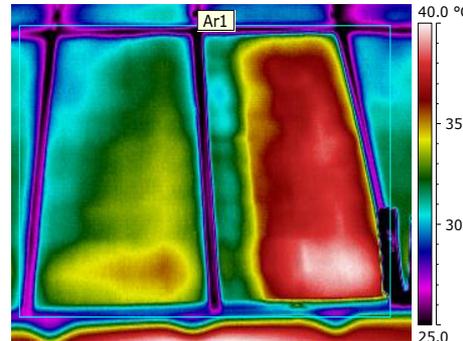


Exceptional service in the national interest



SAM Webinars 2017: PV Reliability Performance Model in SAM

Geoff Klise – Sandia National Laboratories
Janine Freeman – National Renewable Energy Laboratory

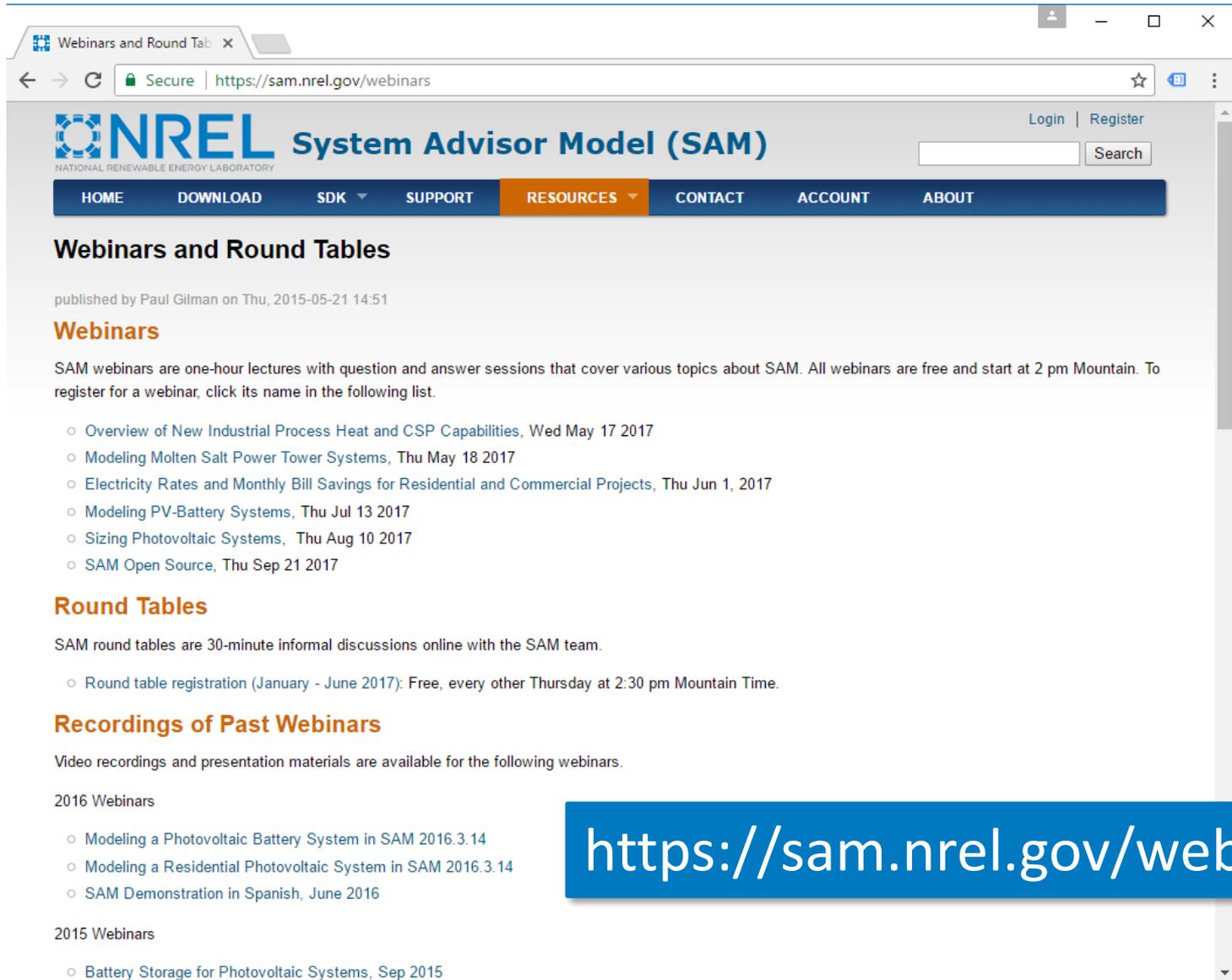
December 7, 2017
SAND2017-13406 TR

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We will post a recording of this webinar on the SAM website



