Thermal Storage Dispatch Control for Physical Trough Model

Paul Gilman, Draft January 4 2012

Definitions

Storage Dispatch w/Solar

Determines the minimum energy in storage at which the TES can deliver energy for daytime hours when the solar energy incident on the field is greater than zero. It is a fraction of TES capacity, which is determined by the Full Load Hours of TES input and displayed as TES Thermal Capacity on the Thermal Storage page.

The storage dispatch fraction does not determine the power block load. SAM determines the power block load in a given hour based on the value of Turbine Output Fraction and the amount of energy available from the solar field, TES, and, if applicable, the Fossil Fill Fraction for that hour.

For example, consider a system with a 100 MWe nameplate capacity under the following conditions for an hour when the sun is shining. If the TES is 60% full, the power block will operate at 75 MWe for that hour using both energy from the solar field and from storage. However, if the TES is 20% full in that hour, the power block will operate at 10 MWe using only energy from the solar field.

- Storage Dispatch w/solar = 0.25
- Storage Dispatch w/o solar does not apply in this hour
- Turbine Output Fraction = 0.75
- Fossil Fill Fraction = 0 (no fossil backup)
- Solar field output is 10% of the power block's design thermal input

For hours of sunshine when Fossil Fill Fraction is zero:

- Storage Dispatch w/Solar = 0 will dispatch energy from storage in the hour if energy in storage is greater than zero (and the storage discharge rate can meet the power block load requirement defined by the turbine output fraction).
- Storage Dispatch w/Solar = 0.25 will dispatch energy from storage in the hour if energy in TES is 25% of capacity or greater (TES is at least 25% full).
- Storage Dispatch w/Solar = 1 will not dispatch TES energy in the hour

Storage Dispatch w/o Solar

Determines the minimum energy in storage at which the TES can deliver energy for nighttime hours when the solar energy incident on the field is zero. This value works in the same was as Storage Dispatch w/Solar, but for hours when there is no sunshine.

For example, consider a system with a 100 MWe nameplate capacity under the following conditions for an hour when the sun is not shining. If the TES is 60% full, the power block will operate at 75 MWe for that hour using both energy from storage. However, if the TES is 20% full in that hour, the power block will not operate.

- Storage Dispatch w/solar = 0.25
- Storage Dispatch w/o solar does not apply in this hour
- Turbine Output Fraction = 0.75
- Fossil Fill Fraction = 0 (no fossil backup)

Fossil Fill Fraction

Determines how much energy can be delivered from a natural gas-powered backup boiler in a given hour. It is a fraction of the power block design gross output on the Power Cycle page.

For example, for a system with a 100 MWe nameplate capacity under the following conditions in an hour when the sun is shining, the solar field output is 10% of the power block's design gross output, and the TES is 20% full in that hour, the power block will operate at 70 MWe using energy from both the solar field and backup boiler.

- Storage Dispatch w/solar = 0.25
- Storage Dispatch w/o solar does not apply in this hour
- Turbine Output Fraction = 0.75
- Fossil Fill Fraction = 0.60
- Solar field output is 10% of the power block's design thermal input

Thermal Storage Dispatch Control Example

Inputs

Period 1 (early morning to late afternoon):

Requirement: Plant generates electricity at nameplate rating using solar field energy with fossil backup to cover cloud transients. Charge TES with excess solar field energy.

- **Storage Dispatch w/Solar = 1**
  Ensures that TES energy is not used to cover cloud transients
- **Storage Dispatch w/o Solar = 1**
  Does not apply in this daytime period, but you can set it to 1 as a reminder that the system will not dispatch TES energy during this period.
- **Turb. Out. Fraction = 1**
  Sets the power cycle's maximum load to its nameplate capacity.
- **Fossil Fill Fraction = 1**
  Allows the backup boiler to supply up to 100% of the energy required to run the power block at nameplate capacity. (The power block will run at nameplate capacity even if the solar field energy drops to zero.

Period 2 (midnight to early morning):

Requirement: Plant does not generate electricity. Some power is required to maintain HTF and storage fluid temperatures and other parasitic loads.

