
Mike Wagner

May 18, 2017
SAM Webinars 2017

• Overview of New Industrial Process Heat and CSP Capabilities, May 17
• **Modeling Molten Salt Power Tower Systems, May 18**
• Electricity Rates and Monthly Bill Savings for Residential and Commercial Projects, June 1
• Modeling PV-Battery Systems, July 13
• Sizing Photovoltaic Systems, August 10
• SAM Open Source, September 21
Registration Links and Webinar Recordings

Webinars and Round Tables

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Webinars

SAM webinars are one-hour lectures with question and answer sessions that cover various topics about SAM. All webinars are free and start at 2 pm Mountain. To register for a webinar, click its name in the following list.

- Overview of New Industrial Process Heat and CSP Capabilities, Wed May 17 2017
- Modeling Molten Salt Power Tower Systems, Thu May 18 2017
- Electricity Rates and Monthly Bill Savings for Residential and Commercial Projects, Thu Jun 1, 2017
- Modelling PV-Battery Systems, Thu Jul 13 2017
- Sizing Photovoltaic Systems, Thu Aug 10 2017
- SAM Open Source, Thu Sep 21 2017

Round Tables

SAM round tables are 30-minute informal discussions online with the SAM team.

- Round table registration (January - June 2017): Free, every other Thursday at 2:30 pm Mountain Time.

Recordings of Past Webinars

Video recordings and presentation materials are available for the following webinars.

2016 Webinars

- Modelling a Photovoltaic Battery System in SAM 2016.3.14
- Modelling a Residential Photovoltaic System in SAM 2016.3.14
- SAM Demonstration in Spanish, June 2016

2015 Webinars

- Battery Storage for Photovoltaic Systems, Sep 2015

https://sam.nrel.gov/webinars
- Model updates and improvements
- Demo
  - Design point DNI
  - Optimizing solar field geometry
  - Dispatch optimization
- Question & Answer (20 minutes)
Model updates and improvements
System description
How SAM models MSPT systems

1. Design stage
   - Optimization
   - Final layout
2. Optical characterization
3. Performance simulation
   - Plant operations schemes: heuristic dispatch or optimized dispatch
Updates and improvements

- User-defined power cycle
- Dispatch optimization
- Hourly time-of-dispatch factors
- Improved solar field performance availability specification
- User specification of attenuation loss coefficients
User-defined power cycle

- Allows specification of detailed performance of a custom cycle
- Performance depends on:
  - HTF mass flow
  - HTF temperature
  - Ambient temperature
- Interactions between variables can be modeled

Select option from dropdown
Dispatch optimization

- By default, SAM generates power whenever energy is available in the storage system.
- Dispatch optimization calculates the best times to generate, and determines an optimal operating profile (more on this later!).

Enable with checkbox
Hourly time-of-dispatch factors

Enable with dropdown

Click to edit time series data

Enter factors in the table – one for each time step
Improved solar field performance availability specification

Choose how to specify losses

Enter time series data, if desired

Click to edit data
Atmospheric attenuation models the loss due to atmospheric scattering between each heliostat and the receiver. This varies as a function of aerosol optical depth (AOD). AOD is highly location-dependent and varies throughout the day and year. SAM’s defaults are for 25 km visibility in the US southwest and are likely not appropriate for MENA sites. Polynomial is evaluated for each heliostat position to determine overall performance.
## Attenuation loss example

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Clear (25km)</th>
<th>Hazy (5km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.006789</td>
<td>0.01293</td>
</tr>
<tr>
<td>1</td>
<td>0.1046</td>
<td>0.2748</td>
</tr>
<tr>
<td>2</td>
<td>-0.017</td>
<td>-0.03394</td>
</tr>
<tr>
<td>3</td>
<td>0.002845</td>
<td>0</td>
</tr>
<tr>
<td><strong>Avg.</strong></td>
<td><strong>9%</strong></td>
<td><strong>26%</strong></td>
</tr>
</tbody>
</table>

