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SAND2011-4778
Unlimited Release
July 2011

Utility-Scale Grid-Tied PV Inverter Reliability Workshop Summary Report

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Abstract

A key to the long-term success of the photovoltaic (PV) industry is confidence in the reliability of PV systems. Inverters are the most commonly noted cause of PV system incidents triggered in the field. While not all of these incidents are reliability-related or even necessarily failures, they still result in a loss of generated power. With support from the U.S. Department of Energy's Solar Energy Technologies Program, Sandia National Laboratories organized a Utility-Scale Grid-Tied Inverter Reliability Workshop in Albuquerque, New Mexico, January 27-28, 2011. The workshop addressed the reliability of large (100-kilowatt+) grid-tied inverters and the implications when such inverters fail, evaluated inverter codes and standards, and provided discussion about opportunities to enhance inverter reliability. This report summarizes discussions and presentations from the workshop and identifies opportunities for future efforts.

ACKNOWLEDGMENTS

The authors would like to thank Tom Key and Aminul Huque of the Electric Power Research Institute, Satish Ranade of New Mexico State University, Raja Ayyanar of Arizona State University, and Mark A. Smith of Sandia for sharing their extensive notes from the workshop and Bryan Pai of SRA International, Inc. for leading the facilitated discussions.

The authors would also like to thank all of the presenters who prepared insightful and informative briefings on key inverter reliability issues and all the participants for their contributions to the workshop.

CONTENTS

NOMENCLATURE

AC or ac	alternating current
ALT	Accelerated Life Testing
DC or dc	direct current
DOE	U.S. Department of Energy
HALT	Highly Accelerated Life Test
HASS	Highly Accelerated Stress Screen
IEC	International Electrotechnical Commission
IGBT	insulated gate bi-polar transistor
JEDEC	Joint Electron Devices Engineering Council
LCOE	Levelized Cost of Electricity
MOSFET	metal oxide semiconductor field-effect transistors
MW	megawatt
NEC	National Electric Code
O&M	operations and maintenance
PV	solar photovoltaics
PVRAM	Photovoltaics Reliability and Availability Predictive Model
SCADA	Supervisory Control and Data Acquisition
Si	silicon
SiC	silicon carbide
SwSOA	Switching Safe Operating Area
UL	Underwriters Laboratories

1. OVERVIEW

1.1 Background

A key to the long-term success of the photovoltaic (PV) industry is confidence in the reliability of PV systems. Enhancing the reliability, safety, and performance of PV systems will support high penetration of solar by proving the technology as a dependable, low-cost source of electricity that can be successfully integrated into new and existing grid systems.

> PV Systems Reliability Work is performed within the Technology Validation activity in the Systems Integration sub-program area of the U.S. DOE Solar Energy Technologies Program.
>
> The missions of the technology validation team are to:
>
> - Reduce installed system and operations and maintenance (O&M) costs by improving photovoltaic (PV) product and system performance, lifetime, durability, and availability
> - Reduce uncertainty in performance, lifetime, durability, and availability, thereby reducing risk and the cost associated with that risk (cost of and time to obtain financing, cost of warranties and service agreements, etc.)

PV system reliability is directly linked to both initial system cost and Levelized Cost of Electricity (LCOE). A lack of confidence or poor understanding of the reliability of a PV system and its components can add to initial and long-term costs through higher project financing and higher insurance rates. Additionally, low reliability leads to high operation, maintenance, and system replacement costs as well as low system availability - thereby affecting LCOE.

System reliability impacts apply across the spectrum of PV technology improvements, including modifications to current technologies and the commercialization of new ones. In the case of new technologies, even a modest – yet unforeseen – failure rate could prevent broad acceptance of new, lower-cost technologies, implying that the PV community might be forced to accept higher cost products.

Inverters are the most commonly noted cause of PV system incidents triggered in the field. While not all of these incidents are reliability-related or even necessarily inverter failures, they still result in a loss of generated power. To date, there has not been a concerted effort to develop tests for inverter reliability. The U.S. Department of Energy (DOE) is currently supporting the development of accelerated test protocols and standards for inverter components. DOE's Sandia National Laboratories is executing this work through real-time inverter testing, accelerated life testing (ALT), and collaborative work with the Solar America Board for Codes and Standards on the development of a technical basis for inverter standards.

In addition to driving potential standards development, Sandia's work will also be incorporated into its PV Reliability and Availability Predictive Model (PVRAM).

DOE and Sandia National Laboratories recently hosted a workshop to discuss photovoltaic (PV) inverter reliability at the utility scale. Attendees included inverter manufacturers, integrators, utilities, independent engineers, and national laboratory and academic researchers. This was the first in a potential series of workshops addressing inverter reliability at various power ratings; utility-scale inverters were selected first because of the overall potential impact of their failures on the PV market. Future plans may include workshops for micro- and/or residential-scale inverters.

The goals of this utility-scale inverter workshop included:

- Examining the perceived and actual reliability of large (100 kW+) utility-scale grid-tied PV inverters
- Evaluating current codes and standards in the industry and identifying a path forward for additional or revised codes and standards
- Identifying reliability implications for installed systems
- Defining opportunities to enhance how reliability is addressed by inverter manufacturers
- Discussing reliability best practices and potential technology advances to enhance reliability

These objectives are aligned to advance the industry-wide goal of making PV a significant part of the U.S. electricity generation portfolio and to support DOE's missions to mitigate risk; reduce LCOE; improve the appeal of solar energy systems by quantifying connections among initial cost and performance, long-term reliability, and operations and maintenance (O&M); and reduce the cost and time needed to certify new technologies and components. This work directly supports DOE's SunShot Initiative, which aims to make solar energy technologies cost-competitive with other forms of energy by reducing the cost of solar energy systems by about 75% before 2020.

The workshop was supported by DOE's Office of Energy Efficiency and Renewable Energy, though its Solar Energy Technologies Program.

2. Meeting Structure and Content

The meeting was structured to encourage interaction and discussion of reliability issues and needs. Key topic areas of the meeting were as follows:

- Overview and perspectives on reliability
  - Inverter manufacturer perspective
  - Integrator perspective
  - Owner/Operator perspective
- Insulated gate bipolar transistor (IGBT) reliability
  - Issues and needs
  - Si- and SiC-based switch reliability
- Capacitor reliability
- Codes and standards / UL 1741 overview
- Accelerated Lifetime Testing
- Technology and reliability
- Action items and next steps

This report provides an overview of the workshop contents and summarizes the key discussion and outputs. Presentation titles are linked to downloads of the presentation files.

2.1 Presentation Summaries / Workshop Content

Inverter Manufacturer Perspective on Reliability (Jim Perkinson, *Satcon*)

Jim Perkinson from Satcon, a global manufacturer of utility-scale inverters, presented the inverter manufacturer perspective of reliability from design to service and monitoring.

