Generator and Area Real Power Control

- Scaling Case Load and Generation
- Control of generator real power
- Generator cost models
- Area interchange control
- Modeling MW transactions
- Areas the belong to multiple islands
Generator MW Control

- Real power output of generator can be changed either
  - manually
    - Generator dialog
    - Case information displays
    - Generator fields
    - System Scaling display
  - automatically
    - Participation factor AGC
    - Economic dispatch
    - Area slack bus control
    - Injection group area slack control
    - Optimal power flow (OPF)
System Scaling Display

- Permanently changes load, generation and shunts at a user specified set of buses.
- Buses are selected either by
  - entering a range of values
  - entering a range of areas
  - individually on a list display
- Both real and reactive load can be scaled.
- To Display: **Tools** ribbon tab ➔ **Scale Case**
Scaling by Area, Zone, Injection Group, and Owner

• Scaling by Area or Zone
  – This can be different than just selecting all the buses in an area/zone.
  – Generators, Loads, and Shunts may be in a different area/zone than their terminal bus.

• Can also scale according to Injection Group or Owner
Generator Dialog (Run Mode)

Specify whether generator is available for Automatic Generation Control (AGC)

Current MW output
Minimum and maximum limits
Enforcing generator MW limits can also be disabled for entire case on the Simulator Options dialog

Used with participation factor AGC

\[ \frac{\partial P_{\text{AreaLosses}}}{\partial P_{G_i}} \]
Generator Dialog (Run Mode)

Can also use piecewise linear cost model

Cubic cost model
Oneline Generator MW Control

Current MW output; spin button allows output to be changed manually.

Right-click on generator symbol to view local-menu.

Gen field indicates generator is on AGC. Manually changing output takes generator off AGC unless disabled in Simulator Options → Environment Tab.

Specifies change in generator MW per click on the spin button.
Generator Records

- Fields on the dialog are also available on the Generator Case Information Displays.

Change Gen MW field from this dialog to get change to occur in simulation; AGC field will change automatically when Gen MW field is changed manually.
Generator Cost Model, Cubic

- Total generator operating cost is modeled using cubic function

\[ C_i(P_{gi}) = F_i + (A_i + B_i P_{gi} + C_i(P_{gi})^2 + D_i(P_{gi})^3) \times f_c + V_{OM} P_{gi} \]

Units are $ / hour

Variable O&M ($/MWh)

Fuel cost ($/MBtu)

Fixed Costs (costs at zero MW output)

Fuel Cost Independent Value ($/hr)

Fuel Cost Dependent Value (MBtu/hr)

Total Fixed Costs ($/hr)

Fuel cost ($/hr)

Variable O&M ($/MWh)

Convert Cubic to Linear Cost

Number of Break Points

Convert to Linear Cost
Generator Cubic Cost Curves in the Case Information Display

- Go to the Model Explorer and choose Network → Generators → Cost Curves Cubic
  - F, A, B, C, D Coefficients, Fuel Cost, and Variable O&M
Generator Cost Model
Piecewise Linear

Fuel Cost

<table>
<thead>
<tr>
<th>Cost Model</th>
<th>None</th>
<th>Cubic Cost Model</th>
<th>Piecewise Linear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Fuel Cost ($)</td>
<td>2.040</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable O&amp;M ($)</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed Costs ($)</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Cost Independent Value ($)</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Cost Dependent Value (MBtu/hr)</td>
<td>373.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Fixed Costs ($)</td>
<td>761.94</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Piece-wise Linear Cost Curve

Note: The cost function must be strictly increasing.

<table>
<thead>
<tr>
<th>MW</th>
<th>$/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.0</td>
<td>16.34</td>
</tr>
<tr>
<td>200.0</td>
<td>16.87</td>
</tr>
<tr>
<td>300.0</td>
<td>17.40</td>
</tr>
</tbody>
</table>

Linear cost curve breakpoints and costs

Note: When you change the fuel cost, Simulator will prompt you asking you whether you want to change the bid curve points.
Piecewise Linear Cost Curve Input

Piecewise Linear Cost Curve (units = $/h)

Fixed Cost

Slope of line is First “$/MWh” Point

[$/MWh 1]

Slope of line is First “MW” Point

[MW 1]

Slope is

[$/MWh 2]

Slope is

[$/MWh 3]

Output (MW)

Input variables are highlighted and bold
Piecewise Linear Load Benefit Input

Piecewise Linear Benefit Curve (units = $/h)