The screenshot shows a web browser window displaying the NREL System Advisor Model (SAM) website. The browser's address bar shows the URL <https://sam.nrel.gov/webinars>. The website header includes the NREL logo, the text "System Advisor Model (SAM)", and a search bar. A navigation menu contains links for HOME, DOWNLOAD, SDK, SUPPORT, RESOURCES, CONTACT, ACCOUNT, and ABOUT. The main content area is titled "Webinars and Round Tables" and includes a publication date: "published by Paul Gilman on Thu, 2015-05-21 14:51".

Webinars

SAM webinars are one-hour lectures with question and answer sessions that cover various topics about SAM. All webinars are free and start at 2 pm Mountain. To register for a webinar, click its name in the following list.

- Overview of New Industrial Process Heat and CSP Capabilities, Wed May 17 2017
- Modeling Molten Salt Power Tower Systems, Thu May 18 2017
- Electricity Rates and Monthly Bill Savings for Residential and Commercial Projects, Thu Jun 1, 2017
- Modeling PV-Battery Systems, Thu Jul 13 2017
- Sizing Photovoltaic Systems, Thu Aug 10 2017
- SAM Open Source, Thu Sep 21 2017

Round Tables

SAM round tables are 30-minute informal discussions online with the SAM team.

- Round table registration (January - June 2017): Free, every other Thursday at 2:30 pm Mountain Time.

Recordings of Past Webinars

Video recordings and presentation materials are available for the following webinars.

2016 Webinars

- Modeling a Photovoltaic Battery System in SAM 2016.3.14
- Modeling a Residential Photovoltaic System in SAM 2016.3.14
- SAM Demonstration in Spanish, June 2016

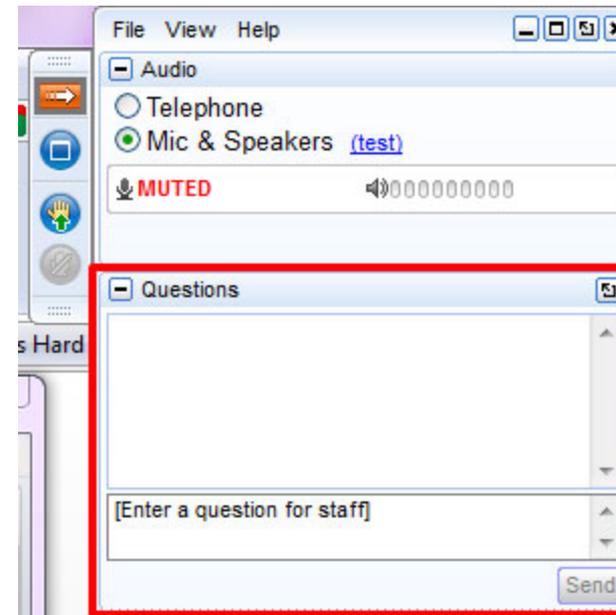
2015 Webinars

- Battery Storage for Photovoltaic Systems, Sep 2015

<https://sam.nrel.gov/webinars>

If you have a question or comment:

- Type it in the Questions box.
- Click the “Raise hand” button.
- We may unmute your phone so you can ask your question or follow up.



Outline

- Introduction
- What is PV-RPM and why would I use it?
- Setting up a simulation
- Demonstration
- Analyzing Results
- References

What is PV-RPM and why would I use it?

The screenshot shows the PV-RPM (Photovoltaic Reliability Performance Model) software interface. The top navigation bar includes 'Modeling Dashboard', 'Failure Modes Dashboard', and 'Results Dashboard'. The main section is titled 'failure modes dashboard' and is divided into 'Model Inputs' and 'Inverter Inputs'.