In terms of designing for reliability, Perkinson noted that components should be selected in such a way as to reduce stresses and component count. Special attention must be paid to reduce defects in interconnects, wiring harnesses, and moving parts, all of which Perkinson identified as 'high infant mortality' items.

Perkinson identified several steps Satcon takes to ensure reliability as pertains to power availability: Internet-connected devices that permit quick fault reporting and diagnostics; remote debugging and repair capabilities; redundant systems; and the ability to operate even when full capacity is hindered. Technician training is also critical. The company uses advanced algorithms and prognostics to monitor and manage inverter reliability.

As would be discussed throughout the workshop, Perkinson noted that temperature is the "all-important" variable in reliability, and environmental conditions are the "wild card."

Integrator Broad Perspective on Reliability – Customer Needs and Field Data (Tom Levitsky, *First Solar*)

Tom Levitsky of First Solar presented the integrator's perspective on reliability. He led off by noting that availability and reliability do not have a one-to-one relationship; availability is a combination of component reliability and system design, and there is a 'gray area' between failure and lower performance.

Levitsky explained that the distributed nature of PV systems, combined with a variable energy source, create difficulties in understanding the effects of component reliability. Additionally, individual components impact reliability at different points in the system and vary in their impact on system availability. At the AC level reliability affects grid and system stability, external protection and controls, and advanced grid requirements. These areas of the system contain fewer components but are subject to greater standards and carry the potential for more significant consequences on the overall system. At the DC level, modules, wiring, combiner boxes, and ground fault protection can all impact reliability. While DC effects are typically less significant, they can be more challenging to define and analyze.

Levitsky also noted numerous non-technical results from reliability issues, including effects on standards and specifications, operational logistics and safety, vendor relationships, and testing.

Owner/Operator Perspective on Reliability – Customer Needs and Field Data (Tassos Golnas, *SunEdison*)

The PV system owner/operator perspective on reliability was presented by Tassos Golnas from SunEdison. The company focuses on three primary objectives in monitoring its systems: maintaining uptime, meeting or exceeding production targets, and minimizing O&M costs.

Golnas emphasized the importance of a continuous improvement process that provides feedback to engineering, procurement, construction, vendors, and finance. The company receives feedback from two sources: (1) the SunEdison Energy & Environmental Data System, or SEEDS™ gateway, which provides meter, inverter, and weather feeds; and (2) input from field service technicians.

Data from SunEdison's maintenance records identify the inverter as the cause in 51% of their maintenance tickets (per affected subsystem). Of identifiable causes in the inverter[1], key issues noted are control software (16% of total tickets per affected component) and the card/board (11% of total tickets).

Golnas noted that distributed generation is much more sensitive to reliability. While capital costs have traditionally been the most important factor in inverter procurement, SunEdison feels total cost of ownership as reflected in LCOE is a more accurate metric and still includes the effect of inverter reliability.

Survey Results and Summary (Michael Quintana, *Sandia National Laboratories*)
The pre-workshop survey provided information about the companies in attendance and the practices currently utilized to institute and monitor reliability. Results revealed that companies at the workshop have manufactured and installed a range of inverter sizes - less than 30 kW to more than 1 megawatt (MW) - in a variety of climates, especially hot/dry.

The majority of the attending companies have been in the PV business 0-10 years and have installed a total of more than 50 MW in total inverter capacity. Warranties offered range from one year to 15 years for standard warranties, with a majority of the respondents indicating that they also offer customized warranties outside specific ranges.

Respondents agree that components are the top reliability driver for their companies but note that non-technical issues are also a critical factor. Such issues include business practices related to reliability, such as cost and time constraints, supply chain management, warranties and service.

DOE $1/Watt Workshop and DOE Goals (Mike Cliggett, *DOE*)
Michael Cliggett from DOE's Solar Energy Technologies Program (SETP) discussed DOE goals and future directions. DOE hosted a workshop in August 2010 highlighting the Department's objective to drive down the installed cost of photovoltaic systems to $1/Watt. The workshop was attended by 86 representatives from the federal government, academia, and industry, and included breakout sessions to discuss potential next steps towards DOE's goals.

[1] "Other" represented the majority of causes in inverter tickets.

The DOE effort includes four primary goals for both centralized and decentralized power electronics: reduce first cost; improve reliability to 30 years; integrate smart grid functionality; and understand implications for system cost. SETP continues to seek input from solar stakeholders in both PV and concentrating solar power on reducing installed cost.

The $1/Watt objective has been superseded by DOE's SunShot Initiative, which aims to reduce the cost of solar energy systems by about 75% before 2020.

Sandia's Approach to Reliability – Overview (Jennifer Granata, *Sandia National Laboratories*)
Jennifer Granata from Sandia National Laboratories discussed the lab's activities in reliability testing and analysis. The objective of these activities is to partner with industry to develop and apply tools for predictable PV system reliability, and to provide identification and prioritization of reliability issues. The lab uses a systems approach, evaluating the reliability of individual components with regard to how each fits within the overall system.

Sandia's primary reliability activities focus on six key areas:

- Real-Time Reliability
- Failure Modes and Effects Analysis
- Accelerated Life Testing
- Diagnostics
- Predictive Model Development
- Standards Development

For its real-time reliability activities, Sandia conducts long-term inverter exposure testing and temperature monitoring of inverters, and maintains an O&M database. The lab also develops protocols and data for modeling as part of its accelerated testing work and in support of a data-based model that integrates reliability, weather, performance, and cost to predict kWh and cash flow of PV systems. Sandia's work in standards includes collaboration with Arizona State University to evaluate existing standards and guidelines for power electronics which may be applicable to inverters.

Granata noted that a critical aspect of Sandia's continued work is ongoing and expanded collaborations with and input from industry.

IGBT Reliability Issues and Needs (John Donlon, *Powerex*)
John Donlon from power electronics manufacturer Powerex discussed insulated-gate bipolar transistors (IGBTs). IGBTs are power semiconductor devices; in solar applications, they manage power switching.

Donlon noted that IGBTs have several failure modes, including voltage, current, temperature, Switching Safe Operating Area (SwSOA), and mechanical failures such as cycling and fatigue. An IGBT's specific voltage rating must never be exceeded, as the devices have limited 'avalanche capability.' Donlon suggested using voltage margin, a low inductance bus, or snubbers to help mitigate IGBT voltage failures.

Temperature and thermal effects can also have significant effect on IGBT performance and should be planned for and controlled. Donlon suggested that companies can increase switching scheme robustness by planning for switching margins and the application and environment in which each IGBT will be utilized, limiting aggressiveness in designing systems, and conducting regular field tests.

