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Photovoltaic System Reliability & Maintainability Data Collection and Analysis Using a FRACAS Tool

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Problem Statement

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- Collect, organize, and analyze large amounts of data for numerous operational photovoltaic systems
- Implement an efficient tool for data collection and organization
- Example: A photovoltaic generating facility can be composed of thousands of modules and infrastructure components

Data Requirements for Reliability & Availability Analysis

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- Data collected from an operating system is censored data
  - Not all components have failures, a mixture of failures and suspensions (right censored data)
  - Exact time of failure for some components may not be known (interval or left censored data)
- Minimum Data Required for Photovoltaic Generating Systems
  - Times to failure or times to suspension for all components
  - All sources of downtime
    - Restoration times for all repairs/replacement
    - Preventive maintenance times
      - Upgrades
      - Inspections
    - External effects on system
      - Grid perturbations
      - Lightning strikes
      - Other environmental effects

Failure Data Organization for Analysis
Censored Data—Not All Failures

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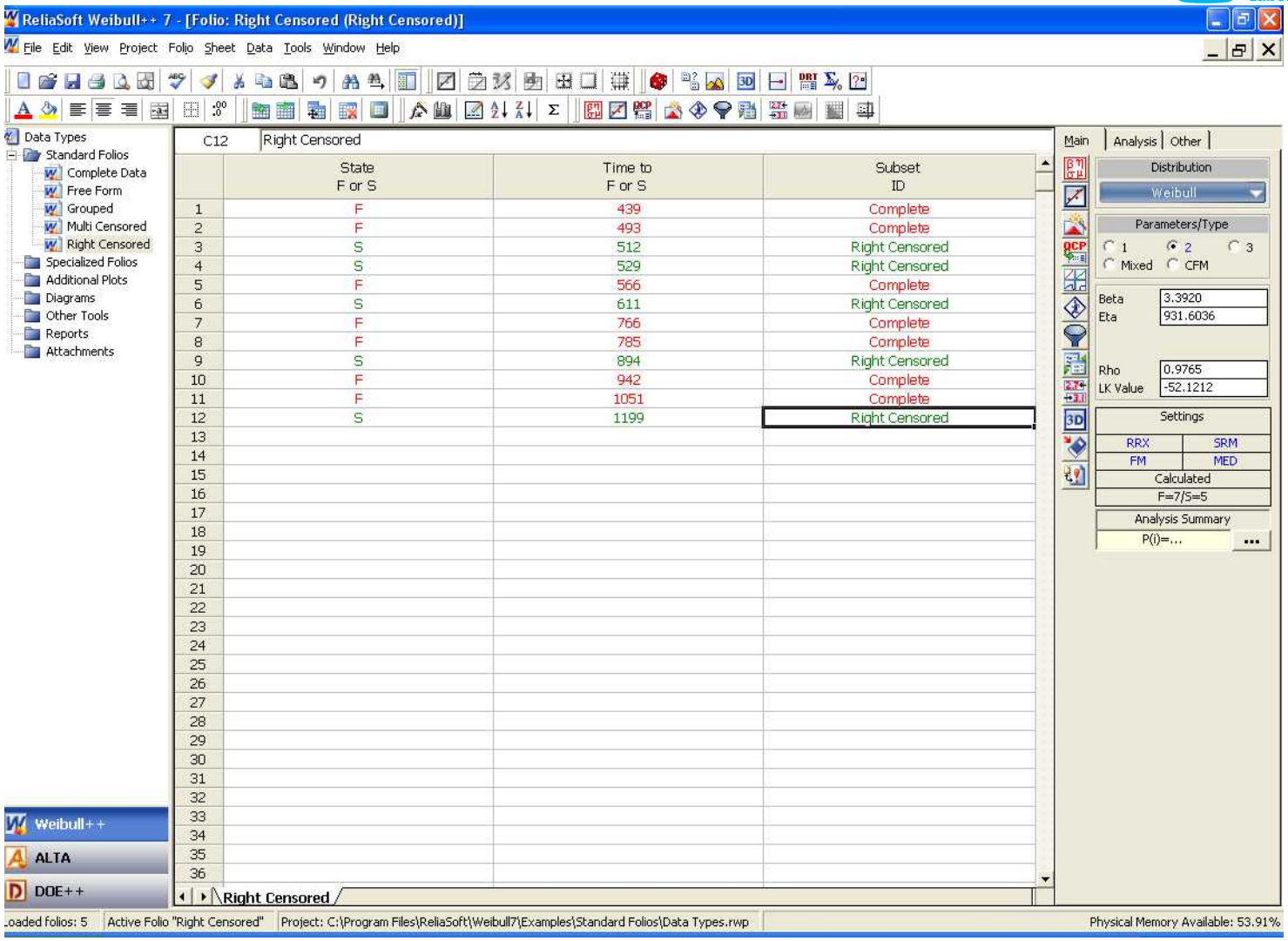