- **Storage Dispatch w/Solar = 1**
  Ensures that TES energy is not used
- **Storage Dispatch w/o Solar = 1**
  Ensures that TES energy is not used
- **Turb. Out. Fraction = 0**
  Causes no thermal energy to be delivered to the power cycle
- **Fossil Fill Fraction = 0**
  Ensures that the backup boiler delivers no energy to the power cycle

Period 3 (early morning):

Requirement: Plant generates electricity at nameplate capacity using solar field energy with fossil backup to cover low sunlight conditions.

- **Storage Dispatch w/Solar = 1**
  Ensures that TES energy is not used if the incident solar radiation is greater than zero in the hour
- **Storage Dispatch w/o Solar = 1**
  Ensures that TES energy is not used if the incident solar radiation is zero in the hour
- **Turb. Out. Fraction = 1**
  Causes power cycle to operate at nameplate capacity as long as there is sufficient energy from the solar field or backup boiler
- **Fossil Fill Fraction = 1**
  Ensures that the backup boiler can deliver up to 100% of the power block nameplate capacity

Period 4 (late afternoon):

Requirement: Plant generates electricity at nameplate capacity using solar field energy with TES to cover low sunlight conditions. Backup boiler does not run.

- **Storage Dispatch w/Solar = 0**
  If there is some sunlight, the TES will dispatch energy as long as there is some thermal energy in storage
- **Storage Dispatch w/o Solar = 0**
  If there is no sunlight, the TES will dispatch energy as long as there is some thermal energy in storage
- **Turb. Out. Fraction = 1**
  Causes power cycle to operate at nameplate capacity as long as there is sufficient energy from the solar field or TES. Otherwise it will operate at part load.
- **Fossil Fill Fraction = 0**
  No energy will be delivered from the backup boiler.

Period 5 (late afternoon to midnight):

Requirement: Plant generates electricity at nameplate capacity using TES energy.

- **Storage Dispatch w/Solar = 0**
  Does not apply at night, but setting it to zero may help remind you that you intend for the TES to deliver energy during this period.
- **Storage Dispatch w/o Solar = 0**
  If there is no sunlight, the TES will dispatch energy as long as there is some thermal energy in storage.
- **Turb. Out. Fraction = 1**
  Causes power cycle to operate at nameplate capacity as long as there is sufficient energy from the TES. Otherwise it will operate at part load.
- **Fossil Fill Fraction = 0**
  No energy will be delivered from the backup boiler.

Thermal Storage Dispatch Control

Current dispatch schedule:

No library match.

Dispatch schedule library...

Note:

Schedule libraries do not affect the Storage Dispatch, Turbine Output and Fossil Fill fractions below.

	Storage Dispatch w/ solar*	Storage Dispatch w/o solar*	Turb. out. fraction*	Fossil fill fraction*	Payment Allocation Factor
Period 1:	1	1	1	1	1
Period 2:	1	1	0	0	1
Period 3:	1	1	1	1	1
Period 4:	0	0	1	0	1
Period 5:	0	0	1	0	1
Period 6:	0	0	1	0	1
Period 7:	0	0	1	0	1
Period 8:	0	0	1	0	1
Period 9:	0	0	1	0	1

Notes:

1. Storage dispatch fractions apply to the maximum energy storage.

2. Turbine output and fossil fill fractions apply to the design turbine thermal input.

3. Payment Allocation Factors apply to Utility Dispatch and Utility Bid Price financing only.

Weekday Schedule

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5	5
Feb	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5	5
Mar	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5	5
Apr	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5	5
May	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5
Jun	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5
Jul	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5
Aug	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5
Sep	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5	5
Oct	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5	5
Nov	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5	5
Dec	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5	5

