A Distributed Solar Energy System Design with Storage

Solar District Cup Final Deliverable Presentation
April 2020

Team: Solar Eagles, Embry-Riddle Aeronautical University

<table>
<thead>
<tr>
<th>Name</th>
<th>Primary focus</th>
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<tbody>
<tr>
<td>Mr. Adi Alharbi</td>
<td>Energy system design, elect. distribution, OpenDSS</td>
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<tr>
<td>Mr. Benjamin Aulenback</td>
<td>Energy system design, Horseshoe design</td>
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<tr>
<td>Ms. Kristen Holman</td>
<td>Solar analysis, Financial system analysis, MBA</td>
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<td>Ms. Qi Jiang</td>
<td>Development Plan, Construction timeline, ArcGIS</td>
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<td>Ms. Chenge Liu</td>
<td>Financial system analysis, SAM, CREST, REOpt</td>
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<tr>
<td>Mr. Raymond Miller</td>
<td>PV design and layout, Aurora</td>
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</tbody>
</table>
The District:
New Mexico State University
System Design Summary

• Solar PV Panels:
  • 8 buildings, 2.2MW
  • Field, 6.7MW, 14 Acres
  • +2 additional power lines

• Energy Storage System:
  • 8.7MW / 32.1 MW-hr
  • ½ Acre battery area

• Horseshoe Design:
  • Interactive solar-powered benches
  • To promote community awareness
  • To display environmental stewardship
The System’s Conceptual Design
Section 1: Conceptual Design & Development

The conceptual design process is listed:

1. Building loads provides the District’s electrical consumption
2. The Las Cruces NM location determines available solar resource. Aurora provides irradiance and shading analysis.
3. Rooftop PV was placed on each building and the open area to supply daytime building loads during on-peak hours.
4. Evening and off-peak loads are provided by the local utility grid.
5. A battery energy storage system is designed for peak-shaving to reduce monthly demand charges.
Panel Selection

• After comparing 15+ different panels our selection was the Panasonic HIT N330 DC panel (VBHN330SA17)
  • Panel Rating = 330W
  • Module Efficiency = 19.7%
  • Power Temp Coef (pmpp) = -0.258%
  • Panel DE-rating = 0.94
• This low pmpp allows the panels to remain effective and efficient during high temperatures
• With this panel, approx. 26,705 modules are required to meet the loads
Battery Selection

- Similarly, after comparing 25 different battery options, the EOS Aurora 100|300 & 1000|4000 series were selected.
  - Power Output: 100 – 1000 kW
  - Energy Capacity: 300 – 4000 kWh
  - SOC Operating Range: 0% - 100%
  - Round Trip Efficiency: 75% at 100% DOD
  - Operating Temperature: 50 to 113°F

- In total, 27 Eos Aurora 100|300 and 6 Eos Aurora 1000|4000 batteries were placed in close proximity to the Geothermal Substation
The Systems Design

- Each panel is connected in series to the one next to it with 10-gauge wires for a max string length of 19 panels.

- Each string is then connected to a Solectria XGI 1500 inverter for conversion from DC to AC current.

- Each inverter can handle 17-19 panels per string or 170 kW of PV power

- From there the system can provide power using the buildings breaker boxes or be connected to the local grid via a transformer
Horseshoe Design
Two Standalone Systems, Both Completely Off Grid.

System 1: Solar Benches
- Benches with solar panel umbrella, Wireless & USB charging ports, dusk sensitive LED lights, & a deep cycle battery to power it all.

System 2: Solar Stands
- Solar-panel-on-a-stick. All the same features as the solar bench, but you provide your own bench.
The Distribution System Impact
Section 2: OpenDSS Rooftop PV Power Flow

- PV only
- Load
- PV + Load

- Pan-Am Center: 792 kW
- Milton: 215 kW
- Corbett: 216 kW Volt-var
- Science: 392 kW
- Engineering: 137 kW
- Thomas: 51 kW
Open Area

Substation Transformer

6.7 MW

Storage System:
8.7 MW / 32.1 MW-hr.
OpenDSS Power Simulation Results

PV Power Production

Battery Charge and Discharge Cycles

<table>
<thead>
<tr>
<th>Voltage Violations</th>
<th>High voltage Side</th>
<th>Low voltage Side</th>
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<tbody>
<tr>
<td></td>
<td>Under voltage</td>
<td>Over voltage</td>
</tr>
<tr>
<td></td>
<td>hours</td>
<td>hours</td>
</tr>
<tr>
<td>NMSU Circuit</td>
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<td>0</td>
</tr>
<tr>
<td>NMSU PV Batt</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Difference</td>
<td>0</td>
<td>0</td>
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The Finances
Section 3: Financial Analysis

- Determining if the system has a positive economic benefit
- Payback period is less than 20 years
- Used NREL’s System Advisory Model & MBA HeatSpring Model
- Indirect Capital Costs including
  - Operation & Maintenance
  - Taxes & Incentives
  - Construction
  - Balance of System (BOS) Elements
  - Overhead & Contingency
Financial Inputs