XFRACAS Tool Description

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- **XFRACAS, a web-based application, provides all of the tools to troubleshoot issues as they occur in the lab or in the field,**
  - **captures the data required for important reliability, quality, safety and other analyses,**
  - **facilitates teamwork to resolve underlying problems,**
  - **builds a "knowledge base" of lessons learned that assists future troubleshooting and development efforts.**
- **XFRACAS supports the entire incident management process, from the initial development stages to complete tracking of fielded serialized units.**

Ideal Data Collection Tool Characteristics versus XFRACAS Capabilities

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Data Collection Tool Characteristic	Capability Present in XFRACAS	User Mod to XFRACAS	Comments
Handle multiple system & component populations	X		Passwords and permissions protect proprietary information
Contain customizable query and sort features	X		User configurable
Handle both legacy and real-time data entry	X		
Discriminate independent vs. dependent failures at all levels	X		
Keep track of restoration times	X		
Keep track of retired & replaced components	X		
Export data in “organization for analysis” format into reliability & availability tools		X	Downtime and subsystem reliability growth analyses require custom SQL queries and post-processing in Excel
Offer “intuitive” user-friendly interface		X	User-specific operating instructions are needed

Steps Necessary to Import Legacy Field Failure & Repair Data into XFRACAS

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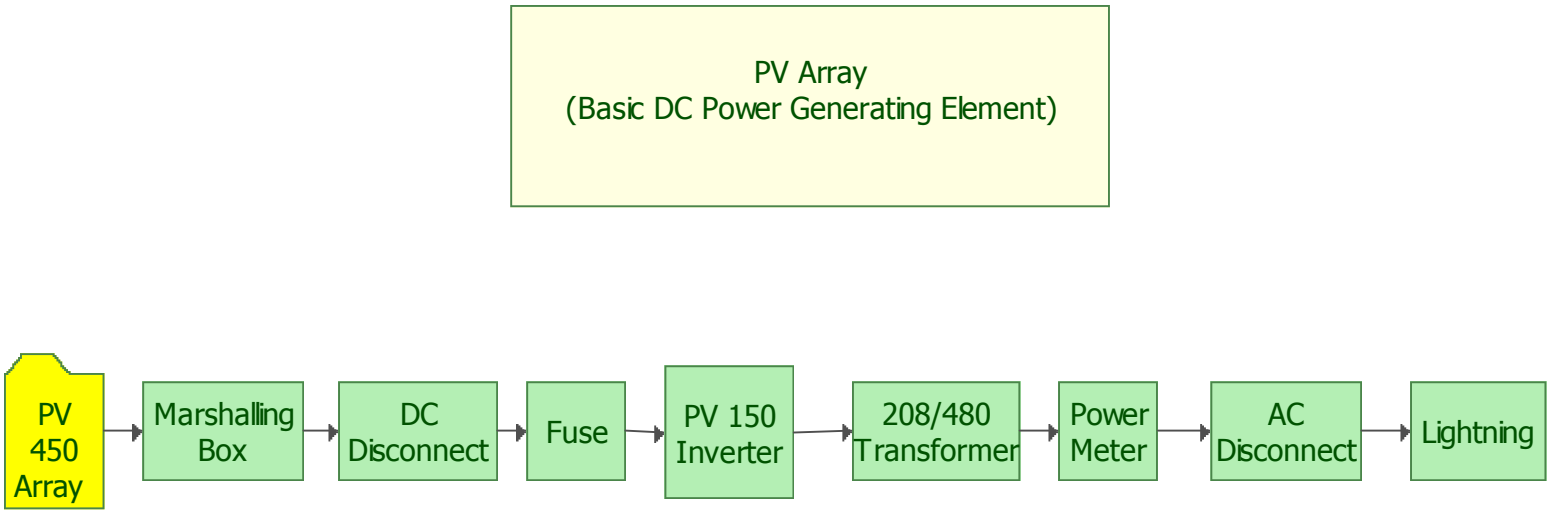
- **Create a serialized bill of material *consistent with* system reliability block diagram**
- **User-configure data import template**
- **Populate template with field data**
- **Import template into XFRACAS**