Weekend Schedule

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5	5
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May	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5
Jun	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5
Jul	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5
Aug	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5
Sep	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5	5
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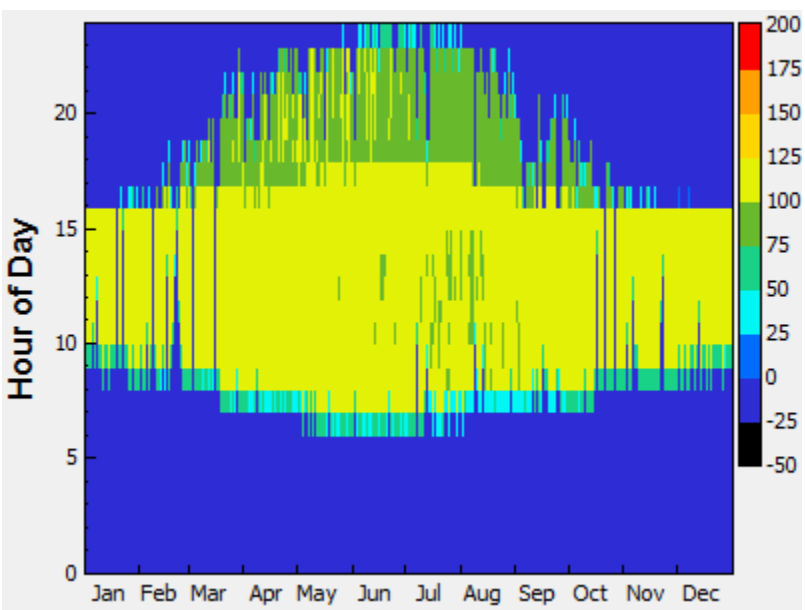
Nov	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5	5
Dec	2	2	2	2	2	2	3	3	1	1	1	1	1	1	1	1	4	5	5	5	5	5	5	5

Results

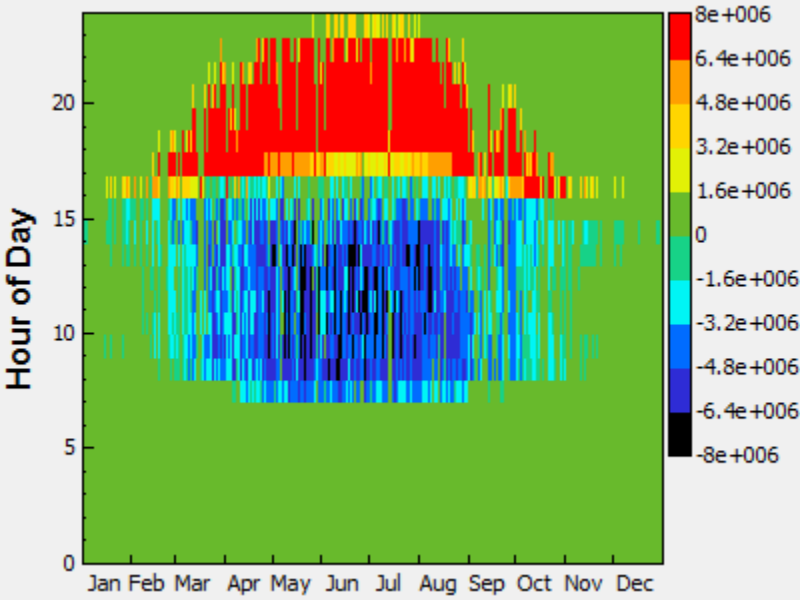
Net Electric Output (MWe)

From early morning to midnight, power block operates at nameplate capacity (100 MWe) except for winter nights when there is insufficient TES energy.



