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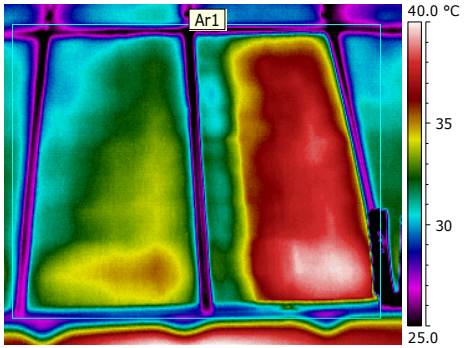

Standardizing PV O&M Practices - A Reliability Perspective

PV Operations & Maintenance USA 2014

Geoffrey T. Klise
Sandia National Laboratories
November 20, 2014

U.S. DEPARTMENT OF ENERGY

SunShot U.S. Department of Energy

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Sandia Labs R&D for Improving PV Reliability

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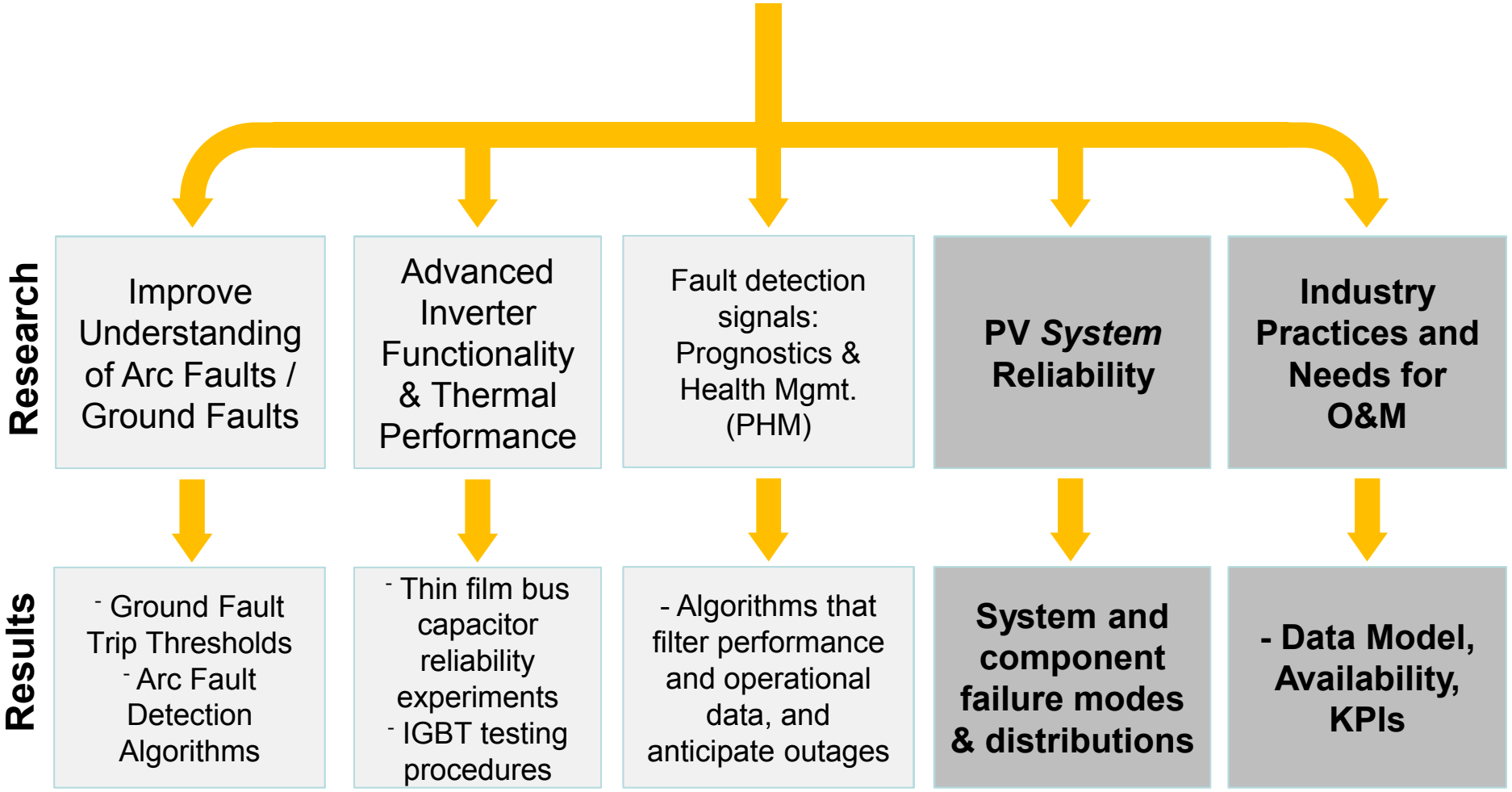
Safety | *Performance* | *Operations* | *Best Practices*