Model Inputs:

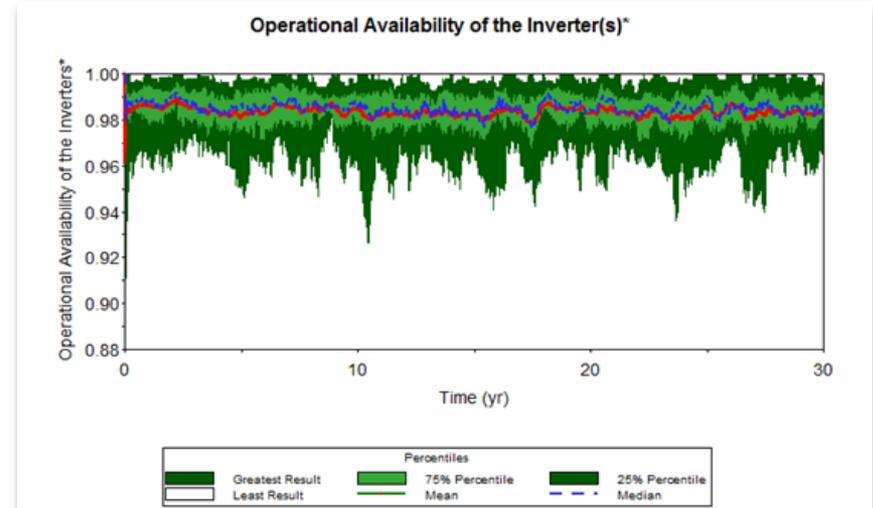
- Module Failure Rates:** Includes options for 'Use Poisson Failure Mode' (checked) and 'Use the Bathub Curve'. The 'Poisson Failure Rate' is set to 0.1. 'Define the Bathub Curve' has parameters: $\lambda = 20$, $\mu = 0.5$, $\sigma = 25$, and $\rho = 4$.
- Module Repair Times:** Mean is 30 days, std. dev. is 14 days. There is a 'Module Repair Time' button.
- Module Degradation Rates:** Includes options for 'Use the same module degradation rate every realization' and 'Sample the module degradation rate every realization'. The 'Module degradation rate (1/yr)' is set to 0. Parameters for the triangular distribution are: $\mu = 0.1$ (1/yr minimum) and $\mu = 0.2$ (1/yr maximum).

Inverter Inputs:

- Inverter Failure Rates:** Describes inverter failures as random events. The 'Triangular Distribution for the inverter failure rate' has parameters: $\mu = 1$ (minimum value), $\mu = 2$ (most likely value), and $\mu = 4$ (maximum value).
- Inverter Repair Times:** Mean is 7 days, std. dev. is 3 days. There is an 'Inverter Repair Time' button.

A green checkmark icon and text at the bottom indicate: 'If the Model Settings and the Failure Modes Dashboards settings have been completed, proceed to the Results Dashboard to run the simulation >>'.

- 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)

What is PV-RPM and why would I use it?

- Are you interested in how the failure of the following components impact power production, maintenance costs and LCOE?
 - Module
 - String
 - DC Combiner
 - Inverter
 - AC Disconnect
 - Transformer
 - Tracker
 - External Grid Impacts

Setting up a simulation

Where to download PV-RPM for SAM

<https://sam.nrel.gov/pvrpm>

NREL System Advisor Model (SAM)

HOME DOWNLOAD SDK SUPPORT **RESOURCES** CONTACT ACCOUNT ABOUT

Photovoltaic Reliability Performance Model (PV-RPM v2.0 Beta)

published by Paul Gilman on Fri, 2017-09-01 14:32

What is it:

Sandia National Laboratories (SNL) and National Renewable Energy Laboratory (NREL) have partnered to bring you this public Beta version of the PV Reliability Performance Model Version 2.0 (PV-RPM v2.0) that can be run from the LK scripting environment within SAM. This new feature is provided in SAM to allow users with reliability data the ability to develop and run scenarios where PV performance and costs are impacted from components that can fail stochastically.

The PV-RPM model was initially developed in 2010 by SNL as a proof-of-concept for better simulating the uncertainty when components experience faults or failures in a fielded PV system. As the events occur randomly, they can be represented as a probability distribution with specific parameters to define the severity of the event and when it may occur over a specific time-frame. Repairs or replacements are also represented with probability distributions, where the component remains in a failed state until the repair distribution is sampled and results in the component being returned to an operating state. In 2016, SNL partnered with NREL to move the PV-RPM algorithms from the proof-of-concept platform into SAM, via the LK scripting environment. Doing this allows users to see how the code works and gives them the ability to modify the code for their own purposes.