TEP SGSSS Bill of Material (BOM)

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Serialized BOM for one of 26 SGSSS arrays (Display of XFRACAS Parts Import Template)

Level	Part Number	Part Description	Part Version	Serial Number	Quantity	Build Date	Ship Date	Catalog	Manufacturing Code
1	SGSSS	SGS Solar System Power Block		SGS-1	1	07/13/2001			
2	TXL	480V/34.5kV Transformer		SCL-2	1	07/13/2001			
2	TXS	208V/480V Transformer		TXS-1	1	07/13/2001			
2	ADS	AC Disconnect Switch		ADS-1	1	07/13/2001			
2	DDS	DC Disconnect Switch		DDS-1	1	07/13/2001			
2	ECON	Array Electrical Connections		ECON-1	1	07/13/2001			
2	INV	Inverter		INV-1	1	07/13/2001			
2	LIGHT	Lightning Event		L-1	1	07/13/2001			
2	MOD	PV Module		M-U1-1	1	07/13/2001			
2	MOD	PV Module		M-U1-2	1	07/13/2001			
2	MOD	PV Module		M-U1-3	1	07/13/2001			
2	MOD	PV Module		M-U1-4	1	07/13/2001			
2	MOD	PV Module		M-U1-5	1	07/13/2001			
2	MOD	PV Module		M-U1-6	1	07/13/2001			
2	MOD	PV Module		M-U1-7	1	07/13/2001			
2	MOD	PV Module		M-U1-8	1	07/13/2001			
2	MOD	PV Module		M-U1-9	1	07/13/2001			
2	MOD	PV Module		M-U1-10	1	07/13/2001			
2	MOD	PV Module		M-U1-11	1	07/13/2001			
2	MOD	PV Module		M-U1-12	1	07/13/2001			
2	MOD	PV Module		M-U1-13	1	07/13/2001			
2	MOD	PV Module		M-U1-14	1	07/13/2001			
2	MOD	PV Module		M-U1-15	1	07/13/2001			
2	MOD	PV Module		M-U1-16	1	07/13/2001			
2	MOD	PV Module		M-U1-17	1	07/13/2001			
2	MOD	PV Module		M-U1-18	1	07/13/2001			
2	MOD	PV Module		M-U1-19	1	07/13/2001			
2	MOD	PV Module		M-U1-20	1	07/13/2001			
2	MOD	PV Module		M-U1-21	1	07/13/2001			

XFRACAS Data Needs for Export of Data to Reliability/Availability Analysis Tools

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Data Item	Reliability	Availability	TEP Logs
Incident Occurrence Date/Time	x	x	x
Bill of Material Part Number	x	x	x
Part Serial Number	x	x	
Part Commissioning Date	x	x	x
Incident Description	x	x	x
Incident Category	x	x	x
Service Response Date/Time			
Service Completion Date/Time	x		
Restoration to Duty Date/Time		x	x
Energy Lost (kWh)	x	x	x

How Incidents Are Entered into XFRACAS

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- Process is incident entry driven
- Information collected is identical for legacy and real-time entries (However, legacy data may be incomplete)
- Incidents are classified according to the source of the problem
- Incidents are classified into categories as chargeable or non-chargeable
- Failure types are required for each incident and are similarly classified

Rationale for Classification of Failures and Suspensions

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- **Incident Categories**
  - **Chargeable**
    - Hardware Failure
    - Software Problem
    - Hardware Upgrade Required to Operate
    - Software Upgrade Required to Operate
    - Equipment Installation Problem
    - Hardware Application Problem
    - Software Application Problem
    - Unknown
  - **Non-Chargeable**
    - Hardware Upgrade
    - Software Upgrade
    - Preventative Maintenance
    - Troubleshooting Issue
    - System Upgrade
    - End of Useful Life Failure
    - Grid-induced Failure/Suspension
    - Environment-induced Failure/Suspension
    - Vandalism

Rationale for Classification of Failures and Suspensions (Continued)