Reliability Impacts Asset Value

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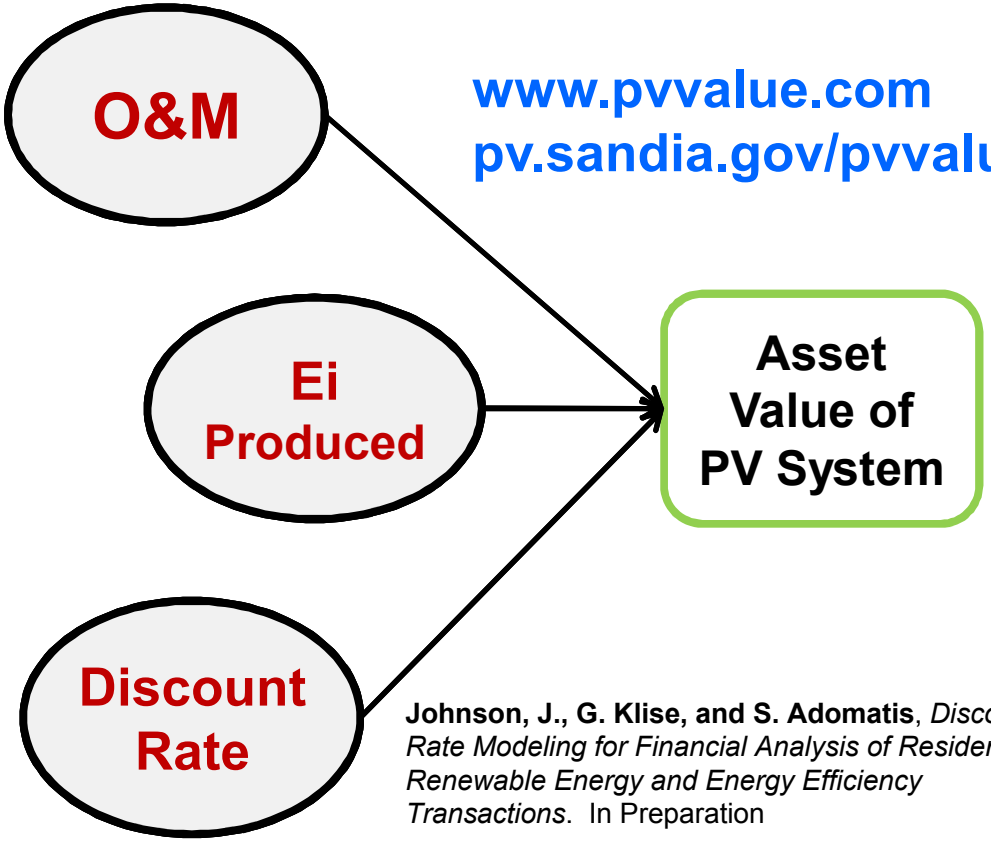
Present Value of future costs
- **Issue:** High degree of uncertainty

Present Value of anticipated energy production
- **Issue:** How much will be lost from all anticipated and unanticipated downtime

Time Value of Money
- **Issue:** What is the basis for risk free rate and risk spread? Very sensitive parameter



www.pvvalue.com
pv.sandia.gov/pvvalue

Johnson, J., G. Klise, and S. Adomatis, *Discount Rate Modeling for Financial Analysis of Residential Renewable Energy and Energy Efficiency Transactions*. In Preparation

If the performance history and reliability database reveals an underperforming asset, or one not maintained properly, the seller may have to take less and financing costs may increase

What Will Drive Quality O&M?

- There are many drivers for the PV industry to provide quality and low cost O&M
- When variable generation facilities evolve & are treated similarly to conv. generation

EPA Clean Power Plan (CPP) Proposed Rule

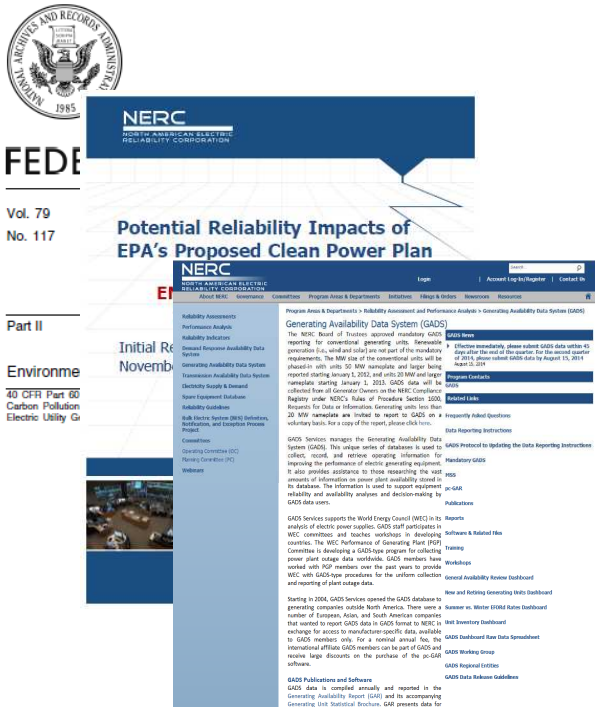
CO2 emissions to be cut 30% below 2005 levels by 2030
With reduction of 108-134 GW of coal power by 2020