The code is available in SAM through an open-source license, with copyright asserted from the DOE Solar Energy Technologies Office on 12/16/2016. The copyright language can be found within each of the SAM LK script files.

To use it:

Please download the **zip file (ZIP 2.7 MB)** and read the included user manual for instructions on how to use PV-RPM v2.0 Beta.

Important notes:

- This feature runs on the **Windows platform ONLY**
- This feature is **not supported** by the SAM Support email address, please use the email address below for questions and problems!

Feedback, comments, and questions:

This model and instructions are still in a Beta release, so you should expect imperfections, bugs, and room for improvement. Please email Geoff Klise, the project lead at Sandia National Laboratories, with any questions, comments, bug reports, or suggestions. We value your feedback!

Tags: Photovoltaic

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Extract Compressed (Zipped) Folders

Select a Destination and Extract Files

Files will be extracted to this folder:
C:\Users\gklise\Documents\PVRPM_beta

Show extracted files when complete

PVRPM_beta

Name	Date modified	Type
PVRPM_beta	12/5/2017 4:02 PM	File folder

PVRPM_beta

Name	Date modified	Type
confidence_interval.xlsx	12/5/2017 4:02 PM	Microsoft Excel
PVRPM_Function.lk	12/5/2017 4:02 PM	LK File
PVRPM_Main_Script.lk	12/5/2017 4:02 PM	LK File
SAM_PVRPM_Beta_instructions_7_07_17v...	12/5/2017 4:02 PM	Adobe Acrobat
sample_small_project.sam	12/5/2017 4:02 PM	System Advisor

PVRPM_beta

Name	Date modified	Type
PVRPM_Results	12/5/2017 4:16 PM	File folder
confidence_interval.xlsx	12/5/2017 4:02 PM	Microsoft Excel W...
PVRPM_Function.lk	12/5/2017 4:02 PM	LK File
PVRPM_Main_Script.lk	12/5/2017 4:16 PM	LK File
SAM_PVRPM_Beta_instructions_7_07_17v...	12/5/2017 4:02 PM	Adobe Acrobat D...
sample_small_project.sam	12/5/2017 4:02 PM	System Advisor M...

Default system parameters for PV-RPM

Table 2 – Small system input parameters

Model Input Steps	User Choice
Location and Resource	
<i>TMY</i>	USA AZ Phoenix (TMY2)
<i>Albedo – Sky Diffuse Model - Irradiance</i>	0.2 / Perez / DNI and DHI
Module (CEC database)	
<i>Manufacturer and Model</i>	SunPower SPR-X21-355-BLK
<i>Temperature Correction</i>	NOCT
Inverter (CEC database)	
<i>Manufacturer and Model</i>	SMA America: SB3800TL-US-22 (240V) CEC 2013
System Design (4 kWdc)	
<i>Modules per String</i>	6
<i>Strings in Parallel</i>	4
<i>Number of Inverters</i>	2
<i>Tracking</i>	Fixed
<i>Tilt (deg)</i>	20
<i>Azimuth (deg)</i>	180
<i>Ground Coverage Ratio</i>	0.3
Shading	None
Losses (Only Subarray 1)	
<i>Irradiance - Soiling</i>	5% for each month
<i>Module Mismatch</i>	2%
<i>Diodes and Connections</i>	0.5%
<i>DC Wiring</i>	2%
<i>AC Wiring</i>	1%
Lifetime	PV simulation over analysis period
<i>Module Degradation Rate</i>	0% ⁱ
<i>Enable lifetime daily DC Losses</i>	Check Box Not Selected ⁱ
<i>Enable lifetime daily AC Losses</i>	Check Box Not Selected ⁱ
Financial Parameters	
<i>Analysis period</i> ⁱⁱ	5 years

i – this will be defined in the script and discussed in a later section.

ii - Even though there are no loan, tax, insurance or salvage costs analyzed by the PV-RPM model, the analysis period needs to be set on this page, and the financial parameters chosen will affect SAM's calculation of the LCOE.