IGBT Si- and SiC-based Switch Reliability Project (Bob Kaplar, *Sandia National Laboratories*)
Bob Kaplar from Sandia National Laboratories continued the discussion about IGBTs with an overview of the lab's work in high current/low voltage stress testing of semiconductor switches in PV inverters. Evaluating IGBT performance in such conditions helps researchers understand how inverters might respond in hot environments and/or conditions of widely variable operating temperatures. Sandia's objective is to establish unbiased, standardized test procedures and reliability models for industry.

During switching in an inverter, IGBTs are briefly subjected to very high power, which generates heat. In this research, IGBTs are subjected to ON states (high current/low voltage) or OFF states (low current/high voltage), with or without temperature stress. These conditions allow researchers to evaluate how improper heat-sinking can degrade device lifetime or cause catastrophic failure.

Sandia is also conducting experiments to evaluate silicon carbide metal oxide semiconductor field-effect transistors (MOSFETs). Additional directions for Sandia's work include continued and expanded IGBT testing, monitoring of IGBTs in actual inverters, stress testing of electrolytics bus capacitors, and modeling of device lifetime and failure mechanisms for inclusion in inverter and system reliability models.

Capacitor Reliability Issues and Needs (Andy Ritter, *AVX Corporation*)
Andy Ritter from AVX Corporation discussed reliability as it relates to capacitors. Ritter noted that solar power inverters are currently trending in two directions: for domestic or small industrial systems, the trend is toward microinverters within each panel, while for large-scale utility applications, high-voltage systems are being developed for better conversion and transport efficiency, reducing power loss in the inverter.

Ritter addressed differences between film and aluminium capacitors, noting that film provides advantages in life expectancy, environmental performance, and power handling capabilities. Failure modes for film capacitors include pinholes, voltage punch-through, and aging of polymer or shrinking. Temperature and voltage accelerate failures in both film and aluminium capacitors. The presentation suggests that film technology is ideal for solar inverters because it does not have a short-circuit failure mode, provides for a calculable lifetime, is mechanically robust, and offers appropriate characteristics to maximize inverter efficiency.

Ritter discussed three key steps to consider in designing capacitors for large-scale PV applications: identify the "Mission Profile" (time spent at certain voltage and current levels over operational lifetime); calculate hot spot temperature for identified mission profile; and calculate fusing activation of film segmentation design.

Overview of UL 1741 (Tim Zgonena, *Underwriters Laboratories*)
Tim Zgonena from Underwriters Laboratories (UL) provided the group with an overview of UL 1741: Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources. This standard addresses product safety for several distributed generation (DG) technologies, including PV, fuel cells, micro-turbines, wind and hydro turbines, and engine generator set interconnect controllers. Standard 1741 is unique in that it addresses issues associated with grid interactive operations of DG products.

Zgonena emphasized that UL 1741 is not specifically written for reliability but does include construction requirements and tests that can lead to more reliable products. Such requirements include appropriate electrical ratings for intended application and operation, electrical and environmental enclosures, and electrical spacings. Zgonena emphasized that product safety and reliability can both be expected to decrease when products are installed and operated outside of manufacturer-specified ratings.

In addition to testing and safety specifications for hardware, UL 1741 also contains considerations for software evaluations during utility interactive testing. Safety critical functions of software can be evaluated by UL under its UL 1998 standard. In the case of inverters, software is viewed as the main critical component since it often controls most of the inverter's utility interaction.

Existing Codes and Standards Summary (Greg Ball, *BEW Engineering*)
BEW is an independent consulting and engineering firm that performs technical due diligence for solar projects and has developed a detailed O&M model that utilizes a bottom-up approach, evaluating O&M costs at the component level. The company also participates in standards development for PV components.

Ball noted that while there are no standards that specifically address reliability, there are numerous safety and component standards that account for some reliability. Specific standards noted include UL1741, the International Electrotechnical Commission's 62109 and 62093, MIL-Specs for components, and JEDEC standards. Ball also discussed how lessons from developing and using module standards might be used in the effort to establish reliability standards for inverters and other components.

One critical issue raised by Ball is the contradictory nature of codes and standards in general: Such specifications often create a cost constraint for manufacturers but provide a source for improvements. Ball noted that standards which allow companies to develop innovative approaches for addressing qualifications can help reduce cost burdens and enhance the value of standards.

ALT/Acceleration Factors (Rob Sorensen, *Sandia National Laboratories*)
Sandia National Laboratories researcher Rob Sorensen detailed the lab's activities in Accelerated Life Testing (ALT). The lab uses high-stress component testing and failure analysis to produce acceleration factors for predicting long-term performance degradation and PV component lifetimes.

Accelerated testing currently used in industry includes qualitative tests such as HALT and HASS as well as quantitative applications of accelerated stresses. However, empirical models do not always capture valid degradation, a critical element to determining accurate acceleration factors. Other issues with ALT include difficulty in controlling and characterizing defects, unknown and variable use environments, changes in mechanisms due to environmental stress, and an inability to identify failure mechanisms.

Sandia's activities in ALT attempt to reduce some of these issues by using controlled statistical analysis, electrical system models, and field data to produce thoroughly vetted acceleration factors. By linking accelerated aging data to performance, the lab is developing factors that can characterize and predict end-of-life. Results from Sandia's work will help industry understand how various stress factors may affect PV component reliability.

Technology Advances to Improve Reliability – Broad View (Diganta Das, *CALCE University of Maryland*)
Diganta Das from the University of Maryland's Center for Advanced Life Cycle Engineering (CALCE) provided an overview of technological approaches being utilized to evaluate reliability. CALCE is a National Science Foundation Center of Excellence in systems reliability and is funded for testing and failure analysis by more than 150 of the world's leading companies. The center focuses on a Physics-of-Failure (PoF) approach to build reliability into the product life cycle.

PoF assesses the impact of hardware configuration and life-cycle stresses, materials at potential failure sites, and root-cause failure mechanisms. Data is analyzed and used to manage life cycles to minimize failure over a product's lifetime.

CALCE approaches failure analysis with a comprehensive system reliability assessment, first evaluating the entire system, then a series of sub-systems, and finally the components of each sub-system and related failure mechanisms. The center has identified several primary inverter failure mechanisms: electrolytics capacitors, ceramic capacitor cracking, insertion mount cracking/fatigue, and breakdowns in the film capacitor.

Other failure evaluation methodologies utilized by CALCE include Failure Modes, Mechanisms and Effects Analysis methodology and a fusion version of prognostics that combines PoF lifecycle knowledge with data-driven statistics and probabilistic analysis. Das noted that prognostics are likely to play a greater role in reliability analysis going forward and should provide more detailed estimates of product lifetimes and potential failure modes.

2.2 Facilitated Discussion – Day One

One of the primary goals of this workshop was to engage participants in effective discussion about inverter reliability issues. The primary objective of the discussions was identified up front: To explore utility-scale PV inverter reliability and share the results of the survey on reliability. There was no expectation that the group would come to a unanimous decision on solutions to issues identified, but rather that they could outline critical shared issues and begin to evaluate potential next steps.

