Overview

• Solar Cell Primer
• What is an Array?
• PV Differences
• PV Integration & Growth
• Systems Integration
• Electrical Hazards
• Injury Pathology
• Clearance Distances
• Labeling
• Common Electrical Safety Concerns
Solar Cell Primer

• ~90% of current PV is based on silicon technology.
• Silicon Product Types:
  • Monocrystalline silicon (mono-Si)/(single-crystal-Si)
    • Easily recognizable, uniform look/dark color
    • 15-20% efficiency
  • Polycrystalline silicon - polysilicon (p-Si), multi-crystalline silicon (mc-Si), introduced 1981.
    • 13-16% efficiency
  • String Ribbon panels based on polycrystalline silicon.
    • 13-14% efficiency
Solar Cell Primer

• Thin-film photovoltaic cells (TFPV) include:
  • Amorphous silicon (a-Si)
  • Cadmium telluride (CdTe)
  • Copper indium gallium selenide (CIS/CIGS)
  • Organic photovoltaic cells (OPC)

• 1+ layer deposition of photovoltaic material onto a substrate.
A module is a collection of PV cells connected in series and/or parallel.

Cells are incorporated into an environmentally protective laminate. Example:

- ~0.5 volt/cell
- 36 cells connected together produce enough energy to charge 12 volt batteries and run pumps and motors
- 72-cell modules (standard for utility systems) have a nominal 24V operating at ~30V.
What is a PV Array?

- Home use system can contain 10-20 modules.
- Mounted at a fixed azimuth (South facing) or implemented with a sun position tracking device.
- Multiple modules integrated together to create an array.
- Industrial/Utility applications incorporate numerous modules (sometimes hundreds) into an array.
- Utilities can incorporate a large number of arrays to produce required voltages.
PV Differences

• DC circuits requiring novel design and equipment.
• May have multiple energy sources, incorporate unique disconnects required to isolate components.
• Energy flows can be bi-directional.
• Utility-Interactive arrays will be required to interface with AC utility grid requirements and may need unique operational requirements.
  • May require considerations not realized in normal grid systems.
Systems Integration

• Price ($/W DC)/Installed
  • Residential
    • 2011 - $6.00
    • 2013 - $4.75
  • Business
    • 2011 - $5.00
    • 2013 - $4.60
  • Utility
    • 2011 - $3.50
    • 2013 - $2.00
Systems Integration

• US Electrical Generation Capacity in beginning of 2014:
  • Geothermal 1%
  • Natural gas 4%
  • Wind 20%
  • Solar 74%
  • Other ~1%
Basic PV Components

Interactive System

PV Source Circuits

Combiner

PV Output

Invertor Input

Invertor

Invertor Output

Production & Distribution Connection
Basic PV Components

- Change Controller
- Energy Storage
- Inverter
- Main Supply AC
- Main Supply DC

Stand-Alone System
Electrical Safety Control

- Engineer out the hazard
  - If normal maintenance must occur then engineer out the potential.
    - Positive effect on controlling Arc Flash Hazard.

- Administrative controls
  - Safe Work Practices
    - Rated Equipment and Tooling

- PPE
  - Voltage Rated
    - <=600 V Nominal industry best practice is 1000V rated gloves.
  - PPE rated for Arc Flash Category
Vector of Exposure: Injury

Electrical Exposures (NSC)

- 30,000 Exposures/yr.
- 600 Fatalities/yr.

- Electrocution (Fatality)
- Electrical Shock
- Burns
CURRENT

• DC Current
  • Always flows in one direction.
    • Batteries, some motors, magnetic lifting devices, welding, PV panels.

• AC Current
  • Changes rapidly in both direction and value.
  • Common in industry
  • Cheaper production
Vector of Exposure: Elements

Amount (E & I)

Duration

Path

E = I x R
E = Voltage
I = Amperage
R = Resistance
Vector of Exposure: Resistance

- Resistance
  - Impedes or Increases Exposure Potential

- Wet
  - Dramatically Lowers Resistance

- Dry
  - Dramatically Increases Resistance
Effects of AC Electricity

- **VOLTAGE** - electromotive force (EMF)
- **CURRENT** - Measured in Amperes it is a movement of electrons past a given point.
- **RESISTANCE** - It is the opposition to electron movement.
  - Generates heat, controls current flow, & supplies specified voltage/current.
  - At higher amperages/voltages: Internal Organ Damage, Increased Burn Severity, Blood Clotting, Broken bones due to extreme muscle contractions.
- **Electroporation**

**It is all about amperage:**
- More than 3 mA - Painful shock - cause indirect accident
- More than 10 mA - Muscle contraction - “No Let Go” danger
- More than 30 mA - Respiratory paralysis
- 100 mA to 200 mA - Ventricular fibrillation
- Over 4 A - Severe tissue burns, cardiac damage
Vector of Exposure: Potential

- **Touch Potential**: Path through body
- **Step Potential**: Similar to a voltage drop with shorter distance and higher current potential.
Injury Pathology: Burns

- Can be multi-modal:
  - Equipment Thermal Exposure
  - Electrical Exposure
  - Arc
    - High Temperature Plasma Arc

Rule of Nines

Heat Transfer:
- Conductive (Geometry of Contact)
- Convective (Respiratory & Dermal)
- Radiative
Injury Pathology: Arc

• Copper expands >67,000 (Water ~1.67K)
  - One cubic inch of copper expands to 1.44 cubic yards of vaporized copper.