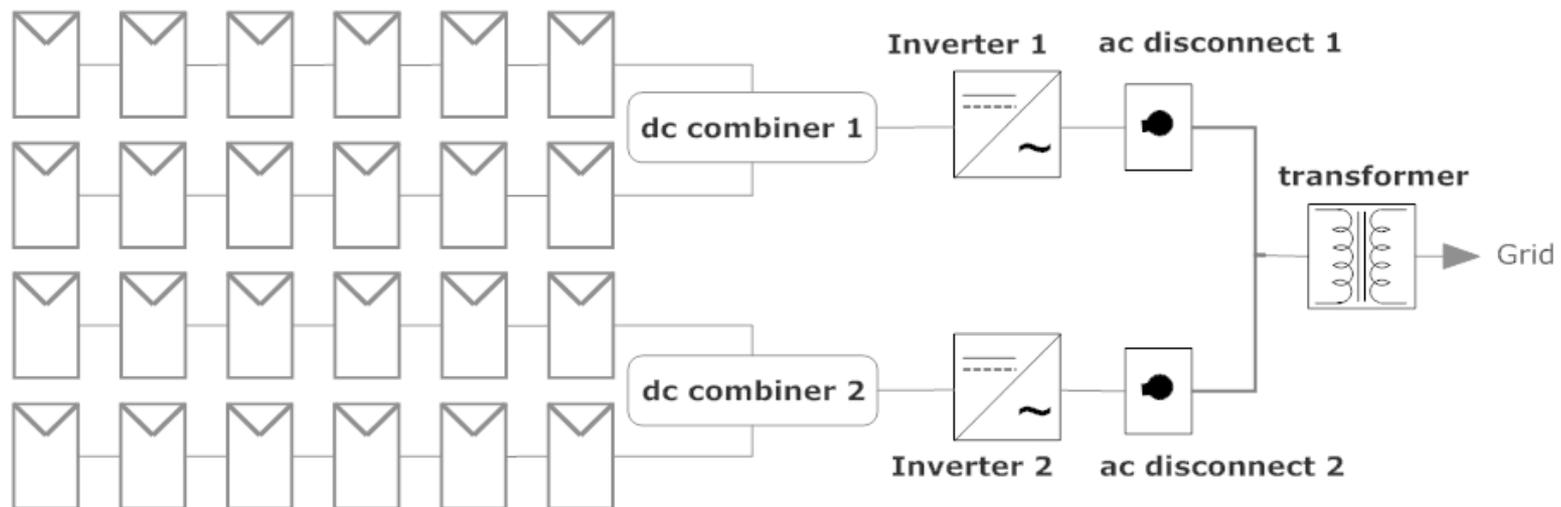
Layout of default PV system

Defined in main SAM window

- # of modules
- Modules per string
- Strings in parallel
- # of inverters

Defined in LK “Main Script”

- # of combiners
- # of transformers
- # of trackers
- Calculated AC disconnect – 1 per inverter



Probability distributions used in SAM

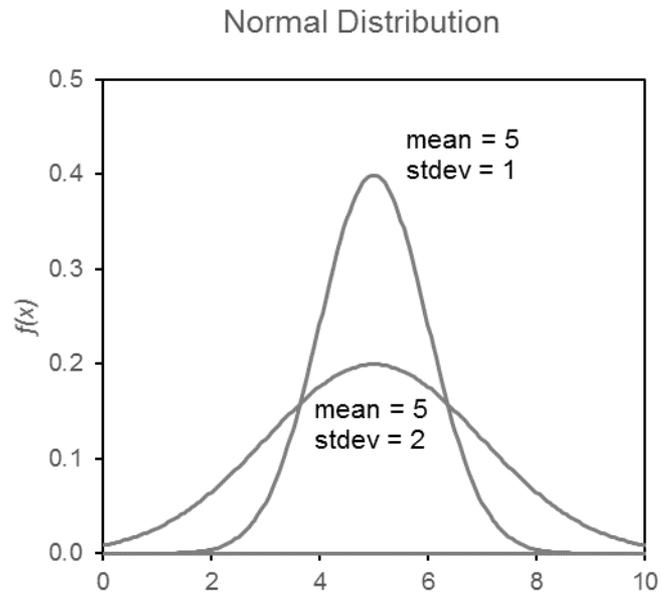
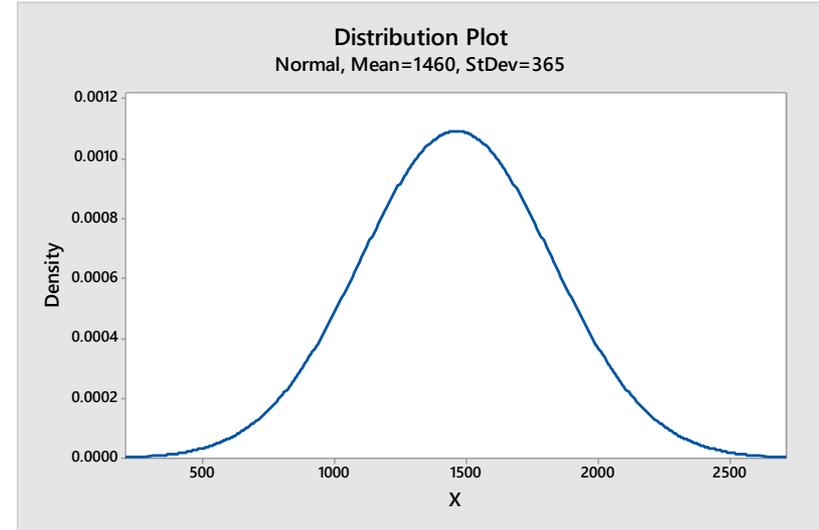
Table 1 – SAM LHS available distributions