NERC Reliability Compliance

"The changing resource mix introduces changes to operations and expected behaviors of the system; therefore, more transmission and new operating procedures may be needed to maintain reliability."

NERC BES reporting > 75 MVA & > 100 kV interconnection

NERC GADS reporting for wind is now "voluntary." Will that change? What about PV?



"In regards to solar energy, a task force is currently assessing the proper method for data collection and reporting. A separate report outlining the voluntary data reporting instructions will be drafted in the future." ***NERC GADS FAQs 8/2014***

What are the O&M Gaps?

- **First, existing efforts documented that fill real gaps identified by industry**
- **Second, Identify the Standards and Best Practices Gaps as they relate to O&M activities**
- **Areas being addressed by Sandia**
  - Fault and Failure Data Collecting and Analysis
    - *"PV Reliability Operations Maintenance (PVROM) Process"* Data collection and analysis
  - Availability definition - deconstruction
  - Information Model for Availability, KPIs, Faults and Failures
  - Preventative Maintenance Best Practices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SAND2014-19432
Unlimited Release
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Solar PV O&M Standards and Best Practices – Existing Gaps and Improvement Efforts

Geoffrey T. Klise – Sandia National Laboratories
John R. Balfour – High Performance PV
T.J. Keating – SunSpec Alliance

Prepared by
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Albuquerque, New Mexico 87185 and Livermore, California 94550

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What are the O&M Gaps?

- **First, existing efforts documented that fill real gaps identified by industry**
- **Second, Identify the Standards and Best Practices Gaps as they relate to O&M activities**
- **Areas that still need attention:**
  - Homologized Standards
  - Job tasks and training programs for O&M practitioners
  - Specification with O&M focus – guidance document
  - Consistency for the insurance and finance industries – long-term cost and equipment performance trends


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Best Practice for Fault & Failure Analysis

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PVROM data covers ~36MW spanning 38 sites

- California (5), Arizona (32) and Pennsylvania (1)
  - Larger systems a mixture of thin-film technology
  - Smaller systems are all crystalline
  - Some inverters under warranty, others not covered by warranty

What is the O&M Challenge?

- Understanding how and when components in a system fail
- When failure modes known, when to perform preventative maintenance
- How to develop sparing strategy so part is on hand or can be delivered quickly, when it is known to, or anticipated to fail
- Reveal new failure modes with newer system architecture

PVROM Analysis - Example

1st analysis, 6 years of ~5 MW PV plant in Arizona

- ***Non-repairable*** **failure distribution parameters**

Component	Distribution	1st Model Parameter	2nd Model Parameter
AC Disconnect Switch	Lognormal	$\mu = 7.048$	$\sigma = 3.863$
Photovoltaic Modules	Weibull	$\beta = 0.825$	$\eta = 4.498 \times 10^{6}$
480/34.5 kV Transformer	Weibull	$\beta = 0.668$	$\eta = 2{,}554$

Notes: β (Shape Parameter of Weibull Distribution), η (Characteristic Life of Weibull Distribution), μ (log-geometric mean of the Lognormal Distribution), σ (log-geometric standard deviation of the Lognormal Distribution). Model parameters based on time metric of **days**.