![Diagram](image)
Design-point DNI selection
Design-point DNI selection

• Definition: *The direct normal irradiance (DNI) available at the design point*

• Increasing this value indicates that fewer heliostats are needed to achieve the reference condition power

• Should represent the DNI at which your plant should achieve the specified thermal rating

• SAM uses the sun position at noon on the summer solstice (June 21 north of the equator, and December 21 south of the equator)
Selecting a design-point DNI value – default case

View data for Daggett, CA location
Selecting a design-point DNI value – default case

- Exclude zero values
- Select PDF/CDF
- View Beam irradiance
Selecting a design-point DNI value – default case

DNI value at 95% CDF value is reasonable: Receiver thermal power rating exceeded ~5% of sunlight hours.
Example for different climate – Sevilla, Spain

~840 W/m²
• Heliostat count does not scale linearly!
Potential pitfalls:
• DNI design point and solar multiple control separate design aspects
  o Solar multiple describes the relative thermal size of the *receiver* and *power cycle*
  o DNI design point controls the relative thermal size of the *heliostat field* and the *receiver*
• Several inputs should be aligned with the selected design point
  o Design and operation limits on the Tower and Receiver page
  o Maximum receiver flux – if design DNI is below maximum observed

![Design and Operation Parameters](image1.png)
![Receiver Flux Modeling Parameters](image2.png)
Optimizing solar field geometry
Motivation

- MSPT design process is not as straightforward as other technologies
- Changes in sizing, site, or components requires new solar field design
- Many variables *could* be optimized
- SAM optimizes tower height, receiver height, receiver diameter, and heliostat positions
- SAM provides a tool to automate this process
  - Generate heliostat layout (for current receiver and tower geometry)
  - Optimize solar field geometry
• Consider a “peaking” plant that generates during limited high-value time periods

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design turbine gross output</td>
<td>MWe</td>
<td>115</td>
</tr>
<tr>
<td>Solar multiple</td>
<td>-</td>
<td>1.3</td>
</tr>
<tr>
<td>Peak hours</td>
<td>-</td>
<td>7-9; 17-21</td>
</tr>
<tr>
<td>Peak multiplier</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Hours of TES</td>
<td>Hours</td>
<td>8</td>
</tr>
</tbody>
</table>
System design settings

**Design Point Parameters**
- **Heliostat Field**
  - Design point DNI: 950 W/m²
  - Solar multiple: 1.3

- **Power Cycle**
  - Design turbine gross output: 115 MWe
  - Estimated gross to net conversion factor: 0.9
  - Estimated net output at design (nameplate): 104 MWe

- **Tower and Receiver**
  - HTF hot temperature: 574 °C
  - HTF cold temperature: 290 °C

- **Thermal Storage**
  - Full load hours of storage: 8 hours

- **Solar Field hours of storage**: 6.15385 hours
TOD settings

PPA price multipliers, or TOD factors, apply to the PPA price according to the weekday and weekend schedules.

TOD factor data in SAM’s library may not be applicable to your project. Be sure that your assumptions are consistent with the requirements described in the appropriate solicitation documents.
Choosing optimization settings

- **Initial values**
  - Can affect success of optimization run!
  - Choose values that are initially feasible (flux limit and thermal power requirement met)
  - Multiple runs with different initial values improve confidence of the result
- **Initial step size**
  - Determines how far the algorithm will jump to assess impact of changing variable values
- **Maximum optimization iterations**
  - Limits the number of iterations before terminating algorithm
- **Optimization convergence tolerance**
  - Smaller value implies more iterations before convergence
- **Maximum receiver flux** (Tower and Receiver page)
  - Flux on receiver evaluated at each iteration to determine feasibility

![Optimization Settings Table]

<table>
<thead>
<tr>
<th>Setting</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial optimization step size</td>
<td>0.06</td>
</tr>
<tr>
<td>Maximum optimization iterations</td>
<td>200</td>
</tr>
<tr>
<td>Optimization convergence tolerance</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Running the optimization

- Run time proportional to number of heliostats
- Can take some time!

