NREL
NATIONAL RENEWABLE ENERGY LABORATORY

# NREL Photovoltaic Reliability Workshop—Golden, Colorado

## February 24–27, 2015

## Agenda for Wednesday, February 25, 2015

Inverter Workshop

In parallel with the module-focused PVQAT workshop, this workshop will be devoted to presentations and discussions about inverters and especially about inverter reliability. Its scope will extend from large inverters used in utility applications to module-embedded electronics. This workshop will be a follow on to the inverter workshops that Sandia National Laboratories has hosted in the past (http://energy.sandia.gov/?page_id=14873).

Attendees are welcome to move back and forth between the PVQAT and Inverter workshops.

### Chairs

Jack Flicker

### Committee

Paul Parker

Chris Deline

Olga Lavrova

Tim Peshek

Rob Sorensen

Greg Ball

Faraz Ebneali

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Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

## AGENDA Wednesday, February 25

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| **7:30–8 a.m.** | Continental Breakfast |
| **8–9:15 a.m.** | **Utility-Scale Inverters**—Greg Ball (Chair), DNV GL<br>**8:00 -** Inverter Reliability—Matt Ursino, Solectria<br>**8:15 -** Accelerated Reliability Testing of Commercial and Utility PV Inverters—Ron Vidano, Advanced Energy<br>**8:30 -** Michael Mendik, SMA<br>**8:45 -** Discussion |
| **9:15–9:30 a.m.** | **Coffee Break** |
| **9:30–10:45 a.m** | **Module Level Power Electronics**—Jack Flicker (Chair), Sandia National Laboratories<br>**9:30 -** Standardization and Reliability Testing of Module-Level Power Electronics (MLPE)—Govindasamy Tamizhmani, TUV PTL<br>**9:45 -** Eric Boskin, Maxim Integrated<br>**10:00 -** Managing Large Inverter Fleets—Mark Baldassari, Enphase Energy<br>**10:15 -** Discussion |
| **10:45 a.m.–12 p.m.** | **Advanced Inverter Functionality**—Faraz Ebneali (Chair), ReneSola<br>**10:45 -** Smart Inverter Grid Support Functions and Potential Impact on Reliability—Aminul Huque, EPRI<br>**11:00 -** The Impact of Smart Inverters: How Rule and Regulation Will Transform DG into Smart Systems—John Berdner, Enphase Energy<br>**11:15 -** Discussion |
| **12–1 p.m.** | **Lunch and Poster Viewing** |
| **1–2:15 p.m.** | **Failure Modes**—Chris Deline (Chair), NREL<br>**1:00 -** IGBT Failure Modes in Inverters—Diganta Das, CALCE<br>**1:15 -** Corrosion of Electronics—Rob Sorensen, Sandia National Laboratories<br>**1:30 -** Nanocoatings: The Solution to All of Our Environmental Protection Problems?—Greg Caswell, DfR Solutions<br>**1:45 -** Discussion |
| **2:15–3:30 p.m.** | **Accelerated Testing** —Tim Peshek (Chair), Case Western Reserve University<br>**2:15 -** PV Inverter Accelerated Testing for High-Humidity Environments—Paul Parker, SunPower<br>**2:30 -** Michael Mills-Price, DNV GL<br>**2:45 -** Predictive Reliability Modeling for Inverters Based on Electro-Thermal Phenomena—Ken Armijo, Sandia National Laboratories<br>**3:00 -** Discussion |
| **3:30–4 p.m.** | **Coffee Break** |
| **4–5 p.m.** | **Presentation of survey results** —Jack Flicker (Chair), Sandia National Laboratories |

**ROOM ASSIGNMENTS**

PVQAT Sessions: Ballroom Salons A-D

Poster Sessions: Ballroom Salons E-H

Inverter Group Sessions: Aspen/Snowmass (downstairs)

PVQAT QMS Breakout – Keystone/Telluride

PVQAT Climate Specific Breakout – Ballroom Salons A-D

Note that Copper Creek Restaurant Private Dining Room is available at all times for side meetings as needed.

# POSTER SESSIONS

Poster presenters have been asked to leave their posters up all day Tuesday, Wednesday, and Thursday for adequate viewing. We ask that poster presenters be available next to their posters for discussion during the following times.