During the first facilitated discussion session, Michael Quintana from Sandia National Laboratories reviewed the results of the pre-workshop survey. The survey found that the inverters manufactured and installed by participants cover a broad range of sizes and types, and are in use in areas across the climate spectrum. Generally, companies represented at the workshop service their inverters while under warranty, and warranty lengths range from one year to multi-year custom arrangements.

Inverter companies represented at the workshop perform a range of reliability testing, with the majority using product design/design for reliability. Other tests include California Energy Commission, Highly Accelerated Life Testing (HALT), Highly Accelerated Stress Screen (HASS), Accelerated Life Testing (ALT), national laboratory testing, test-to-failure, and others. Respondents identified their top three vulnerabilities in reliability as thermal management, grid issues, and component degradation.

Grid issues related to transients, overvoltage, surge protection, and operating environment were also noted as key sources of reliability failures. Additional survey results are summarized in the presentation.

As part of the discussion surrounding the survey, participants were asked to expound upon results. Some issues and suggestions identified by the group during the survey discussion include (full results are in appendix D)[2]:

- Reliability is often hardware-focused…however software reliability is absent from the conversation - context: SCADA, Control Interface, Algorithms/State Spec Flows, etc…
- Emphasize what works well and not just what fails
- Need to create PV application-specific performance criteria and test protocols - large or small[3] -inside or outside the fence
- Classify inverter topologies and control algorithms and correlate them with failure types
- Standardize communications protocols (i.e., EGD, EtherIP, Profinet, etc.) and response times of control features, data acquisition
- Develop anonymous failure-reporting templates for database entry and pay for access by selling memberships; and/or incentivize submission with discounts.
- Develop guidelines for estimating heat gain due to exposure to direct sunlight, i.e., for components installed in full sun. The National Electric Code (NEC) and UL do not currently consider this issue for inverters, combiners, etc., though some guidelines exist for wire and conduit.
- Embrace full organization/scope and work with other international organizations to: 1) Learn/ use best practices in high-deployment areas, i.e., European Union, 2) Share best practices/i.e., in emerging areas like India.

Suggestions fell into four primary areas:

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[2] Ed. Note: In some cases, discussions at the workshop focused more on overall performance than reliability. An attempt has been made to identify performance-related feedback or draw parallels to reliability for purposes of this report.

[3] Ed. Note: The terminology "large or small" is verbatim from a participant feedback card during the workshop, so specific definitions are not available.

(1) *Whether and how to develop a more universally accepted definition of reliability*. The group agrees that while there are currently listings and standards pertaining to certain facets of reliability, there is no universally accepted definition of inverter reliability. Participants also point out that there is similarly no definition for failure; i.e., if a fuse blows, is that a failure or did the fuse perform as expected?
(2) *Whether and how U.S. standards and metrics align or do not align with standards being used in other countries*. Several participants noted that the standards being developed in the United States will be outdated or apply largely to obsolete technology by the time they actually take effect.
(3) *How the industry can share information and best practices such that the industry as a whole benefits, while still respecting competitive advantage*. As noted above, one suggestion is to create a shared database that can be accessed via fees or for which participation is otherwise incentivized.
(4) *Whether research should focus on small components, large components, or complete systems.* The general agreement is that systems approaches can provide the most broadly useful data and efforts to date may have focused too much on failure of large components.

In the second facilitated discussion session on DAY ONE, the group brainstormed various approaches to reliability. The full list of results posited by the group is in appendix E. Some of the suggested approaches included:

- Development of standard metrics and a roadmap such as the International Technology Roadmap for Semiconductors (ITRS) Roadmap
- Characterization of the "mission profile"; capture environmental and operational interactions and develop tests for reliability based on specific profiles; also capture non-operational time mission profiles
- Use of a combination of on-going field and lab tests, rather than relying on previously conducted/published research
- Segment the reliability discussion based on plant size; i.e., 1 MW inverters do not have the same performance issues as 30 kW inverters
- Adopt string inverter manufacturing methods into central inverter manufacturing
- Understand failures of subassemblies and complex components, e.g., PCBs, power supplies, and discuss whether they could be built for longer lifetimes (~100 years); component selection and assembly process have to be examined to identify room for improvement

Cost was a frequently raised issue during this discussion segment. When asked about the relationship of LCOE to inverter reliability, the group agreed that LCOE is an important measure that should be considered when evaluating solutions to reliability. Several participants pointed out, however, that the assumptions behind LCOE must also be validated and tested on a regular basis to ensure that costs are not incorrectly skewed as the energy market changes.

Participants also noted that the cost of maintenance and reliability is currently pushed back and forth between manufacturers and operators via warranties and Power Purchase Agreements, respectively. The concern is which party or parties will bear the cost if inverter reliability is not improved, and, similarly, which party will bear the cost to actually improve reliability. If one party pays but benefits flow primarily to the second party, long-term reliability improvements are unlikely to be sustainable.

Participants were asked whether they would prefer (or thought the market would prefer) low upfront costs for equipment with known reliability issues and higher O&M, or higher upfront costs for equipment with more predictable reliability and lower O&M. The group agreed that the answer depends on each individual company's business model and that aiming at one of these two solutions to the exclusion of the other may not be viable for the PV market.

A final key cost discussion centered on the cost of *not having* reliability vs. the cost of *paying for* reliability. Participants agree that these are two different factors and that both should follow the question: Do we know what type of reliability is actually needed for inverters? Without an answer to that question, participants are concerned that calculations aimed at the valuation of increased reliability will be incorrect. Participants noted that there is no baseline cost for inverter reliability at present, and that such a value may be necessary before the industry can plan where to go next.

The final facilitated discussion of day one included an informal 'survey' of participants regarding the value of creating thermal profiles of operational inverter components and standardized test protocols. While most of the participants indicated that they currently collect temperature profiles within their inverters, most agreed that more comprehensive study and a higher volume of data related to component temperatures would be useful. Manufacturers identified a lack of reliable and plentiful data as a primary issue in developing models to predict inverter reliability.

The group also noted that other industries, such as the automobile industry, are better at information-sharing but are also working with a higher volume in the field so data are more readily available. A DOE-sponsored study would be valuable to this end, as huge variations in the field and competitive concerns make it nearly impossible to gather data from manufacturers. Participants agree that simulations in which conditions could be varied and a range of components could be tested would provide critical information for inverter manufacturers.

Environmental conditions were raised as a primary issue to be researched and addressed. Thermal management failures are often attributed to dirt and bugs, given the large amount of air necessary to cool inverters. Ambient, interior, and IGBT temperatures are also noted areas for improved testing and monitoring. Participants would like to have tools that help manufacturers better understand material stresses related to temperature elements.   Manufacturers would also like to have a better understanding of solar gain and a baseline thermal model similar to that developed by Sandia for AC modules.

