Service & service architecture – yield monitoring, optimization and reporting for commercial-scale solar utility installations

Steve Voss, **Dr. Tassos Golnas**, **Steve Hester** & **Mark Culpepper**, Sun Edison LLC, Beltsville, Maryland, USA

This paper first appeared in the fifth print edition of *Photovoltaics International* journal.

ABSTRACT

Over the past five years the primary metric for the PV industry has evolved from watts to kilowatt-hours. This transition has emphasized the importance of PV asset monitoring, operation and maintenance. The need to maximize system economics, by increasing uptime and decreasing service costs, requires a complex set of high quality data to drive decision making and continuous improvement efforts and is driving a rapid maturation of the PV industry, as discussed in this paper.

Introduction

Incentive structures based on kWh production, such as feed-in-tariffs, performance-based incentives and renewable energy credits, have become the norm in the PV industry. Additionally, many companies are now applying the structures and principles of project finance to PV projects. The purpose of project finance is to create a business structure which brings together multiple entities, aligns their interests, and allocates the project's inputs and outputs (i.e. risks and rewards) in such a way that the overall benefits derived from the project are maximized.

In the simplest possible scenario, this has meant a transition from a simple cash transaction between integrator and host to a more complex transaction involving a third-party financing partner. Historically, under the cash sale model, photovoltaic systems were built by integrators who purchased equipment through distributors and maintained minimal responsibility for the long-term operation of the systems. This created a disconnected supply chain with little or no accountability for the ultimate operation and productivity of the system beyond the initial transaction. Even today, it is difficult for many OEM suppliers to account for the ultimate destination and performance of their products. This disconnect has been made possible in part by the inherent reliability of photovoltaic systems which operate without moving parts. However, no system is failsafe and as a result many assets underperformed or were inadequately monitored to ensure proper operation. This mode of operation is unsustainable since it ignores the ultimate purpose of a photovoltaic system: the reliable delivery of power (capacity) and energy.

The introduction of power purchase agreements (PPAs) to the solar industry goes a long way towards rectifying this disconnect, enabling the host to avoid the high capital investment and only pay for kilowatt-hours delivered or peak energy savings. However, to focus on the PPA exclusively is to oversimplify the symbiotic relationships created through project finance. When properly applied to the photovoltaics industry, project finance will align the interests of all parties involved in the finance, construction and operation of a power plant, including host, integrator, project investor, utility, subsidizing agency and OEM provider alike. This is accomplished by creating a project entity whose economic engine is driven by the value creation of the asset throughout its operational life. This entity is the Solar Energy Services Provider (SESP).

Initially, the SESP is responsible for managing the complex contractual relationships required. Project finance is built on a series of contracts which define the roles, responsibilities and obligations of the various parties involved. With regards to power production, project finance typically involves four primary contracts: 1) a construction and equipment contract; 2) a long-term fuel contract; 3) a long-term power purchase agreement; and 4) an operating and maintenance contract [1]. For solar projects the fuel contract is obviously eliminated; however, it is frequently replaced by a contract for the environmental attributes of the system, which under some incentive structures can represent a significant portion of project revenues.

This deal structure has most frequently been applied to extremely large projects which can justify relatively high transactional costs. PV projects – particularly on the commercial scale – are small in comparison. The successful SESP must therefore focus on efficiency, strong relationships, repeatability and risk mitigation.