## TUESDAY, February 24, 2015

### POSTER SESSION I

1. Alex Bradley, Tanya Dhir, Yves Poissant Initial analysis of 22-year old PV system in Quebec, Canada

4. Andrew M. Gabor, Rob Janoch, Andrew Anselmo and Halden Field Solar panel design factors to reduce the impact of cracked cells and the tendency for crack propagation

7. Cordula Schmid, Rubina Singh, Philipp Zimmermann, Jacqueline Ashmore Development of Qualification Tests for Glass-Less c-Si Modules

10. David Näsvall Requirements on accelerated testing to ensure 25 years without moisture ingression problems in the toughest climates

13. Devin A. Gordon, Abdulkerim Gok, Cara Fagerholm, David M. Burns, Timothy J. Peshek, Laura S. Bruckman, Roger H. French Degradation Analysis of Poly(ethylene terephthalate) via Fluorescence Spectroscopy

16. I.E. Anderson, M. Osborne, G. Alers Backsheet reliability of modules for greenhouse application

19. J. Gallon, G. S. Horner, J. E. Hudson, L.A. Vasilyev PV Module Hotspot Detection

22. John Naumovitz, Kumar Nanjundiah, Lisa Madenjian Maximizing Reliability Performance with Polyolefin Encapsulants

25. L.L. Kazmerski, Antonia Sonia A.C. Diniz, Cristiana M. Brasil, Lauro V. Machado Neto, Marcelo Machado, Leila de Oliveira Cruz, G. TamizhMani Emerging Reliability Issues for Photovoltaic (PV) Modules: Surface Conditions and Fundamental Photon Coupling

28. MaoYi Chang, Haomin Chen, Chienyu Chen, C. H. Hsueh, W. J. Hsieh Water Cooking for Backsheet and PV Module Endurance Evaluation

31. Michael Gostein and Bill Stueve Accurately Measuring PV Power Loss Due to Soiling

34. Nicholas Riedel, Larry Pratt, Erica Moss, and Michael Yamasaki 600 Hour Potential Induced Degradation Testing on Silicon, CIGS and HIT Modules

37. O. Bamiduro, R. Konda Defects during the synthesis of a one-step electrodeposited $CuIn_xGa_xSe_2$/Mo/glass films at atmospheric conditions

40. Soh Suzuki, Tadanori Tanahashi, Takuya Doi and Atsushi Masuda Sorting test of bending load on the interconnector in crystalline silicon photovoltaic modules

43. Tadanori Tanahashi, Soh Suzuki, Norihiko Sakamoto, Akihiro Mito, Katsuhiko Shirasawa and Hidetaka Takato *In-situ* AC impedance measurement in c-Si PV modules during rapid thermal cycling test

46. Yasunori Uchida Tj measurement of bypass diode for PV modules

49. Sean Fowler Effects of water spray on specimen temperature exposed during proposed xenon arc and fluorescent UV lamp weathering test cycles for backsheet materials

52. John Lippiatt Robustness of SunPower Cells to Wind Stress via High-Cycle Vibration Testing

55. Tatsuo Nakamura Utilization of Ultra-Intense UV Weathering Chambers for Rapid Acceleration of PV Component Testing

58. Tony Sample Long-term soiling in a moderate subtropical climate

61. Eric Schindelholz Characterization of Fire Hazards of Aged Photovoltaic Balance-of-System Connectors

64. Davis Hemenway, Hiroshi Sakurai, Walajabad Sampath, and Kurt Barth Thermal Modeling of PV Modules Using Computational Simulation

## TUESDAY, February 24, 2015

### POSTER SESSION II

2. Benjamin Figgs, D. Martinez, T. Mirza PV Soiling Rate Variation over Long Periods in Desert Environment

5. Dr. Lars Podlowski, Bernd Litzenburger, Stefan Janke, Daniel Cormode, Stefan Wendland Worst-case partial shading conditions for crystalline silicon solar cells with different reverse-current characteristics

8. Eric Schneller, Joe Walters, Stephen Barkaszi Performance analysis of c-Si module deployed at FSEC after 10 years exposure

11. Russell Geisthardt, John Raguse, Andrew Moore, and James Sites Tracking PV Changes: Bridging Between Thin-Film Cells and Modules

14. Jayesh G. Bokria, Sean A. Ferrigan, Kyle B. Smith, and Luke A. Strzegowski Role of EVA-based encapsulants on Potential Induced Degradation of Crystalline Silicon PV Modules

17. Jeff Thompson, Yoshiaki Takezawa, Clarissa Miller Increased Hydrolytic Stability of Neutral Cure Silicone Adhesives Improves Long-term Module Reliability

