# Introduction to PowerWorld Simulator: Interface and Common Tools

## I8: Generator and Area MW Control through Interconnected System Operation

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# 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

# 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**

# System Scaling Display

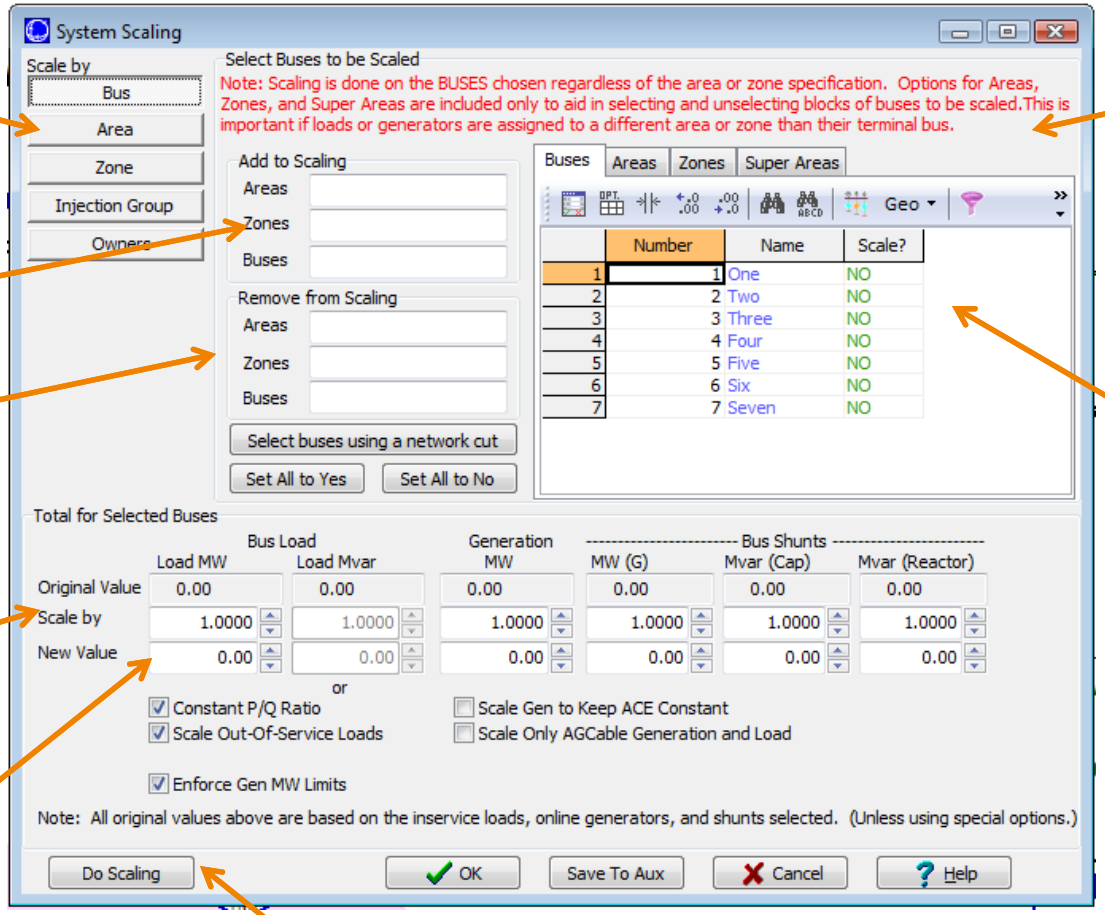
Choose to scale by object

Add a range of objects

Remove range

Enter either a scaling factor

Or directly enter a new value




Note Description

Select to add/remove Entire area

Select to actually scale the values

# 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

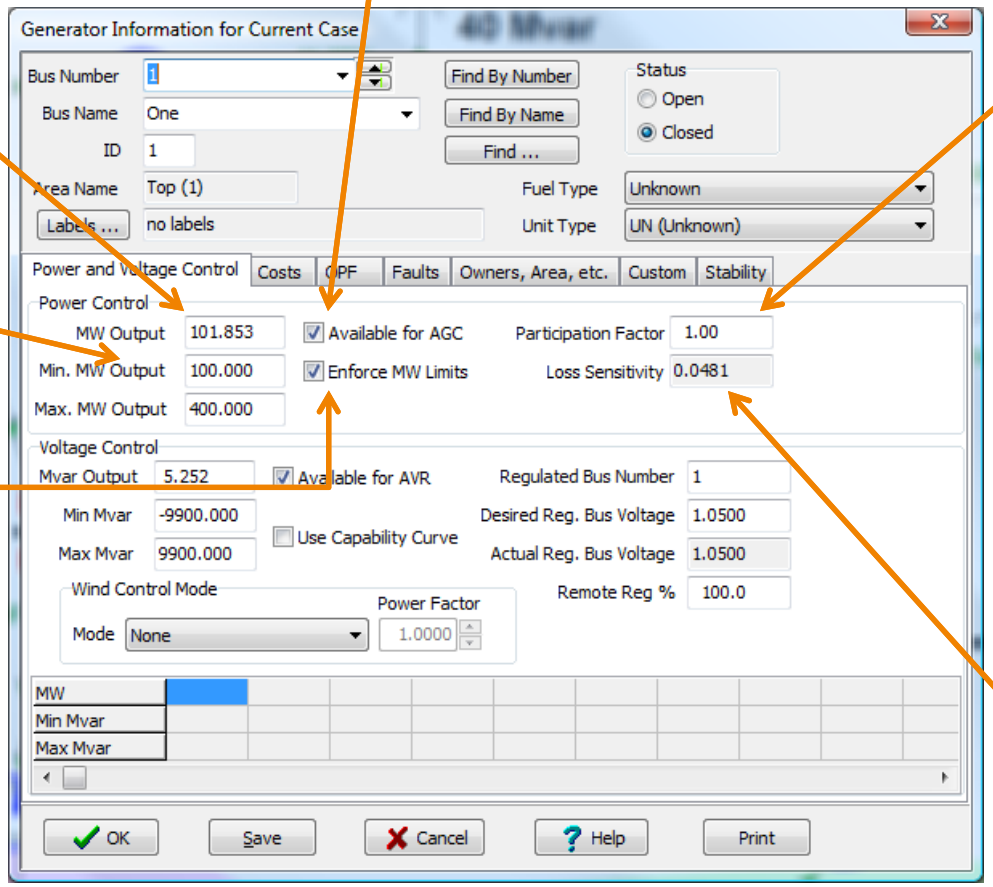
# Generator Dialog (Run Mode)

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

Present MW output

Minimum and maximum limits

Enforcing generator MW limits can also be disabled for entire case on the Simulator Options dialog

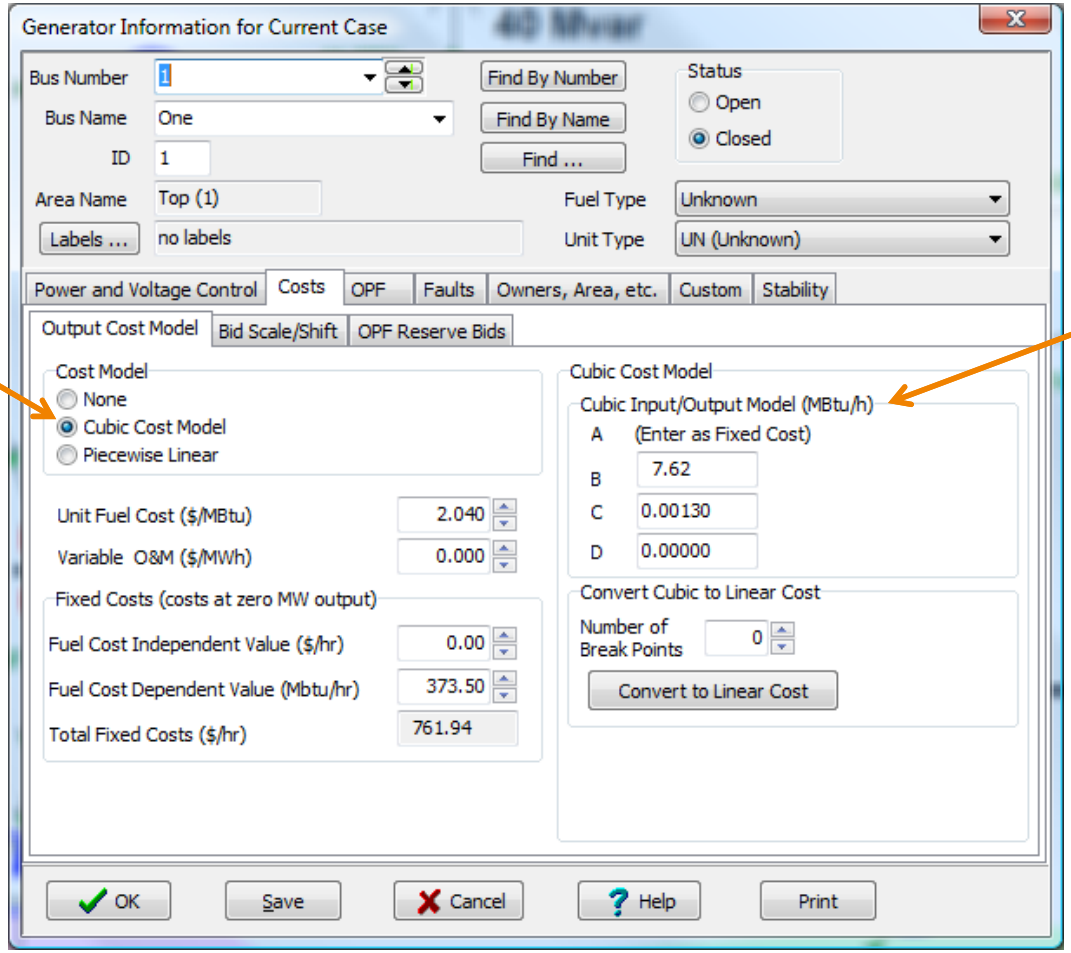



Used with participation factor AGC

$$\frac{\partial P_{AreaLosses}}{\partial P_{G_i}}$$

# Generator Dialog (Run Mode)

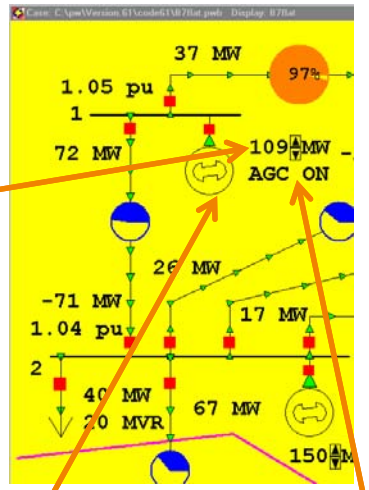
Can also use piecewise linear cost model