From an operational perspective, this requires a complete auditable trail

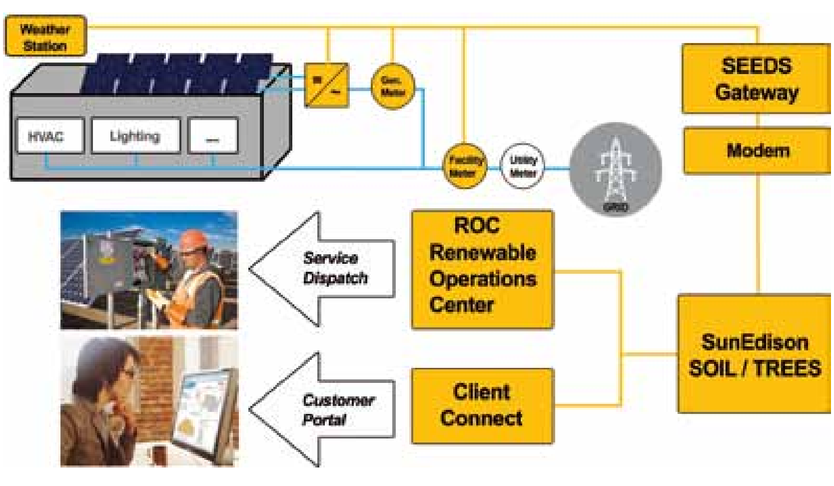

Figure 1. ECO infrastructure example for a net-metered rooftop system.

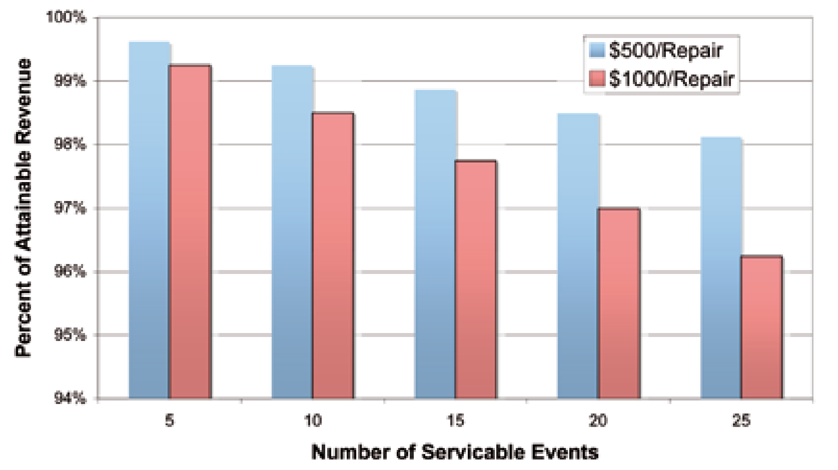

Figure 2. Example of possible impact of O&M expenditure on a 1MW portfolio of PV assets with a fixed uptime of 98.5%. The make-up of the outages – in terms of frequency and average cost to repair – has a significant impact on realized cash from operations.

of system components, generation data and system performance metrics which provide accountability and transparency to project performance and value delivered to the various stakeholders. In other words, in order for this business model to be sustainable, all parties must be able to validate that all covenants, contracts and commitments are being honoured.

The ECO architecture

ECO (Energy Costs Optimization) is the services architecture developed by SunEdison for monitoring and operating a portfolio of solar PV power plants. ECO increases solar savings for host customers and reduces investment risks for financiers by providing information necessary for effective decision making. ECO includes the following components:

- **SEEDS** (SunEdison Energy & Environmental Data System) – the equipment and software platform for remote monitoring and control of solar PV power plants.
- **SOIL** (Site Objects & Information Ledger) – the asset management system, data repository, and analytics engine for site and monitoring information, storing data in 1-min or 15-min intervals, and providing a comprehensive listing of site components.
- **TREES** (Tariff and Rate Engine for Energy Systems) – the billing and monetization engine that enables the company to automate energy billing and to calculate customers' energy costs and savings.
- **ROC** (Renewable Operations Center) – the facility where company staff monitor power plants, detect and diagnose issues, process service tickets and dispatch service crews.
- **Client Connect** – the online monitoring portal that the company's customers use to access solar energy production, environmental attributes, energy costs, and SunEdison bills.

All the components of the ECO architecture are necessary to efficiently operate and service a portfolio of photovoltaic power plants. By combining information on operation and economics, disseminating the information and enabling efficient response to the information, this toolset serves two fundamental needs. The first is the transparency and accountability required to operate effectively under the project finance model, while the second is the provision of actionable information required to maximize the economic value of the assets monitored.

From the standpoint of the PV power plant, energy yield (or kilowatt hours produced) is the key metric driving economic value. The ability to rapidly detect, respond to and restore underperforming systems is essential to maximizing that energy yield. However, over time, it is also important to minimize the cost of achieving high uptimes, especially when dealing with a portfolio of distributed assets where the fixed costs of a 'truck roll' or service deployment are relatively high. The calculus used to evaluate system uptime must include: the economic value of the energy (opportunity cost), the cost to repair the system and the frequency and duration of outages.