Input variables are highlighted and bold
Generator Linear Cost Curves in the Case Information Display

- In the Model Explorer go to **Network** → **Generators** → **Cost Curves Linear**
  - Fuel Cost, Fixed Cost, Bid Curve Points

- Note: when you change the Fuel Cost value, Simulator will prompt you asking if you want to change the bid curve points as well
  - If you double the fuel cost, it will double the bids
Generator Cost Curves

- Four curves derived from generator operating cost model and fuel-cost
  - Input-Output (IO) Curve: MW versus Mbtu/hr
  - Fuel Cost Curve: MW versus $ / hr (IO curve multiplied by fuel-cost)
  - Incremental Cost Curve: MW versus $/MWhr (fuel-cost curve differentiated w.r.t. MW)
  - Heat Rate Curve: MW versus average Mbtu/MWhr
Generator Cost Curves

Four different generator cost curves are available on the generator local-menu.

- Input-output curve
- Right-click on axes to change their scaling
- Current operating point

Right-click on axes to change their scaling.
Saving Generator Cost Curves in Text Files

• Similar to generator reactive capability curves, generator cost curves can also be stored in external text files.

• Text files allow easy transfer of cost data between cases.
  – In the Model Explorer select **Network → Generators**
  – Right-Click and choose **Save As → Auxiliary File** (only fuel cost information)
  – Choose the filename to save and Click **OK**
  – the *.aux file can then be manually edited
Area Interchange Control

- Interchange of power between areas can be controlled so area export is set equal to the scheduled value.
- Generator MW outputs are modified either by
  - Participation factor AGC
  - Area slack control
  - Injection group area slack control
  - Economic dispatch
  - Optimal power flow (OPF)
Area Interchange Control

• For Area Interchange Control, **Disable Automatic Generation Control (AGC)** must NOT be checked on Simulator Options dialog, Power Flow Solution page, Common Options tab.

![Disable Automatic Generation Control (AGC)]

• Area Interchange is set for each area on either the Area Records display or on the Area dialog.

• To view Area dialog, either right-click on area on Area Records display, or use oneline local menu.
Area Records

- In the Model Explorer select Aggregations ➔ Areas to view the Area Records display.
- Display shows summary information about all areas in case.
- Entries can be sorted by clicking on the column labels.
- Right-click in the row of a desired area and select Show Dialog to view the area’s information.
Area Interchange Control

Double-click on field to change AGC status

Right-click to view Area dialog

Total area MW interchange

Access Tie-line flows

MW Interchange by area

Tolerance for MW area control
Economic Dispatch Example

- For B7FLAT Case, verify that all three areas are on economic dispatch control.

<table>
<thead>
<tr>
<th>Area Num</th>
<th>Area Name</th>
<th>AGC Status</th>
<th>Gen MW</th>
<th>Load MW</th>
<th>Tot Sched MW</th>
<th>Int MW</th>
<th>ACE MW</th>
<th>Lambda</th>
<th>Loss MW</th>
<th>Auto Shunts</th>
<th>Auto XF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Top</td>
<td>ED</td>
<td>366.96</td>
<td>360.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>16.90</td>
<td>6.96</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>2</td>
<td>Left</td>
<td>ED</td>
<td>200.33</td>
<td>200.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>17.22</td>
<td>0.33</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>3</td>
<td>Right</td>
<td>ED</td>
<td>200.65</td>
<td>200.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>22.01</td>
<td>0.65</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>

- Open load at bus 2; notice how only generators in TOP area change. Place load back in service.

- Change generator 1 fuel cost to 1.5. Restart simulation. Notice how other generators in area are set to their lower limits.
Economic Dispatch Example

Load goes out of service – All generators respond to reduce generation cost in top area
Participation Factor Example

- On B7FLAT case, set participation factors for all three TOP area generators to 1.0.
- Place TOP area on participation factor control.
- Verify that as load is modified, generator outputs all change proportionally – cost information is not used.
Participation Control Example

Load at bus 2 increased from 40 MW to 70 MW—Each generator responds by equal amount because participation factors are same
Area Slack Bus Control

- An “Area Slack Bus” is NOT the same as the “Island Slack Bus”. This is bad nomenclature, but is commonly used throughout the power industry
  - Area Slack – Used in MW Control Loop (see earlier section) of Power flow to meet ACE of an area
  - Island Slack – Used in the Inner Power Flow loop (see earlier section) to actually solve a set of equations