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- Failure Types
  - Chargeable
    - Primary Failure
  - Non-Chargeable
    - Preventative Maintenance Suspension
    - Corrective Maintenance Suspension
    - Grid-induced Failure
    - Lightning-induced Failure
    - Other-induced Failure
    - Grid-induced Suspension
    - Lightning-induced Suspension
    - Other-induced Suspension
- Failure is the logical AND of chargeable failure type and chargeable incident category
- Suspensions are all other combinations

SGSSS Legacy Data Entry

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2	Occurrence Date	Repair Duration	BOM Level 1 Part Number	Level 1 Part Serial Number	BOM Level 2 Part Number	Service Response Date	Incident Status	Incident Category	Report Type
3	2/7/03 3:54:00 AM	6	SGSSS	SGS-9	DDS		closed	Hardware Failure	Unplanned Field
4	2/14/03	0	SGSSS	SGS-10	INV		closed	Software application problem	Unplanned Field
5	2/11/03	5	SGSSS	SGS-3	MOD		closed	Hardware Failure	Unplanned Field
6	3/9/03 8:21:00 PM	3	SGSSS	SGS-3	DDS		closed	Hardware Failure	Unplanned Field
7	3/1/03	0	SGSSS	SGS-10	INV		closed	Hardware application problem	Unplanned Field
8	4/1/03 7:30:00 AM	25	SGSSS	SGS-10	INV		closed	Hardware application problem	Unplanned Field
9	4/1/03	0	SGSSS	SGS-10	INV		closed	Equipment Installation Problem	Unplanned Field
10	4/29/03 7:30:00 A	1	SGSSS	SGS-9	INV		closed	Preventive Maintenance	Planned Field Ev
11	4/8/03	128	SGSSS	SGS-3	MOD		closed	Hardware Failure	Unplanned Field
12	5/29/03 1:17:00 P	0	SGSSS	SGS-6	DDS		closed	Hardware Failure	Unplanned Field
13	6/10/03	70	SGSSS	SGS-7	ECON		closed	Preventive Maintenance	Planned Field Ev
14	6/28/03 3:44:00 P	6	SGSSS	SGS-12	INV		closed	Unknown	Unplanned Field
15	6/30/03 4:31:00 P	17	SGSSS	SGS-12	INV		closed	Hardware Failure	Unplanned Field
16	7/1/03	0	SGSSS	SGS-8	MOD		closed	Hardware Failure	Unplanned Field
17	7/11/03 7:14:00 A	0	SGSSS	SGS-3	INV		closed	Grid-induced Failure/Suspension	Unplanned Field
18	7/11/03 7:14:00 A	0	SGSSS	SGS-5	INV		closed	Grid-induced Failure/Suspension	Unplanned Field
19	7/11/03 7:14:00 A	0	SGSSS	SGS-13	INV		closed	Grid-induced Failure/Suspension	Unplanned Field
20	7/11/03 7:14:00 A	0	SGSSS	SGS-7	INV		closed	Grid-induced Failure/Suspension	Unplanned Field
21	7/11/03 7:14:00 A	0	SGSSS	SGS-12	INV		closed	Grid-induced Failure/Suspension	Unplanned Field
22	7/11/03 7:14:00 A	0	SGSSS	SGS-8	INV		closed	Grid-induced Failure/Suspension	Unplanned Field
23	7/11/03 7:14:00 A	0	SGSSS	SGS-9	INV		closed	Grid-induced Failure/Suspension	Unplanned Field
24	7/11/03 7:14:00 A	0	SGSSS	SGS-10	INV		closed	Grid-induced Failure/Suspension	Unplanned Field
25	7/11/03 7:14:00 A	0	SGSSS	SGS-11	INV		closed	Grid-induced Failure/Suspension	Unplanned Field
26	7/21/03 4:53:00 P	124	SGSSS	SGS-1	INV		closed	Environment-induced failure/suspe	Unplanned Field
27	7/21/03 4:53:00 P	124	SGSSS	SGS-5	INV		closed	Environment-induced failure/suspe	Unplanned Field
28	7/21/03 4:53:00 P	83	SGSSS	SGS-6	INV		closed	Environment-induced failure/suspe	Unplanned Field
29	7/21/03 4:53:00 P	124	SGSSS	SGS-7	INV		closed	Environment-induced failure/suspe	Unplanned Field
30	7/21/03 4:53:00 P	148	SGSSS	SGS-8	INV		closed	Environment-induced failure/suspe	Unplanned Field
31	7/21/03 4:53:00 P	124	SGSSS	SGS-9	INV		closed	Environment-induced failure/suspe	Unplanned Field
32	7/21/03 4:53:00 P	360	SGSSS	SGS-11	INV		closed	Environment-induced failure/suspe	Unplanned Field
33	7/21/03 4:53:00 P	1032	SGSSS	SGS-12	INV		closed	Environment-induced failure/suspe	Unplanned Field