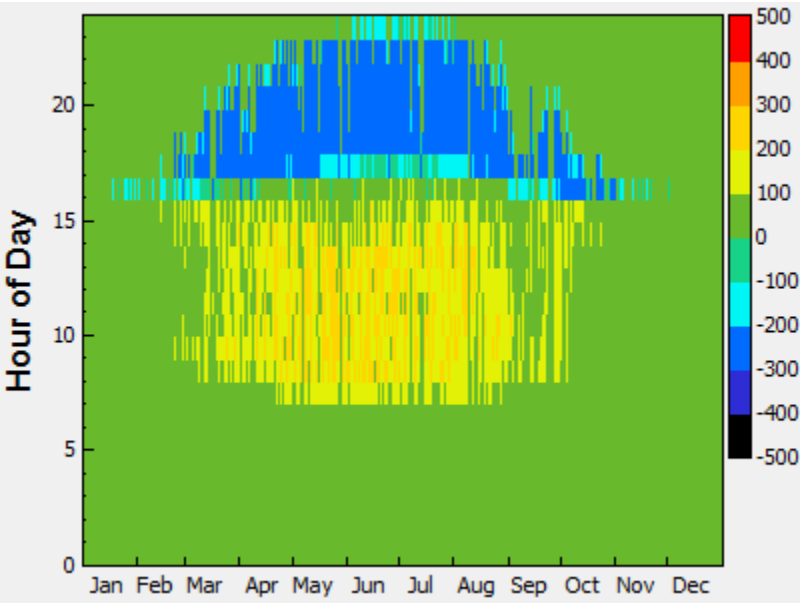
TES Discharge Mass Flow Rate (kg/hr)

TES discharges at late afternoon and night, but not at early morning or between midnight and early morning.



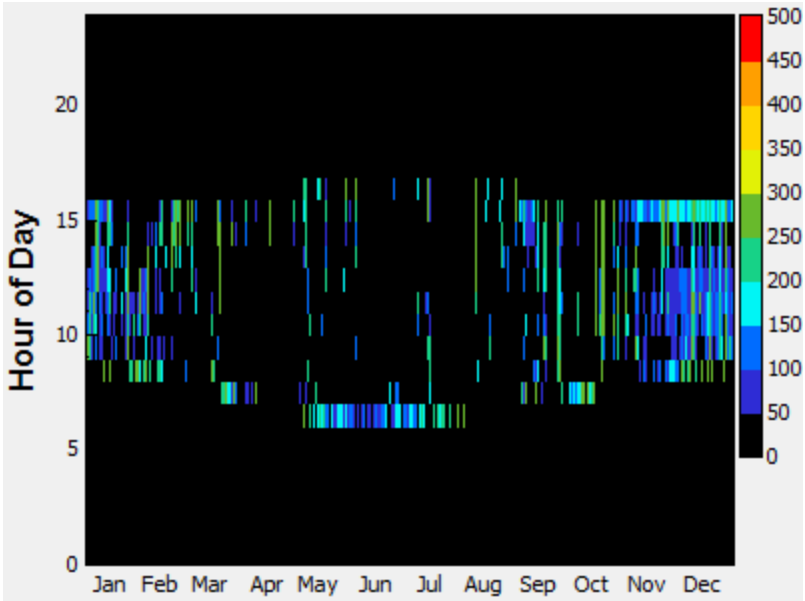
Energy to Thermal Storage (MWh)

TES charges during daytime hours, and discharges only from late afternoon to midnight.



Thermal Energy Delivered by Aux Backup (MWh)

Backup boiler covers cloud transients during the day, and covers low light periods in early morining.



Adjust Backup Boiler Operation to Minimize Winter Operation

The backup boiler operates during winter months during the day. If that is undesireable, we can change the dispatch schedule as follows.

Thermal Storage Dispatch Control

Current dispatch schedule:

No library match.

Dispatch schedule library...

Note:

Schedule libraries do not affect the Storage Dispatch, Turbine Output and Fossil Fill fractions below.

	Storage Dispatch w/ solar*	Storage Dispatch w/o solar*	Turb. out. fraction*	Fossil fill fraction*	Payment Allocation Factor
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Period 2:	1	1	0	0	1
Period 3:	1	1	1	1	1
Period 4:	0	0	1	0	1
Period 5:	0	0	1	0	1
Period 6:	1	1	1	0	1
Period 7:	0	0	1	0	1
Period 8:	0	0	1	0	1
Period 9:	0	0	1	0	1

Notes:

1. Storage dispatch fractions apply to the maximum energy storage.

2. Turbine output and fossil fill fractions apply to the design turbine thermal input.

3. Payment Allocation Factors apply to Utility Dispatch and Utility Bid Price financing only.

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Nov	2	2	2	2	2	2	6	6	6	6	6	6	6	6	6	6	4	5	5	5	5	5	5	5
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Weekend Schedule

