PV System Reliability:
An Operator’s Perspective

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SunEdison
Solar O&M Maturation

Before 2000
- Direct Sales ($/W)
- DIY O&M

2000-2010
- FIT, PBI, PPAs
- Professional Maintenance

Future
- Expansion to Operations
- Power vs. Energy
The Importance of Reliability to an Operator

- **Low-reliability systems:**
  - Need attention → drive up service costs
  - Are less productive than expected → drive down revenue

- **Collateral issues:**
  - Increased monitoring needs (and capital/service costs)
  - Reputation cost (with customer and/or investor)
  - Lengthier procurement process
  - Increased risk of safety-related incidents
The Cost of Reliability and Time-To-Repair

- 27 systems
- 17 MWp
- $1000 per truck-roll
- 5 sun-hours per day
- $0.10/kWh

**INTRODUCTION**

**SYSTEMS**

**INVERTERS**

**MODULES**

**FUTURE**
SunEdison Services

- 750 plants with over 700 MW across 3 continents:
  - North America: US (15 states), Canada, Puerto Rico
  - Europe: Spain, Italy, Bulgaria
  - Asia: South Korea, India, Thailand

- 3 Renewable Operations Centers (ROC):
  - North America: Belmont, CA
  - Europe: Madrid, Spain
  - Asia: Chennai, India
Geographical distribution
Diversity of systems

- 15+ inverter vendors
- 30+ PV module vendors
  - x-Si (>80% of units)
  - CdTe
  - a-Si
- Structure types
  - Rooftop, fixed (ballasted and mounted)
  - Ground, fixed
  - Ground, tracking (single axis, dual axis)
- Climates
  - Tropical, Desert, Coastal, High Desert, etc
- Age
  - Up to 7 years
Tickets, Outages, and Impairments

- **Service ticket:**
  - A record of an issue affecting the PV system
    - May impact energy output, or not
    - Failure Area *(Where did the issue manifest?)*
      - Subsystem and Component level
    - Root Cause *(Why did the issue manifest?)*
      - General and Specific

- **Outage:**
  - An issue affecting a critical subsystem
  - Visible immediately
  - To be addressed urgently

- **Impairment:**
  - An issue affecting a non-critical subsystem
  - Visible with advanced analytics or high-granularity monitoring
  - Can be addressed in opportune timing

- **Sensor or communications issue:**
  - Not affecting production
  - Usually visible immediately
  - To be addressed immediately
3600 service tickets for 450 systems in 27 months
- January 2010 – March 2012

Unrealized energy generation:
- ~1% of total production in 27 months
Failure Areas: Frequency and Energy Impact

- Inverter
- AC Subsys
- External
- Other
- Support Struct
- DC Subsys
- Planned Outage
- Modules
- Weather Stn
- Meter

Tickets
Energy Loss
Root Causes: Frequency and Energy Impact

- **Parts/Materials**: 50% Tickets, 45% Energy Loss
- **External**: 20% Tickets, 35% Energy Loss
- **Software**: 15% Tickets, 10% Energy Loss
- **Other**: 5% Tickets, 5% Energy Loss
- **Unknown**: 10% Tickets, 10% Energy Loss
- **Construction**: 7% Tickets, 7% Energy Loss
- **Preventive Maint.**: 3% Tickets, 3% Energy Loss

**INTRODUCTION**
**SYSTEMS**
**INVERTERS**
**MODULES**
**FUTURE**
Cumulative Energy Loss: the 80/20 rule
Conclusions - I

- **Inverters**
  - Highest frequency of issues
  - Largest share of energy loss

- **75% of energy losses manifest at mission critical nodes**
  - Inverter
  - AC subsystem
  - External subsystems (Interconnection, Grid)

- **50% of tickets and energy loss due to component failures**

- **33% of energy losses attributed to external agents**

- **50% of energy loss caused by 5% of incidents**

- **Largest losses represent long outages**
Inverter Components that Fail

0% 5% 10% 15% 20% 25% 30%
Control Software
Card/Board
AC Contactor
Fan(s)
Matrix/IGBT
Power Supply
AC Fuses
DC Contactor
Surge protection
GFI Components
Capacitors
Internal Fuses
Internal Relay/Switch
DC Input Fuses
Additional fields