- ***Repairable*** **failure distribution parameters**

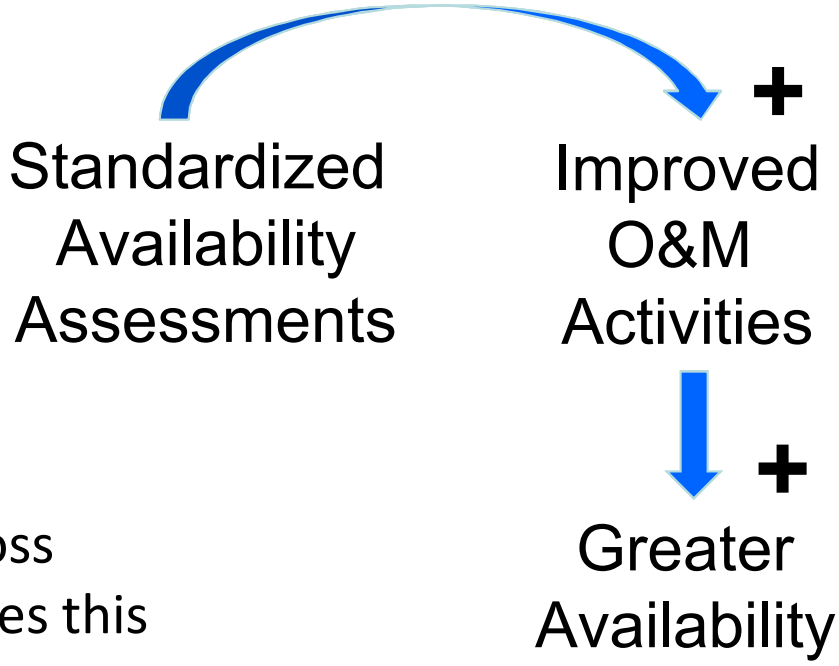
Component	Beta (Shape)	Lambda (Scale)
DC Disconnect Switch	0.470	0.0496
Array Electrical Connections	1.239	3.486×10^{-5}
Inverter – Corrective and Preventative Maintenance	1.029	2.264×10^{-3}
Inverter - Induced Outages	1.041	4.799×10^{-3}

Availability

How does a better understanding of Availability improve O&M and vice-versa, how does better O&M improve Availability?

What Is Available?

- Equipment?
- Energy?
- Equipment impacts to energy production?
- Is it necessary to have a standard definition and/or equation?
- Evidence of different equations across many different O&M contracts? Does this necessitate standardization?
- Has different meaning to each stakeholder



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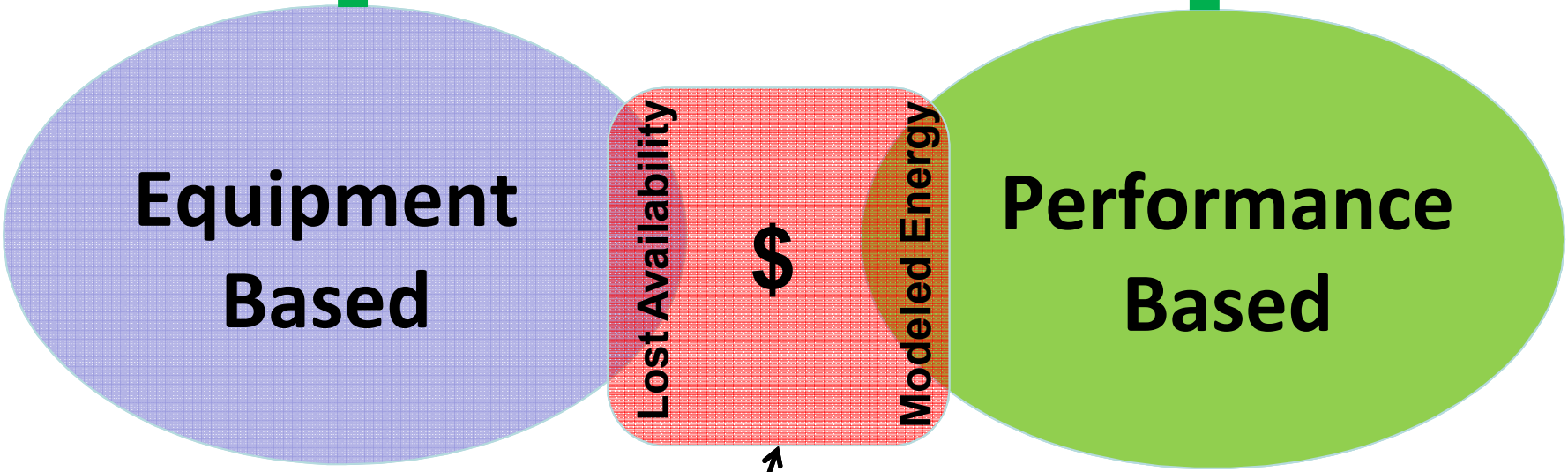
A Sandia-facilitated working group is **developing a flowchart** and eventual **guidance document** of both **equipment** and **non-equipment** impacts to Availability

Availability Guarantee

~99% range

Performance Guarantee

~100% range



Availability penalty:

- Measured Avail. < Guaranteed Avail. (function of inverter hours)
- Where the two metrics meet (in some cases)