2.3 Facilitated Discussion – Day Two

The first guided discussion of day two pertained to codes and standards specifically related to inverter reliability. The group was asked to focus on two primary questions:

- What is the single most important code/standard that is not universally accepted but should be?
- What are the gaps in codes/standards as applied to utility-scale inverters?

Although the group did not come to consensus in a code or standard that should be universally accepted, they did identify three that were generally agreed upon as important:

- IEEE 1413: Standard Framework for Reliability Prediction of Hardware
- IEEE1624: Standard for organizational reliability capability
- JEDEC's JEP 148: Reliability Qualification of Semiconductor Devices Based on Physics of Failure and Risk and Opportunity Assessment

Overall, the opinion was that codes and standards for inverter reliability are still lacking. Participants suggested that work to improve codes and standards should start with a thorough review of existing standards such as the International Electrotechnical Commission's (IEC's) 62093. Once holes and weaknesses in current standards are identified, work can be conducted to integrate new sections and address new technologies. Participants agree that this is likely to be a faster and more market-responsive approach than developing a series of entirely new standards.

Suggestions that codes and standards define qualification (HALT/HASS) and/or reliability (via ALT) were noted as the most immediately important. Additional topics for proposed codes/standards included (full results are in Appendix F):

- Need a PV Inverter Reliability Test Standard (maybe modified IEC 62093) that could be added to a safety certification as ADJUNCT Testing
- Need standards to include solar gain
- Standards need segmentation for different utility-scale inverters
- Using telecom industry as a basis and consider other existing standards, i.e., IAS IEEE Gold Book Standard 49 (Emerging Communications Standards) and PES-Power Plants Indices Standard 762 (Distribution Reliability Standard – *draft*)
- Condition-based Maintenance (CBM); requires in-depth knowledge of wear-out/failures, lifetime-needs data, but can minimize cost (as can component life tracking)

One concern participants expressed is whether codes, standards, and/or performance testing can fully address reliability issues. One attendee noted that there is currently a disconnect between what is expected from equipment that has undergone performance testing and the actual expected life of the product; tests are helpful but certainly not foolproof[4]. Suggestions to address this include offering certifications based on levels of de-rating and relying on qualification tests as the basis for reliability tests rather than the only source of performance verification.

Participants also questioned what the relationship is or should be between certification and warranties/service. The group agrees that certification can help raise performance bars across the industry, but there is a concern about whether changing certain system components in an effort to improve overall system reliability could void a previously applied certification. Participants suggested that feedback loops be implemented, through which certifications can be reviewed and revised.

[4] Refers to performance-related feedback and is not specifically related to reliability.

One participant raised the question of whether a reliability standard can even exist, given that reliability requirements are a function of the market and can vary based on a company's business model (i.e., some companies prefer low upfront costs and higher O&M, and some prefer the reverse). A suggestion to remedy this is to define a standard about how to *test* for reliability – i.e., standardized test protocols – instead of trying to establish a standard for reliability per say.

The second guided discussion on day two pertained to technology advances. When asked which advances are a must to improve reliability across the industry, participants offered numerous suggestions, including (full results are in appendix G):

- Manufacturing quality improvements
- Full characterization of inverter
- Better coordination for open protocols for communications
- Qualified and experienced power electronics, controls and power systems engineers
- Technology that facilitates design for maintainability - could include tools
- Design for serviceability: Must avoid too many wires, connectors
- Defined inverter use environments (temp, electric, frequency, dust, etc…). Require this?

The industry needs to better understand where the 'pain point' lies in PV systems and how business practices can be streamlined to implement new technology more effectively. In addition, participants emphasize that even superior technology is of little value to the industry if the economics don't work; without getting to grid parity, any advance lacks real meaning.

Participants agree that sometimes the worst failures occur in small components of the system and that expanded research on how individual components operate in various environmental conditions – and as part of a total system - is critical. One participant noted that every connection in a PV system is a potential failure point and current inverter designs require so many individual connections that ensuring reliability across all of them is virtually impossible. Despite this, the group agreed that a design standard could hinder creativity and future technological advances, so the answer may lie in better understanding system-level behavior, including the numerous environmental conditions in which PV systems operate and how each environment contributes to potential failures.

When asked what technology advances would be 'nice' to have, participants identified the following (full results are in appendix G). Again, it was noted that technology is only part of the puzzle and needs to be developed and understood within the confines of environmental conditions and varying business models:

- For large plants, a 'nice to have' is some variable control of MV transformers taps to allow for voltage variations on collection systems, especially in VAR control mode
- Advanced forecasting for energy
- Advanced SCADA (remote control for inverter-kW control, everything)
- Intelligent data and sensor/alarm handling
- If asked (in an increased PV penetration situation), inverters could provide voltage support and ride-through capabilities

- More sensor (temp, etc…) intelligence to provide fault report logs

The final facilitated discussion of the workshop was an opportunity for the group to identify specific next steps with the potential to address inverter reliability issues. Some suggestions noted by the group include (full results are in appendix H):

- Work on revision of IEC 62093 and get more input from workshop participants
- Test the effects of solar gain
- Investigate back-of-PV environment[5]; help to extend IEC 61215 to include micro-inverters and distributed electronics.
- Work with IEC to modify existing reliability standards to better apply to inverters
- Push for a basic protocol/standard that inverter manufacturers will embrace
- Develop system-level reliability analysis tools that will incorporate condition, systems and environmental sensor data
- Convene another workshop in approximately 12 months (Oct 2011 or March 2012)[6]
- Work to get more data sharing
- Work on developing requirements for qualification standards, especially electrical stress test: dynamic models for inverters, grid models and grid simulations
- Explore business models and frameworks to share diagnostics from inverters
- Figure out accelerated tests for inverter components
- Increase support for developing IEC 62093 inverter qualification standard

It should be noted that many of the suggestions for next steps pertain to the revision of codes and standards, but few suggest the development of entirely new standards. This follows the previous discussion about codes and standards, during which the group agreed that entirely new standards would be too time-consuming and revision of existing standards is more viable.

The group also noted several Sandia-specific suggestions, including:

- In situ monitoring and characterize IGBT's at Sandia; continue to talk to IGBT manufacturing; learn what is done; some type of informational blog?
- Develop a reliability protocol based on "how-to"- use IPC9592A as a guide
- Develop an inverter model to tie into the integrated systems model

Sandia has outlined a comprehensive approach to inverter reliability, including work to determine an appropriate proposal for a standard or a guideline. This includes real-time studies to assess inverter failures in the field, development and application of accelerated tests, working with industry to determine what testing and standards are already in use, and leading additional workshops that will address various inverter sizes. Current focus at Sandia is to develop, apply, and evaluate accelerated test protocols for inverter components. The results will be incorporated into the PV Reliability and Availability Predictive Model and used to guide development of a reliability standard proposal.