Distribution	First Parameter	Second Parameter	Third Parameter
Uniform	Min	Max	
Normal	Mean (μ)	Std. Dev. (σ)	
Lognormal*	Mean	Std. Dev.	
Lognormal-N	Mean	Std. Dev.	
Triangular	A	B	C
Gamma	Alpha	Beta	
Poisson	Lambda		
Binomial	P	N	
Exponential	Lambda		
Weibull	Alpha or k (shape)	Beta or Lambda (scale)	

*The Sandia LHS library included in SAM requires mean and error factor inputs into lognormal function. The Lognormal-N function requires the mean and standard deviation of the UNDERLYING normal distribution. However, we anticipate that most users will have the mean and standard deviation of the actual lognormal distribution. Therefore, the LHS function implemented in the PV-RPM script translates from input mean and standard deviation to the error factor before calling the lognormal LHS function. The translation equations used can be found at <https://dakota.sandia.gov/content/latest-reference-manual>, Keywords>Variables>lognormal_uncertain.

Distribution Examples

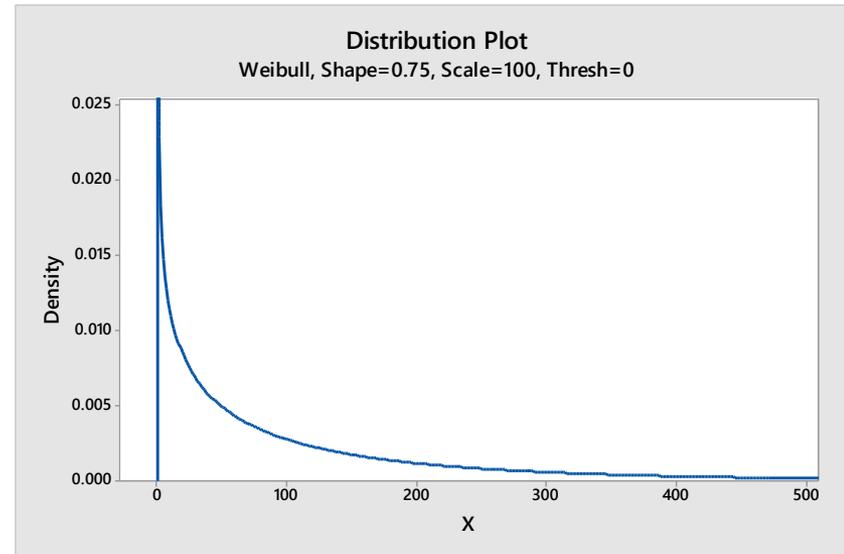
```
//failure mode 1: normal failures  
meta.module.failure[0].distribution = 'normal';  
meta.module.failure[0].parameters = [4 * 365, 1 * 365];  
//mean, std, years converted to days
```