Performance penalty is function of energy value and performance difference

Availability Guarantee

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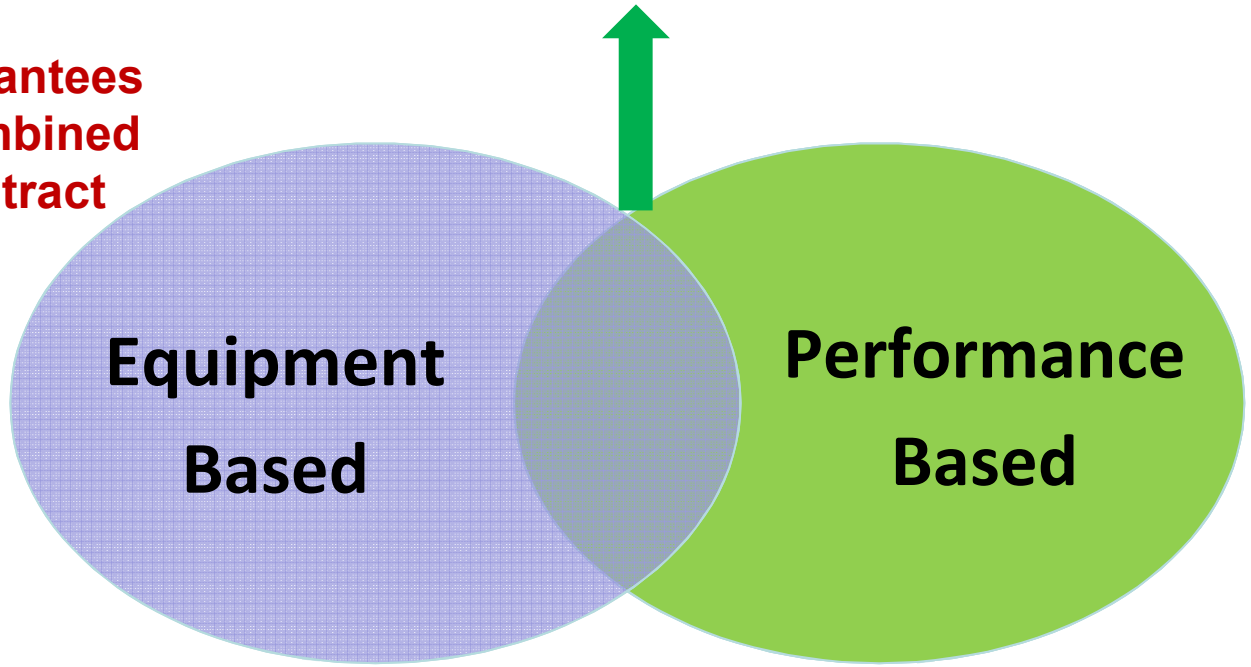
These guarantees may be combined in O&M contract



Equipment availability is buried in performance calculations as a function of kWh produced

Availability Differences

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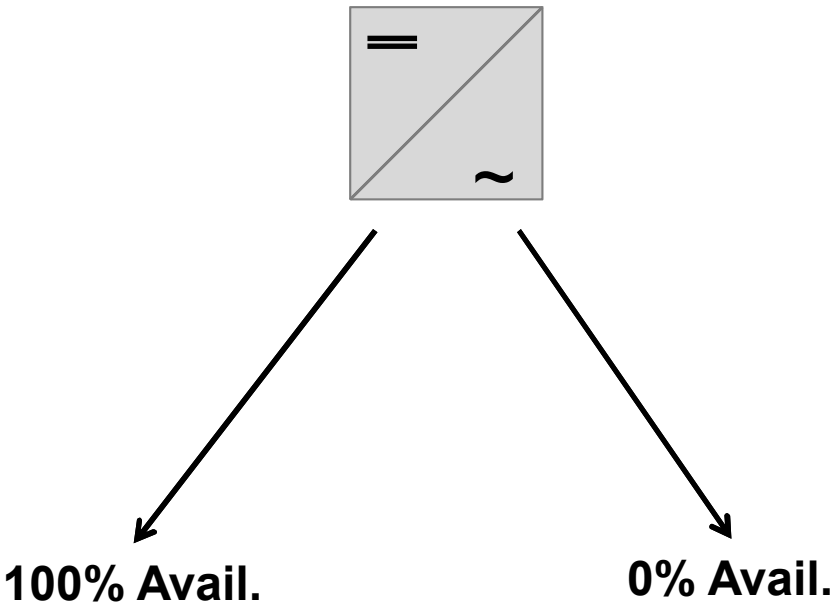
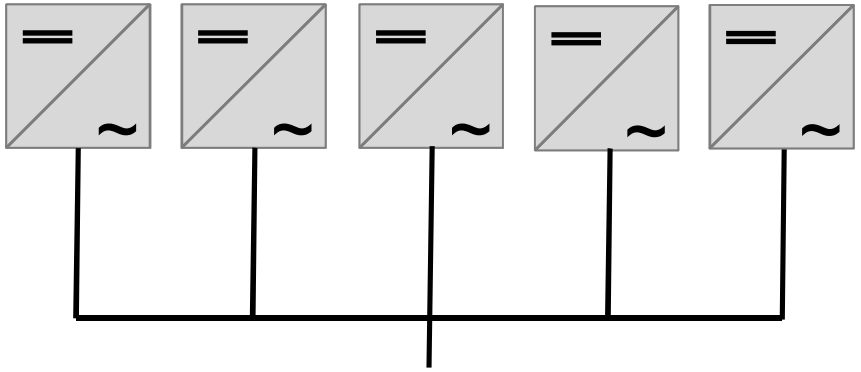
Single Inverter