[5] Stated as indicated by participants; assumed to mean the backside of the PV module.
[6] Specific workshop type was not identified in the participant feedback card; the assumption is that this refers to another utility-scale PV inverter reliability workshop.

3. REFERENCES

None

APPENDIX A

U.S. Department of Energy and
DOE's Sandia National Laboratories
Utility-Scale Grid-Tied PV Inverter Reliability Technical Workshop

Phillips Technology Institute Collaboration Center
Albuquerque, New Mexico

AGENDA

Thursday January 27, 2011		
8:30	- Welcome and Workshop Overview - Purpose of Meeting	Stan Atcitty, *Sandia* Mike Cliggett, *U.S. Department of Energy (DOE)*
8:30	Inverter Manufacturer Perspective on Reliability	Jim Perkinson, *Satcon*
9:00	Integrator Broad Perspective on Reliability – Customer Needs and Field Data	Tom Levitsky, *First Solar*
9:30	Break	
9:45	Owner/Operator Perspective on Reliability – Customer Needs and Field Data	Tassos Golnas, *SunEdison*
10:15	Survey Results and Summary	Michael Quintana, *Sandia*
11:35	Discussion Time for Survey Results	Led by Bryan Pai, *SRA International*
12:15	Lunch	On-site
1:15	DOE $1/Watt Workshop and DOE Goals	Mike Cliggett, *DOE*
1:40	Sandia's Approach to Reliability – Overview	Jennifer Granata, *Sandia*
2:15	Break	
2:25	IGBT Reliability Issues and Needs	John Donlon, *Powerex*
2:55	IGBT Si- and SiC-based Switch Reliability Project	Bob Kaplar, *Sandia*
3:25	Capacitor Reliability Issues and Needs	Andy Ritter, *AVX Corporation*
3:55	Facilitated Discussion – Approaches to Reliability	
5:05	Second Survey Based on First Day of Discussion	
5:30	Adjourn	

Friday January 28, 2011		
8:30	Welcome and Recap of Day One	Stan Atcitty, *Sandia*
8:35	Results of Second Survey	Bryan Pai, *SRA International*
9:00	Existing Codes and Standards (Summary) – *What codes and standards exist for modules and how do they compare to inverters?*	Greg Ball, *BEW Engineering*
9:20	Overview of UL 1741	Tim Zgonena, *Underwriters Laboratories*
9:40	ALT/Acceleration Factors – *Is more work needed in this area? What is currently available and how it is applied to existing systems?*	Rob Sorensen, *Sandia*
10:00	Facilitated Discussion – Codes and Standards • What is the single most important code/standard that is ***not*** universally accepted but should be? • What are the gaps in codes/standards as applies to utility-scale inverters?	
10:45	Break	
10:55	Technology Advances to Improve Reliability – Broad View	Diganta Das, *CALCE University of Maryland*
11:15	Facilitated Discussion – Technology Advances • What advances are a "must"? • What advances would be "nice" to have?	
12:30	Working Lunch Facilitated Discussion – Wrap-up • Action Items- DOE/SNL/ Attendees – What are we going to do? – When are we going to do it? – How are we going to do it? – Who else needs to know about these steps and what method(s) can be used to communicate effectively with them?	Led by Bryan Pai, *SRA International*
2:00	Adjourn/Leave for Sandia's Distributed Energy Technologies Laboratory (DETL)	
2:15	Optional DETL Tour	
4:00	Return to Phillips Technology Institute/Airport	

APPENDIX B

UTILITY-SCALE GRID-TIED PV INVERTER RELIABILITY WORKSHOP
January 27-28, 2011

COMPANY PARTICIPATION LIST

Arizona State University
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AVX Corporation
BEW Engineering
Center for Advanced Life Cycle Engineering - University of Maryland
Eaton Inc.
Electric Power Research Institute
First Solar
Fotowatio Renewable Ventures
infiniRel Corporation
INGETEAM
National Renewable Energy Laboratory
New Mexico State University
Powerex, Inc.
Princeton Power Systems
Ridgetop Group Inc.
Sandia National Laboratories
Satcon
Siemens AG
SMA Solar Technology / SMA America, LLC
Southern California Edison
SolarEdge Technologies, Inc.
SRA International, Inc.
SunEdison
U.S. Department of Energy
Underwriters Laboratories

APPENDIX C

UTILITY-SCALE GRID-TIED PV INVERTER RELIABILITY WORKSHOP
January 27-28, 2011

PRE-WORKSHOP SURVEY

Thank you for participating in the Large Inverter Reliability survey. An answer is required for each question. To ensure anonymity, your IP address will NOT be recorded during this survey. All information will be held in confidence and will be used only in aggregate format. However, if you would like a follow-up call to discuss your responses, please indicate a contact method in the last question.

1. What size inverters does your company produce? Please check all that apply.

- <30 kW
- 30 kW - 50 kW
- 50 kW - 100 kW
- 100 kW - 500 kW
- 500 kW - 1 MW
- >1 MW

2. Where has your company sold inverters for PV systems?

- In the United States only
- Outside the United States only
- In the United States and internationally

3. In which climate zones are your inverters working (to your knowledge)? Check all that apply.

- Hot / dry (e.g., Southwest U.S., Spain)
- Hot / humid (e.g., Southeast U.S., tropical zones)
- Cold
- Temperate
- Low irradiance (e.g., Northeast U.S., Germany)
- High elevation regions (>5000 ft)
- Sea level/coastal regions

4. How many years has your company been in the PV inverter business (round up to closest whole number)?

___________ Years

5. What different types of inverters has/does your company design and market? Check all that apply.

- PV only
- PV with storage
- Indoor rated
- Outdoor rated
- Passively cooled
- Actively cooled
- PV with ancillary services
- Other (please specify:_______________________________________)

6. What is the warranty offered by your company? Check all that apply.

- 2 years
- 5 years
- 10 years
- 15 years
- 15 years for a fee
- Other (please specify___________________________________)

7. Does your company service your inverters?

- Yes while under warranty at no cost
- Yes for a cost
- No
- Other (please specify___________________________________)

8. To date, what is your company's cumulative capacity of PV inverters sold?

- <500 kW
- 500 kW - 1 MW
- 1 MW - 5 MW
- 5 MW - 10 MW
- 10 MW - 50 MW
- >50 MW

9. What reliability testing does your company currently perform?

- None
- CEC testing
- Product design/design for reliability
- Component accelerated testing (which components?)
- HALT
- HASS
- Accelerated life testing (ALT) at a component level
- ALT at a system level
- Other (please specify_______________________________________)

10. What reliability-related standards or guidelines does your company currently use? Check all that apply.

- MIL-Specs for components
- IEC 62093
- JEDEC Standards
- Other (describe)

11. What are your top three (3) vulnerabilities or reliability issues for your inverters? Examples: Grid issues, Communications, Temperature excursions, Temperature mitigation (ex. Fans failing), Transients, Component degradation (which components?), Environmental issues (dust, bugs, water, etc.) Limit of 100 characters per answer.