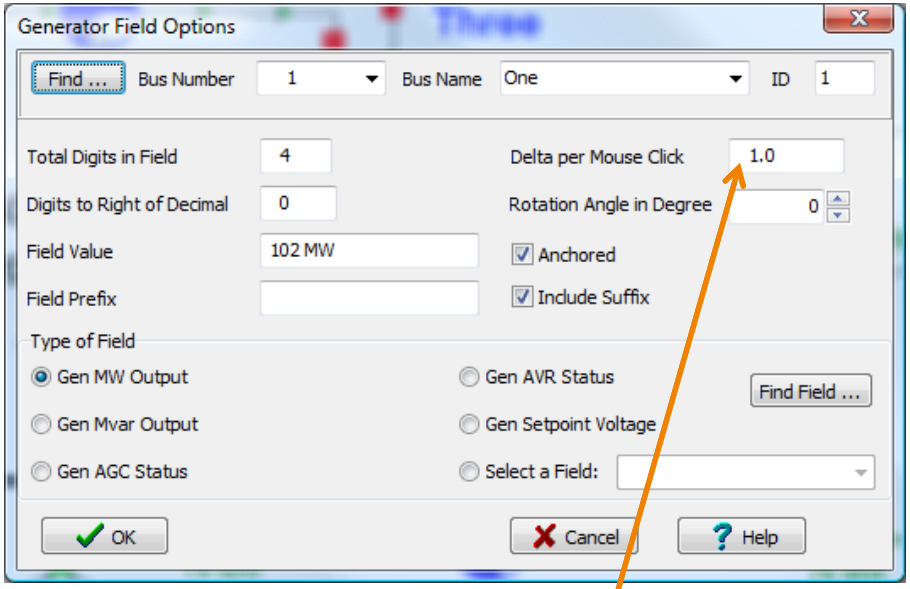



Cubic cost model

# Oneline Generator MW Control

Present MW output; spin button allows output to be changed manually




Right-click on generator symbol to view local-menu

Specifies change in generator MW per click on the spin button

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

# Generator Records

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

Gen Records

Records ▾ Geo ▾ Set ▾ Columns ▾ f(x) Options ▾

Filter Advanced ▾ Generator ▾ Find... Remove

| | Number of Bus | Name of Bus | ID | Status | Gen MW | Gen Mvar | Set Volt | AGC | AVR | Min MW | Max MW | Min Mvar | Max Mvar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | One | 1 | Closed | 101.85 | 5.25 | 1.05000 | YES | YES | 100.00 | 400.00 | -9900.00 | 9900.00 |
| 2 | 2 | Two | 1 | Closed | 170.08 | 33.24 | 1.04000 | YES | YES | 150.00 | 500.00 | -9900.00 | 9900.00 |
| 3 | 4 | Four | 1 | Closed | 95.03 | 19.99 | 1.00000 | YES | YES | 50.00 | 200.00 | -9900.00 | 9900.00 |
| 4 | 6 | Six | 1 | Closed | 200.33 | -6.59 | 1.04000 | YES | YES | 150.00 | 500.00 | -9900.00 | 9900.00 |
| 5 | 7 | Seven | 1 | Closed | 200.65 | 51.29 | 1.04000 | YES | YES | 0.00 | 600.00 | -99999.00 | 99999.00 |

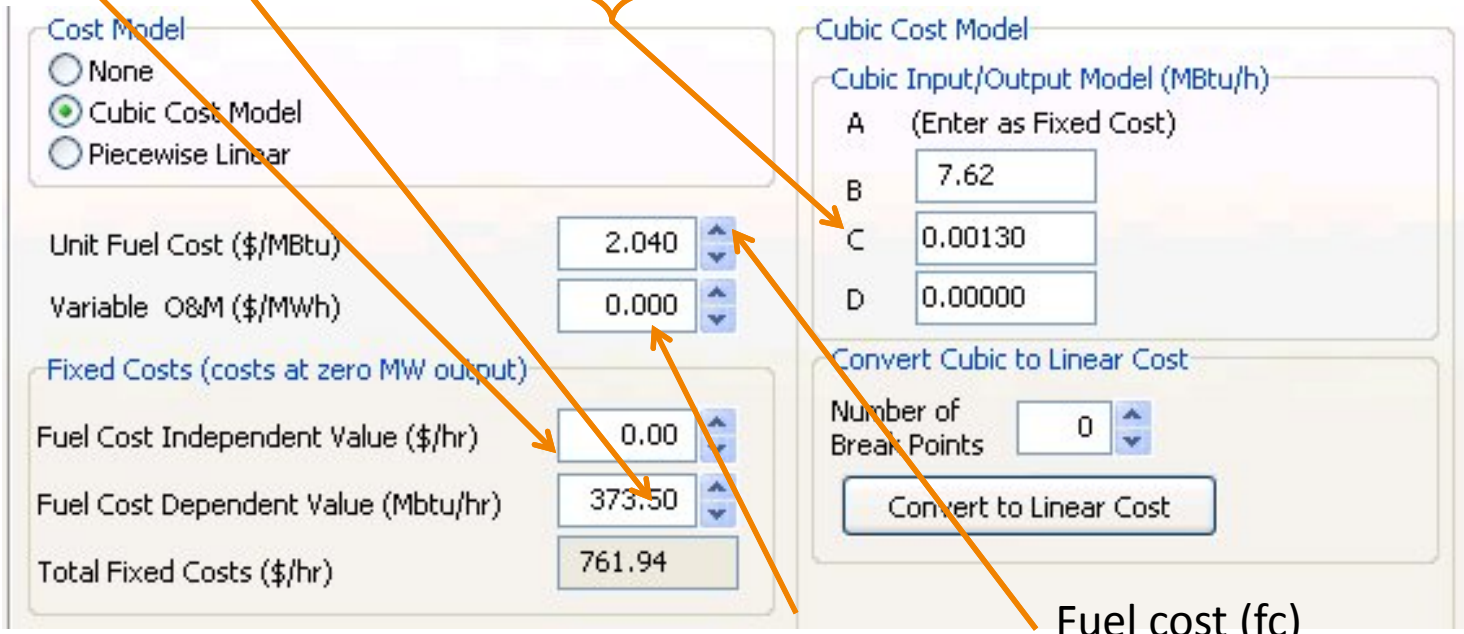
Change Gen MW field from this dialog to get change to occur in simulation; AGC field will change automatically when Gen MW field is changed manually.

# Generator Cost Model, Cubic

- Total generator operating cost is modeled using cubic function

$$C_i(P_{gi}) = F_i + (A_i + B_iP_{gi} + C_i(P_{gi})^2 + D_i(P_{gi})^3) * fc + V_{OM}P_{gi}$$

Units are $ / hour

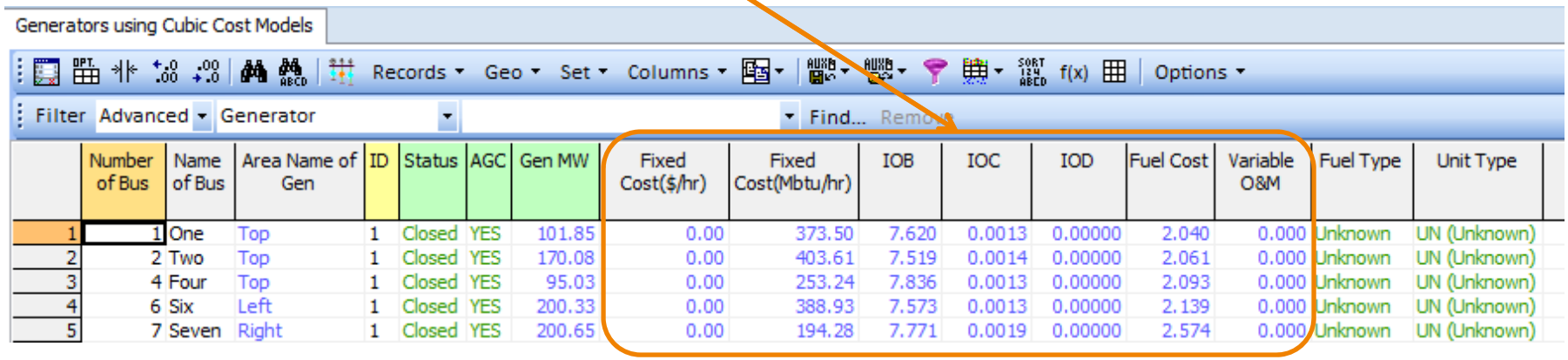



Fuel cost (fc)

Variable O&M ($V_{OM}$)