Multiple Central or String Inverters



All Inverters Operating 100% Available

- Fault covered by warranty, Force Majeure event, or O&M provider, outlined in O&M contract
- No “partial” Availability

Availability Differences

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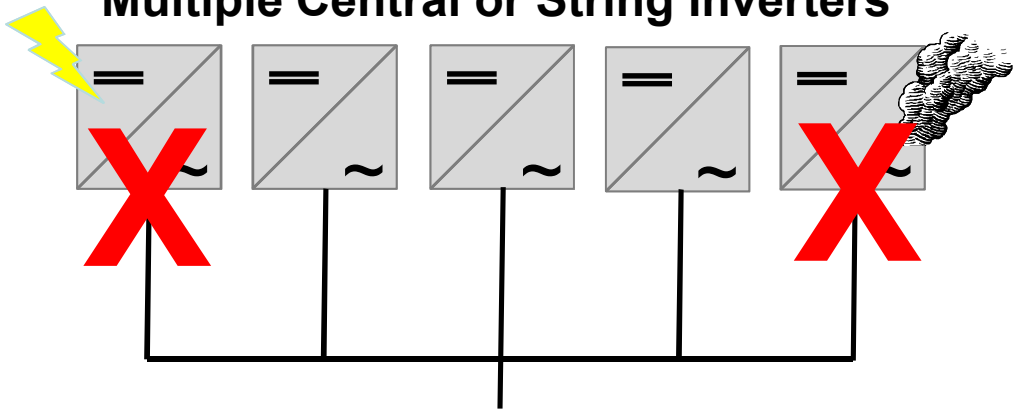
Single Inverter

100% Avail.

0% Avail.

- Fault covered by warranty, Force Majeure event, or O&M provider, outlined in O&M contract
- No "partial" Availability

Multiple Central or String Inverters



4 / 5

4 of 4 Operating **100% Avail.**

4 of 5 Operating **80% Avail.**

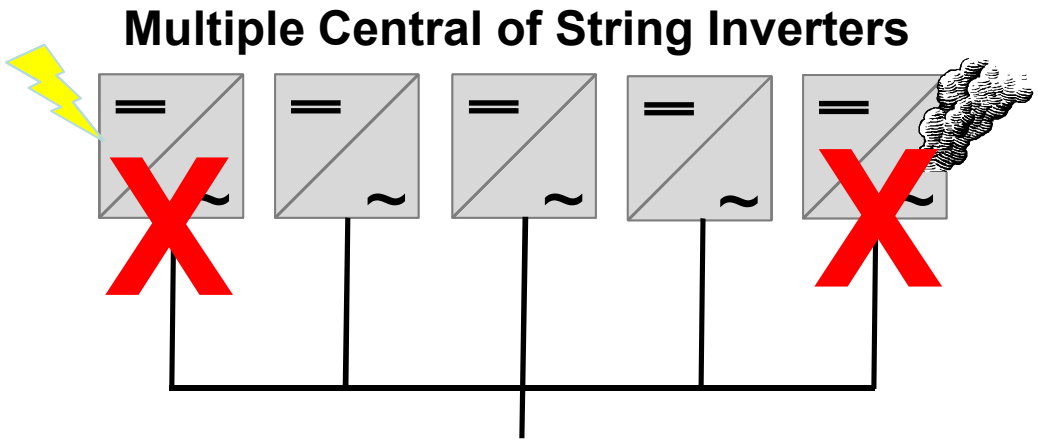
Temporary derate,

- **Force Majeure, or**
- **Warranty issue**

No Temp. derate:

- **Assigned to O&M provider time**

Hypothetical NERC Reporting



4 / 5

4 of 5 Operating 80% Avail.

Unplanned Outage Factor, Unavailability Factor, others… System Operator notification

4 of 4 Operating 100% Avail.

- Temporary derate, due to:
  - Force Majeure, or
  - Warranty issue

4 of 5 Operating 80% Avail.