Enter Answer

12. Where on the list of main sources of critical failures of inverters do you believe each of the following inverter components lie? (1) bottom 50%, (2) top 50%, (3) top 25%, (4) top 10%, (5) top 5%.

Interconnects
IGBT
IGBT drive circuitry
Electrolytic Capacitor breakdown
Transformers
Filter Capacitors
Filter Inductors
Control Circuit Board
DC disconnect
AC disconnect
Fans
Liquid cooling loop
Heat sink
Thermal compound breakdown
Thermal measurement circuitry
Solder Fatigue
Film capacitors
Power supply
Voltage sense circuitry
AC/DC sense circuitry
Surge suppression devices
Cabinet

13. What are your top three (3) reliability drivers you worry about for your company and for the industry as a whole? Examples: Specific component reliability (please explain), technical issues within a system design, warranty history. Limit of 100 characters per answer.

Enter Answer

14. What do you hope to get out of participating in a reliability workshop?

15. If you would like to further discuss the survey and/or your responses, please indicate your preferred choice of contact. A response is NOT required to complete the survey.

APPENDIX D

UTILITY-SCALE GRID-TIED PV INVERTER RELIABILITY WORKSHOP
January 27-28, 2011

FACILITATED DISCUSSION # 1: Pre-Workshop Survey Results

Bullets are the raw suggestions provided by the group via the facilitated discussion exercise.

- Sandia Performance Test Protocol for Evaluating Inverters used in grid-connected PV Systems
- Sandia Reliability Test Protocol - every inverter has at least a few similar hardware and control equipment methodologies
- Widespread PV begins to alter electrical environment=> requiring revisiting compatibility issues
- Keep record of failure modes, which component fails and why - make this public to learn and improve product quality
- Reliability is often hardware-focused…however software reliability is absent from the conversation - context: SCADA, Control Interface, Algorithms/State Spec Flows, etc…
- Reliability Database similar to GADS for Conventional generation
    - NERC GADS PV Working Group
- How to define test criteria for "plus-fest" interoperability, maximizing performance when re-powering the PV plant
- Inverter manufacturers' view of outside impact; define requirements for proper operation and performance
- Also, emphasize what works well and not just what fails (how do you disseminate?)
- Develop guidelines for estimating heat gain due to exposure to direct sunlight, i.e. installed in full sun. Today NEC and UL do not consider this issue for inverters, combiners, etc…some guidelines do exist for wire and conduit
- Need to create PV application-specific performance criteria and test protocols - large or small - inside or outside the fence
- To achieve $1/W goal don't too much pressure on power electronics - this will force manufacturers to cut corners. Rather, emphasis should be to increase cell efficiency
- General dynamic models of inverters for grid-level issues: Dynamic models of grid for inverter design/analysis
- Need a market analysis to understand trends, so that we solve relevant problems - component types, power rating (specs), market needs (environment, stress factors)
- Organization/scope embrace and work with other international organizations to: A) Learn/ use best practices in high-deployment areas …i.e., European Union, B) Share best practices/i.e., in emerging areas like India
- How 'reliable' is 'reliable'?- Create a definition and metric for reliability
    - "Failure" needs to be defined
    - Impacts on financial models
- Develop RBD that all manufacturers can fit inverter designs INTO -> for equal evaluation
- Process: Sys FA 1) Throw spares at it 2) Diagnose failure 3) Conduct system study – results in high costs/expenditures
- Develop anonymous failure reporting templates for database entry and pay for access by selling memberships, perhaps using an EPRI model. Incentivize submission with discounts.

- DOE provides component testing and compliance, and standards, so that popular, good quality components are put into decisions
- Standardize communications protocols (EGD, EtherIP, Profinet, etc.)
- Standardize response times of control features, data acquisition
- Establish performance standards - will aid/help identify “problems” vs. “preferences”
- Keep an open mind on “old” technology. Evaluate benefits of proven reliability vs. leading edge technologies.
- Classify inverter topologies and control algorithms and correlate them with failure types
- Impact of value-added functions on reliability
- Quantify the cost of maintenance in yrs 0-5, yrs 5-10, yrs 10-15
- Have Sandia develop PV inverter-specific FIT MTBF data for major components and standardize methodology for calculating reliability. PV applications are unique and general FIT/MTBF may not apply.

APPENDIX E

UTILITY-SCALE GRID-TIED PV INVERTER RELIABILITY WORKSHOP
January 27-28, 2011

FACILITATED DISCUSSION # 2: Approaches to Reliability

Bullets are the raw suggestions provided by the group via the facilitated discussion exercise.

- LCOE matters, the calculation needs to be done
- Cost of increasing/expanding reliability - who will bear the cost?
- Cost of poor/inadequate reliability - who will bear the cost?
- The baseline cost of reliability needs to be determined
- Must characterize the “mission profile”; know enviro factors and develop tests for reliability
- Must conduct field and lab test in actual applications env/not just books
- Characterize mission profile
- Assumptions behind LCOE need to be validated and tested
- Capture all environmental and operational interactions in mission profile
- Capture non-operational time mission profile
- Challenge assumptions based on experiences and lessons made in different markets [under different financial models] and technical applications
- Not component Pareto but mechanism Pareto
- It is good that there is no MIL 217
- Non-operational conditions
- Do not ignore board failures
- Obsolescence - O&M cost increases if old products are not around
- (Attempt to) Borrow MFR methods from string inverter manufacturing (to what extent can they be adopted in central inverter mfg.)
- Short- vs. long-term costs and reliability issues: 1) Business executives focus on short term financial performance. 2) Externalities - beneficiaries may not bear the cost, especially long-term 3)Need or concern for sustainability
- Integrators drive a model that inverter manufacturers follow on procurement
- Segment the discussion based on plant size, i.e., 1 MW inverter vs. 30 kW inverter
- Scheduled O&M option may require better degradation and failure predictions and/or more sensors and monitoring
- Using condition-based maintenance to decrease truck rolls and increase availability
- Critical sub component mfg methodologies of utility-scale inverter about techniques and lessons learned from string inverters and micro-inverters
- Options: 1) low cost, higher O&M or 2) higher-cost, higher reliability, lower O&M
- Understand failures of subassemblies and complex components e.g. PCBS, power supplies - Can they be built to last 100 years? Component selection and assembly process have to be examined for room for improvement.
- Compare cost/reliability of robust single part to less robust multi-components. Single point vs. redundant.
- Standard metrics
- What is cheaper over 30 years? One 30yr inverter or six 5-yr inverters?
- ITRS Roadmap (i.e., for semiconductors)

APPENDIX F

UTILITY-SCALE GRID-TIED PV INVERTER RELIABILITY WORKSHOP
January 27-28, 2011

FACILITATED DISCUSSION # 3: Codes and Standards

Bullets are the raw suggestions provided by the group via the facilitated discussion exercise.

