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**

System Scaling Display

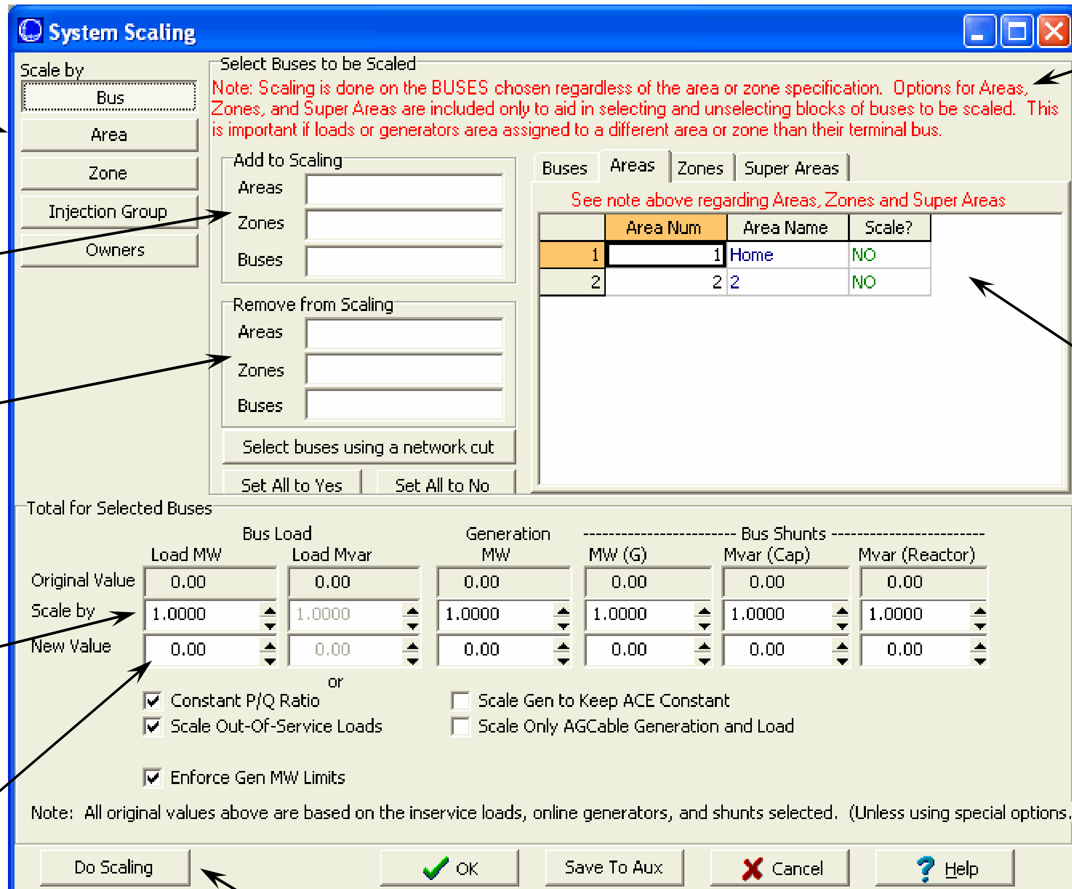
Choose to scale by object

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

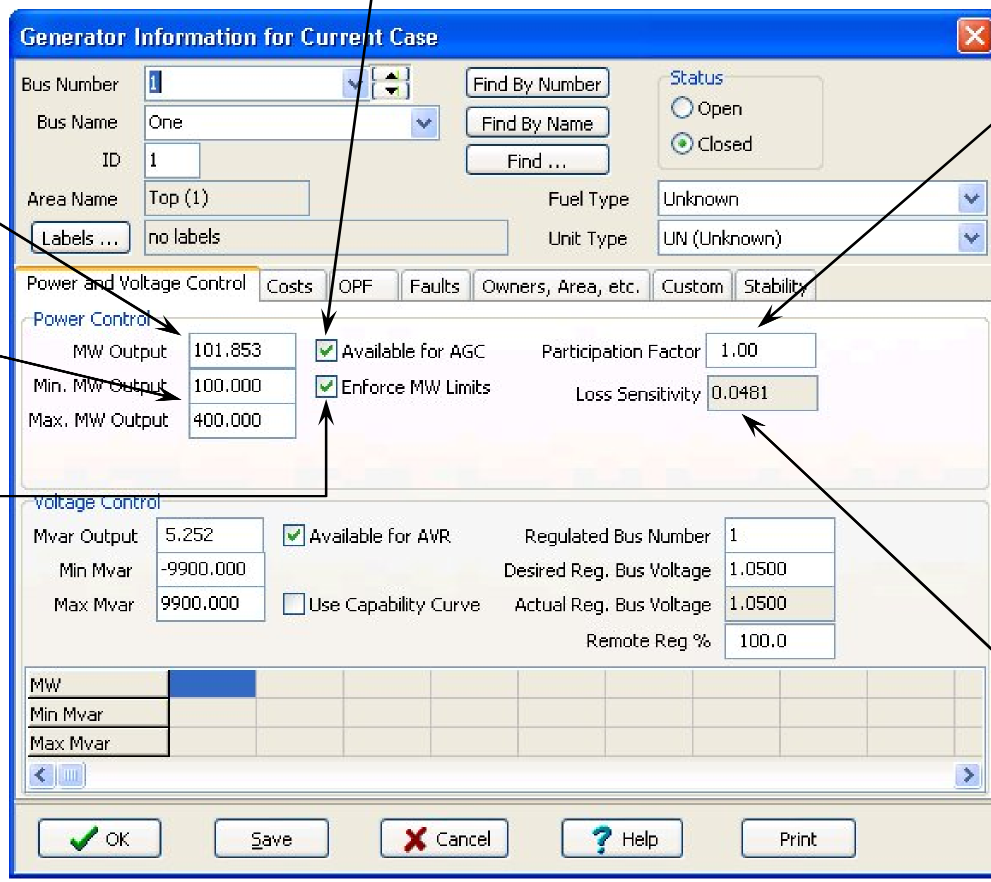
Generator Dialog (Run Mode)