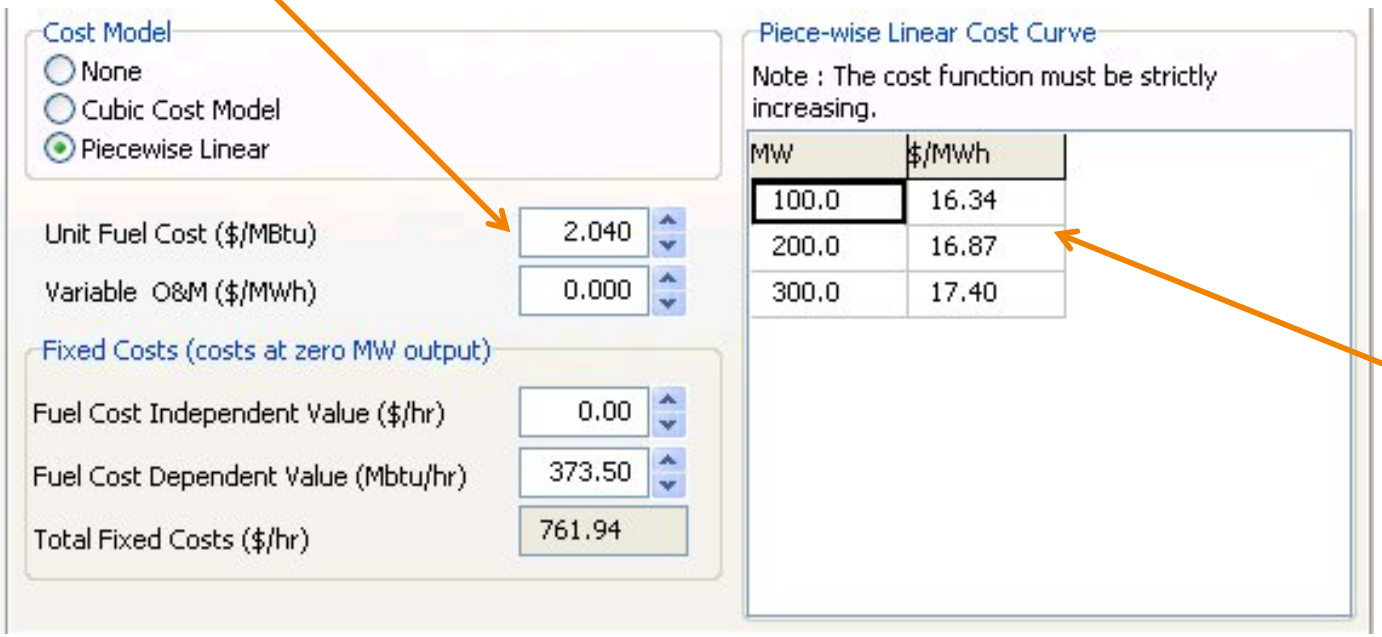
# Generator Cubic Cost Curves in the Case Information Display

- Go to the Model Explorer and choose **Network → Generator\Load Cost Models → Generator Cubic Cost Models**
  - F, A, B, C, D Coefficients, Fuel Cost, and Variable O&M



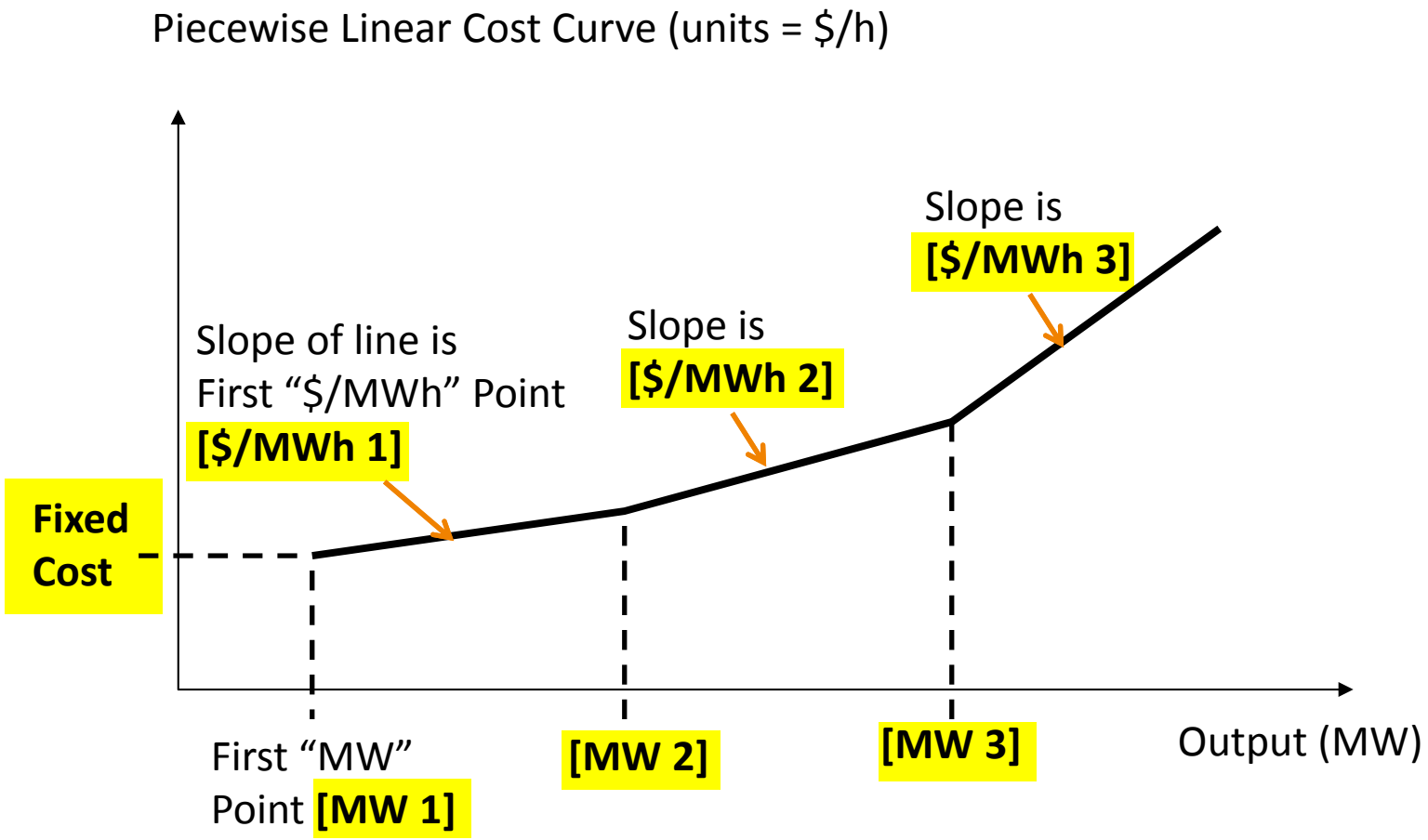

| | Number of Bus | Name of Bus | Area Name of Gen | ID | Status | AGC | Gen MW | Fixed Cost($/hr) | Fixed Cost(Mbtu/hr) | IOB | IOC | IOD | Fuel Cost | Variable O&M | Fuel Type | Unit Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | One | Top | 1 | Closed | YES | 101.85 | 0.00 | 373.50 | 7.620 | 0.0013 | 0.00000 | 2.040 | 0.000 | Unknown | UN (Unknown) |
| 2 | 2 | Two | Top | 1 | Closed | YES | 170.08 | 0.00 | 403.61 | 7.519 | 0.0014 | 0.00000 | 2.061 | 0.000 | Unknown | UN (Unknown) |
| 3 | 4 | Four | Top | 1 | Closed | YES | 95.03 | 0.00 | 253.24 | 7.836 | 0.0013 | 0.00000 | 2.093 | 0.000 | Unknown | UN (Unknown) |
| 4 | 6 | Six | Left | 1 | Closed | YES | 200.33 | 0.00 | 388.93 | 7.573 | 0.0013 | 0.00000 | 2.139 | 0.000 | Unknown | UN (Unknown) |
| 5 | 7 | Seven | Right | 1 | Closed | YES | 200.65 | 0.00 | 194.28 | 7.771 | 0.0019 | 0.00000 | 2.574 | 0.000 | Unknown | UN (Unknown) |