- IEEE 1413
- IEEE1624
- JEP 148
- What has priority? Codes/standards that define Qualification –HALT /HASS or Reliability - > ALT
- Review IEC Standards 62093 and others. Identify holes and weaknesses, work to harmonize or develop new sections as needed.
- Need a PV Inverter Reliability Test Standard (maybe modified IEC 62093) that could be added to a safety certification as ADJUNCT Testing
- Path to new reliability standards easier and quicker if they start by revising existing standards; revising IEC 62093 is faster than starting a new standard.
- Standards don't address solar gain
- Warning - MFR, can/will/sometimes "game" the system. Cost and time are huge factors.
- Segmentation for utility scale inverters –different standards different requirements
- Failures DIST=MTTF +DIST Width
- Disconnect of what a performance test buys and the expected life of the product
- While verifying component ratings, give certifications based on the levels of de-rating that are used. These could be used by manufacturers as justification for charging premium prices.
- A qualification test can be a launch point for a reliability test
- Using Telkom industry as basis; standard form factors
- Define a standard that tests for reliability
- Codes/standards are a common way to make an industry achieve higher reliability
- CBM requires in-depth knowledge of wear-out/failures, lifetimes-needs data
- Condition-based Maintenance (CBM)
- Consider other existing standards- IAS IEEE Gold Book Std 493 – Emerging Communications Standards DNP, SEP – PES- Power plants Indices standard STD 762 – Distribution Reliability Standard STD 1782(draft)
- Component life tracking and CBM minimize cost- This needs lots of data tracking

APPENDIX G

UTILITY-SCALE GRID-TIED PV INVERTER RELIABILITY WORKSHOP
January 27-28, 2011

FACILITATED DISCUSSION # 4: Technology Advances

Bullets are the raw suggestions provided by the group via the facilitated discussion exercise.

What advances are a must?

- Manufacturing quality improvements
- Tech that facilitates design for maintainability - could include tools
- Technology is a tool. Grid parity (Regional) and economics must be focus.
- Must avoid too many wires, connectors - design for serviceability
- Defined inverter use environments (temp, electric, frequency, dust, etc…). Require this?
- Transfer QA/QC from other highly-controlled industries
- We need resolution about whether we will test full inverter systems or subsystems/components in standards we define
- Development: AC/DC test standards, Environmental Test Standards, Communications Test Standards, Performance Standards, Reliability Standards, Unit level, Systems Utility Level
- Open control architecture
- Full characterization of inverter
- As penetration increases; grid issues became very important
- Reduce cost/and or need for transfer trip on large-scale utility systems
- Perceptions matters: Utilities want inverters that look like/ACT like transformers.
- Grid control features (VAR, kW, Pf, LVRT)
- Better coordination for open protocols for communications
- On-going dialogue for failure/modes/mechanisms—blogs/ papers
- Qualified and experienced power electronics, controls and power systems engineers

What advances would be nice to have?

- For large plants, a 'nice to have' is some variable control of MV transformers taps to allow for voltage variations on collection systems, especially in VAR control mode
- Advanced forecasting for energy
- Advanced SCADA (remote control for inverter-kW control, everything)
- Intelligent data and sensor/alarm handling
- If asked (in an increased PV penetration situation), inverters could provide voltage support and ride-through capabilities
- More sensor (temp, etc…) intelligence to provide fault report logs
- Change in rate structure
- Accurate/robust high-resolution data (find middle ground on cost)

APPENDIX H

UTILITY-SCALE GRID-TIED PV INVERTER RELIABILITY WORKSHOP
January 27-28, 2011

FACILITATED DISCUSSION # 5: Suggested Action Items

Bullets are the raw suggestions provided by the group via the facilitated discussion exercise.

- Work on revision of IEC62093 and get more input from workshop participants
- Test the effects of solar gain
- Investigate back-of-PV environment. Help to extend IEC 61215 to include micro-inverters and distributed electronics.
- Explore business models and frameworks to share diagnostics from inverters
- Work with IEC to modify existing reliability standards to better apply to inverters
- Figure out accelerated tests for inverter components
- Push for a basic protocol/standard that inverter manufactures will embrace
- On-board, on-module diagnostics
- Give focus to where we are in reliability; where do we want to be? (transformer) may not be quantitative.
- Unit substation-style package design, i.e., whole installation serviceability replacement
- Work on developing requirements for qualification standards, especially electrical stress test: dynamic models for inverters, grid models and grid simulations
- Estimation model to measure 99% availability- How to accomplish that and cost up to 25 years
- Sandia-specific suggestion: In situ monitoring and characterize IGBT's at Sandia; continue to talk to IGBT mfg-learn what is done; BLOG?
- Characterize DC voltage during AC interruptions- determine thermal equilibrium during CEC 5.5 testing! Caps and heats sinks.
- Review field data and calculate cost of reliability - for systems and components
- Attempt to measure solar gain
- 1)Explore area of collaboration and data sharing opportunities, 2) Initiate dialogue with key labs and agencies, 3) Revise inverter specifications
- Sandia-specific: Develop a reliability protocol based on "how-to"- use IPC9592A as a guide
- Sandia-specific: Develop an inverter model to tie into the integrated systems model
- Participate in standard writing for reliability - continue sanity check on costs vs. needs- work with MFG to implement reliability - focus on construction/designs
- Continue to understand/model environmental effects on inverter operation and reliability
- Increase support for developing IEC 62093 inverter qual standard
- Develop system-level reliability analysis tools that will incorporate condition, systems and environmental sensor data
- Key part reliability prediction and ALT; consider the main steps for design for reliability on inverters
- Participants (InfiniRel and CALCE) will explore the use of high-speed smart sensor technology and RCM/CBM principals and failure pre-cursors for : cap failure, interconnect failure, S/W malfunction prediction
- 1)List of unique needs-impact on reliability 2)Hold IGBT Mtg 3)Respond to DOE RFI 4)Look at if IEEE Reliability Soc. should be involved 4) Find what Chinese manufacturers are doing.
- Convene another workshop approximately 12 months from now - Oct 2011 or March 2012
- Workshop or discussion on bankability
- Develop a CQM "Voice of the Customer" program/ white paper
- Work to get more data sharing
- Include a breakout of participants (integrators, inverter makers, etc…) in meeting notes.

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