Consider a 1MW portfolio of PV assets deployed in Southern California. Assuming a performance-based incentive of US$0.34/kWh, a PPA rate of US$0.11/kWh, maximum production of 1500kWh/kW and an uptime of 98.5%, this portfolio would produce cash flows of US$675,000 per year. Taking the definition of uptime as set out in Equation 1 in the following section, a 1% decrease in uptime translates directly to a 1% reduction in cash from operations. However, the cost to achieve that uptime is determined by the number of outage events and the average cost to repair. Fig. 2 illustrates the impact on total cash flows from the portfolio when the number of outages ranges from five to 25 events and the average cost to repair ranges from US$500-1000 per event. If the events are too frequent and/or too costly to repair, then the advantages of high uptime are soon lost.

At the risk of stating the obvious, the Solar Energy Services Provider must strive to maximize uptime by minimizing the duration and frequency of outage events, while simultaneously minimizing the average cost to repair systems. This can only be accomplished by a thorough understanding of the failure modes and mechanisms. ECO has enabled SunEdison to undertake a rigorous, data-driven approach to identifying, eliminating and reducing the cost impact of system outages and maximizing the financial return of our portfolio of systems.

In the future, as power (as opposed to energy) becomes an increasingly important part of the value equation, availability or firmness will become increasingly important as well. This in turn will reinforce the necessity of maintaining the full suite of tools provided by the ECO architecture.

The effort to eliminate and/or reduce the cost impact of various outage causes is an iterative process that requires defining, measuring, analyzing and controlling key parameters. It is a long-term endeavour aimed at continuous improvement and is of value to all the stakeholders involved in the project finance model. The remainder of this article will be an exploration of some of the operational data derived from ECO and which is being used to drive SunEdison's continuous improvement efforts.

Review of the SunEdison solar fleet

As of June 2009, SunEdison manages more than 70MWp of PV systems in North America and Europe, the vast majority of which are deployed in Distributed Generation sites. Data regarding the reliability of PV systems worldwide are relatively scarce, as research institutions generally manage a small number of small sites. On the other hand, commercial operators are usually very protective of their performance data in the same way as semiconductor device manufacturers tend to be protective of their yield data. We have decided to publish detailed information at this time based on the belief that transparency is of greater value than any potential intellectual advantage.

Number of systems	198
Average size (kWp)	259
Minimum size (kWp)	23
Maximum size (kWp)	1727
Average age (months)	11.9
Minimum age (months)	0.3
Maximum age (months)	44.6

Table 1. SunEdison's systems' statistics.

The systems included in this survey account for 77% of SunEdison's managed fleet in terms of installed MWp and 78% in terms of number of systems under management as of June 2009 (see Table 1). Cumulative operation time of the systems at the end of the survey period was 196 system years. The subset of SunEdison systems surveyed was selected exclusively on the basis of the project's financing scheme, and covers a wide variety of geographic and environmental conditions as shown in Fig. 3.

The following energy production and outage survey covers the period between 1/1/2008 and 4/30/2009, unless stated otherwise.

For the purposes of this paper we define *uptime* as the ratio of the energy produced (as measured by revenue-grade meters installed at the customer facilities) to the energy that *could have potentially been* generated if there was no reduced performance due to component downtime and corrective maintenance:

Uptime = Energy Produced (kWh) / Production Potential (kWh) (1)

Reduced performance events, often loosely described as *outages*, occur when the generated energy is considerably less than the energy expected due to irradiance and temperature conditions. Analysis of extensive historical performance logs allows SunEdison to assign a system-specific expected production value that is modulated by existing conditions.