- Area slack bus control simply means that all change in generator/load/losses in the area is made up by the generators at a Single bus.
  - Equivalent to setting participation factors at all generators to zero and then giving a value only to the generators at the Area Slack buses
Injection Group Area Slack Control

- Allows precise specification of how ACE should be maintained for an area
- Specify group of generators and/or loads that should vary for an area to make up for changes in generation, load, and losses
- Participation factors defined with the injection group determine how each element will respond to MW changes in the area
Area Transactions

• MW Transactions are typically used in static power flow studies
  – list only one amount
  – Accessed in the Model Explorer through Aggregations → MW Transactions

• Multiple transactions may be entered for each set of areas, and transaction may be enabled by economics of OPF (covered in later section)
Area Transactions

• Used to quickly set up transactions between an area and
  – another specific area
  – unspecified areas

• Cost and start/stop times are not specified

• Transaction areas must be on area control
  (Participation Factor, OPF, ED, Area Slack)
Area Transaction Example

- Open B7FLAT, making sure all three areas are on economic dispatch control.
- Right-click near (but not on bus 1) to display the oneline local-menu. Select Area Information Dialog… to display Area Dialog for area TOP.
- In Base Interchange by Area table, set 50 as exports to area 2 and to area 3.
Area Transaction Example

Use the spin button to view other areas.

Load + losses + interchange is equal to generation.

Algebraic sum of actual flow is equal to scheduled.

Schedules are also automatically set for areas LEFT and RIGHT.
Case Information, MW Transactions

- You can also bring up a summary of all the transactions in the case
  - Can show in a Matrix or in a List
Area Transaction Dialog

- Right-click on the list of transactions and choose Show Dialog
- Transaction MW Amount
- All other options on this dialog only affect the Optimal Power Flow and will be discussed in the OPF section later.
Area control across multiple islands

• Prior to Simulator 13, any Area that spanned multiple islands was always automatically set to AGC = Off
• Simulator 13 and after however does a more extensive error check to allow for more complex situations (this was previously only available in the OPF solution)
  – An area that belongs to multiple islands can be placed on control only if at most one of these islands contains multiple areas.
Multiple Island Area Control: Example for Area #1 Control

Control Allowed
Only Island C has multiple areas

Control NOT Allowed
Island A and Island C have multiple areas

This situation occurs for WAPA and ERCOT in Eastern Interconnect cases
Multiple Island Area Control: Why control is NOT Allowed

- Not allowed because Simulator doesn’t have enough information to know which generation should respond when transactions are specified
  - For example: Area 1 – Area 2 transfer
  - Should transfer occur in Island A or Island B?
    - Because Simulator doesn’t know, control is NOT allowed
Converting Heat Rate Data into Cost Information in PowerWorld Simulator

**Input Information:**
- Average Heat Rate Curve Points \([\text{MBtu/}(\text{MWhr}) \text{ vs. MW}]\)
- Fuel Cost \(\$/\text{MBtu}\)