20. Justin Luria, Yasemin Kutes, Bryan Huey Accelerated Aging of CdTe Microcells Using Conductive Probe Atomic Force Microscopy

23. M. Propst, N.A. Olsson Pitfalls of Energy Yield Prediction Models Based on Time 0 and STC Module Characterization

26. Masahiro Iwata, Keisuke Ogawa, Hiroshi Kanno, Hiroshi Inoue, Mikio Taguchi and Shingo Okamoto Stability of encapsulants using various string-ribbons

29. Nancy Phillips Backsheet Weathering Study Comparing Light Sources, Irradiance and Temperature Levels

32. Narendra Shiradkar, Vivek Gade Thermal Resistance Measurement of Bypass Diode / Junction Box

35. Lori Postak and Mike Kempe Edge Seal Testing Update

38. Kristopher Toivola, Paul F. Robusto, Bill Kessler Outdoor Performance of CIGS Modules in Different Climates

41. Rie Tanaka and Hirofumi Zenkoh Encapsulant effect on PID durability of various crystalline PV cells

44. Shubhra Bansal, Rebecca Jones-Albertus PV Module and Device Reliability: An Overview of Current Status and Potential Gaps

47. Steve Johnston and Tim Silverman Photoluminescence and Electroluminescence Outdoor Module Imaging

50. V. Bermudez Effect of process fabrication and annealing conditions on stabilization pre-conditioning of CIGS modules

53. Yan Wang, Yong Sheng Khoo, Thomas Reindl PV Module Reliability Studies in the Tropics–and Beyond

56. Zhu, D. Wu, D. Montiel-Chicharro, M. Owen-Bellini, T.R. Betts, and R. Gottschalg Influences of lamination quality on durability of PV modules under damp-heat exposure

59. Haichuan Zhao, Yinbai Li, and Matt Perry Reliability Test and Analysis of Silicone Sealant Used for Sealing and Bonding on PV Modules

62. Kannan Ramanathan and Rebekah Garris Processing and Device Oriented Approach to CIGS Module Reliability

## POSTER SESSIONS

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### WEDNESDAY, February 25, 2015

#### POSTER SESSION PVQAT

3. **Alex Mikonowicz** What is the US TAG and what is its function: the official IEC TC 82 description

6. **Amy Lefebvre, Greg O'Brien, James D. Knapp, Bryan Douglas, Gunter Moeller, Dana Garcia** Effect of QUV A with Thermal Cycling Exposure on PV Backsheets

9. **Antonia Sonia A. C. Diniz, Marcelo M. Viana, Cristiana B. Maia, Suellen C.S. Costa, Thiago A. Silverio, Marcio E. M. de Souza, Denio A. Cassini, Francisco H. A. F. Souza, Lawrence L. Kazmerski** Field Evaluation of Photovoltaic Modules and Systems

12. **Bengt Jaeckel, Marijo Cosic and Jürgen Arp** Investigation of c-Si Module Degradation and Recovery Effect under High Potential

15. **Brenor Brophy, Sergiu C. Pop, Venkata Abbaraju, Ralf Schulze, Y. Sam Yang, Sina Maghsoodi, Peter Gonsalves** Highly Durable Anti-Reflective Anti-Soiling Coating for PV Module Glass

18. **David C. Miller, Jayesh G. Bokria, Xiaohong Gu, Christian C. Honeker, Naiara Murua, Nichole E. Nickel, Keiichiro Sakurai, Tsuyoshi Shioda, Govindasamy Tamizhmani, Ethan Wang, Shuying Yang, Toshio Yoshihara, and John H. Wohlgemuth** Round-Robin Verification and Final Development of the IEC 62788-1-5 Encapsulation Size Change Test

21. **Donald B. Warfield** System reliability aspects of currently available modules with atypical string length

24. **Doug Vermillion and Tatsuo Nakamura** Utilization of Ultra-Intense UV Weathering Chambers for Rapid Acceleration of PV Component Testing

27. **Eleonora Annigoni, Federico Galliano, Marko Jankovec, Heng Yu Li, Laure-Emmanuelle PerretAebi, Christophe Ballif, Fanny Sculati-Meillaud** Moisture ingress into PV modules: long-term simulations and a new monitoring technique