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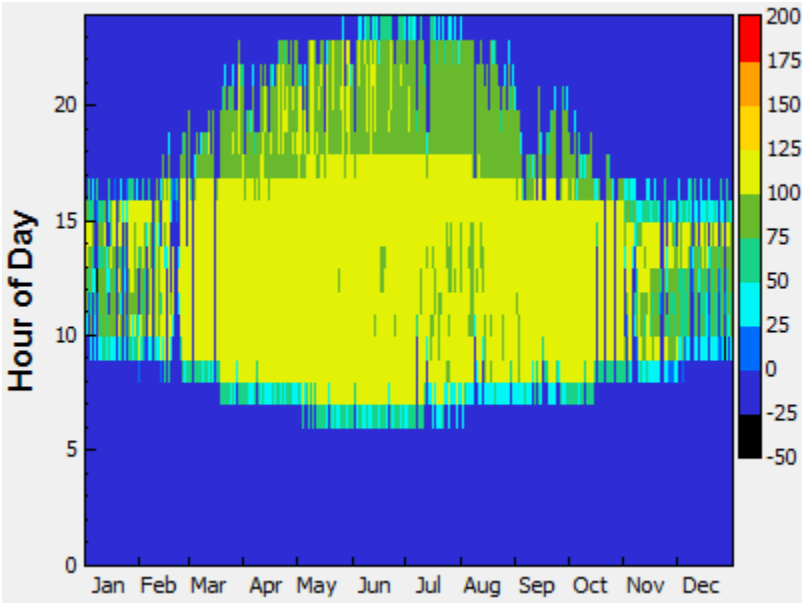
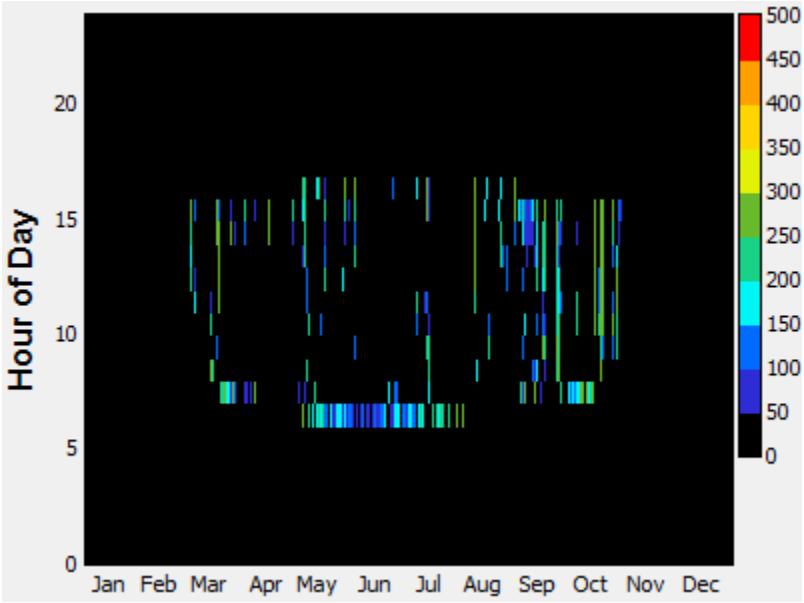
Dec	2	2	2	2	2	2	6	6	6	6	6	6	6	6	6	6	4	5	5	5	5	5	5	5