Tickets
Energy Loss
Reliability of Central Inverters – 5 vendors

- **Inverter-years**
- **Tickets per Inverter-year**
- **H/W and S/W**
- **H/W only**
- **Inverter Age**

**Inverter Age**

**A**

**B**

**C**

**D**

**E**

**A-E**

**STR**

**Fleet**

**FUTURE**
## Tracking Inverter Reliability with Age: Cohorts

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### Monthly Failure Rates (for a specific vendor)

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**Annual Failure Rate:** 0.94
Annual Failure Rate for 4 Inverter Vendors

Based on inverter tickets, filtered for hardware and software root causes

Repeated failures of same inverter in small-population cohorts

Year in Service

1st 2nd 3rd 4th 5th 6th 7th
Most inverter failures manifest at
- the control software
- various PCBs
- the AC contactors

Failures attributed to control S/W may include failures triggered by upstream or downstream issues that cause inverter shutdown without error codes

Typical bathtub behavior is not observed
- Infant mortality issues manifest during installation (before launch)
- Long-term statistics not yet reliable, but some old inverters exhibit repeated issues
Module Components that Fail

- Top Glass: 50% of the tickets
- Cells: 40%
- Backsheet: 30%
- MC Connectors: 20%
- Other: 10%
- J-Box: 5%
- Cables: 5%
- Bypass Diode: 5%

50% of the tickets concern 2 vendors.
Occasionally a system will underperform relative to expectations over an extended period without being affected by an outage.

During maintenance the field crews will check DC connectivity.

If all combiners and strings are connected and the underperformance persists, the field crews will take I-V curves from random strings and modules.

If the results show performance in breach of the power warranty, sampled modules are sent to an independent lab for flash testing.
Example of Suspected Module Degradation

Hourly MPP Voltage @ Module temperature between 30 and 32 °C
Identified module failures represent a very small fraction of service tickets

Vast majority of system data do not indicate that module failures are being overlooked
- There are exceptions, which have led to closer investigation of module performance

Most frequent failure is the breakage of the front glass, which is caused by an external agent
Challenges in Quest for Reliability

**Operator**

- Data integrity
  - Staff training
  - Data entry platform
  - Definition clarity

- Uncontrolled environment
  - Difficult to ID issue and cause

- Issue complexity
  - Lack of tools and product knowledge

**Vendor**

- Data scarcity
  - No contextual information

- Uncontrolled environment
  - Difficult to simulate and test

- Issue complexity
  - Lack of data and system operation knowledge
What Can Be Done About Reliability

- The PV system operator may **manage** reliability
  - Procurement
  - Standardization in design and construction
  - Service dispatch schedule
  - Performance monitoring and analytics
  - Inventory optimization
  - Supply chain QA

- The equipment vendor may **improve** reliability
  - Supply chain QA
  - Standardization in design and manufacturing
  - Continuous improvement
High penetration levels will make passive interconnections for PV unsustainable.

What does it take for PV to be a better citizen of the grid?

- Ability to manage Power as opposed to Energy;
- Response times dramatically reduced;
- More robust solutions;

- Ability to “Say what you’ll do and do what you say.”
The primary challenge today remains sufficiently accurate meteorological forecast;

Second order challenges include:
- Accurate and timely power conversion models;
- Accurate, real-time Availability reporting.
Performance Ratio

- $\text{PR}_{T100i}$

- Temperature Corrected Performance Ratio for hours with 100% inverter availability
“Big Data” for PV

Fleet Analysis of $P_{R_{100i}}$

- Jan ’12
“Big Data” for PV, continued

Fleet Analysis of $PR_{T100i}$

- Jan '12
- Jun '12
“Big Data” for PV, continued
Conclusion

- Continuous improvement of Maintenance practices and system reliability are needed;
- The transition from Maintenance to Operations and Maintenance has begun;
- Under high penetration scenarios, robust O&M of distributed assets will be critical to cost effective integration;
- Robust O&M requires: data quality, sophisticated modeling and data handling, automation and credibility.
Acknowledgments

- SunEdison Services Team
- Tassos Golnas
- Joe Bryan
- Jennifer Granata and Nadav Enbar