Photovoltaics: Safety & Efficiency Codes, Standards and Labelling, (Non)Regulation, and Certification Efforts

Brian Dougherty
Energy and Environment Division
Engineering Laboratory
National Institute of Standards and Technology
U.S. Department of Commerce
Outline

• Solar Photovoltaic (Industry) Highlights
• Questions for You
• Solar PV Industry Priorities
  – Safety first
  – A hierarchy of standards and codes efforts
  – Product Testing and Labelling
• Government Regulations Besides Codes: Financial Incentives
• Certification Efforts
Solar PV Industry Highlights (1 of 3)

• Most solar modules are made using silicon crystalline cells
• The majority of solar cell/modules are manufactured in China
• Over the last 10 years, many companies have entered and left the solar module manufacturing market
• Manufacturers (typically) warranty their solar modules (10 – 30 yrs) and inverters (5 – 15 yrs)
• New and improved modules and inverters are continually introduced; usually a specific product model/line on market for 2 to 4 years
Solar PV Industry Highlights (2 of 3)

- The performance of solar photovoltaic modules are affected by:
  - Solar irradiance level
  - Angle of Incidence
  - PV cell operating temperatures
  - Solar spectrum

- Must minimize shading of the modules – a relatively small amount of shading can have a huge impact on reducing power production

- Sun-to-DC power conversion efficiencies for single-junction solar modules as high as 20%; higher for multi-junction, bi-facial, and concentrating

- NREL maintains world-record cell listing by type
Solar PV Industry Highlights (3 of 3)

• Many companies and on-line tools exist to help with:
  – Evaluating the local solar resource
  – Modelling and designing a solar PV system
  – Evaluating the feasibility of a solar PV system
  – Providing 3rd party testing of modules
  – Conducting an on-site evaluation of an installed system
  – Troubleshooting an installed system and helping with processing a warranty claim

• In most countries (still), the continued growth in solar PV installation is fueled by favorable government-created financial incentives
Example: PV Modeling Guidance

1. **Irradiance and Weather** – Available sunlight, temperature, and wind speed all affect PV performance. Data sources include typical years (TMY), satellite and ground measurements.

2. **Incidence Irradiance** – Translation of irradiance to the plane of array. Includes effects of orientation and tracking, beam and diffuse irradiance, and ground surface reflections.

3. **Shading and Soiling** – Accounts for reductions in the light reaching the PV cell material.

4. **Cell Temperature** – Cell temperature is influenced by module materials, array mounting, incident irradiance, ambient air temperature, and wind speed and direction.

5. **Module Output** – Module output is described by the IV curve, which varies as a function of irradiance, temperature, and cell material.

6. **DC and Mismatch Losses** – DC string and array IV curves are effected by wiring losses and mismatch between series and connected modules and parallel strings.

7. **DC to DC Max Power Point Tracking** – A portion of the available DC power from the array is lost due to inexact tracking of the maximum power point.

8. **DC to AC Conversion** – The conversion efficiency if the inverter can vary with power level and environmental conditions.

9. **AC Losses** – For large plants, there may be significant losses between the AC side of the inverter and the point of interconnection (e.g., transformer).

10. **System Performance Over Time** – Monitoring of plant output can help to identify system problems (e.g., failures, degradation).
Example: Solar Resource Mapping

Global Horizontal Irradiation (GHI)

Average annual sum, period 1999-2013

< 1400 1550 1700 1850 2000 2150 > kWh/m²
Questions for You

• Will your country offer financial incentives to promote the installation of solar energy?
  – First cost of an installed system is (still) substantial.

• Will the solar arrays be connected to a central electrical grid?

• If yes, will your electric utilities offer favorable energy storage options for the solar energy?
  – Yes: electric utilities serve as the storage for excess solar energy
  – No: solar energy owner has to provide energy storage

• Will your country offer financial incentives to promote the manufacturing of solar energy modules and/or inverters?
Solar PV Industry Priorities

1. **Electrical, Mechanical & Fire SAFETY**
   - All components (modules, inverters, combiner boxes)
   - Installed systems
   - Consider only new components / new installed systems

2. **Solar Module Model Pass-Fail Qualification**

3. **Single-Point, New Module Electrical Rating**

4. Module/System Performance over time

5. Multiple-Point Electrical Rating for New Modules

6. Audit/Confirmation Testing and Inspection
Electrical, Mechanical & Fire Safety (1 of 3)

• In the USA, the **National Electric Code (NEC)** contains sections that specifically cover solar-energy and distributed power generation systems
  – Provides specifications on equipment, installation methods, and design protocols
  – Extensive, detailed document on safe electrical practices
  – Revised/updated every 3 years through a rigorous review process.