The *production potential* of a system is estimated based on the available insolation and the characteristics of the system according to the following formula:

Production Potential = Irradiance (sun-hours) * OPR (%) * System Size (kWp) (2)

where *OPR* or *Operational*

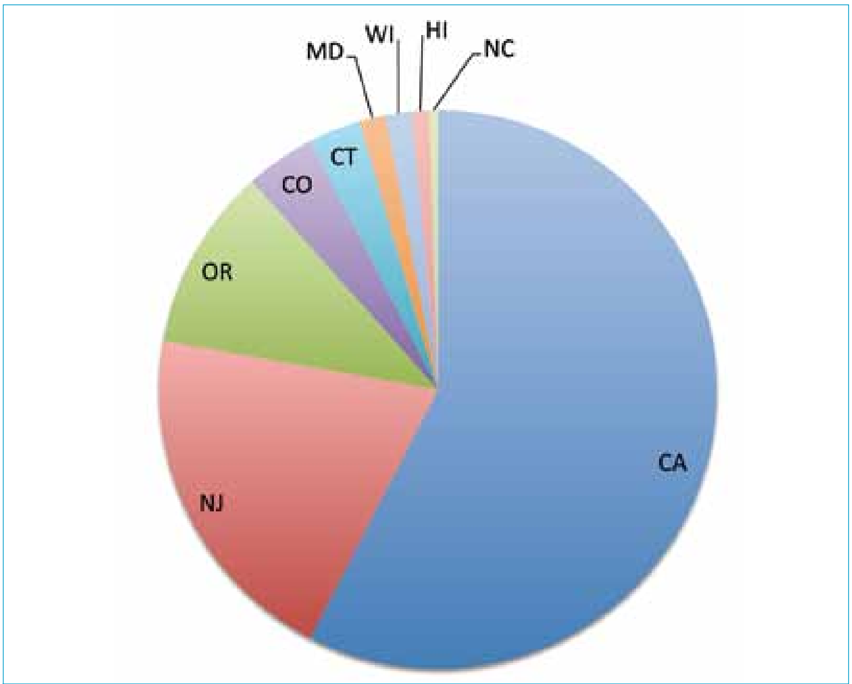

Figure 3. Geographical distribution of surveyed systems. The size of the slices represents the number of systems in each U.S. state.

Performance Ratio is a system-specific, algorithm-based estimate of output based on environmental conditions and historical energy harvest with an accuracy of approximately ±3% for a given one-hour time interval.

Outages are automatically flagged by SunEdison's back office Site Objects and Information Ledger (SOIL) when the production is less than 60% of the expected value. In addition to these automatically generated reports, expert staff at the Renewables Operation Center use advanced algorithms to identify reduced performance events of a less pronounced character. Once an outage is reported, the staff generates a service ticket, determines the severity of the event and dispatches qualified service personnel as necessary.

When the issue is resolved and energy generation is reinstated to its expected levels, we calculate the production potential as defined by Equation 2. This unrealized generation represents the impact of the outage expressed in kWh. For the 198 systems in the period under consideration, the aggregated energy generation statistics are as shown in Table 2.

As mentioned earlier, maintaining a distributed portfolio of assets represents significant challenges beyond those encountered for larger standalone systems. Larger systems are capable of supporting dedicated maintenance staff and on-site spare parts inventories, while distributed assets require a significantly higher degree of coordination and sophistication. Given that two of North America's largest PV plants – Nellis Air Force Base (14MW) and Alamosa (8.2MW) – achieved uptimes of 98.8% [2] and 99.0% [3] respectively in 2008, we believe the accomplishment of a 98.6% uptime rate across a portfolio of 198 DG systems represents quite an achievement.

It is worth noting that 88 (approximately 45%) of the systems under examination did not experience a single outage throughout the 16 months of this survey.

Analysis of the data

First and foremost, it is important to recognize that not all outages are created equally. Fig. 4 shows the cumulative lost production versus the cumulative number of outage events. The first point of note in this chart is the fact that the first 10% of outages account for more than 60% of the total lost production, and are considered to be high-impact events. Secondly, it is important to note that the bottom 50% of outages account for less than 10% of total lost production – these are considered nuisance events. Both categories are of significant concern, but for different economic reasons: the high-impact events because of the lost production, and the nuisance events due to the impact on portfolio O&M costs as described in Fig. 2 earlier.

