Power System Implementation and Demonstration at Camp Katuu, Palau

Clark Boriack, NDCEE/CTC
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<table>
<thead>
<tr>
<th>a. REPORT</th>
<th>b. ABSTRACT</th>
<th>c. THIS PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>unclassified</td>
<td>unclassified</td>
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</tr>
</tbody>
</table>

### 17. LIMITATION OF ABSTRACT
Same as Report (SAR)

### 18. NUMBER OF PAGES
30

### 19a. NAME OF RESPONSIBLE PERSON

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Standard Form 298 (Rev. 8-98)

Prescribed by ANSI Std Z39-18
Outline

• Demonstration Overview
  – Site review
  – Demonstration goals

• Development and Design Considerations
  – Layout
  – Electrical
  – Mechanical

• Critical Design Aspects
  – Safety
  – Component selection
  – Local electrical utility performance
Site Review

- Camp Katuu, located near Koror, Palau; latitude of 7° 30’ North
- NREL PVWatts™ did not have Palau in the historical database so Awassa, Ethiopia; 7° 3’ North latitude was used
Demonstration Goals

• Camp Katuu Installation
  ─ Increase civil outreach and nation building with Palau Government
  ─ Reduce environmental footprint at Camp Katuu
  ─ Increase use of alternative energy
  ─ Demonstrate the feasibility of using alternative energy in the region
  ─ Quantify PV system performance/capability
  ─ Train 249th Engineer Battalion to install Photovoltaic Systems
  ─ Validate camp electrical costs reduction

• Future Installations
  ─ Leverage design aspects for other remote installations (grid frequency and voltage regulation, corrosion, high electricity costs)
  ─ Next generation to include off-grid operation capability with energy storage
Development and Design Considerations

• PV System Layout Considerations
  - Access ways for installation, repair, maintenance
  - Ease of installation
  - Maximize system rating

Camp Katuu Builder’s Shop – PV Array Installation Location
Development and Design Considerations

- PV System Layout Options Considered
### Development and Design Considerations

#### PV System Layout Considerations

<table>
<thead>
<tr>
<th>No.</th>
<th>Consideration</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
<th>Option 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Amount of rail mounting (lf)</td>
<td>1440'</td>
<td>1800'</td>
<td>1800'</td>
<td>1440'</td>
</tr>
<tr>
<td>2</td>
<td>Ease of rail installation</td>
<td>some rail cutting required to clear walkway</td>
<td>requires two level rail mounting system</td>
<td>requires two level rail mounting system</td>
<td>no rail cutting required</td>
</tr>
<tr>
<td>3</td>
<td>Ease of wiring</td>
<td>Intuitive circuit pattern</td>
<td>Very Intuitive circuit pattern</td>
<td>Very Intuitive circuit pattern</td>
<td>odd circuit pattern</td>
</tr>
<tr>
<td>4</td>
<td>Maintenance access</td>
<td>21&quot; horizontal &amp; vertical walkway, does not have direct access to all panels</td>
<td>Accessible with 15&quot; walkways</td>
<td>Direct access to each panel and has a center walkway</td>
<td>No direct access to most panels</td>
</tr>
<tr>
<td>5</td>
<td>System DC Rating (kW DC) [1]</td>
<td>42.300</td>
<td>42.300</td>
<td>39.480</td>
<td>50.760</td>
</tr>
<tr>
<td>6</td>
<td>System AC rating (kW AC) [2]</td>
<td>32.571</td>
<td>32.571</td>
<td>30.400</td>
<td>39.085</td>
</tr>
<tr>
<td>7</td>
<td>Fall Protection System</td>
<td>accommodates rail system</td>
<td>accommodates rail system</td>
<td>accommodates rail system</td>
<td>does not accommodate rail system</td>
</tr>
</tbody>
</table>

### Color Legend

- **green**: most favorable
- **yellow**: more favorable
- **red**: least favorable

---

Note [1] System DC Rating based upon use of 235W solar panels

Note [2] System AC Rating based upon typical .77 conversion factor from DC power to AC power
### Development and Design Considerations