**Output Information**
- Total Cost Curve \(\$/\text{hr vs. MW}\)
## Input Data

### Example Heat Rate Curve Points

<table>
<thead>
<tr>
<th>ID #</th>
<th>Unit Name</th>
<th>Unit No</th>
<th>Cap Level 1</th>
<th>Cap Level 2</th>
<th>Cap Level 3</th>
<th>Cap Level 4</th>
<th>Cap Level 5</th>
<th>Heat Rate 1</th>
<th>Heat Rate 2</th>
<th>Heat Rate 3</th>
<th>Heat Rate 4</th>
<th>Heat Rate 5</th>
<th>Full Load HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>50003</td>
<td>A.B. Paterson</td>
<td>3</td>
<td>14</td>
<td>28</td>
<td>42</td>
<td>56</td>
<td>0</td>
<td>17099</td>
<td>14216</td>
<td>13536</td>
<td>13400</td>
<td>0</td>
<td>13400</td>
</tr>
<tr>
<td>50004</td>
<td>A.B. Paterson</td>
<td>4</td>
<td>21.7</td>
<td>43.5</td>
<td>65.2</td>
<td>87</td>
<td>0</td>
<td>14828</td>
<td>12327</td>
<td>11738</td>
<td>11620</td>
<td>0</td>
<td>11620</td>
</tr>
<tr>
<td>50005</td>
<td>A.B. Paterson</td>
<td>5</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>0</td>
<td>0</td>
<td>17916</td>
<td>15532</td>
<td>14800</td>
<td>0</td>
<td>0</td>
<td>14800</td>
</tr>
<tr>
<td>50008</td>
<td>Agrilectric</td>
<td>1</td>
<td>2.7</td>
<td>5.5</td>
<td>8.2</td>
<td>11</td>
<td>0</td>
<td>13943</td>
<td>11592</td>
<td>11038</td>
<td>10927</td>
<td>0</td>
<td>10927</td>
</tr>
<tr>
<td>50049</td>
<td>Buras GT</td>
<td>8</td>
<td>4.7</td>
<td>9.5</td>
<td>14.2</td>
<td>19</td>
<td>0</td>
<td>25479</td>
<td>18375</td>
<td>16214</td>
<td>15442</td>
<td>0</td>
<td>15442</td>
</tr>
<tr>
<td>50146</td>
<td>Gypsy</td>
<td>2</td>
<td>216.9</td>
<td>249.6</td>
<td>360</td>
<td>436</td>
<td>0</td>
<td>10664</td>
<td>10175</td>
<td>9820</td>
<td>10032</td>
<td>0</td>
<td>10032</td>
</tr>
<tr>
<td>50147</td>
<td>Gypsy</td>
<td>3</td>
<td>325.7</td>
<td>361</td>
<td>412.1</td>
<td>573</td>
<td>0</td>
<td>10881</td>
<td>10505</td>
<td>10315</td>
<td>10179</td>
<td>0</td>
<td>10179</td>
</tr>
<tr>
<td>50148</td>
<td>Gypsy</td>
<td>1</td>
<td>56.6</td>
<td>103.4</td>
<td>196.9</td>
<td>244</td>
<td>0</td>
<td>13581</td>
<td>11253</td>
<td>10195</td>
<td>9978</td>
<td>0</td>
<td>9978</td>
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<tr>
<td>50168</td>
<td>Houma</td>
<td>15</td>
<td>7.65</td>
<td>10.2</td>
<td>11.7</td>
<td>24</td>
<td>0</td>
<td>14357</td>
<td>11510</td>
<td>11131</td>
<td>12215</td>
<td>12215</td>
<td>12215</td>
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<tr>
<td>50169</td>
<td>Houma</td>
<td>16</td>
<td>14</td>
<td>18.4</td>
<td>20.6</td>
<td>39</td>
<td>0</td>
<td>14357</td>
<td>11510</td>
<td>11131</td>
<td>12215</td>
<td>12215</td>
<td>12215</td>
</tr>
</tbody>
</table>
Average heat rate represents the “efficiency” of the plant at particular operating levels.

- MBtu = amount of energy or fuel put in
- MWhr = amount of energy coming out of plant

<table>
<thead>
<tr>
<th>Average Heat Rate [MBtu/MWhr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>hr1</td>
</tr>
<tr>
<td>hr2</td>
</tr>
<tr>
<td>hr3</td>
</tr>
<tr>
<td>hr4</td>
</tr>
<tr>
<td>hr5</td>
</tr>
</tbody>
</table>

Output [MW]

x1 x2 x3 x4 x5
Convert To Input-Output Curve by multiplying by the Output

- Input-Output shows the power going into the generator versus the power coming out
  - MBtu/hr = Input Power = fuel being used per hour
  - MW = Output Power

![Graph showing the relationship between Input [MBtu/hr] and Output [MW]]
Convert to Cost Curve

- Multiply by the fuel cost in $/MBtu and add multiple of Variable O&M and Output to convert the input-output curve to the cost curve
  - Note slopes are noted below have the equations
    \[ s_1 = \frac{x_2(\text{fc} \cdot \text{hr}_2 + \text{VOM}) - x_1(\text{fc} \cdot \text{hr}_1 + \text{VOM})}{\text{hr}_2 - \text{hr}_1} \]
    which has units of [$$/MWhr]
Entering Cost Data in Simulator using a cubic cost model

- Enter six parameters:
  - \( fc \) = fuel cost
  - \( V_{OM} \) = variable O&M
  - \( a, b, c, d \) = coefficients

- The generation cost is then defined as

\[
\text{Generation Cost} = fc \times (a + bx + cx^2 + dx^3) + V_{OM}x
\]

- In order to do this, you would need to curve-fit the input-output curve to determine the coefficients
Entering Cost Data in Simulator using a Piecewise Linear Model

- Because you have individual points on the cost curve, the piecewise linear model is the easiest and most logical to use
  - Note: Simulator OPF uses linear programming to optimize the generation dispatch, therefore it converts cubic curves into piecewise linear models anyway
- To enter a piecewise linear curve, you specify a fixed cost, and then pairs of points corresponding to the slope of the cost curve at various output levels
  - This mimics a “bid” or “offer” curve from a market model
Example Piecewise Linear Data

