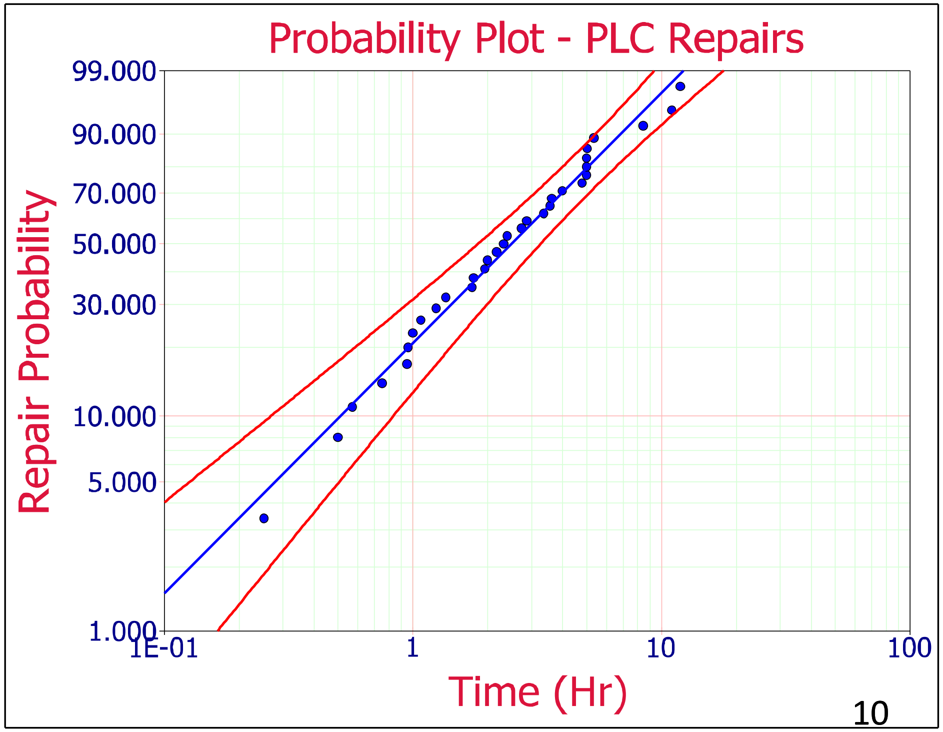
90% double-sided confidence bounds shown by red curves



Prediction of O&M Performance



- With more data, model confidence increases



Sparing Analysis

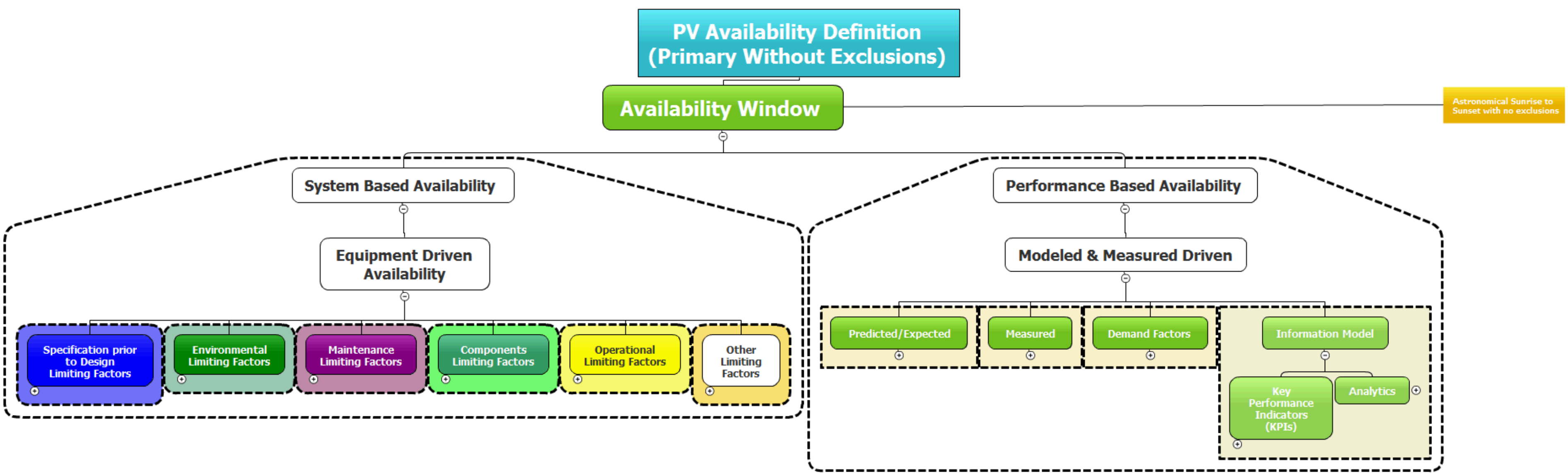
- How many spares do we need (on-site or at a depot) to ensure that we are likely not to run out?
- A risk management approach is employed
  - How many hydraulic cylinder spares should we buy to run less than a 10% risk of having no spares?