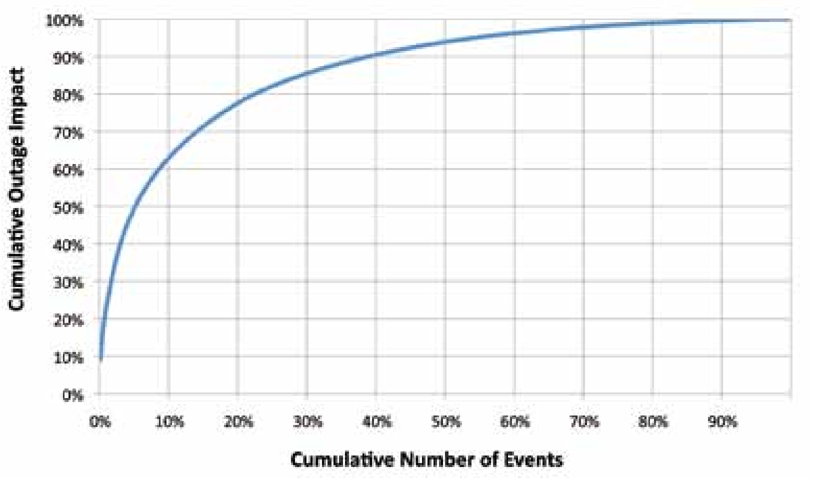

Figure 4. Cumulative impact of outages plotted against the individual events, which are sorted in descending severity. During the period considered, 10% of the outages were responsible for more than 60% of the lost production potential.

A. Expected (Modelled) Generation (kWh)	62,767,945
B. Actual Generation (kWh)	68,863,289
C. Unrealized Production Potential (kWh)	1,196,799
D. Performance or B/A	109.7%
E. Uptime or B/(B+C)	98.6%

Table 2. Aggregated energy generation statistics (SunEdison).

Pareto charts of subsystem failures

The relative energy impact of the outages, categorized according to the subsystem or condition that originated the outage, is presented in Fig. 5. However, as noted above, the frequency of outages is also important. Fig. 6 therefore shows both the impact and frequency of outage events, categorized according to conditions or subsystem of origin.

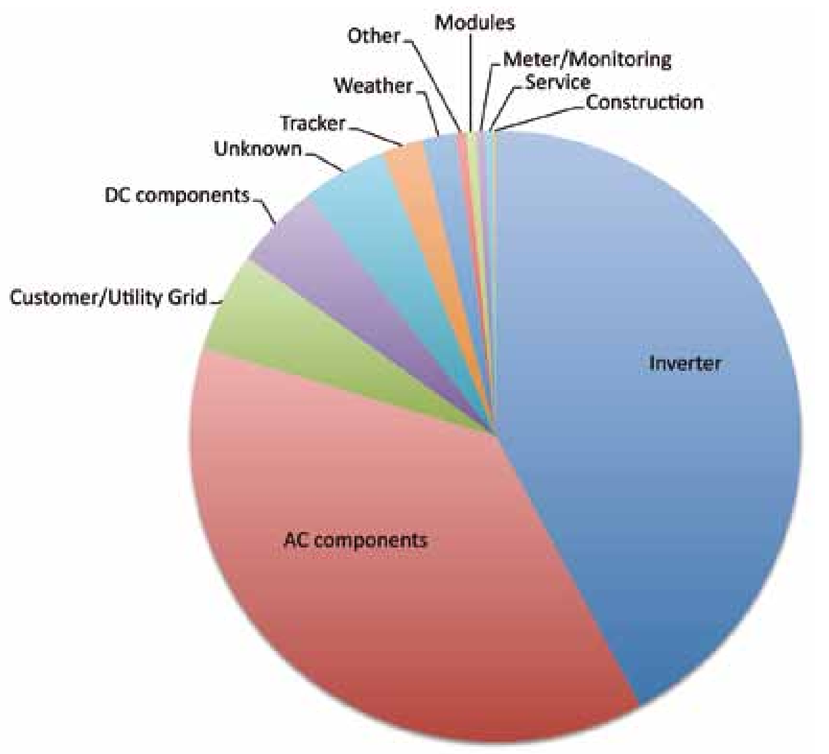

Figure 5. Relative impact of outages in terms of unrealized production potential (shown in descending order). The outages impacted 110 systems (in a fleet of 198) over the 16-month period from January 2008 to April 2009.