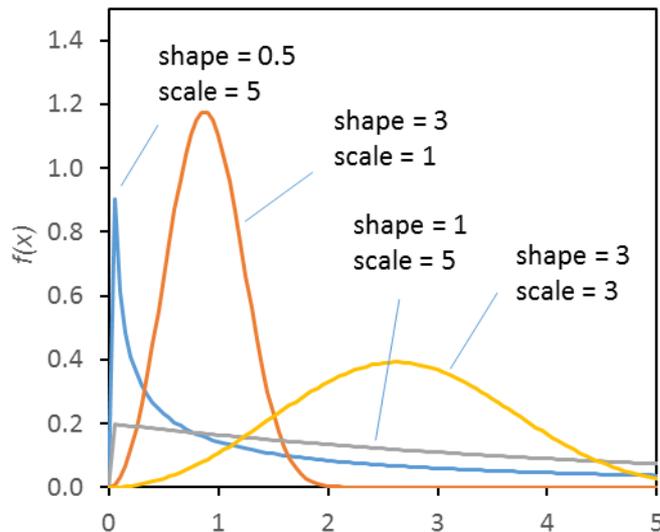
Distribution Examples

//grid failures

```
meta.grid.failure[0].distribution = 'weibull';  
meta.grid.failure[0].parameters = [0.75, 100]; //slope  
(shape factor)- unitless, mean- days
```



2-Parameter Weibull Distribution

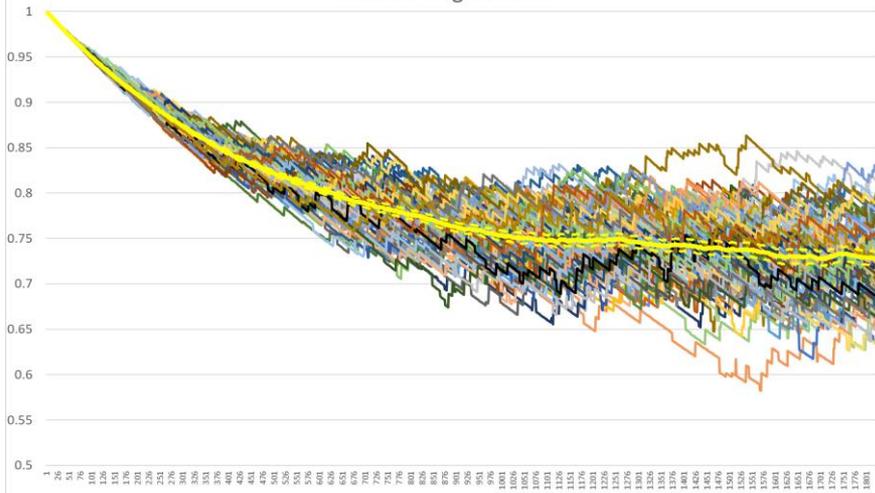


Demonstration

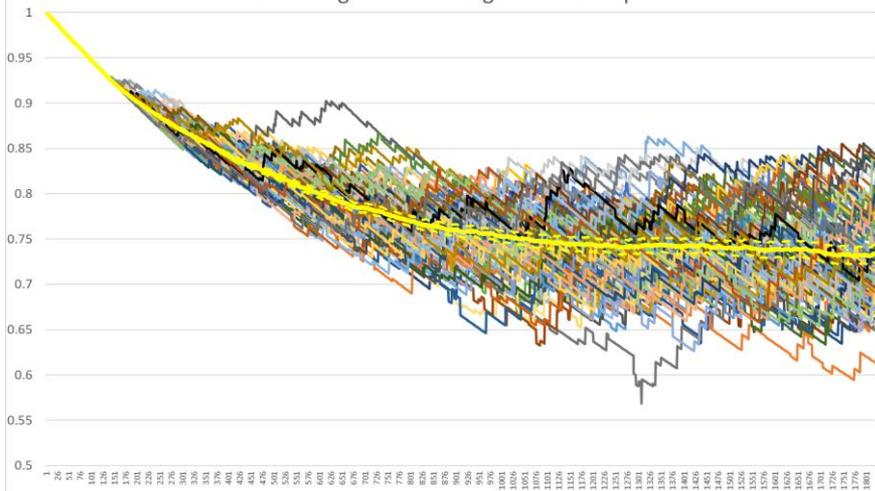
Analyzing Results

Degradation Analysis – accelerated example

100 realizations - 5 years:
Module Degradation



100 realizations - 5 years:
Module Degradation - longer wait for repair



20% module degradation rate, 5-year analysis with 100 realizations on base 4 kW (24 module) system.