- **PV System Layout Selected**

#### Walkways
- Vert: (1) 30"
- Horiz: (1) 21"

#### Fall Protection Rail System

#### Table: Considerations and Impact

<table>
<thead>
<tr>
<th>No.</th>
<th>Consideration</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Amount of rail mounting (lf)</td>
<td>1440'</td>
</tr>
<tr>
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<td>Ease of rail installation</td>
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<td>Intuitive circuit pattern</td>
</tr>
<tr>
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<td>Maintenance access</td>
<td>21&quot; horizontal &amp; vertical walkway, does not have direct access to all panels</td>
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<tr>
<td>7</td>
<td>Fall Protection System</td>
<td>accommodates rail system</td>
</tr>
</tbody>
</table>

**Color Legend**
- most favorable
- more favorable
- least favorable
Economics
Array Azimuth Angle

- The array azimuth angle is defined as the clockwise angle of the array face from true north.
Economics
Array Tilt Angle

• The array tilt angle is the angle of the array face to the sun’s rays
• 4:12 pitch of Builder’s Shop roof provides a tilt angle of 18°
• Ideal 7° pitch improved annual savings from $21.8k to $22.5k
Development and Design Considerations

- Two Groups of 15 panels for each inverter for each side of roof
- Balanced 3 phase system
- Both circuits for each inverter on same side of roof
- Logical organization to support installation/sustainment
Critical Design Aspects
Safety

- **Safety Railing**
  - Maximizes Safety Considerations
  - Supports installation
  - Supports maintenance

- **Access Ways**
  - Supports installation
  - Supports maintenance
  - Beginning to be required
Safety Rail Systems

• Horizontal Cables
  – Pre-engineered but require installation and load testing by a certified vendor
  – Higher mounting height minimizes the possibility of rope catching on panels

• Single Point Anchors
  – Limited mobility and low ease of use  
    ➢ To move from anchor to anchor, must first tie off on second anchor, return to unhook, then move to work area
  – Inexpensive equipment and installation
  – Requires heavy gage material for attachment

• Horizontal Rails
  – Pre-engineered so installation and design costs are minimal
  – Does not require installation and/or inspection by a certified vendor
  – Mounts very close to roof – rope may catch on edges of panels
Cost Benefit Comparison

<table>
<thead>
<tr>
<th>System Type</th>
<th>Equipment Cost</th>
<th>Design Fee</th>
<th>Vendor Installation Fee</th>
<th>Personnel Training Costs</th>
<th>Total Cost</th>
<th>Ease of Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Rail</td>
<td>$5.5k</td>
<td>$0</td>
<td>$0</td>
<td>$5k (vendor travel cost)</td>
<td>$10.5k</td>
<td>8</td>
</tr>
<tr>
<td>Single Point Anchors</td>
<td>$4k</td>
<td>$2k</td>
<td>$0</td>
<td>$5k (vendor travel cost)</td>
<td>$11k</td>
<td>2</td>
</tr>
<tr>
<td>Horizontal Cable</td>
<td>$10K</td>
<td>$2k</td>
<td>$14k (included in installation)</td>
<td>$0</td>
<td>$26k</td>
<td>10</td>
</tr>
</tbody>
</table>

- The horizontal rail system is the most cost effective solution and is easy to use, therefore it is recommended for this application.
- Although the single point anchors are also cost effective, they limit mobility and are not easy to use.
- Horizontal cable systems require vendor installation and certification, making them the most costly - Once installed, they are the easiest to use.
Fall Protection
Roof Rail Systems

- Systems are pre-engineered and can be installed by others
- Fosters safe, efficient travel across roof
- Product support is available for installation and training
- Estimated Material Costs
  - ~$20k FLEXRIDGE™ System
  - ~$6k Uniline™ System
Mounting System
UNIRAC™ Method

Corrosion Contributing Factors:
- Humid, Salty climate
- Galvanic cell between dissimilar metals

Steps to Mitigate Corrosion Risks:
- Barrier material installation
- ASTM B117 corrosion testing to confirm compatibility (500hr test during April 2011)
- PV module has been tested, verified to withstand corrosion by manufacturer; 25 year warranty
Shop Prototype Application
Corrosion Testing

- Predrill
- Steel Tubing
- Insert Riv-nut
- Final Assembly
Wind Load Distribution

• Wind load distribution for enclosed gable roof buildings is as shown

• Dimension “a” is calculated as the lesser of either:
  - 10% of the least horizontal dimension (w) $0.10 \times 40\text{-}0\text{"} = 4\text{-}0\text{"}$
  - $0.4h$
  - $0.4 \times 13\text{-}3\text{"} = 5\text{-}4\text{"}$

• Dimension “a” is taken as 4\text{-}0\text{”}
Shop Prototype Application
Fastener Testing