- **Fixed Cost** = \( x_1(f_c \cdot h_{r1} + V_{OM}) \)
  - Cost at lowest output specified by the pairs entered
- Enter pairs of (output, slope) as follows
  - Mimics a “bid”

<table>
<thead>
<tr>
<th>Output [MW]</th>
<th>Slope [$/MWhr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_1 )</td>
<td>( s_1 )</td>
</tr>
<tr>
<td>( x_2 )</td>
<td>( s_2 )</td>
</tr>
<tr>
<td>( x_3 )</td>
<td>( s_3 )</td>
</tr>
<tr>
<td>( x_4 )</td>
<td>( s_4 )</td>
</tr>
</tbody>
</table>

where

\[
s_1 = \frac{x_2(f_c \cdot h_{r2} + V_{OM}) - x_1(f_c \cdot h_{r1} + V_{OM})}{x_2 - x_1}
\]

etc...
Minor Change to Set minimum “bid” to a specified output

- From looking at your data, it appears that you have a minimum output in mind for each generator.
- Call this minimum output $x_0$
- To model this assume the first slope stays the same, therefore you must only change the output of the first bid to $x_0$, and change the fixed cost.

<table>
<thead>
<tr>
<th>Fixed Cost [$/hr]</th>
<th>Output [MW]</th>
<th>Slope [$/MWhr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_1(fc<em>hr_1+V_{OM}) - s_1</em>(x_1-x_0)$</td>
<td>$x_0$</td>
<td>$s_1$</td>
</tr>
<tr>
<td></td>
<td>$x_2$</td>
<td>$s_2$</td>
</tr>
<tr>
<td></td>
<td>$x_3$</td>
<td>$s_3$</td>
</tr>
<tr>
<td></td>
<td>$x_4$</td>
<td>$s_4$</td>
</tr>
</tbody>
</table>
Convex Requirement

• Cost curves must be “convex”
  – Required in markets as well
    • You can’t sell your “second” block before your first.
  – Required for mathematical reasons
• Convexity for a Piecewise Linear cost model (generator) means that as the output increases, the slopes (or prices) must increase
• Convexity for a Piecewise Linear benefit model (load) means that as the load increases, the slopes must decrease
Example – Generator Cost

Acceptable Curve

<table>
<thead>
<tr>
<th>Output [MW]</th>
<th>Slope [$/MWhr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 MW</td>
<td>20 $/MWhr</td>
</tr>
<tr>
<td>200 MW</td>
<td>24 $/MWhr</td>
</tr>
<tr>
<td>300 MW</td>
<td>26 $/MWhr</td>
</tr>
<tr>
<td>400 MW</td>
<td>28 $/MWhr</td>
</tr>
</tbody>
</table>

Unacceptable Curve

<table>
<thead>
<tr>
<th>Output [MW]</th>
<th>Slope [$/MWhr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 MW</td>
<td>20 $/MWhr</td>
</tr>
<tr>
<td>200 MW</td>
<td>26 $/MWhr</td>
</tr>
<tr>
<td>300 MW</td>
<td>24 $/MWhr</td>
</tr>
<tr>
<td>400 MW</td>
<td>28 $/MWhr</td>
</tr>
</tbody>
</table>

Decrease in slope
Example – Load Benefit

Acceptable Curve

<table>
<thead>
<tr>
<th>Output [MW]</th>
<th>Slope [$/MWhr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 MW</td>
<td>28 $/MWhr</td>
</tr>
<tr>
<td>200 MW</td>
<td>26 $/MWhr</td>
</tr>
<tr>
<td>300 MW</td>
<td>24 $/MWhr</td>
</tr>
<tr>
<td>400 MW</td>
<td>20 $/MWhr</td>
</tr>
</tbody>
</table>

Unacceptable Curve

<table>
<thead>
<tr>
<th>Output [MW]</th>
<th>Slope [$/MWhr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 MW</td>
<td>28 $/MWhr</td>
</tr>
<tr>
<td>200 MW</td>
<td>26 $/MWhr</td>
</tr>
<tr>
<td>300 MW</td>
<td>24 $/MWhr</td>
</tr>
<tr>
<td>400 MW</td>
<td>20 $/MWhr</td>
</tr>
</tbody>
</table>

Increase in slope

Cost [$/hr]

Load [MW]

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