Performance Analysis of 258 kWac Solar Demonstration Project

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Company Overview

- 28 member cooperatives
- 1.7 million consumers
- 88,000 miles distribution
- 1,575 employees
- 4th largest G&T in the nation
- 910 employees (MN & ND)
- 3,718 MW generation
  - 710 MW renewables (Wind, Hydro, Solar, Biomass)
- 4,696 miles transmission
Project Overview – 258 kWac

Solar Panels
95.4 kWdc
122 kWdc
54 kWdc

Inverters
100 kWac
108 kWac
50 kWac
Procurement & Construction

- “Made in USA” & “Made in MN” equipment
- Manufacturer ownership changes
- Equipment lead times (current issue for 2016)
- Economies of scale pricing
- Tariffs on cells & module price/availability impacts
- Safety & NEC compliance, cable management
Performance – monthly peak

258 kWac
Performance – capacity factor

Maple Grove Combined - Capacity Factor

- January: 13.6%
- Other months show varying capacity factors with different months having different capacities in 2014 and 2015.

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Performance – capacity factor

Maple Grove Solar - Year 1 Performance

- Sharp
- tenKsolar
- Suniva

Month: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec
Performance – cloudy days

<table>
<thead>
<tr>
<th>Month</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal Output</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>10%</td>
<td>19%</td>
<td>10%</td>
<td>13%</td>
<td>10%</td>
<td>18%</td>
<td>16%</td>
<td>17%</td>
<td>13%</td>
<td>10%</td>
</tr>
<tr>
<td>Partially Ideal Output</td>
<td>23%</td>
<td>32%</td>
<td>23%</td>
<td>20%</td>
<td>23%</td>
<td>10%</td>
<td>6%</td>
<td>19%</td>
<td>18%</td>
<td>23%</td>
<td>23%</td>
<td>13%</td>
<td>20%</td>
</tr>
<tr>
<td>Erratic Output</td>
<td>77%</td>
<td>68%</td>
<td>77%</td>
<td>70%</td>
<td>70%</td>
<td>80%</td>
<td>81%</td>
<td>71%</td>
<td>64%</td>
<td>61%</td>
<td>60%</td>
<td>74%</td>
<td>70%</td>
</tr>
</tbody>
</table>
Ideal day output

Great River Energy tenKsolar Array

March 28th, 2015
816 kWh(ac) Generated
1,296 kWh(ac) Theoretical Max
63% of Possible Production
Grid management

Typical Power Swing

Power Swing Summary
- 99% to 36% in 12 seconds
- 36% to 98% in 34 seconds
- 98% to 51% in 12 seconds
- 51% to 98% in 31 seconds
Performance – snow recovery

Sharp Solar Panels

21 days to recover!

<table>
<thead>
<tr>
<th>Array</th>
<th>Dec 26 snowfall recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suniva</td>
<td>5 days (1/2/15)</td>
</tr>
<tr>
<td>TenKsolar</td>
<td>8 days (1/5/15)</td>
</tr>
<tr>
<td>Sharp</td>
<td>21 days (1/18/15)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Array</th>
<th>Winter average recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suniva</td>
<td>3 days</td>
</tr>
<tr>
<td>TenKsolar</td>
<td>3.5 days</td>
</tr>
<tr>
<td>Sharp</td>
<td>9.8 days</td>
</tr>
</tbody>
</table>
# Statewide Capacity Factors

<table>
<thead>
<tr>
<th>Month</th>
<th>Average Capacity Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>5.7%</td>
</tr>
<tr>
<td>February</td>
<td>9.7%</td>
</tr>
<tr>
<td>March</td>
<td>15.8%</td>
</tr>
<tr>
<td>April</td>
<td>16.6%</td>
</tr>
<tr>
<td>May</td>
<td>15.3%</td>
</tr>
<tr>
<td>June</td>
<td>17.4%</td>
</tr>
<tr>
<td>July</td>
<td>18.4%</td>
</tr>
<tr>
<td>August</td>
<td>15.9%</td>
</tr>
<tr>
<td>September</td>
<td>14.1%</td>
</tr>
<tr>
<td>October</td>
<td>10.8%</td>
</tr>
<tr>
<td>November</td>
<td>5.3%</td>
</tr>
<tr>
<td>December</td>
<td>3.8%</td>
</tr>
</tbody>
</table>

[http://solar.greatriverenergy.com](http://solar.greatriverenergy.com)
Statewide output balancing?

(Erratic Output Day)

% Power Output (KW AC)

0.00% 20.00% 40.00% 60.00% 80.00% 100.00% 120.00%

4:48 AM 7:12 AM 9:36 AM 12:00 PM 2:24 PM 4:48 PM 7:12 PM 9:36 PM

IMCEA %
Arrowhead %
Goodhue %
Kandiyohi %
Lake Region %
East Central %
Dakota %
Combined %

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Performance - Harmonics

IEEE-1547 Compliance

Table 3—Maximum harmonic current distortion in percent of current (l)\textsuperscript{a}

<table>
<thead>
<tr>
<th>Individual harmonic order h (odd harmonics)\textsuperscript{b}</th>
<th>h &lt; 11</th>
<th>11 \leq h &lt; 17</th>
<th>17 \leq h &lt; 23</th>
<th>23 \leq h &lt; 35</th>
<th>35 \leq h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent (%)</td>
<td>4.0</td>
<td>2.0</td>
<td>1.5</td>
<td>0.6</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Total demand distortion (TDD) = 5.0

\[ TDD_I = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + I_5^2 + K}}{I_L} \]
Current Harmonics

Fundamental (1st Order)

Current (amps)

9/23/2014

TenK Solar
Solectria
Advanced Energy

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Current Harmonics

Total Demand Distortion - TDD (3rd, 5th, 7th)

9/23/2014
Shading impacts: not just power loss

Hot spots due to partial shading on module
DG Metering Options
Lessons learned

- Procurement volatility in the industry
- Large and rapid power swings
- Significant seasonal output variance
- Snow shed ability dependent on racking design
- Demonstrated value for energy storage
- No observed harmonic issues
- Shading impacts on equipment life