- Partnership Flip
- Incentives
  - Federal ITC tax credit
  - MACRS Depreciation
  - Sustainable Building Credit
  - New Mexico state tax credit
- Balance of System Elements
  - UNIRAC racking
  - Wiring
  - Grounding Equipment
Financial Inputs

- Utility Rate
  - $0.038 per kWh weighted average
  - On peak of $0.09
  - Off peak of $0.004

- PPA Price
  - $0.037

- NPV of customer savings of $16,292,000
PV System Financial Outputs

- PV System with a project cost of $16,109,000
  - Customer
    - NPV of $16,292,000
  - Cash Equity Investor
    - NPV of $5,692,000 & Tax and Cash Flow IRR of 5.05%
  - Tax Equity Investor
    - NPV of $3,346,000 & Tax and Cash Flow IRR of 11.75%
Battery Energy Storage

- The net battery power is 8.7 MW
- The net battery energy is 32.1 MWh
- The estimate cost for the batteries including construction and supplies is $16 million
- The replacement will happen at year 15
- The Net Present Value is $34,440,444
Total Cash Flow For PV And Battery

Cash Flow with Revenue for PV with Battery

- Battery Replacement
- Payback Period
The Development Plan
Section 4: Building And Land Utilization

The building and land utilization approach is:
- Utilize rooftop PV for most buildings
- Utilize remote field for balance of PV and energy storage system

- Milton and Pan-Am power Corbett
- Obstructions and shading prevent PV on:
  - Goddard – Power-line limited
  - Hernandez – Unusual roof
  - Jett – Roof obstructions

<table>
<thead>
<tr>
<th>Building Name</th>
<th>Number of Panels</th>
<th>Area (m²)</th>
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</thead>
<tbody>
<tr>
<td>Branson</td>
<td>739</td>
<td>1235.76</td>
</tr>
<tr>
<td>Breland</td>
<td>656</td>
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<td>Computer</td>
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<td>Engineering I</td>
<td>414</td>
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<td>Science</td>
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<td>1986.64</td>
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<tr>
<td>Thomas</td>
<td>156</td>
<td>260.87</td>
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<tr>
<td>Milton*</td>
<td>652</td>
<td>1090.31</td>
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<tr>
<td>Pan-Am*</td>
<td>2401</td>
<td>4015.08</td>
</tr>
<tr>
<td>Open Area</td>
<td>20301</td>
<td>46363.1</td>
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*powers Corbett
Development Plan And Building Codes

• State Building and Reroof Permit
  • Application, occupant load, structure, site plan, engineering calculation, soil investigation report, etc.

• Special Permit
  • Application, site plan, letter of intent & boundary survey

• Electrical Permit

• Fences Permit

• Valid license issued by CID (Construction Industries Division)
Construction Timeline

- The Site View and Construction Preparation
- Project Financing
- Construction on PV System
- Install of Transmissions, Inverters and Meters
- Final Inspection & Recloser Test
The Innovation
Optimized Design

- PV system capable of meeting all daytime loads experienced by the buildings we were given
- Battery system capable of meeting all peak demand loads to reduce peak demand charges
  - As an added bonus, we project a slight reduction in the HVAC cooling loads placed on the buildings due to the rooftop panels
- To ensure maximum charging efficiency, the battery system is supplied from the local electric grid at off-peak times
System Operation

Daily Routine

- Sunrise-Sunset:
  - School loads met by PV

- 8am-12pm:
  - Battery is charged from the grid

- When solar generation cross peak load:
  - School loads met by Battery

- After sunset/peak demand period-8am:
  - Battery is on standby, school loads are met by grid
The Optimization Strategy
PV + Storage Design Process

1. Evaluate provided electrical loads: .xlsx
2. Choose storage strategy: **Peak shaving**
3. Compile candidate panel/battery list: ($/kW-hr)
4. Update battery + PV configuration
5. Evaluate electrical performance
6. Evaluate financial limitations
7. Evaluate site plan limitations

Done.
Meets all requirements
Optimization Process

Space-Defined PV System → Load-Shifting Battery Charged with PV → Peak-Shaving Battery Charged with Grid
Tools For Optimization

Aurora → PV Design Spreadsheet → Battery Design Spreadsheet → MATLAB → OPENDSS → Development Plan Spreadsheet → Construction Timeline → ARCGIS – Site plan → SAM

Battery Supplier List

PV Supplier List

Crest Spreadsheet

HeatSprings Spreadsheet
In Conclusion

• Rooftop and ground mounted PV for daytime loads
• Peak-shaving storage system avoids high demand charges
• Payback Period of 6.5-7 years
• Cost effective: saves NMSU $250k/yr for 20 years
• Reliably distributes solar power to loads
• Designed for resilience despite variable weather conditions
References

• Department of Energy
  • https://www.energy.gov/eere/solar/solar-district-cup

• NREL - Direct Normal Irradiance Maps
  • https://www.nrel.gov/gis/solar.html

• NREL - U.S. Solar Photovoltaic System Cost Benchmark
  • https://www.nrel.gov/docs/fy19osti/72399.pdf

• Panasonic Datasheet