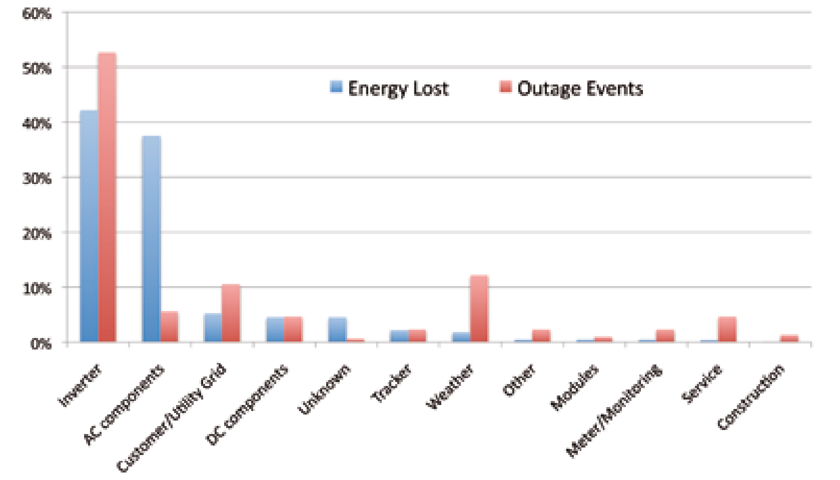

Figure 6. Pareto of relative outage impact with indication of corresponding event frequency. The impact of the inverter outages is proportional to the outage frequency, but the impact of AC component and weather-related outages are inversely proportional to their frequency.

From these it becomes clear that the subsystem most susceptible to outages is the inverter while it is also responsible for a very large percentage of the lost production potential. Another obvious conclusion is that failures of AC components, though infrequent, were observed to have a disproportionately large impact in terms of energy loss. Conversely, weather conditions (mainly snow) may frequently cause reduced performance, but their energy impact is minimal. Based on these observations, we have focused our continuous improvement efforts on the inverter and the AC components, which are discussed in detail later.

Inverter outages

As the most active component in the system, the inverter is also naturally the most vulnerable component. It is therefore worthwhile to take a closer look at the causes behind the outages to which it is related. As mentioned in the data analysis section, each ticket contains a diagnosis of the primary cause of the outage. The common primary causes of inverter failures have been identified and reduced to 19 categories based on the experience of SunEdison service operations personnel.

From the chart in Fig. 7, it is evident that control board failures were the most severe and most frequent cause of inverter-related unrealized production potential. The failing cards were specific to a particular inverter model and the components were replaced under warranty. In terms of the impact on uptime, board failures amounted to only 0.14% of the total production potential of the surveyed systems; however, their financial impact was more pronounced as the identification and troubleshooting of the failures required dispatching of service personnel at a rate proportional to the frequency of the events. At the end of the day, we have been quite pleased with the ability of our OEM partner to identify and address this issue through their own rigorous continuous improvement and quality assurance programs and we expect this particular outage category to be dramatically reduced in the next reporting period.

The next inverter outage category is unfortunately 'unknown.' This represents an unacceptable level of uncertainty and we are currently working to better integrate inverter fault codes in SEEDS and SOIL to address this issue.

Fans and software were also behind numerous failures; however, their impact on uptime was relatively lower. Both of these causes fall under the nuisance category. Recent development efforts enable the company to address a subset of outages by remote inverter controls initiated through the ROC. Software errors can be cleared in this manner; fan faults currently require a visit by field service. The ability to clear certain fault categories remotely drives stronger service financials by reducing both the duration and the cost to repair those faults by eliminating the need for dispatching service personnel.

Conversely, defective internal wiring – albeit infrequent – caused the loss of a disproportionate amount of energy due to the complexity of the repair. Here again, we will rely on the ongoing efforts of our OEM partners to reduce the instances of this outage category.

With regards to inverter outages our efforts rely heavily on the capabilities of our OEM partners. The most important thing that SunEdison can do in this area is to ensure that we establish and maintain a high degree of visibility into outage causes, thus enabling us to provide valuable feedback, validate the efficacy of changes made by the OEM and finally to ensure that we can leverage remote reset capabilities to the greatest extent possible. These efforts will likely result in an overall reduction in the frequency, duration and average cost of repair for inverter-related faults.