Predrill
Steel Tubing
Insert Riv-nut
Final Assembly
Mounting System
Original Fastener

- Sufficient Pull Out Rating for load
- Insufficient for Pull Out for installation
- Select rivet-nut instead of self-drilling fastener

### Selection Guide

<table>
<thead>
<tr>
<th>ECP Code</th>
<th>Size</th>
<th>L Length</th>
<th>Drive System</th>
<th>Point Size</th>
<th>Max.</th>
<th>D Maximum Clamping Length*</th>
<th>Pieces per 1/16&quot;</th>
<th>Job Pack Pieces per Box?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alin13</td>
<td>15-1.6</td>
<td>3/16&quot;</td>
<td>Hex Washer Head</td>
<td>2</td>
<td>.110&quot;</td>
<td>0.925&quot;</td>
<td>6000</td>
<td>250</td>
</tr>
<tr>
<td>Alin14</td>
<td>15-1.2</td>
<td>1/2&quot;</td>
<td>Hex Washer Head</td>
<td>2</td>
<td>.140&quot;</td>
<td>1.000&quot;</td>
<td>2500</td>
<td>125</td>
</tr>
<tr>
<td>Alin15</td>
<td>15-1.0</td>
<td>1/2&quot;</td>
<td>Hex Washer Head</td>
<td>2</td>
<td>.175&quot;</td>
<td>1.000&quot;</td>
<td>2000</td>
<td>75</td>
</tr>
<tr>
<td>Alin20</td>
<td>15-1.0</td>
<td>1/2&quot;</td>
<td>Hex Washer Head</td>
<td>2</td>
<td>.315&quot;</td>
<td>1.000&quot;</td>
<td>1500</td>
<td>50</td>
</tr>
<tr>
<td>Alin25</td>
<td>15-1.0</td>
<td>1/2&quot;</td>
<td>Hex Washer Head</td>
<td>2</td>
<td>.500&quot;</td>
<td>1.000&quot;</td>
<td>1500</td>
<td>50</td>
</tr>
<tr>
<td>Alin30</td>
<td>15-1.0</td>
<td>1/2&quot;</td>
<td>Hex Washer Head</td>
<td>2</td>
<td>.500&quot;</td>
<td>1.000&quot;</td>
<td>1500</td>
<td>50</td>
</tr>
<tr>
<td>Alin35</td>
<td>15-1.0</td>
<td>1/2&quot;</td>
<td>Hex Washer Head</td>
<td>2</td>
<td>.500&quot;</td>
<td>1.000&quot;</td>
<td>1500</td>
<td>50</td>
</tr>
<tr>
<td>Alin40</td>
<td>15-1.0</td>
<td>1/2&quot;</td>
<td>Hex Washer Head</td>
<td>2</td>
<td>.500&quot;</td>
<td>1.000&quot;</td>
<td>1500</td>
<td>50</td>
</tr>
<tr>
<td>Alin45</td>
<td>15-1.0</td>
<td>1/2&quot;</td>
<td>Hex Washer Head</td>
<td>2</td>
<td>.500&quot;</td>
<td>1.000&quot;</td>
<td>1500</td>
<td>50</td>
</tr>
<tr>
<td>Alin50</td>
<td>15-1.0</td>
<td>1/2&quot;</td>
<td>Hex Washer Head</td>
<td>2</td>
<td>.500&quot;</td>
<td>1.000&quot;</td>
<td>1500</td>
<td>50</td>
</tr>
</tbody>
</table>

### Flat Head Reamer s/wing

| EINO140 | 15-1/2" | #2 Phillips | 3 | .140" | 0.800" | 3500 | 125 |
| EINO345 | 12-24 | 3/16" | Phillips | 5 | .500" | 1.710" | 1500 | 50  |
| EINO455 | 1/2| 3/16" | Phillips | 5 | .500" | 1.710" | 1500 | 50  |

### Flat Head Undercut

| EINO200 | 15-1/2" | #3 Phillips | 2 | .140" | 0.000" | 4000 | 150 |
| EINO240 | 12-1/2" | #3 Phillips | 2 | .140" | 0.000" | 2500 | 125 |

### Performance Data

<table>
<thead>
<tr>
<th>Drill (Ube)</th>
<th>Pull-Out Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel 3008-7S</td>
<td>250G</td>
</tr>
<tr>
<td>Aluminum 6063-T6</td>
<td>250G</td>
</tr>
</tbody>
</table>