# Generator Cost Model
# Piecewise Linear



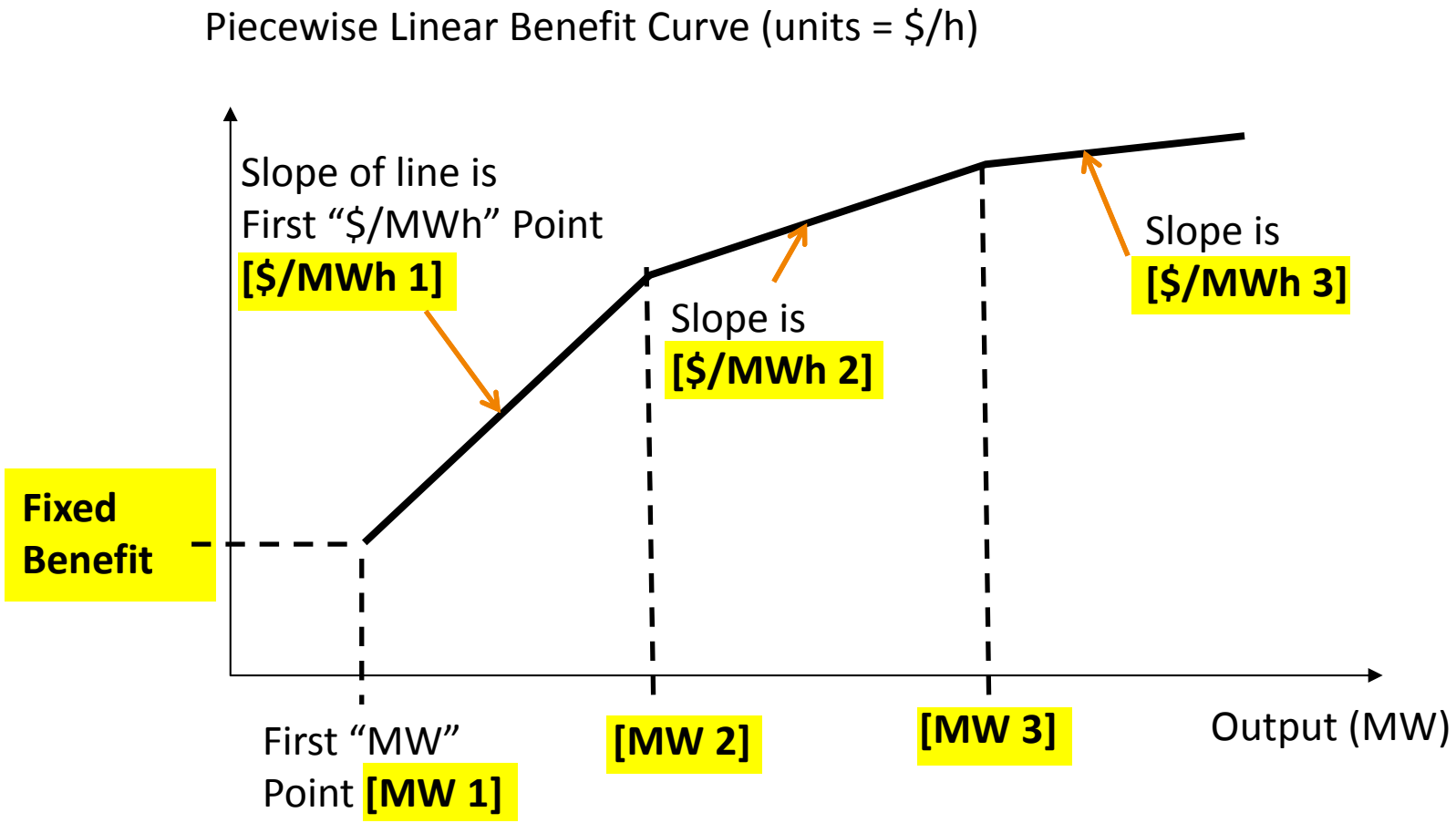

Note: When you change the fuel cost, Simulator will prompt you asking you whether you want to change the bid curve points

# Piecewise Linear Cost Curve Input




Input variables are highlighted and bold

# Piecewise Linear Load Benefit Input




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

Generators using Linear Cost Models

| | Number | Name | Area Name of Gen | ID | Fuel Cost | Fixed Cost($/hr) | Fixed Cost(Mbtu/hr | MW Break1 | MWh Price1 | MW Break2 | MWh Price2 | MW Break3 | MWh Price3 | MW Break4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | One | Top | 1 | 1.300 | 0.00 | 0.00 | 100.00 | 16.34 | 200.00 | 16.87 | 300.00 | 17.40 | |
| 2 | 2 | Two | Top | 1 | 2.061 | 0.00 | 403.61 | 150.00 | 15.50 | 300.00 | 16.50 | | | |
| 3 | 4 | Four | Top | 1 | 2.093 | 0.00 | 253.24 | 50.00 | 16.40 | 100.00 | 19.00 | | | |
| 4 | 6 | Six | Left | 1 | 2.139 | 0.00 | 388.93 | 150.00 | 16.20 | 300.00 | 18.00 | | | |
| 5 | 7 | Seven | Right | 1 | 2.574 | 0.00 | 194.30 | 0.00 | 7.77 | 100.00 | 12.00 | | | |

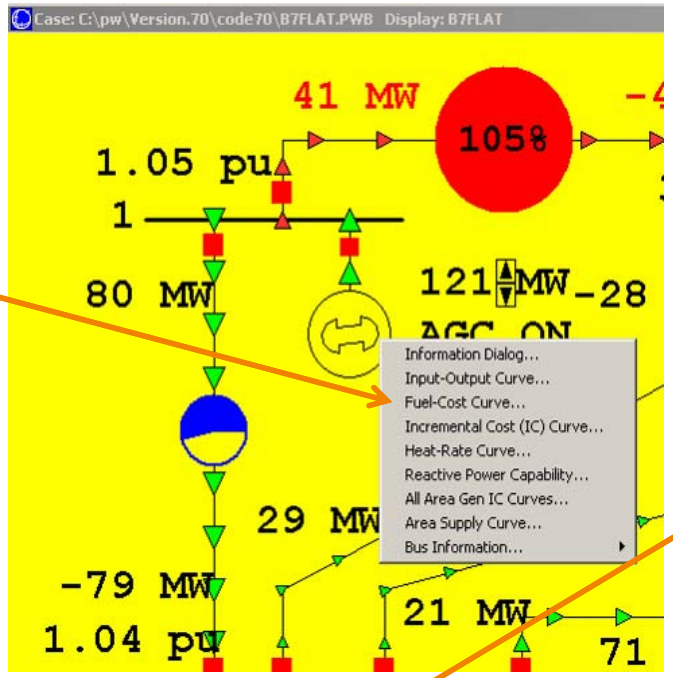
- Note: when you change the Fuel Cost value, Simulator will prompt you asking if you want to change the bid curve points as well
  - If you double the fuel cost, it will double the bids

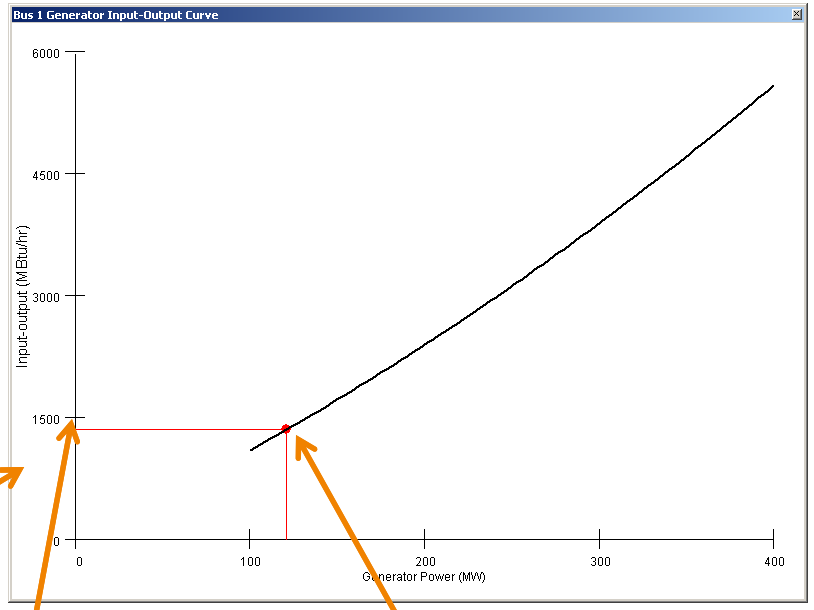
# Generator Cost Curves

- 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

Present operating point

# 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

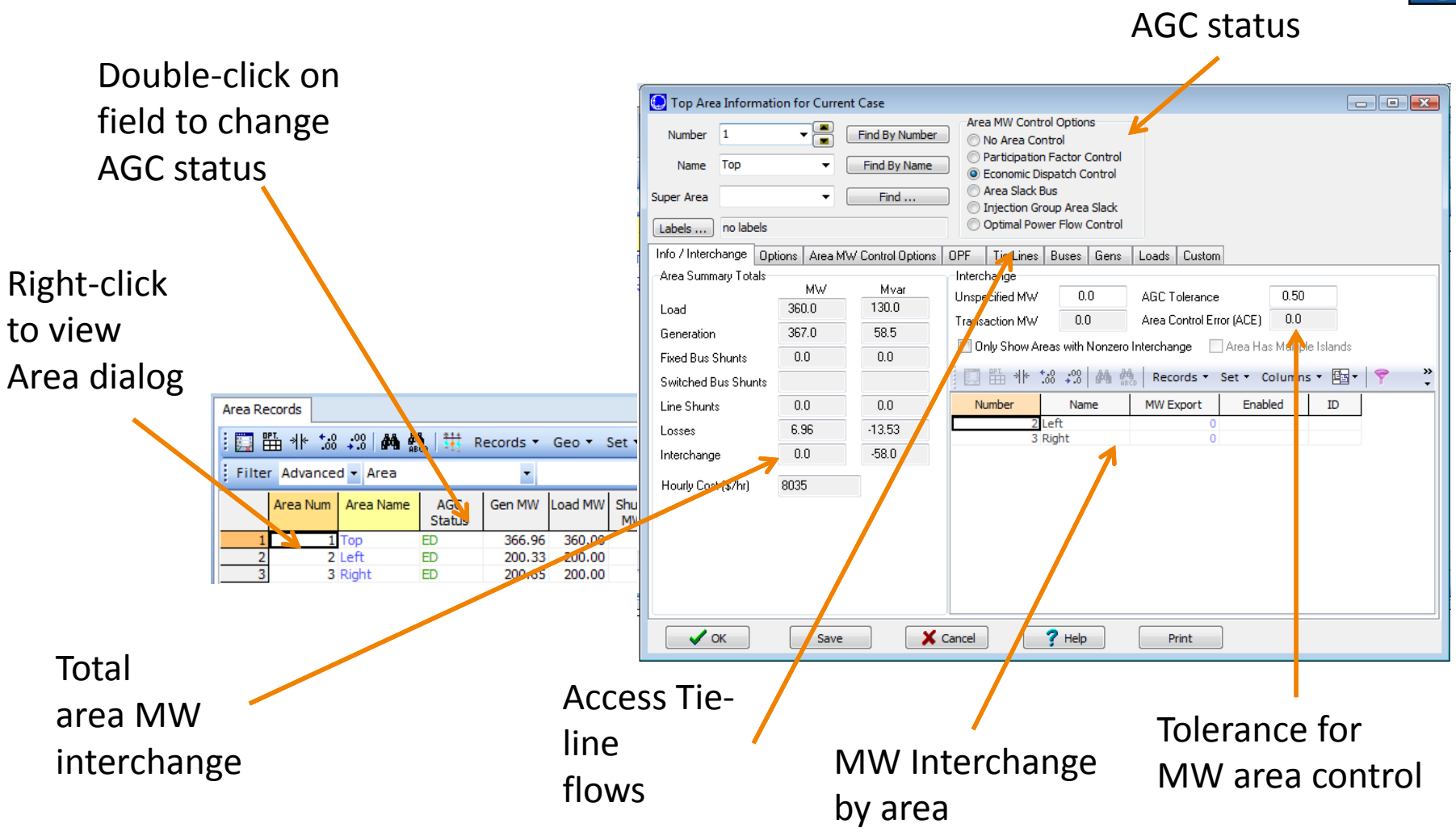

For Area Interchange Control, **Disable Automatic Generation Control (AGC)** must NOT be checked on Simulator Options dialog, Power Flow Solution page, Common Options tab.