<table>
<thead>
<tr>
<th>Tower height</th>
<th>Rec. height</th>
<th>Rec. diameter</th>
<th>Objective</th>
<th>Flux</th>
<th>Plant cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>193.458</td>
<td>21.6029</td>
<td>17.65</td>
<td>1126.57</td>
<td>724.996</td>
</tr>
<tr>
<td>2</td>
<td>205.065</td>
<td>21.6029</td>
<td>17.65</td>
<td>1135.07</td>
<td>739.003</td>
</tr>
<tr>
<td>3</td>
<td>193.458</td>
<td>22.8991</td>
<td>17.65</td>
<td>1139.29</td>
<td>694.992</td>
</tr>
<tr>
<td>4</td>
<td>193.458</td>
<td>21.6029</td>
<td>18.709</td>
<td>1137.41</td>
<td>700.863</td>
</tr>
<tr>
<td>5</td>
<td>188.195</td>
<td>20.7236</td>
<td>17.0378</td>
<td>1110.24</td>
<td>762.119</td>
</tr>
<tr>
<td>6</td>
<td>182.23</td>
<td>20.0058</td>
<td>16.344</td>
<td>1094.71</td>
<td>788.867</td>
</tr>
<tr>
<td>7</td>
<td>167.757</td>
<td>19.5456</td>
<td>14.7312</td>
<td>1076.33</td>
<td>790.979</td>
</tr>
<tr>
<td>8</td>
<td>159.48</td>
<td>17.1304</td>
<td>14.5839</td>
<td>1055.49</td>
<td>855.401</td>
</tr>
<tr>
<td>9</td>
<td>163.742</td>
<td>16.7101</td>
<td>12.5304</td>
<td>1037.94</td>
<td>994.939</td>
</tr>
<tr>
<td>10</td>
<td>147.454</td>
<td>15.2777</td>
<td>11.5775</td>
<td>1029.49</td>
<td>1093.53</td>
</tr>
<tr>
<td>11</td>
<td>159.663</td>
<td>14.4192</td>
<td>13.2368</td>
<td>1025.53</td>
<td>1063.57</td>
</tr>
<tr>
<td>12</td>
<td>175.554</td>
<td>14.4792</td>
<td>14.7801</td>
<td>1032.9</td>
<td>1062.58</td>
</tr>
<tr>
<td>13</td>
<td>148.142</td>
<td>14.4856</td>
<td>13.3354</td>
<td>1030.74</td>
<td>1010.67</td>
</tr>
<tr>
<td>14</td>
<td>138.595</td>
<td>13.7948</td>
<td>13.5635</td>
<td>1033.96</td>
<td>1009.83</td>
</tr>
<tr>
<td>15</td>
<td>148.117</td>
<td>14.384</td>
<td>13.0109</td>
<td>1028.39</td>
<td>1043.86</td>
</tr>
<tr>
<td>16</td>
<td>154.417</td>
<td>15.4345</td>
<td>12.9151</td>
<td>1032.73</td>
<td>1006.2</td>
</tr>
</tbody>
</table>

Algorithm converged:
tht= 154.417  rec_height= 15.4345  rec_diameter= 12.9151
Objective: 1032.73

The final result
Accepting optimal results

- Results are **not** automatically applied
- You can choose whether to accept the new design
• Note the difference between optimizing solar field geometry vs. simply updating heliostat positions
After optimizing...