No Temp. derate:

- Assigned to O&M provider time

Information Model

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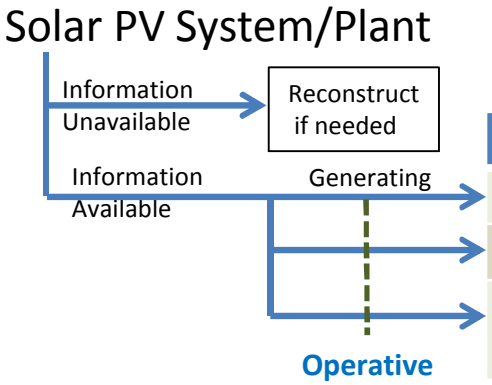
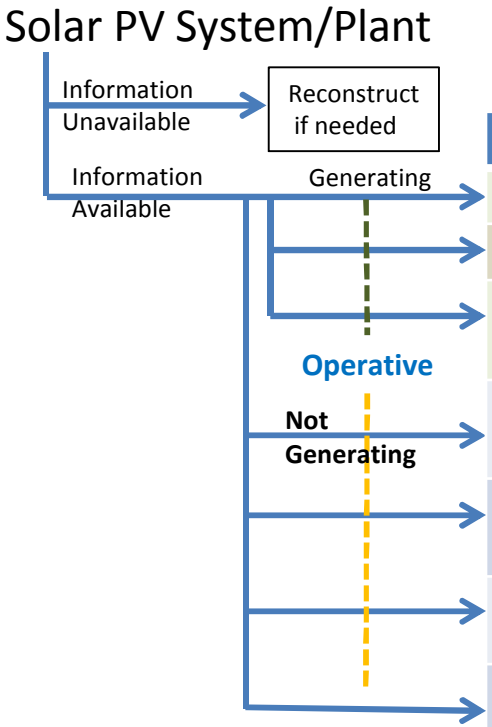
Condition State	Example
Full performance	Function with no limits or restrictions
Partial performance	Functioning with limitations and/or restrictions
Technical standby	Temporarily nonfunctioning due to controlled and/or predefined tasks required - e.g. self-testing, ramp-up
Out of environment spec	Operative but not functioning as the environment is out of design specs
Requested shutdown	Operative but stopped by an external request-i.e. curtailment
Out of electrical spec	Operative but not functioning as the electrical parameters are out of design specs - i.e. grid outage
Scheduled maintenance	Scheduled maintenance prevents system components for performing the intended functions
Planned corrective action	Actions required to retain, restore, or improve the intended functions that are not part of normal scheduled maintenance
Forced outage	Action taken as unforeseen damage, faults, failures or alarms are detected
Suspended	Activities in SCHEDULED MAINTENANCE, PLANNED CORRECTIVE ACTION and FORCED OUTAGE are interrupted or cannot be initiated due personal safety or equipment integrity - e.g. extreme weather
Force Majeure	Extraordinary event or circumstance beyond the control of the parties, prevents the parties from fulfilling their obligations

Information Model



Condition State	Example
Full performance	Production Reporting
Partial performance	
"Throttled" Production	

Information Model



Condition State	Example
Full performance	Function with no limits or restrictions
Partial performance	Functioning with limitations and/or restrictions
"Throttled" Production	Clipped Inverter operation to limit maximum power or broaden production "shoulders." This needs further consideration.
Technical standby	Out of Control States
Out of environment spec	
Requested shutdown	
Out of electrical spec	

Information Model

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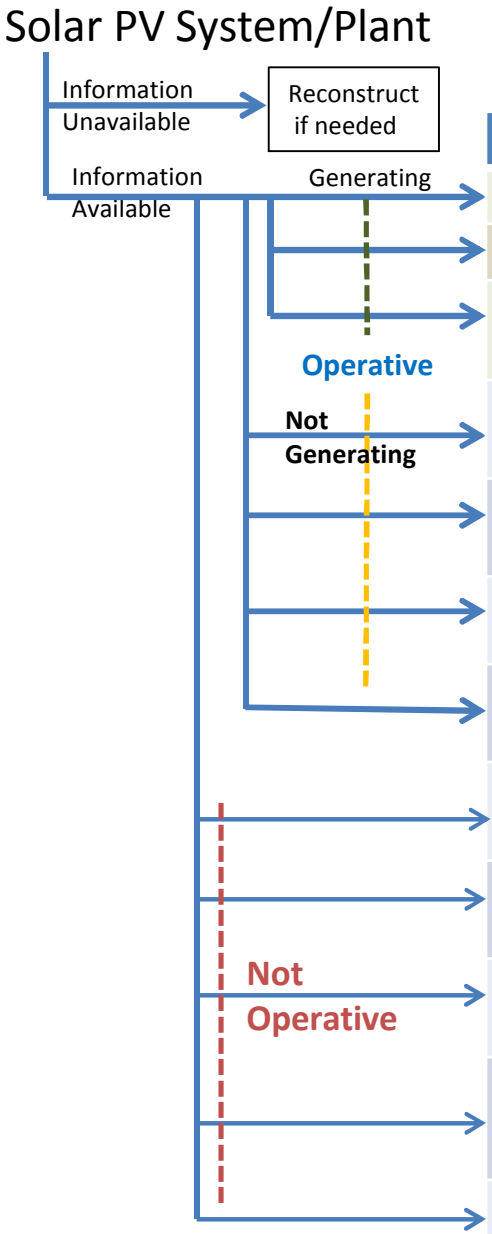