- 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 Area display object

# Area Records

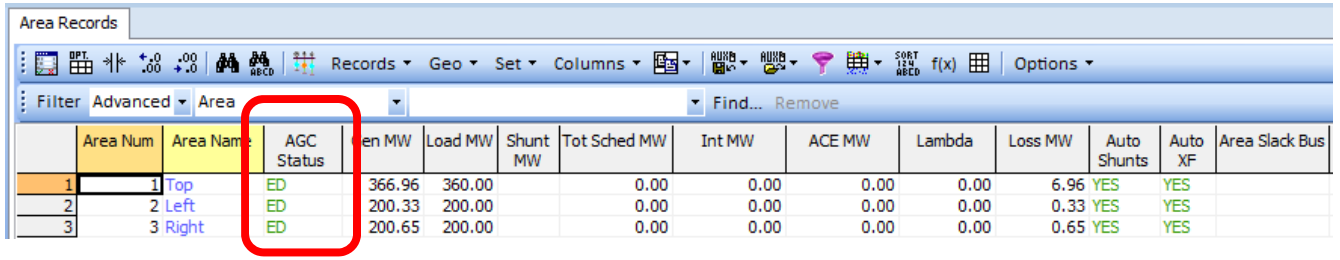
- In the Model Explorer select **Aggregations** → **Areas** to view the Area Records display.
- Display shows summary information about all areas in case.
- Entries can be sorted by clicking on the column labels.
- Right-click in the row of a desired area and select Show Dialog to view the area's information

# Area Interchange Control



# Economic Dispatch Example

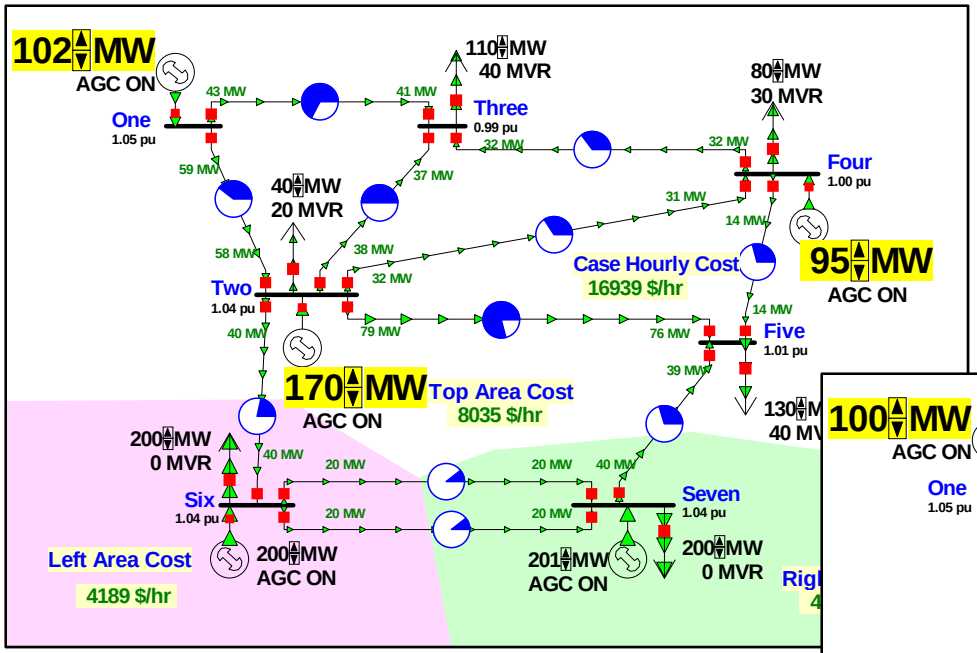
- For B7FLAT Case, verify that all three areas are on economic dispatch control.

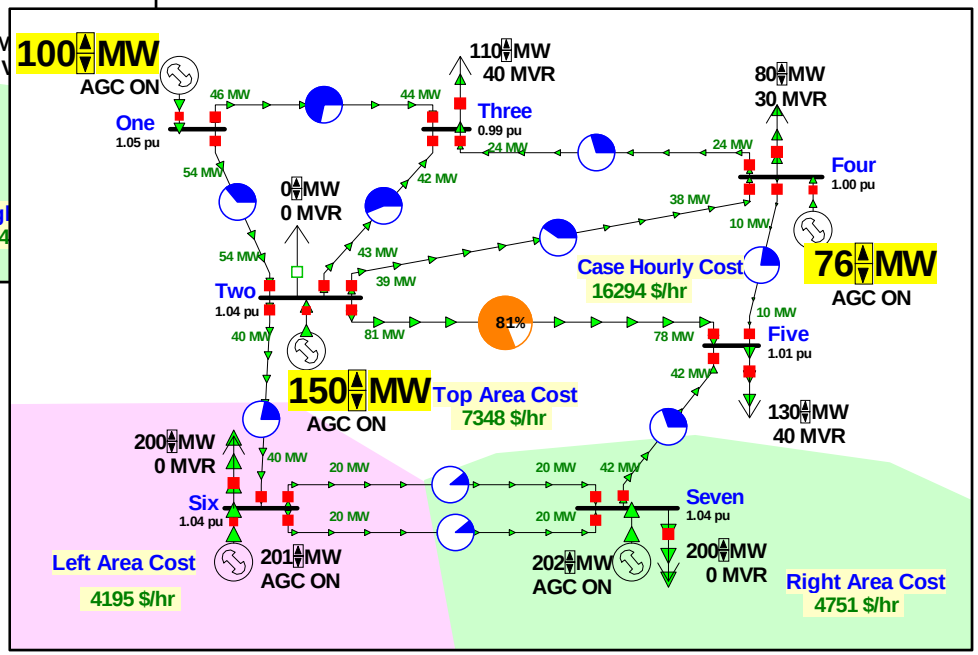



| | Area Num | Area Name | AGC Status | Gen MW | Load MW | Shunt MW | Tot Sched MW | Int MW | ACE MW | Lambda | Loss MW | Auto Shunts | Auto XF | Area Slack Bus |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Top | ED | 366.96 | 360.00 | | 0.00 | 0.00 | 0.00 | 0.00 | 6.96 | YES | YES | |
| 2 | 2 | Left | ED | 200.33 | 200.00 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.33 | YES | YES | |
| 3 | 3 | Right | ED | 200.65 | 200.00 | | 0.00 | 0.00 | 0.00 | 0.00 | 0.65 | YES | YES | |