Incident / Repair Replace / Details / Status of Troubleshooting / Team Members / Instructions /

SGSSS Legacy Data Entry (continued)

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2	Description of Incident	Restored to Duty Date	Incident Resolution	Service Completed Date	Initiating Event	Clock Hours	AC kWh Loss
3	Tripped with a Door Interlock fault Interlock Inv	2/8/2003 7:07:00	repaired			4563	560
4	Over and Under frequency faults Unknown Inve	2/14/2003	repaired			3600	0
5	ASE module shorted positive to ground PV m	2/12/2003	replaced			13032	30
6	DC interlock fault Interlock Inverter U-3	3/10/2003 12:11:0	repaired			13676	395
7	Over and Under frequency faults Inverter U-10	3/1/2003	repaired			3960	15
8	Replacement controller card for Inverter U-10 (	4/2/2003 08:40:00	repaired			4711	760
9	Recurrent over- and under-frequency faults for	4/26/2003	repaired			4704	0
10	U-9 controller card replaced resulting in B pha	4/29/2003 11:43:0	repaired		new board didn't	6511	2190
11	short to ground in module PV module U-3 Rov	4/30/2003	repaired		wire found pinch	14376	90
12	Tripped with a DC Interlock fault Interlock Inve	5/29/2003 4:55:00	repaired			12757	350
13	loss of small amount of capacity Row box Arr	6/22/2003	repaired		row box fuse in	7512	260
14	indication of High C phase current Controller li	6/28/2003 4:52:00	repaired			9471	144
15	indication of High B&C phase current Controll	7/1/2003 4:51:00	repaired			9520	34
16	module dead PV module U-8 Row 4	7/1/2003	replaced			8016	480
17	Low AC volts Environmental Inverter U-3	7/11/2003 7:18:00	repaired			16639	368
18	Low AC volts Environmental Inverter U-5	7/11/2003 7:18:00	repaired			15031	2
19	Low AC volts Environmental Inverter U-13	7/11/2003 7:18:00	repaired			895	2
20	Low AC Frequency Environmental Inverter U-7	7/11/2003 7:18:00	repaired			8263	2
21	Low AC Frequency Environmental Inverter U-1	7/11/2003 7:18:00	repaired			9775	2
22	High AC Frequency Environmental Inverter U-8	7/11/2003 7:18:00	repaired			8263	2
23	High AC Frequency Environmental Inverter U-9	7/11/2003 7:18:00	repaired			8263	2
24	High AC Frequency Environmental Inverter U-1	7/11/2003 7:18:00	repaired			7135	2
25	High AC Frequency Environmental Inverter U-1	7/11/2003 7:18:00	repaired			9175	2
26	U-1 OOS due to lightning activity	8/12/2003	repaired			17728	2
27	U-5 OOS due to lightning activity	8/12/2003	repaired			15280	4980
28	U-6 OOS due to lightning activity	8/5/2003	repaired			14032	4980
29	U-7 OOS due to lightning activity	8/12/2003	repaired			8512	3320
30	U-8 OOS due to lightning activity	8/16/2003	repaired			8512	4980
31	U-9 OOS due to lightning activity	8/12/2003	repaired			8512	5940
32	U-11 OOS due to lightning activity	8/5/2003	repaired			9424	4980
33	U-12 OOS due to lightning activity	8/12/2003	repaired			10024	320

Incident | Repair Replace | Details | Status of Troubleshooting | Team Members | Instructions