Year	Expected Number of Failures (in year)	Required Spares (for year)	Risk of Not Having a Spare
1	3.5	6	9.4%
2	18.7	23	9.4%
3	20.1	24	9.2%
4	18.4	22	9.1%
5	19.5	23	9.0%

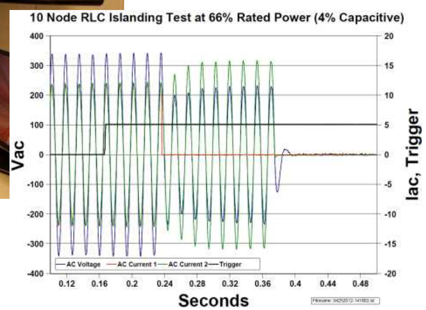
Recommended spares will vary due to the wear-out failure mode of the component in question

Availability Flow Charting

- PV system "Availability" – where reliability engineering and PV system performance meet
- Goal is to simplify and standardize Availability definition
- Sub-group is working to define terms and relationships

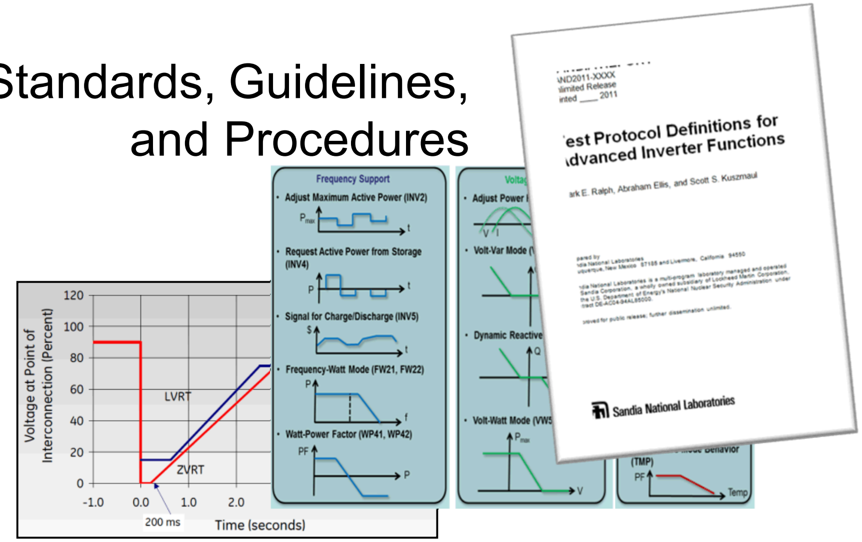


PV Grid Integration at Sandia



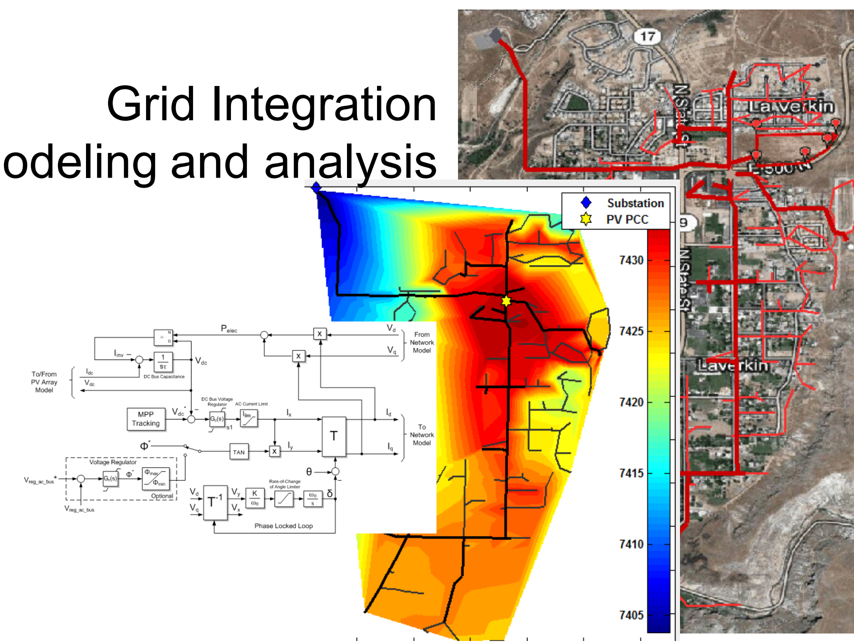
Grid compatibility characterization

Standards, Guidelines, and Procedures



Technology development and demonstration

Grid Integration modeling and analysis



Grid compatibility characterization

Facilities

PSEL & DETL

Photovoltaic Systems Evaluation Laboratory (PSEL) Mission

- Supports Sandia's DOE Program Areas
  - Emerging Technologies
  - Modeling and Analysis
  - Derates
  - Reliability
  - Regional Test Center
- Outdoor and Indoor Module Characterization Facilities
- Outdoor Small Systems Characterization
- Focus on DC measurements

Distributed Energy Test Laboratory (DETL) Array

Table 1: DETL Array Field Overview

Array #	Tech.	Strings	Modules /Str	Instl. Date	Name Plate Rating (kW)
1	a-Si	70	1	2002	3.06
2	c-Si	4	20	2004	6.00
3	mc-Si	4	22	2005	7.04
4	mc-Si	4	22	2005	7.04
5	c-Si	6	7	2005	9.31
6	c-Si	3	28	2005	7.04
7	a-Si	3	2	2006	3.26
8	c-Si	3	21	2006	7.92
9	c-Si	24	12	2008	50.50

Sandia-owned PV Array

- Approximately 95 kW. Used to test fielded performance and reliability of inverters
- Strings are reconfigurable to test various inverter sizes and configurations
- All but one system at fixed latitude tilt
- PSEL performs initial DC acceptance test, and periodic DC performance assessments
- Conducted power degradation analysis in 2008, now looking at backsheet degradation

Thank you

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