- 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



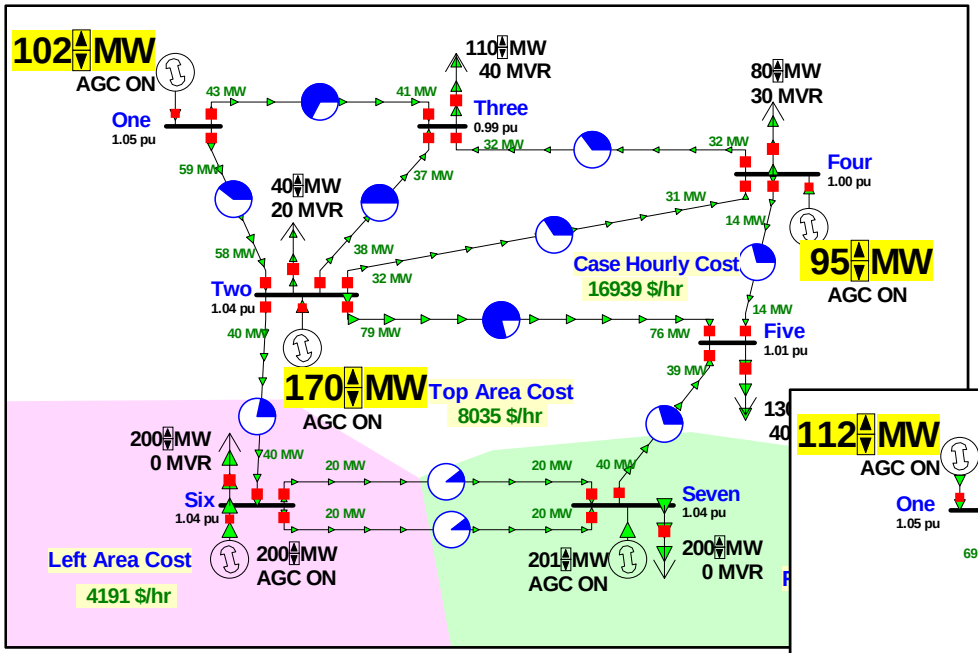



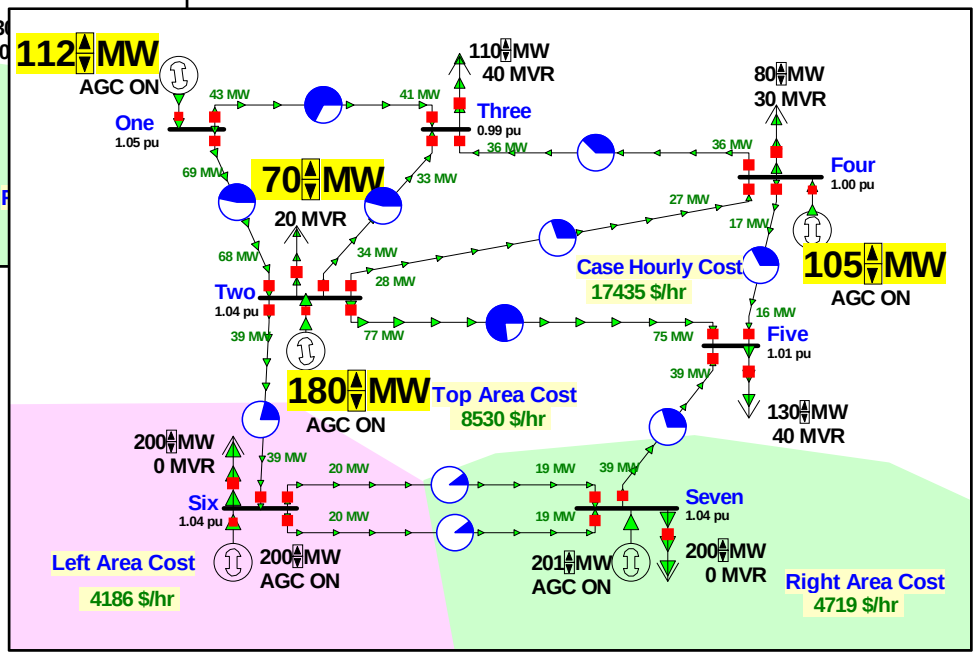

Load goes out of service – All generators respond to reduce generation cost in top area

# 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”.
  - 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

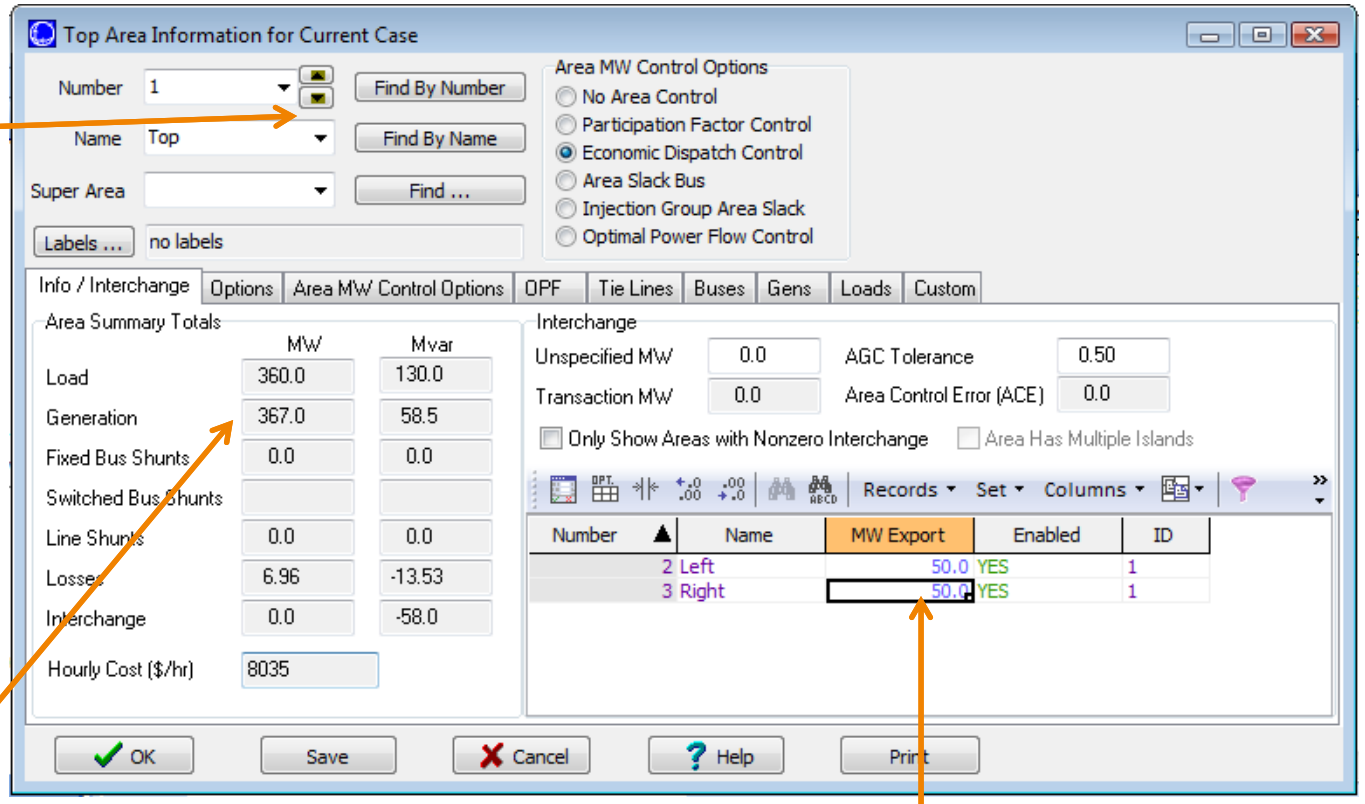
- Used to quickly set up transactions between an area and
  - another specific area
  - unspecified areas
- Cost and start/stop times are not specified
- Transaction areas must be on area control (Participation Factor, OPF, ED, Area Slack)

# 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

# Model Explorer, 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

Matrix of Transactions | List of Transactions

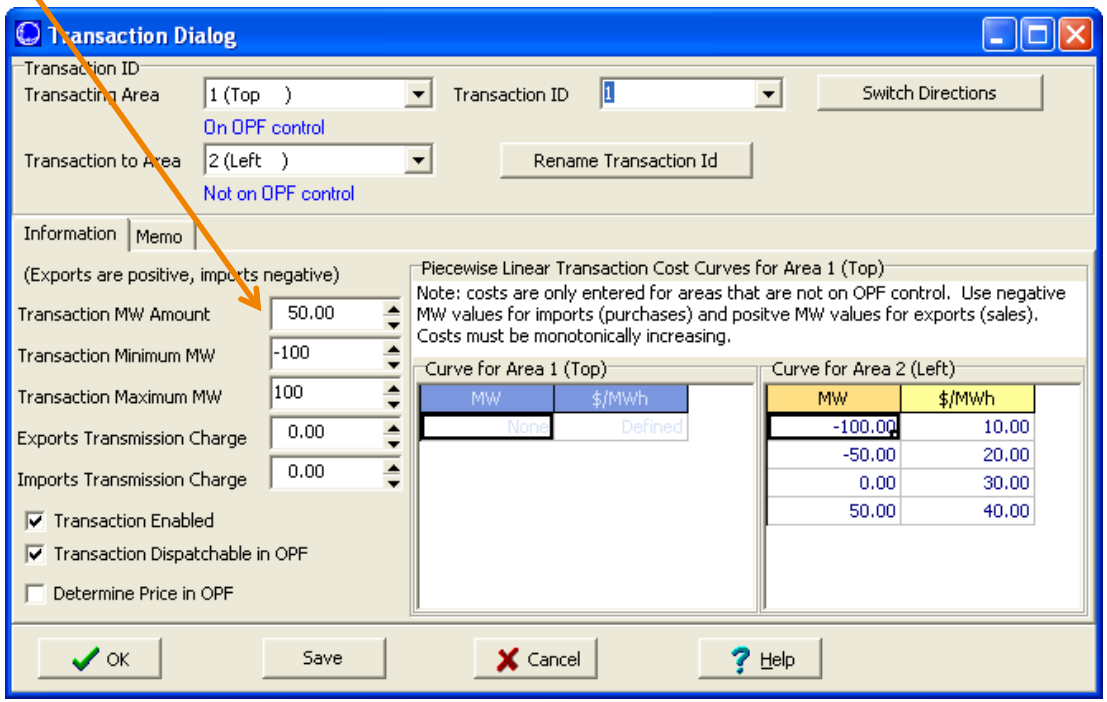
| | Area Num | Area Name | ACE MW | 1 (Top) | 2 (Left) | 3 (Right) |
|---|---|---|---|---|---|---|
| 1 | 1 | Top | -100.00 | | 50.00 | 50.00 |
| 2 | 2 | Left | 50.00 | -50.00 | | |
| 3 | 3 | Right | 50.00 | -50.00 | | |

Matrix of Transactions | List of Transactions

| | Export Area Number | Export Area Name | Import Area Number | Import Area Name | ID | MW Transfer | Enabled | OPF Dispatchable | Determine Price in OPF |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Top | 2 | Left | 1 | 50.00 | YES | NO | YES |
| 2 | 1 | Top | 3 | Right | 1 | 50.00 | YES | NO | YES |

# 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.



# Converting Heat Rate Data into Cost Information

- Input Information:
  - Average Heat Rate Curve Points [MBtu/(MWhr) vs. MW]
  - Fuel Cost [$/MBtu]
- Output Information
  - Total Cost Curve [$/hr vs. MW]