- Check different initial values of tower height, receiver dimensions
- Flux limit can constrain the solution
  - E.g., algorithm “bumps into” flux constraint, and cannot immediately determine whether violation is due to tower height or receiver dimensions
  - Resolve by temporarily relaxing flux limit, starting with different guess values, or decreasing convergence tolerance
Optimizing dispatch
• Stored energy can be used over a range of possible times
• Determining when and to what extent energy should be used is not straightforward; consider:
  o Production forecast
  o Pricing forecast
  o Component performance and startup behavior
  o Day-to-day operations
• Heuristic approach uses simple rules to decide when to run the cycle
  o Maximizes energy production
  o Operates when energy in TES exceeds minimum needed to run turbine
  o Exhausts TES before shutting down
  o Does not anticipate future use
• Optimized dispatch seeks a revenue-maximizing, cost-minimizing operating profile for both the solar field and power cycle
How does it work?
Dispatch optimization settings

- **Time horizon for dispatch optimization**
  - Number of future hours considered for each optimization run

- **Frequency for dispatch optimization**
  - How often is dispatch re-optimized? (Daily recommended)

- **Startup cost penalties**
  - Cost penalty applied when startup occurs (not included in financial model!)

- **Objective function time weighting exponent**
  - Decisions at time $t$ are discounted at the specified rate; e.g., revenue in time $t=30$ is $0.99^{30} \approx 0.74$ times that in $t=0$

- **Solver settings**
  - Limit number of iterations, optimality gap, or total solver time (expert)

- **Max net power to the grid**
  - When optimizing, control gross generation to not exceed a net power output limit

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### Dispatch Optimization Configuration

<table>
<thead>
<tr>
<th>Setting</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enable dispatch optimization</td>
<td>Yes</td>
</tr>
<tr>
<td>Time horizon for dispatch optimization</td>
<td>48 hours</td>
</tr>
<tr>
<td>Frequency for dispatch reoptimization</td>
<td>24 hours</td>
</tr>
<tr>
<td>Cycle startup cost penalty</td>
<td>$10,000 / start</td>
</tr>
<tr>
<td>Receiver startup cost penalty</td>
<td>$950 / start</td>
</tr>
<tr>
<td>Power generation ramping penalty</td>
<td>$0.1 / kW-hour</td>
</tr>
<tr>
<td>Objective function time weighting exponent</td>
<td>0.99</td>
</tr>
<tr>
<td>Maximum branch and bound iterations</td>
<td>35,000</td>
</tr>
<tr>
<td>Solution optimality gap tolerance</td>
<td>0.001</td>
</tr>
<tr>
<td>Optimization solver timeout limit</td>
<td>5 sec</td>
</tr>
<tr>
<td>Max. net power to the grid</td>
<td>$1 \times 10^8$ MWe</td>
</tr>
<tr>
<td>Max. net power to the grid (incl. availability)</td>
<td>$9.6 \times 10^7$ MWe</td>
</tr>
</tbody>
</table>
Comparison of performance

<table>
<thead>
<tr>
<th>Metric</th>
<th>Heuristic</th>
<th>Optimized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual energy (year 1)</td>
<td>301,607,488 kWh</td>
<td>289,253,696 kWh</td>
</tr>
<tr>
<td>Capacity factor (year 1)</td>
<td>33.30%</td>
<td>31.90%</td>
</tr>
<tr>
<td>PPA price (year 1)</td>
<td>9.59 ¢/kWh</td>
<td>5.96 ¢/kWh</td>
</tr>
<tr>
<td>Levelized COE (real)</td>
<td>11.95 ¢/kWh</td>
<td>12.44 ¢/kWh</td>
</tr>
</tbody>
</table>
TES charge state management

Heuristic

Optimized
Understanding the dispatch projection vs. actuals

- The dispatch model is simplified
- The performance model is detailed
- The simplified and detailed models may differ slightly
- SAM reports both the dispatch expected and actual performance:
  - *Actual* is accurate, *expected* is used for control
Understanding the simulation log

- If the solver cannot identify a solution for a given day, it reports the error. Each error corresponds to a single day, not the entire simulation!
  - Failed optimization reverts to heuristic dispatch
- A complete log of the optimizer results is shown on the Notices tab
- If a large proportion of results are suboptimal or failed, consider modifying solver settings

Finished with notices.
Thank You!