Real-time Failure Data Entry
Incident Wizard Screen

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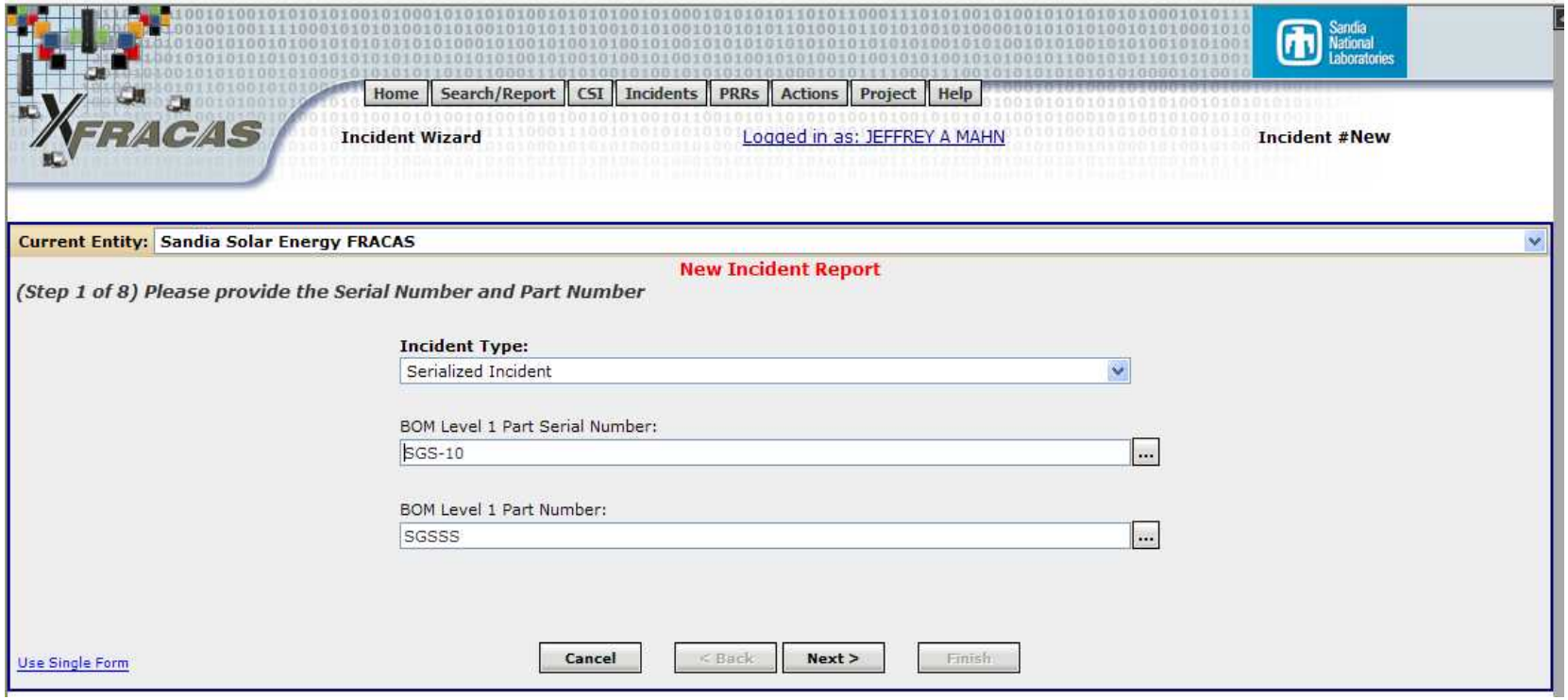

Analyses Supported By XFRACAS Data Exports

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- Reliability growth analysis
- Life data analysis
- Downtime analysis
- Reliability and availability analysis
- System simulation
- Comparisons of suppliers, operating sites, similar hardware, etc.

Inverter Parametric Recurrence Data Analysis
Cumulative and Instantaneous MTBF per Inverter