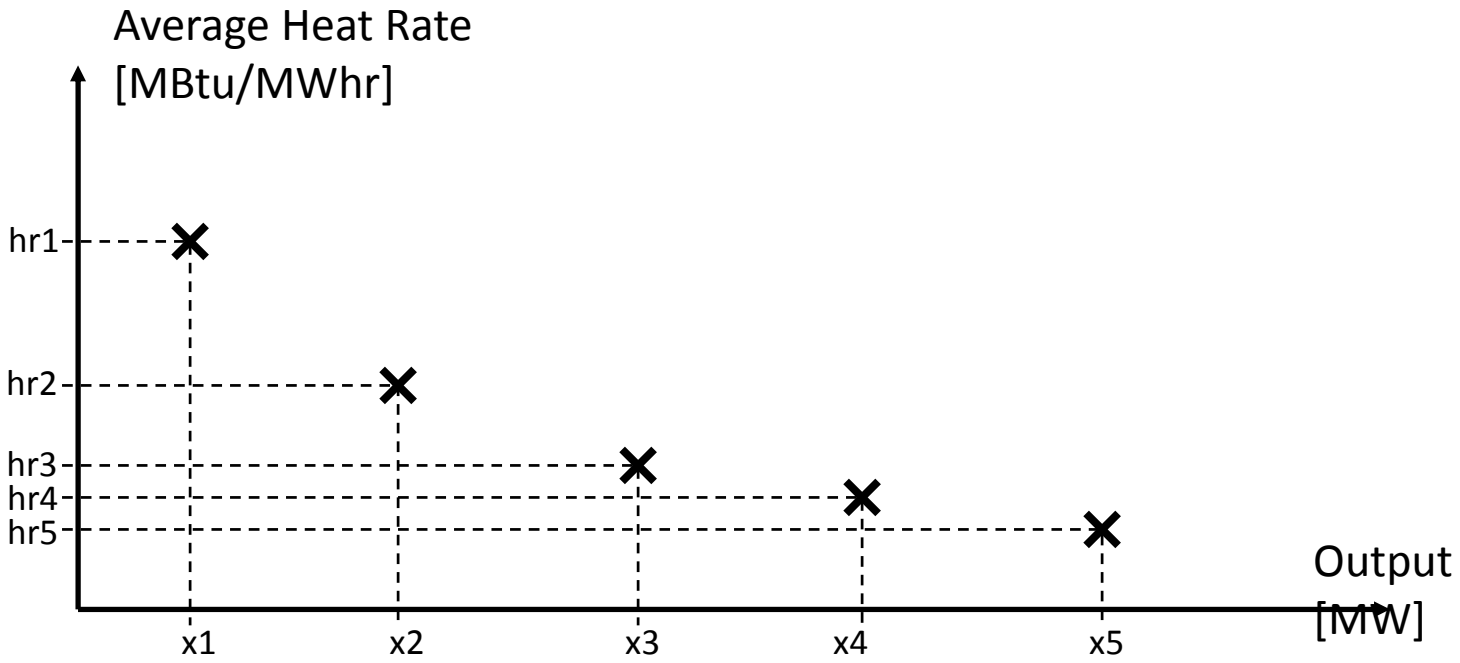
# Input Data

- Example Heat Rate Curve Points

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

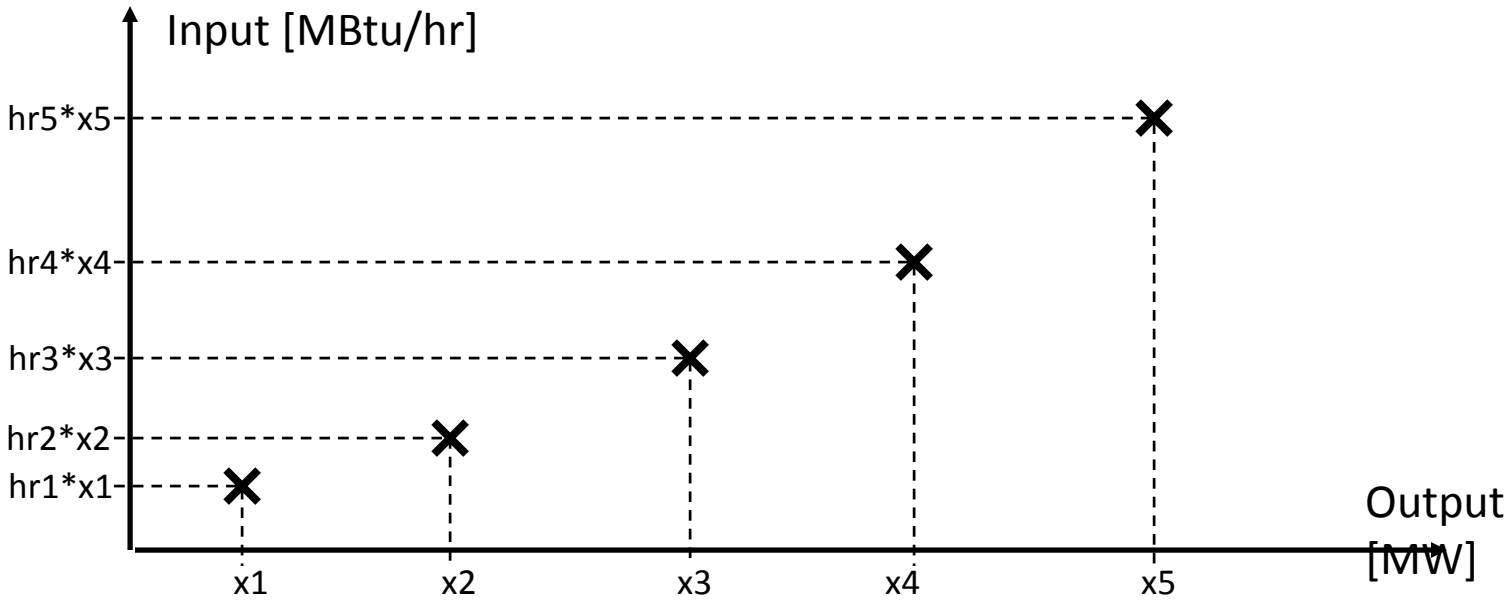
# Average Heat Rate Curve Graphically

- 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



# Convert To Input-Output Curve by multiplying by the Output

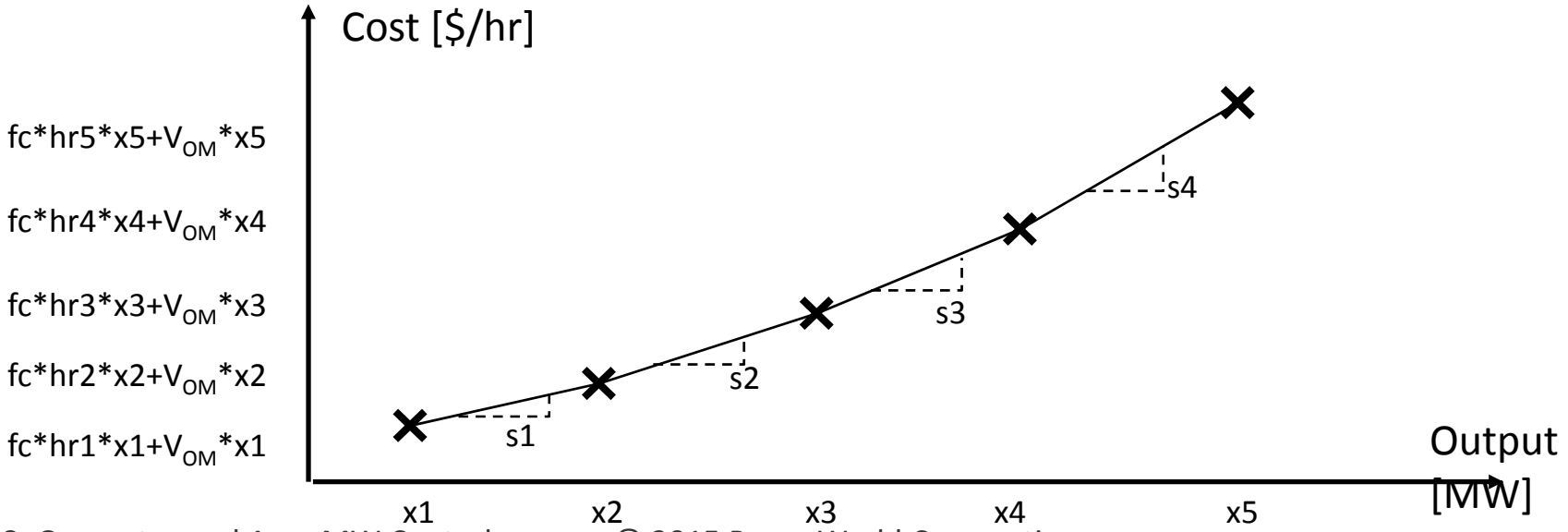
- Input-Output shows the power going into the generator versus the power coming out
  - MBtu/hr = Input Power = fuel being used per hour
  - MW = Output Power



# 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

$$s1 = \frac{x2\left(fc * hr2 + V_{OM}\right) - x1\left(fc * hr1 + V_{OM}\right)}{x2 - x1}$$ which has units of [$/MWhr]



# Entering Cost Data in Simulator using a cubic cost model

- Enter six parameters:
  - fc = fuel cost
  - VOM = variable O&M
  - a, b, c, d = coefficients
- The generation cost is then defined as

$$\text{Generation Cost} = \text{fc} * (\text{a} + \text{bx} + \text{cx}^2 + \text{dx}^3) + \text{V}_{\text{OM}}\text{x}$$