### Ultimate Strengths

**Values are for 300 series stainless fastener threaded shank**

** Table:**

<table>
<thead>
<tr>
<th>Size</th>
<th>Tensile (Ube)</th>
<th>Shear (Ube)</th>
<th>Average Use Ultimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/16</td>
<td>1847</td>
<td>1282</td>
<td>1900</td>
</tr>
<tr>
<td>1/14</td>
<td>2628</td>
<td>1950</td>
<td>2584</td>
</tr>
<tr>
<td>1/12</td>
<td>3459</td>
<td>2840</td>
<td>2800</td>
</tr>
</tbody>
</table>

**Figures:**

Before Installation

After Installation

- Material Thickness Range
- B
- C
- D
- E
- Max.
# PV Module Comparison Results

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>length (in)</td>
<td>64.5</td>
<td>59.1</td>
<td>64.6</td>
<td>65.0</td>
<td>65.6</td>
<td>65.6</td>
</tr>
<tr>
<td>width (in)</td>
<td>38.7</td>
<td>39.0</td>
<td>39.1</td>
<td>37.5</td>
<td>39.4</td>
<td>39.4</td>
</tr>
<tr>
<td>thickness (in)</td>
<td>1.57</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>weight (lbs)</td>
<td>44.1</td>
<td>39.7</td>
<td>44.1</td>
<td>41.0</td>
<td>42.8</td>
<td>42.8</td>
</tr>
<tr>
<td><strong>Electrical Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>power output (dc w)</td>
<td>235</td>
<td>215</td>
<td>224</td>
<td>215</td>
<td>215</td>
<td>230</td>
</tr>
<tr>
<td>panel open circuit voltage rating (volts)</td>
<td>36.9</td>
<td>33.2</td>
<td>36.6</td>
<td>23.1</td>
<td>36.5</td>
<td>36.7</td>
</tr>
<tr>
<td>panel maximum power voltage rating (volts)</td>
<td>29.8</td>
<td>26.6</td>
<td>29.3</td>
<td>18.7</td>
<td>29.1</td>
<td>29.1</td>
</tr>
<tr>
<td>panel current rating (amps)</td>
<td>7.90</td>
<td>8.09</td>
<td>7.66</td>
<td>11.23</td>
<td>7.40</td>
<td>7.90</td>
</tr>
<tr>
<td><strong>Other Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cost/panel</td>
<td>$ 479.36</td>
<td>$ 479.57</td>
<td>$ 456.66</td>
<td>$ 456.66</td>
<td>$ 490.45</td>
<td></td>
</tr>
<tr>
<td>cost/watt</td>
<td>$ 2.04</td>
<td>$</td>
<td>$ 2.14</td>
<td>$ 2.12</td>
<td>$ 2.12</td>
<td>$ 2.13</td>
</tr>
<tr>
<td>power output warranty (years)</td>
<td>25</td>
<td>20</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>delivery (weeks)</td>
<td>STOCK</td>
<td>12</td>
<td>STOCK</td>
<td>STOCK</td>
<td>STOCK</td>
<td>STOCK</td>
</tr>
</tbody>
</table>
PV Module
Recommended Product

- Highest Power Output
- Tested for Corrosion
- Best Value
- Stock Item

**Key Features**
- Top ranked PVUSA (PTC) rating in California for higher energy production
- 6 years product warranty (materials and workmanship); 25 years module power output warranty
- Industry leading plus only power tolerance: +5W (+2%)
- Strong framed module, passing mechanical load test of 5400Pa to withstand heavier snow load
- Ultra reliable in corrosive atmosphere, verified by IEC61701 “Salt Mist Corrosion Testing”
- The 1st manufacturer in the PV industry certified for ISO/TS16949 (The automotive quality management system) in module production since 2003
- ISO17025 qualified manufacturer owned testing lab, fully complying to IEC, TUV, UL testing standards

**Applications**
- On-grid residential roof-tops
- On-grid commercial/industrial roof-tops
- Solar power stations
- Other on-grid applications

**Quality Certificates**
- IEC 61215, IEC 61730, IEC 61701, UL 1703, CEC Listed, CE, KEMCO and MCS
- ISO9001: 2008: Standards for quality management systems
- ISO/TS16949:2009: The automotive quality management system
- QC880000 HSMP: The Certification for Hazardous Substances Regulations