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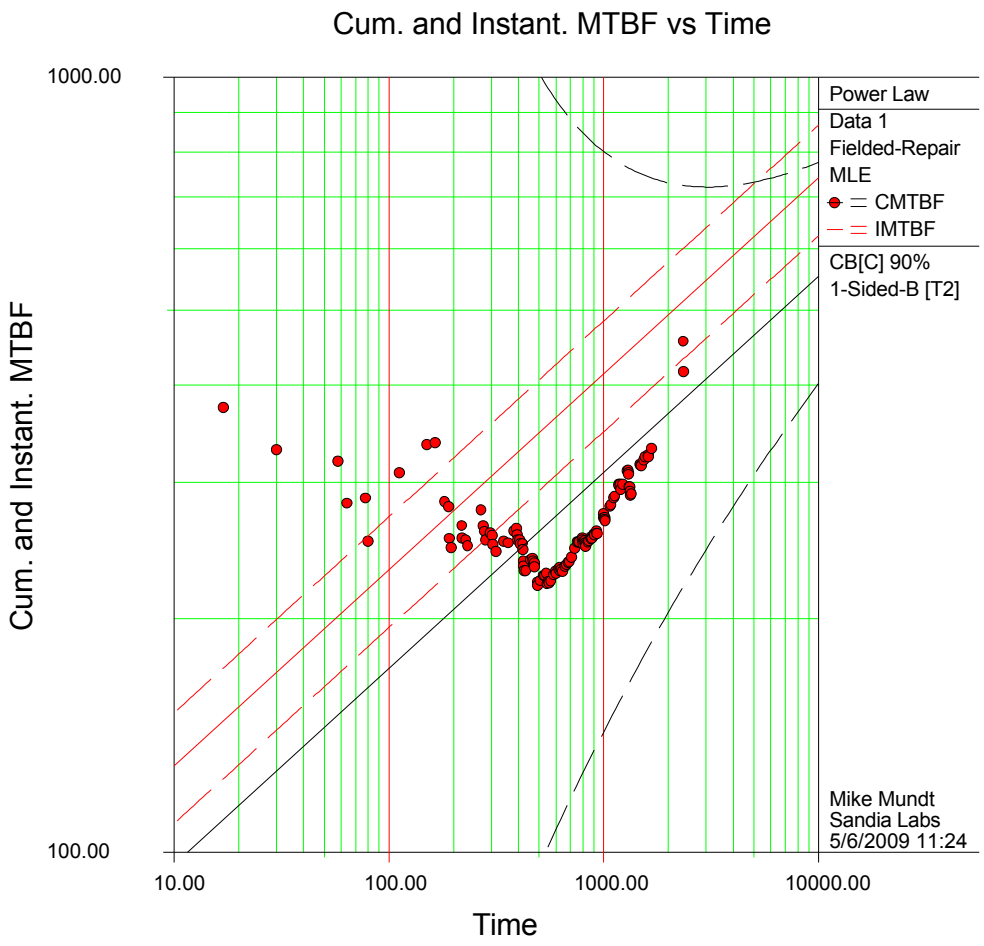
ReliaSoft's RGA 6 PRO - RGA.ReliaSoft.com



Beta=0.7471, Lambda=0.0186

Predictable reliability growth is occurring with field repair by finding problems and applying fixes to all the inverters.

Instantaneous MTBF is improving with time.

Solid red line is instantaneous line fit, and solid black line is cumulative line fit.

Time is in days.

Conclusions

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- Collaborated with ReliaSoft to upgrade XFRACAS features to export data for reliability/availability analyses
- Successfully demonstrated import of legacy data into XFRACAS and export of data in analysis format to Weibull++ and RGA
- Successfully demonstrated entry of additional real-time data into XFRACAS and export to analysis tools
- Automated data collection, entry, and organization for analysis increases efficiency and accuracy of analysis results

Future Work

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- Sandia's DOE Photovoltaic Reliability Program is interested in partnering with Renewable Energy manufacturers, installers and operators to develop baseline reliability data for Photovoltaic components.
- A single database like XFRACAS could support a life cycle approach for managing conceptual development through retirement of fielded PV systems by recording and tracking:
  - Design iterations and upgrades
  - Review boards
  - Failure analyses
  - Corrective actions
  - Field operations
  - Test results
  - Data for reliability growth and system availability predictions
- Reliability and availability descriptions can be integrated with higher-level models like GOLDSIM to simulate variations in weather, seasons, and geography on the kWh performance of photovoltaic systems.

Acknowledgements

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- We wish to acknowledge Tucson Electric Power for sharing failure and maintenance data for the Springerville, AZ Photovoltaic Generating Facility. Also, we thank Tom Hansen and Kaleb Brimhall who assisted in interpretation of the data logs. This work would not have been possible without this valuable information.
- ReliaSoft™ reliability analysis commercial software was used for modeling and data analysis.
  - XFRACAS
  - Weibull++ 7
  - RGA 6
  - BlockSim 7

References

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