The Effects of Temperature on PV Systems

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Agenda

- Quick Introduction to Enphase
- The Enphase Microinverter System
- Effects of Temperature on PV Systems
- Enphase Test Results
- Questions
Introducing Enphase
Our Company

- Headquarters in Petaluma, California
- Founded in March 2006
- Publicly traded on NASDAQ (ENPH)
- 300+ employees worldwide
- 100+ patents filed or issued
- Offices in United States, Canada, France, Italy, United Kingdom, New Zealand, and China
Improving Performance & Simplifying Installation

- 2008: 94%
- 2009 - 2010: 95%
- 2011 - 2012: 96%

1st Gen
2nd Gen
3rd Gen
“Microinverters are the fastest growing segment in the solar industry.” —Greentech Media
Enphase System
End-to-End Solution

Enphase Microinverters

Envoy Gateway

Enlighten Software
Grid-tied Microinverter
One Microinverter per PV Module
Per-module MPPT
Certified to: UL 1741, IEEE 1547, CSA C22.2
Rugged:
- Environmental & lifecycle testing beyond IEC 61215
- NEMA6 (IP67) enclosure
- -40 °C to +65 °C
- **‘Inverter on a Circuit Board’**
  - One platform across portfolio
  - Economies of scale similar to hi-tech electronics

- **Digital Power Control**
  - “System on a chip” does sensing, control & communication
  - High speed & precision enables single-stage power conversion
**Envoy Communication Gateway**

- **Powerful Networking**
  - Monitors microinverters through Powerline Communication
  - Bi-directional communications for web-based management

- **Simple Setup**
  - Auto-detection of microinverters
  - Plug and Play connection to broadband router
Enlighten Monitoring Software

- **Per-Module Monitoring**
  - Monitors each module & microinverter
  - Flexible views & graphs
  - No additional cost

- **Automated Reports & Alerts**
  - Monthly email summaries
  - Automatic issue notification for owner & installer
Enphase

Standard Inverter

Per-module Power Conversion

Maximum Harvest

Performance
Reliability

Unit & System Protected for 25 Years
"All AC" Makes Installation

Fast & Flexible
Safety to Prevent Fires

- High Voltage DC is a Danger for Firefighters
- DC Disconnects are for Service Personnel and do Little for Firefighters
High Voltage DC Dangers

- Faults pose serious risk of fire or electrocution
- Sustained arc faults up to 2700 Degrees Celsius
Microinverter safe for emergency workers

DC ~38 V

AC

Single Module

Microinverters & AC Electrical

Utility

Load Center
No High-Voltage DC Means Safer Solar
Effects of Temperature on PV Systems
Why is Temperature Important?
  - What is the Temperature Outside?
  - How Hot is it Under the Module?
- Power and Voc are inversely proportional to temperature
- As temperature goes up, PV Power and Voc go down

**PV Power and Voc vs. Temperature**

- $P = P_{mpp}(1 + TC_{Pmpp}(T - 25)/100)$
- $Voc = Voc(1 + TC_{Voc}(T - 25)/100)$
- $Voc = 37(1 - 0.37(T-25)/100)$
- NFPA 70: NEC 2008 supplies ampacity tables and describes calculation methods
- See Section 310.15 and Table 310.16

**Conductor Ampacity vs. Temperature**

![Graph showing the effect on conductor ampacity vs. temperature. The graph includes lines for 10 AWG, 6 AWG, and 2 AWG conductors, demonstrating how ampacity decreases with increasing temperature.](image-url)
Determining Outside Ambient Temperature

- NOAA, Weather Underground, iPhone apps, etc.
- American Society of Heating, Refrigeration and Air-Conditioning Engineers, ASHRAE.org
  - Solar America Board for Codes and Standards, SolarABCs.org
Experiment

- Measure temperature on typical residential Rooftop in Phoenix Arizona
Thermocouple Readings at Locations on Module
Site in Phoenix, AZ, May 28-29 2012

Max Temp @ 1:13 PM

Temperature (°C)

Day/Time

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Temperature Results

- PV Module, Upsolar UP-M240P-60, 240 W
- PV Glass
- PV Backsheet
- Enphase M215 Microinverter
- Top of Microinverter
- Attached to Top of Microinverter
- Attached to PV Backsheet
- Attached to Roof Top
- Attached to PV Backsheet
- Racking Roof Mount
- Unirac Racking
- Hot Day in Phoenix Arizona, 29 May 2012, 1:13 PM
- 33.4°C Daytime Temperature as reported by Weather Underground
- 40.4°C Ambient Air Under PV Module
- 43.8°C Rooftop Surface
- 44.9°C Bottom of Microinverter
- 45.0°C Top of Microinverter
- 52.3°C PV Backsheet
Conclusions

- Temperature affects PV Power and Voc

- ASHRAE data is referenced in the NEC as a reliable source for historical temperature data

- Temperature on the roof determines conductor ampacity, use the Code

- Temperature under the PV module is not as hot as you might think
Experience Enphase