- 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

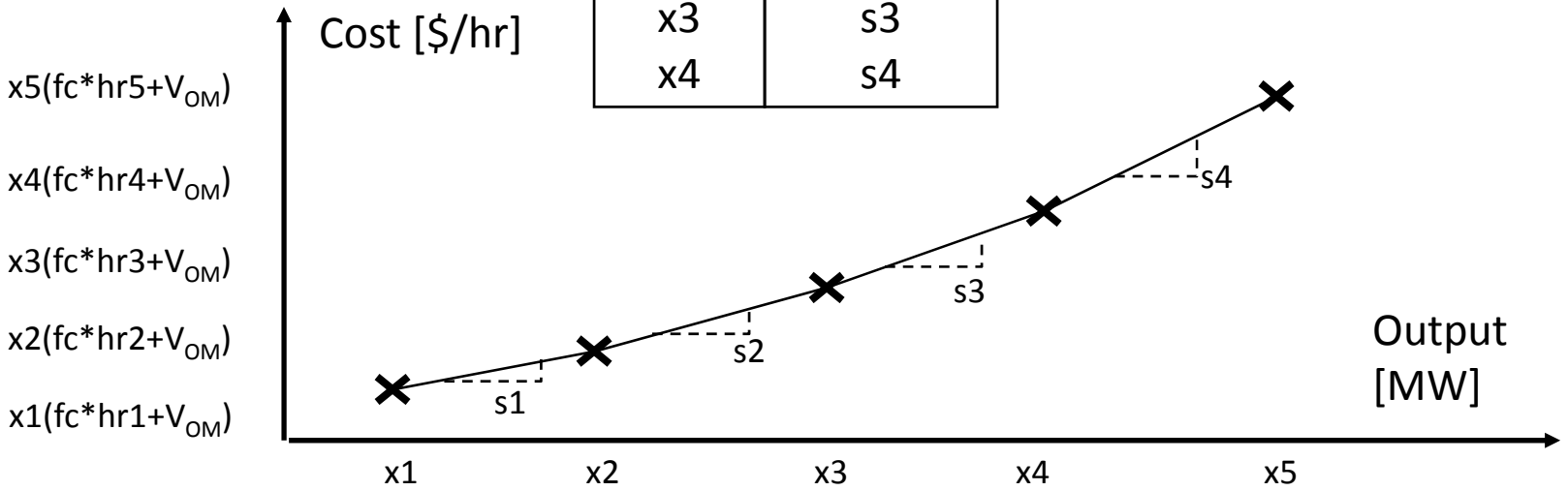
- Fixed Cost = x1(fc*hr1+$V_{OM}$)
  - Cost at lowest output specified by the pairs entered
- Enter pairs of (output, slope) as follows
  - Mimics a "bid"

| Output [MW] | Slope [$/MWhr] |
|---|---|
| x1 | s1 |
| x2 | s2 |
| x3 | s3 |
| x4 | s4 |

where

$$s1 = \frac{x2(fc*hr2 + V_{OM}) - x1(fc*hr1 + V_{OM})}{x2 - x1}$$

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 x0
- To model this assume the first slope stays the same, therefore you must only change the output of the first bid to x0, and change the fixed cost

| Fixed Cost [$/hr] |
| --- |
| $x1(fc*hr1+V_{OM}) - s1*(x1-x0)$ |

| Output [MW] | Slope [$/MWhr] |
| --- | --- |
| x0 | s1 |
| x2 | s2 |
| x3 | s3 |
| x4 | s4 |

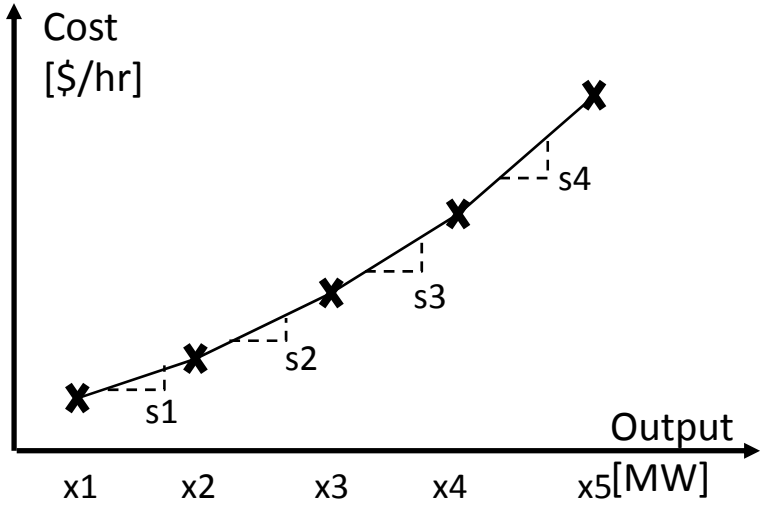
# Convex Requirement

- Cost curves must be “convex”
  - Required in markets as well
    - You can’t sell you “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**

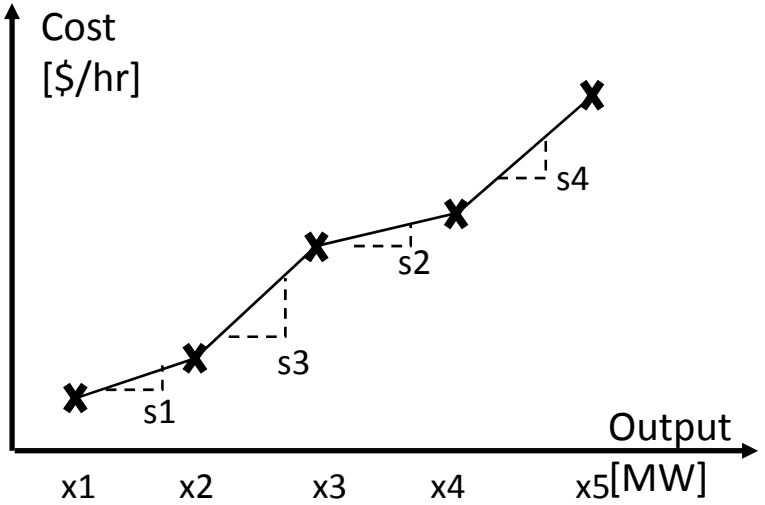
| Output [MW] | Slope [$/MWhr] |
|---|---|
| 100 MW | 20 $/MWhr |
| 200 MW | 24 $/MWhr |
| 300 MW | 26 $/MWhr |
| 400 MW | 28 $/MWhr |




**Unacceptable Curve**

| Output [MW] | Slope [$/MWhr] |
|---|---|
| 100 MW | 20 $/MWhr |
| 200 MW | 26 $/MWhr |
| 300 MW | 24 $/MWhr |
| 400 MW | 28 $/MWhr |

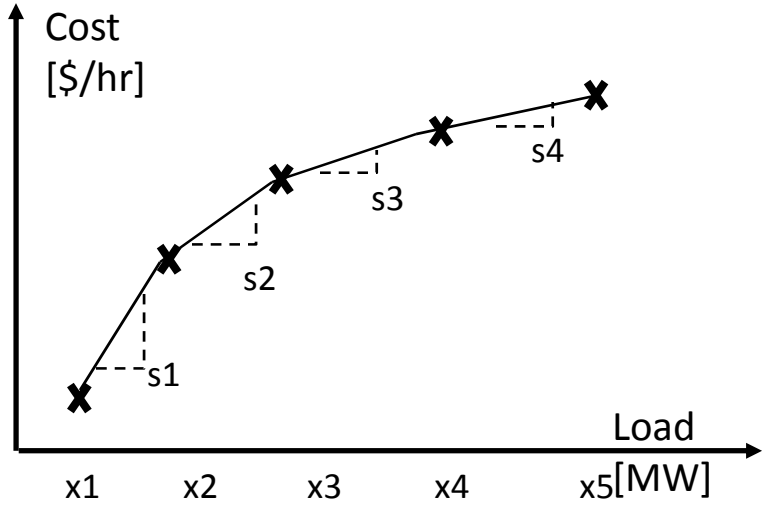
**Decrease in slope**



# Example – Load Benefit

**Acceptable Curve**

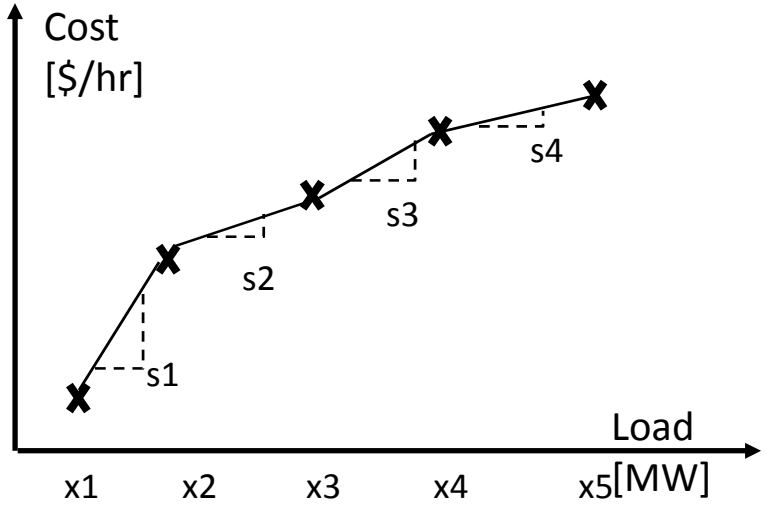
| Output [MW] | Slope [$/MWhr] |
|---|---|
| 100 MW | 28 $/MWhr |
| 200 MW | 26 $/MWhr |
| 300 MW | 24 $/MWhr |
| 400 MW | 20 $/MWhr |




**Unacceptable Curve**

| Output [MW] | Slope [$/MWhr] |
|---|---|
| 100 MW | 28 $/MWhr |
| 200 MW | 24 $/MWhr |
| 300 MW | 26 $/MWhr |
| 400 MW | 20 $/MWhr |

**Increase in slope**



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