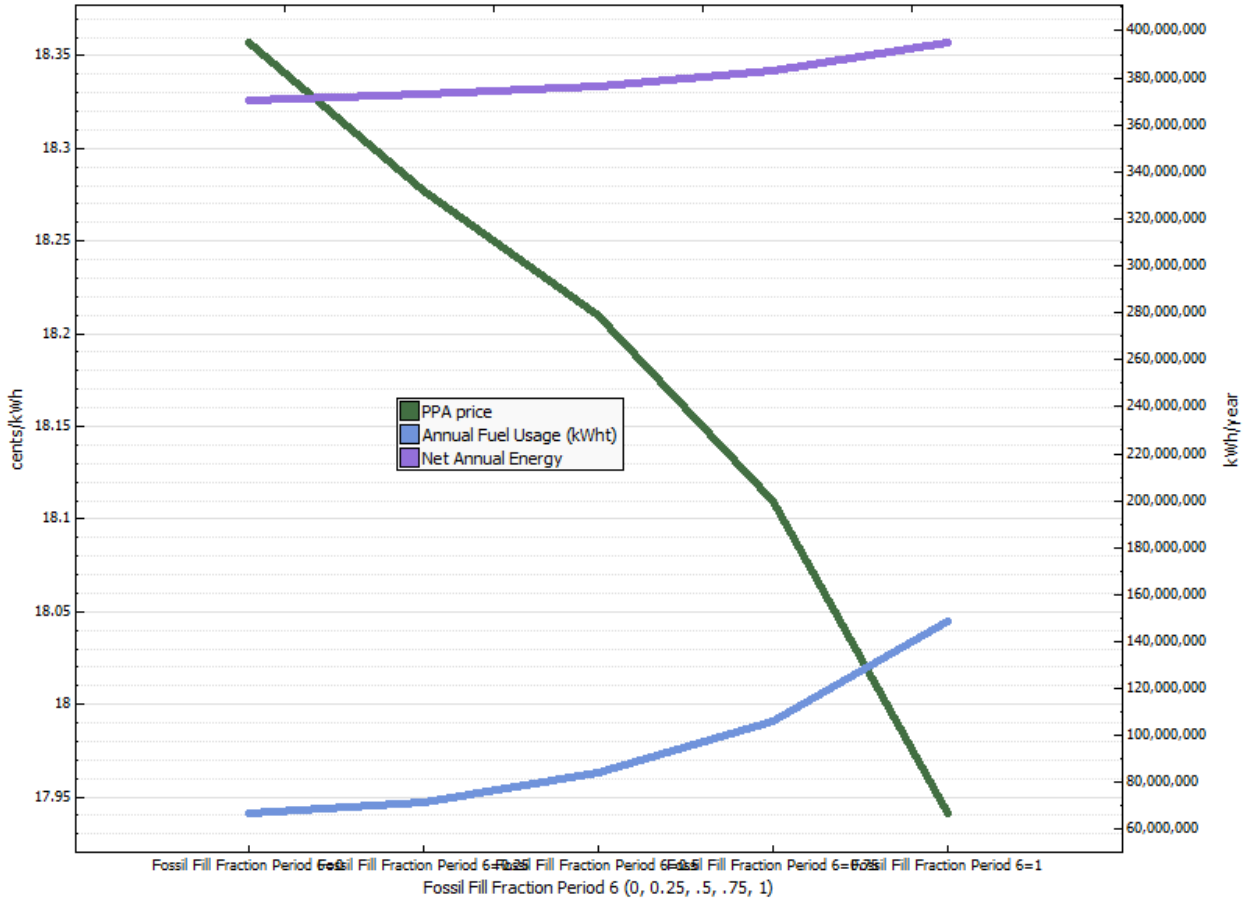
Net Electric Output (MWh)



Thermal Energy Delivered by Aux Backup (MWh)



A parametric analysis on the fossil fill fraction for Period 6 shows how it affects gas consumption for the backup boiler during this period, as well as the PPA price, and net electric output:


18.35
18.3
18.25
18.2
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18
17.95
cents/kWh
400,000,000
380,000,000
360,000,000
340,000,000
320,000,000
300,000,000
280,000,000
260,000,000
240,000,000
220,000,000
200,000,000
180,000,000
160,000,000
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
kWh/year
PPA price
Annual Fuel Usage (kWht)
Net Annual Energy
Fossil Fill Fraction Period 6=0
Fossil Fill Fraction Period 6=0.25
Fossil Fill Fraction Period 6=0.5
Fossil Fill Fraction Period 6=0.75
Fossil Fill Fraction Period 6=1
Fossil Fill Fraction Period 6 (0, 0.25, .5, .75, 1)