AC component outages

As illustrated in Fig. 6, a relatively small number of AC component outages cause a disproportionately large amount of production potential to remain unrealized. In fact, five of the top 10 outages for the period analyzed were attributed to issues between the inverter output and the point of common coupling. While these events were rare, they resulted in long duration outages due to the degree of inspection and re-work required to ensure that the issues had been thoroughly addressed and the systems could be safely restarted. The severity of such instances led the Engineering, Construction and Service departments to prescribe solutions that have addressed the cause of these events, including: performing facility coordination studies, best practices to avoid ground faults, quality inspections for equipment receiving, and use of more robust materials suited to harsh conditions. As a result, we expect to see a further reduction in outages related to faults on the AC side of the system.

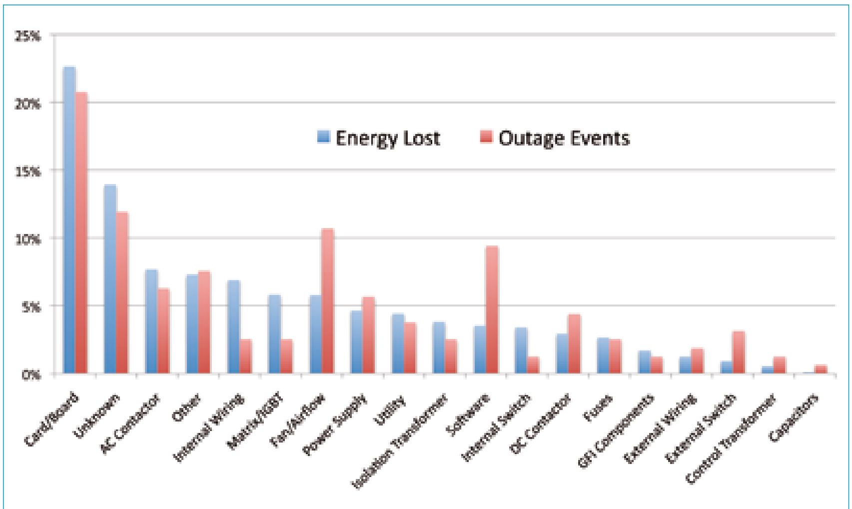

Figure 7. Energy impact Pareto of primary causes for inverter outages with indication of corresponding relative frequency. The percentages refer to the inverter-specific subtotals for energy lost and outage events.

Call to action – what remains to be done?

Consistency and verifiability of data is the basis of all continuous improvement in this regard. Through the process of fulfilling our responsibilities as a Solar Energy Services Provider, SunEdison has built the tools that enable the collection of the required trustworthy data. The data has been critical to achieving the high uptimes and energy production described earlier across a diverse and distributed portfolio of assets. Furthermore, the information is critical to creating the internal feedback loops between Field Operations, Design & Engineering and Procurement teams within the company, and will be strengthened to ensure improved operations.

For example, the current analysis details issues encountered after systems have been commissioned for commercial operation. Extending this level of portfolio-wide analysis to include issues encountered prior to system acceptance will be important for a truly thorough and robust continuous improvement program. Additionally, improving the time and geographic resolution for various outage causes (e.g. for inverter fan failures) will be important to improving preventative maintenance programs.

As partners, Solar Energy Services Providers and OEM suppliers need to continue to strengthen the feedback loop between system failures and product development and management, which necessitates an open two-way dialogue.

In the future, operational data will also be critical to the shaping of code, standards and certification requirements. The data requirements necessary to inform and guide this type of decision-making are undoubtedly different from the data required for product development and maintenance purposes. In time, it is likely that PV-related codes and standards can be made more liberal and robust. These outcomes are not mutually exclusive assuming that the industry is capable of demonstrating what is legitimately required to ensure safe and reliable long-term operation. For this reason, it is critical that Solar Energy Service Providers and other system operators be open about failure modes and causes – particularly those related to design and construction.