• Arc Blast Pressure levels can reach levels in excess of 400 lbs./ft³

• Sound Pressure levels can reach 140dB.

• Plasma Arc = 35,000F
  - Fatal Burns at >10 feet

• 1.2 calories/cm² will induce a recoverable 2nd degree burn

<table>
<thead>
<tr>
<th>Temperature</th>
<th>2nd Degree Burn</th>
<th>3rd Degree Burn</th>
</tr>
</thead>
<tbody>
<tr>
<td>122 F</td>
<td>1 Minute</td>
<td>5 Minutes</td>
</tr>
<tr>
<td>140 F</td>
<td>2 Seconds</td>
<td>5 Seconds</td>
</tr>
<tr>
<td>149 F</td>
<td>&lt;1 Second</td>
<td>2 Seconds</td>
</tr>
</tbody>
</table>
PV Systems and Rated Equipment

• Not a constant voltage source, there can be significant differences between rated operating voltage and field open voltage conditions.
  • Higher performance with lower temperatures.

• Bipolar System (Positive and Negative Voltages) must sum absolute values to determine the rated open circuit voltage.
  • Temperature Dependent Factors

• 125% factor needed due to PV module output currents that can exceed rated short circuit currents near solar noon.

• DC fault currents are harder to interrupt. Devices listed only for AC should not be used.
Guarding of Live Parts

- Enclosures
- Terminals
- Panels
- Buss Bars
- PV Conductors
### Clearance Distances/ft.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Live/NG</th>
<th>Live/Grounded</th>
<th>Live/Live</th>
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</thead>
<tbody>
<tr>
<td>0-150</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>151-600</td>
<td>3.0</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>601-2500</td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td>2501-9000</td>
<td>4.0</td>
<td>5.0</td>
<td>6.0</td>
</tr>
<tr>
<td>9001-75kV</td>
<td>6.0</td>
<td>8.0</td>
<td>10.0</td>
</tr>
<tr>
<td>&gt;75kV</td>
<td>8.0</td>
<td>10.0</td>
<td>12.0</td>
</tr>
</tbody>
</table>

1. Panel board doors must open at least 90 degrees.
2. Equipment must not impede working space.
   - Provides grounding path to employee.

Factors of Concerns Include:
- Gypsum Board
- Concrete
- Expanded Metal/Unistrut
- Paint

Not the same as Limited, Restricted, & Prohibited Approach Boundaries.
Clearance Distances

• Working distance width shall be the width of the equipment or 30”, whichever is greater.

• Height to extend from grade or floor to a height of 6.5 feet or the height of the equipment (if greater).
PV Incident Energy

• PV systems can have significant Fault Current.
• Resistance can impede Over Current Protection Device Trip Time.
• There may be variation in power production driven by weather, time of day, etc.
• Cracked panel can provide direct exposure access
• All breakers, feeder, & branch circuits need to be properly labeled identifying use.
• Associated Arc Flash labeling.
• Warning labels must be easily located on the utility-interactive inverter or ground fault indicator:

  Warning
  Electrical Shock Hazard
  If a Ground Fault is Indicated.
  Normally Grounded Conductors May Be Ungrounded and Energized.
PV Labels

• Bipolar Source & Output Circuits:

  Warning
  Bipolar Photovoltaic Array. Disconnection of Neutral or Grounded Conductors May Result in Overvoltage in Array or Invertor.

• Single 120V Supply

  Warning
  Single 120-Volt Supply. Do Not Connect Multiwire Branch Circuits!
PV Labels

• Building or Structure Disconnecting Means:
  Warning
  Electric Shock Hazard
  Do Not Touch Terminals.
  Terminals on Both The Line
  And Load Sides May Be Energized
  In the Open Position.

• PV Power Source Conductors:
  Warning: Photovoltaic Power Source
PV Labels

- Junction Boxes, Combiners, Disconnects, and devices with energized or ungrounded conductors that may be exposed during maintenance or testing activities:

Warning
Electric Shock Hazard. The DC Conductors Of This Photovoltaic System Are Ungrounded And May Be Energized.
Common Electrical Safety Issues:

• Limited Personnel in Remote Areas
  • Communication
  • Buddy System
  • First Aid/PPE, etc.
• UV Degradation
• Environmental Impact
  • Rain, Snow, Freezing Temperatures
• Cord Damage
• Unguarded Parts
• Loose Terminals
Common Electrical Safety Issues:

• Improperly Placed Equipment Infringing on Clearance Distances
• Buss Shunting/Fault Condition
• Grounding
• Securing PV Conductors
• Cracked Panels
  • Just because it is cracked doesn’t mean that electrical energy is not present?
  • Water can be a significant exposure issue!
References:

- CDC: http://www.cdc.gov/niosh/topics/electrical/
- NFPA 70 (Installation/Design): http://www.nfpa.org/codes-and-standards/document-information-
References:

- NESC (Worker Training)
  http://standards.ieee.org/about/nesc/
- IEEE 1584-2 (Design)
  http://www.ieee1584.com/
- ANSI Z244 (Energy Control)
- NFPA 70B (Maintenance Practices)
- NFPA 70E (Safe Work Practices)
  http://www.nfpa.org/catalog/category.asp?category_name=NFPA%2070E
- NFPA 79 (Install/Design)
Questions?