30. **Gerhard Kleiss** Quality and Reliability—Sometimes the Customer Wants More

33. **Jane Kapur, Kate Stika, Craig Westphal, Sergiu C. Pop, Ralf Schulze, Xiaoguang Wang, Beihai Yuan, Andreas Meisel** Prevention of PID with Ionomer film by reducing Sodium-ion Accumulation in Photovoltaic modules

36. **J.P.D. Cook, C.T. Li, J. Haysom, K. Hinzer, and H. Schriemer** TETRA—Thermal Environment by Transient Response Analysis: Auto-Calorimetry Toward Material and Structure Evolution Studies in Concentrator Photovoltaic Cells

39. **Jia Ying Ye, Teck Cheng Tan, REC Solar** Rolling Reliability Test and Field Degradation Correlation Investigation in REC Solar

42. **Mark Reusser, Matthew Dorogi, Larry McClung** Financial Implications of Module Degradation Uncertainty for Utility-Scale Solar Facilities

45. **Matevž Bokalič, Kristijan Brecl, Marko Topič** Outdoor Stabilization of Thin-Film Photovoltaic Module Performance

48. **Nia Thompson** The Limiting Effects of Temperature on the Performance of a Crystalline-SI Solar Array in Trinidad and Tobago's Climatic Conditions

51. **Ranier Grischke** Prolonged Lifetime Performance of Meyer Burger`s Hetero Junction Solar Modules

54. **Soo-Young Oh** An Open Platform to Speed-up and Cost-down the PV Reliability R&D

57. **Xiaohong Gu, Chiao-Chi Lin, Peter Krommenhoek, Stephanie Watson** Depth Profiling of Chemical and Mechanical Degradation of PV Backsheets after Accelerated Laboratory Exposure under Simultaneous UV, Temperature and Moisture

60. **Thomas Weber, Juliane Berghold, Floreian Heilmann, Margarete Roericht, Stefan Krauter, and Paul Grunow** Test Sequence Development for Evaluation of Potential Induced Degradation on Thin Film Modules

63. **Patrick Trippel** Reliability Test and Analysis of Silicone Sealant Used for Sealing and Bonding on PV Modules

65. **W. Gambogi, J. Kopchick, T. Felder, S. MacMaster, A. Bradley, B. Hamzavytehrany, C.-F. Wang, H. Hu, Y. Heta, and T. J. Trout** Sequential and Weathering Module Testing and Comparison to Fielded Modules

### WEDNESDAY, February 25, 2015

#### POSTER SESSION INVERTER

66. **Kenneth Armijo, Jay Johnson, Benjamin Yang, Michael Hibbs and Richard Harrison Arc** Fault Photovoltaic Reliability and Plasma Physics of Failure Investigations

67. **Faraz Ebneali** Sustainability through Product Quality and Compliance

68. **Timothy J. Peshek, Mohammad A. Hossain, Roger H. French** A Seat at the "Big Table": Temporal Analytics of Inverter Performance

### THURSDAY, February 26, 2015

#### POSTER SESSION IECRE

69. **Jonathan O'Neill and Karen Maxwell** Reliability Concerns with Module Level Rapid Shutdown

70. **Rue Phillips** Commissioning, Certification, Acceptance and Performance Testing: What Do They Mean?

71. **Richard Lawrence** NABCEP PV System Inspector Job Task Analysis

### FRIDAY, February 27, 2015

#### POSTER SESSION PV SOLAR RESOURCE

**Viktar Tatsiankou, John P.D. Cook, Frédérick Carle, Karin Hinzer, Richard Beal** The SSIM: Low-Cost Spectral Measurement

**Eiji Takeuchi, EKO Instruments Co., Ltd.** Study on Performance Transition of PV System by Monitoring

**Paul Thienpont, Marie Schnitzer, Rebecca Tilbrook, Whitney Wilson** How much is plant overproduction costing you? A review of the impacts of solar resource data and energy modeling on project financing

**Taylor Thomas, Dave Johnson, Patrick Morgan, Dave Heinicke, Dayle McDermitt, George Burba, Rex Peterson, John Wurm, and Bill Biggs** A New Silicon Photovoltaic Pyranometer for Measuring Solar Irradiance in Meteorological and Solar Resource Applications

**Mark Campanelli** Quantifying Uncertainty in PV Performance Delta Measurements

This workshop was made possible by the U.S. Department of Energy Solar Energy Technologies Office. NREL is appreciative of additional organizational support provided by Sandia National Laboratories. We also appreciate participation from the greater solar research community, both in the organization and execution of this workshop.

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