• The International Residential Code (IRC) and the International Energy Conservation Code (IECC) reference related standards that apply if installing, respectively, a residential or commercial PV system.

• The International Fire Code (IFC) establishes solar provisions relating to fire access and fire safety.
Electrical, Mechanical & Fire Safety (2 of 3)

- Primary source of PV safety standards in the USA:
  - Underwriters Laboratory (UL)
  - Institute of Electrical Engineering and Electronics (IEEE)
- PV modules and inverters models are independently tested and labelled for safety performance: UL, Intertek, TUV
- Secondary source of PV standards in the USA: ASTM International
- Both IEC and ASTM Intl publish numerous PV standards; many are very similar and so redundant.
• The ISEP is:
  – a collection of recommendations from various building and electrical codes on both solar thermal and PV
  – all safety related
  – just being published
Solar Module Model Pass-Fail Qualification (1 of 2)

- A series of pass-fail torture tests designed to identify near term failures in the new model of PV module
- The specific series of tests are specified in standards of the IEC
  - IEC Standard 61215 (modules with silicon crystalline cells)
  - IEC Standard 61646 (modules with thin-film cells)
- These two IEC standards reference several other related IEC standards

- NOCT/outdoor test
- UV test
- Damp heat/Thermal cycle/HF test
• PV module manufacturers voluntarily conduct these series of tests (in order to better compete)
• Testing only conducted on new modules
• Modules are labeled to confirm passing the applicable suite of IEC qualification tests
• Although sometimes used to infer module lifetime, not designed to do so; alternative ways being developed to perform accelerated aging testing
Failure Rate for Qualification

TUV Rheinland PTL, USA (Design Quality Evolution)

Qualification Failure Rate of c-Si Modules
(16 Years: 1997-2013; ~5100 Modules Tested)

Ref: 2014 IEEE PVSEC, TUV Rheinland
**Single-Point, New Module Electrical Rating**

- A single test that is used for rating PV modules
- Favorable test conditions that correspond to the modules peak DC electrical output
  - used in sizing a PV system: maximum current, voltage, and power
  - Most times based on STC; California requires a slight de-rate by requiring PVUSA test conditions
- Modules typically tested indoor using a flash solar simulator
- IEC and ASTM standards cover the testing steps/requirements
  - Tests and requirements of the solar simulator and reference cell or module
- A very small sample of modules are independently tested to confirm the manufacturers’ published ratings
Typical $I$-$V$ and $P$-$V$ curves for a PV module
Module Electrical Performance

- Independent measurements available from a few sources
- California Energy Commission: Go Solar California
  - List modules that have past their requirements for allowing a solar PV installation to be eligible for financial incentives
  - www.gosolarca.com
- Photon International Magazine
  - Has an outdoor monitoring facility
  - Report on changes in performance over time
  - Must subscribe to the magazine for access
- TUV Rheinland
  - Combination of laboratory and field testing to characterize modules
  - Fee based
  - Program just being introduced
Government Regulation

- Besides codes, government impact on the solar industry in the USA comes mainly via economic incentives.
- Otherwise, participation at the U.S. federal government level is limited to offering fee-based calibration services for manufacturers and independent testing laboratories; *nothing comparable to DOE appliance performance regulations*.
- A few States in the USA do have performance requirements:
  - California (big impact)
  - Florida (little impact)
- Many States offer financial incentives or enact laws that aid the installation/ownership of PV:
  - Net metering laws and adopting interconnection & permitting standards
  - Renewable Portfolio Standards (leads to renewable energy certificates/credits)
  - Tax breaks, grants, rebates, loans, and some feed-in tariffs
Certification Efforts

• Currently limited to 3rd party testing of new modules and inverters
  – IEC Qualification Tests
  – Single-Point Power Rating In Certain Cases
    • Required as part of the buyers contract
    • Required by the government (e.g., State of California)
  – Selection of tested units often decided by the manufacturer

• At least in the USA, nothing comparable to the audit testing conducted on appliances

• Past efforts to create a voluntary audit/certification program have never got traction (e.g, PowerMark)

• But, IEC now developing a testing and certification program for renewable energy equipment (IECRE)