Additionally, as inverters and photovoltaic systems become increasingly aware and responsive to the grid, real-world data on scenarios and responses will be critical to the process of defining what is appropriate and what is not. Companies must be committed to working with utility partners based on the strength of their data-collection capabilities. SunEdison has made a substantial financial commitment to establishing the Solar Technology Acceleration Center (Solar TAC) in Aurora, Colorado. Xcel Energy, Abengoa Solar and SunEdison constitute the organization's founding members with other important utility and industry partners also preparing to join. In the near future, Solar TAC will establish itself as an important venue for the testing and validation of new technologies and integration approaches which will help to shape the way solar systems perform and interact with the grid.

Conclusion

As a fleet, the SunEdison portfolio of projects continues to exceed expectations both in terms of energy produced and in production lost due to outages. With uptimes in excess of 98% firmly established, the company is working to continuously improve the efficiency with which these uptimes are maintained by reducing the frequency of nuisance outages, reducing the likelihood of major outages and reducing the lost production resulting from unavoidable equipment failures through faster and more focused responses.

ECO contains all the essential components required to effectively manage our portfolio: from monitoring and communications, through back-office functionality to outward-facing tools that enable the monetization of asset performance. And at the end of the day, this ability to reliably monetize asset performance is what matters most.

Using the ECO architecture, it is possible to institute economic dispatch protocols whereby ROC operators are able to prioritize response and repair efforts based on the economic impact of outages. SunEdison has been able to institute data-driven continuous improvement programs to maximize system reliability while minimizing O&M costs, and have also provided our partners with transparent data on the monetary value of our systems.

As the industry continues to evolve, the ability to translate operational inputs into economic outputs will only become more important. Efficiencies will improve, functional capabilities will be expanded, and business and finance models will evolve – but transparency, accountability and demonstrable economic value will remain as fundamental requirements.

By demanding a higher level of financial transparency and operational accountability, the project finance business model has helped push the solar industry into the steep acceleration stage of a learning curve which is essential to the future of solar as a viable – and material – long-term energy solution. The result of this learning curve will be an industry capable of going beyond grid parity to a point where distributed generation PV assets will provide quantifiable operational and economic benefits to consumers, investors and grid operators throughout the value chain.

References

[1] Esty, B.C. 2004, *Modern Project Finance*, John Wiley & Sons, Inc.

[2] Alami, A. & Batista, R. 2009, "2008 Performance Analysis of a Large Scale Grid Connected Solar System", *34th IEEE Photovoltaic Specialists Conference*, Philadelphia, PA, USA.

[3] SunEdison internal communication.

About the Authors

Steve Voss is the Director of Applied Engineering and Development for SunEdison, where he oversees technology evaluation and development. Before joining SunEdison in 2006, he held engineering roles at the National Renewable Energy Laboratory (NREL), Applied Materials and at Siemens Solar (later Shell Solar). He holds a B.Sc. in physics from the University of Colorado at Boulder, an M.Sc. in materials science and engineering from Stanford University, and an M.B.A. from the University of Wisconsin, Madison.

Dr. Tassos Golnas is SunEdison's Solar Technology Analyst. His responsibilities include managing relations with emerging technology vendors and contributing to the definition of the company's technology roadmap. He spent seven years in R&D and technical management positions at companies such as Advantest, NeoPhotonics and Applied Materials. He received his B.Sc. in physics from Aristotle University of Thessaloniki, Greece, and his M.Sc. and Ph.D. in materials science and engineering from Stanford University.

Steve Hester is a Senior Electrical Engineer at SunEdison, in which role he provides technical oversight, performance analysis, and operational evaluations of SunEdison's various PV systems. With over 31 years of grid-connected PV experience, he worked at Pacific Gas and Electric's R&D group for over 20 years and performed a variety of roles including PV Program Manager, PV Group Leader and PVUSA Project Manager. Steve holds a B.Sc. in electrical engineering from the University of Colorado at Boulder.

Mark Culpepper is responsible for shaping SunEdison's service-oriented architecture for data acquisition and power plant control, creating the connection between solar energy data and customers' immediate financial and energy savings. With over 18 years in the telecommunications and IT security industries, his mission is to simplify solar energy services, providing government, commercial and utility customers the real-time data and analytics needed to optimize solar production and asset performance.

Enquiries

Sun Edison LLC.
12500 Baltimore Avenue
Beltsville, MD 20705, USA
Website: www.sunedison.com