**PV Module Specifications**

<table>
<thead>
<tr>
<th>Mechanical Attributes</th>
<th>Canadian Solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (in)</td>
<td>64.5</td>
</tr>
<tr>
<td>Width (in)</td>
<td>38.7</td>
</tr>
<tr>
<td>Thickness (in)</td>
<td>1.57</td>
</tr>
<tr>
<td>Weight (lbs)</td>
<td>44.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electrical Attributes [1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Maximum Power Output at STC (Pmax)</td>
</tr>
<tr>
<td>Voltage at Pmax (Vmp)</td>
</tr>
<tr>
<td>Current at Pmax (Imp)</td>
</tr>
<tr>
<td>Open Circuit Voltage (Voc)</td>
</tr>
<tr>
<td>Short Circuit Current (IsC)</td>
</tr>
</tbody>
</table>

[1] Standard Test Conditions for panel ratings: 1,000 Watts/M², AM 1.5, 25 C

**Figure 9: PV Module Specifications**
Inverter System

SMA 7000US

- Six SMA 7000US Inverters for system
- Reliable Product
- Rated for Outdoors Use
- Simple interface
- Integral DC Disconnect
- Several Options
- Stock Item
Critical Design Aspects

- Local Electrical Utility Performance

<table>
<thead>
<tr>
<th>Nominal frequency</th>
<th>Trip limit</th>
<th>Trip frequencies</th>
<th>Trip times</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 HZ</td>
<td>&gt; 60.5 Hz</td>
<td>60.45 Hz ... 60.55 Hz</td>
<td>max. 0.1602 s</td>
</tr>
<tr>
<td></td>
<td>&lt; 57.0 Hz ... 59.8 Hz (default 59.3 Hz)</td>
<td>56.95 Hz ... 59.85 Hz (default 59.25 Hz ... 59.35 Hz)</td>
<td>adjustable 0.16 s ... 300 s (default max. 0.1602 s)</td>
</tr>
<tr>
<td></td>
<td>&lt; 57.0 Hz</td>
<td>56.95 Hz ... 57.05 Hz</td>
<td>max. 0.1602 s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nominal voltage</th>
<th>Trip limit</th>
<th>Trip voltages line-to-neutral*</th>
<th>Trip voltages line-to-line*</th>
<th>Trip times</th>
</tr>
</thead>
<tbody>
<tr>
<td>208 V</td>
<td>50 %</td>
<td>57.6 V ... 62.4 V</td>
<td>99.8 V ... 108.2 V</td>
<td>max. 0.1602 s</td>
</tr>
<tr>
<td></td>
<td>88 %</td>
<td>103.2 V ... 108.0 V</td>
<td>178.9 V ... 187.2 V</td>
<td>max. 2.002 s</td>
</tr>
<tr>
<td></td>
<td>110 %</td>
<td>129.6 V ... 134.4 V</td>
<td>224.6 V ... 233.0 V</td>
<td>max. 1.001 s</td>
</tr>
<tr>
<td></td>
<td>120 %</td>
<td>141.6 V ... 146.4 V</td>
<td>245.4 V ... 253.8 V</td>
<td>max. 0.1602 s</td>
</tr>
</tbody>
</table>
Critical Design Aspects

Default Voltage Operating Range is acceptable
Available Frequency Operating Range is acceptable
Maintenance Features

• Safety Railing
  – Maximizes Safety Considerations
  – Supports installation and maintenance

• Access Ways
  – Supports installation and maintenance
  – Beginning to be required

• Metering
  – Automatic Data Collection to quantify system performance
  – Scheduled data reports to minimize communications system impact

• Component Support
  – Global Manufacturer Technical Support (phone and online)
  – Commercial-off-the-Shelf (COTS) components
  – 10 year inverter warranty, 25 year module warranty
  – Critical spares provided to mitigate failure downtime
Maintenance Requirements

- Module Cleaning - Remove dirt, dust and debris may collect on the modules. Power washing of modules in Palau is recommended every 6 months.
- Inverter Fan Cleaning – Remove dirt, dust collected on inverter intake fans and exhaust fins every 3 months.
- System Performance – Measure and compare string voltages to identify connection or module issues every 3 months.

Simple, easy system to maintain
SUMMARY

- Training and transfer of design applications and methods to 249th EN BN
- Remaining Camp Katuu PV System Schedule (commissioning to end of monitoring and turn over to PACOM)
- System monitoring and metrics
- Estimated Camp Cost savings per year
Points of Contact

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