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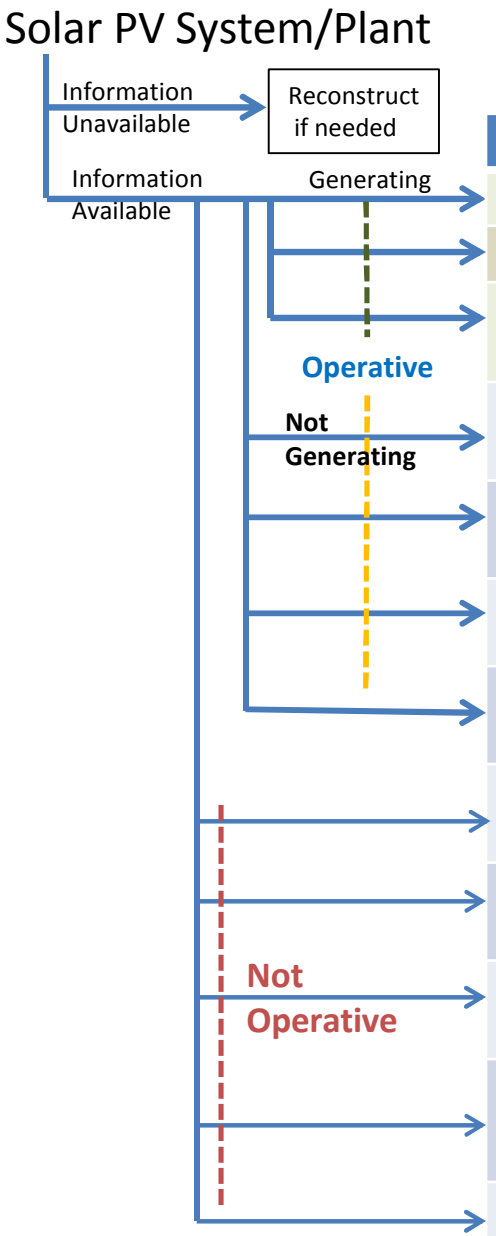
Out of electrical spec	Operative but not functioning as the electrical parameters are out of design specs - i.e. grid outage
Scheduled maintenance	Maintenance and Failure States
Planned corrective action	
Forced outage	
Suspended	Out of Control States
Force Majeure	

Information Model



Condition State	Measured Time Impacts to PV Plant – Energy Impacts
Condition State	Measured Time Impacts to PV Plant
Condition State	Measured Time for External Caused Event
Full performance	Production Reporting
Partial performance	
"Throttled" Production	
Technical standby	Out of Control States
Out of environment spec	
Requested shutdown	
Out of electrical spec	
Scheduled maintenance	Maintenance and Failure States
Planned corrective action	
Forced outage	
Suspended	Out of Control States
Force Majeure	

Remaining Availability Issues

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- **Sunup and sunrise changes throughout the year**
  - Set irradiance amounts need to consider multiple factors including near and far shading
- **High DC to AC Ratio.** It may create an incentive to limit O&M activities based on contract incentives
  - Less frequent preventative and reactive maintenance activities,
  - which can turn into an O&M Issue that will may impact PV system availability
- **Storage may help with some of the "Equipment Availability" impacts to power performance**
  - Power available through short-term faults and failures
  - Allow for longer operational time. Changes sunrise to sunset irradiance thresholds
  - Greater reliability from NERC standpoint

Remaining Availability Issues

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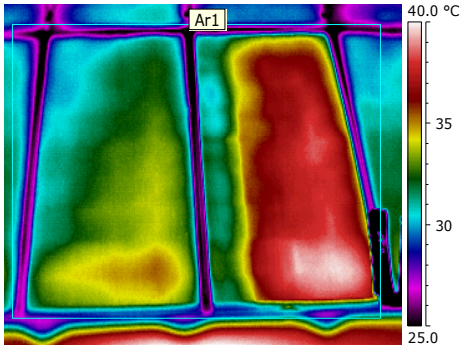
- **Case for separating Equipment/Operational Availability and Performance Guarantees**
  - Insufficient irradiance (clouds, high wind leading to stow) could create problems when weather is integrated with equipment
  - There is no standard that says any predictive model should have any degree of accuracy or validation. How do you know your plant is either underperforming, or your model is bad?
  - These types of scenarios reveal impacts to O&M service provider based on performance models they may not have control over



Thank You

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