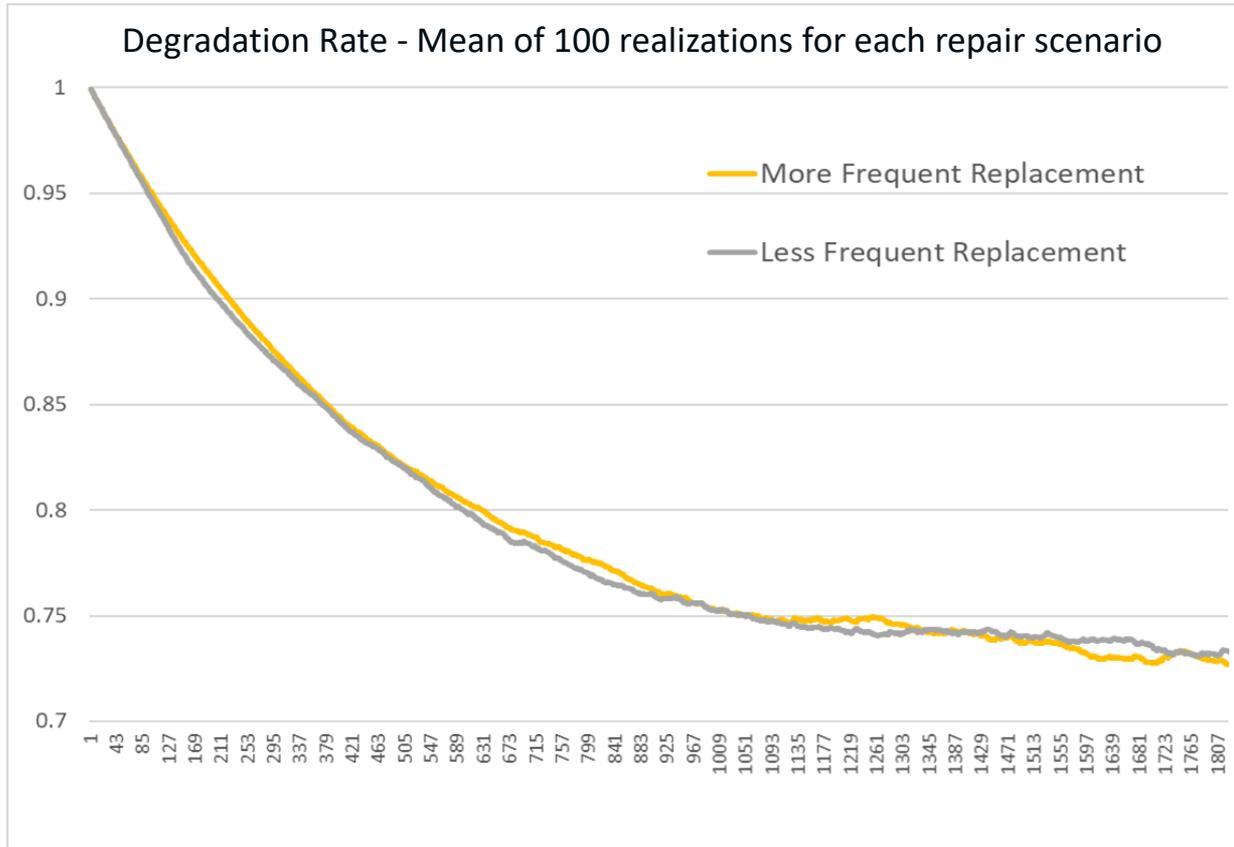
- Default “lognormal” *repair* distribution for modules. Two failure distributions, one ‘normal’ (increasing failure rate), and one ‘exponential’ (constant failure rate).
- Mean (60), Standard Deviation (20) [days]

Plot shows Mean of 100 realizations plus upper and lower 95% confidence interval

- Changed repair distribution for modules
- Mean (200), Standard Deviation (20) [days]

Plot shows Mean of 100 realizations plus upper and lower 95% confidence interval

Degradation Analysis – accelerated example



More frequent replacement:

- Mean of 48 module failures over 5 years
- Mean Availability 0.93

Less frequent replacement:

- Mean of 57 module failures over 5 years
- Mean Availability 0.73

References

- User manual – available in PV-RPM download
- <https://sam.nrel.gov/pvrpm>
- Sandia PV-RPM validation report
<http://energy.sandia.gov/download/41153/>
- PV-RPM three system comparison (proof-of-concept)
http://energy.sandia.gov/wp-content/gallery/uploads/SAND2012-10342_final.pdf
- Reliability and Availability study (proof-of-concept)
<http://energy.sandia.gov/download/20994/>

Thank you

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www.nrel.gov