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

Current MW output

Minimum and maximum limits

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

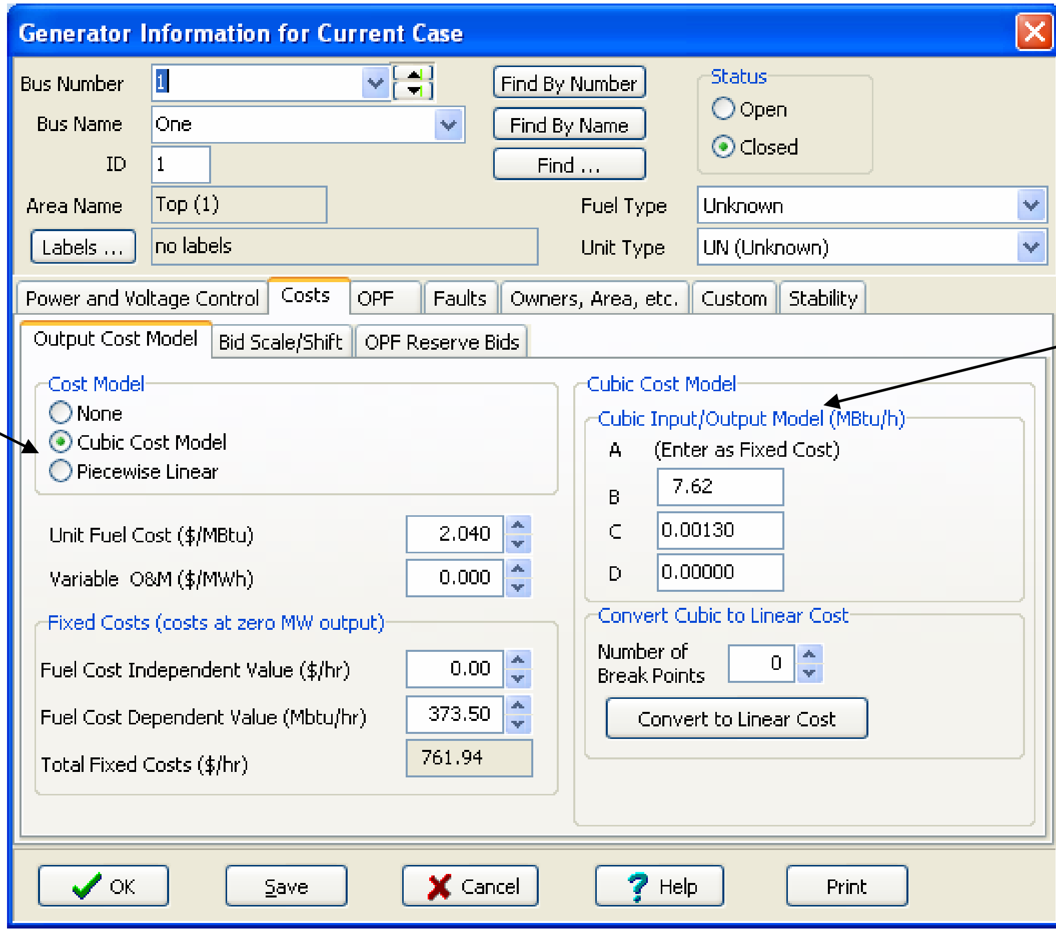


Used with participation factor AGC

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

Generator Dialog (Run Mode)

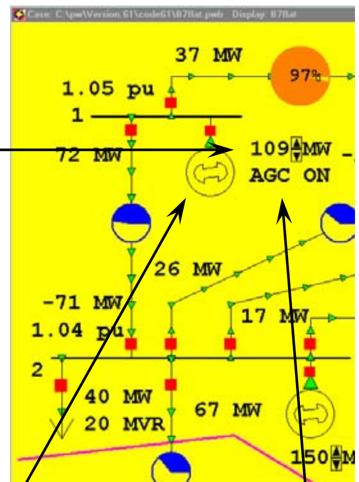
Can also use piecewise linear cost model

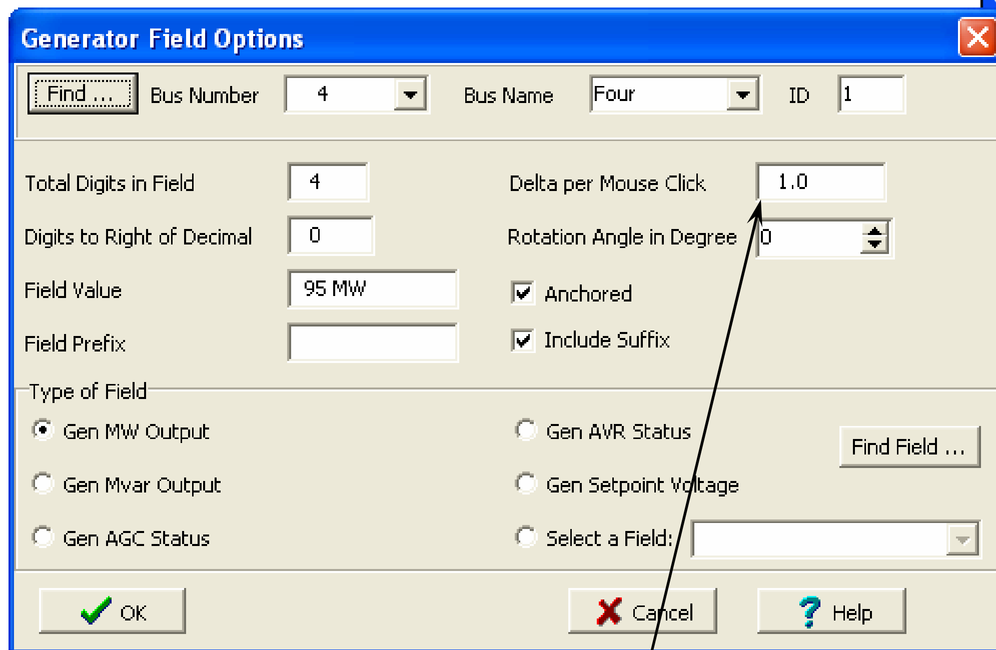


Cubic cost model

Oneline Generator MW Control

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





Right-click on generator symbol to view local-menu

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

	Number	Name	ID	Status	Gen MW	Gen Mvar	Set Volt	AGC	AVR	Min MW	Max MW	Min Mvar	Max Mvar	Par
1	1	1	1	Closed	120.81	-0.41	1.05	YES	YES	100.00	400.00	-9900.00	9900.00	1
2	2	2	1	Closed	150.00	40.05	1.04	YES	YES	150.00	500.00	-9900.00	9900.00	1
3	4	4	1	Closed	120.81	10.81	1.00	YES	YES	50.00	200.00	-9900.00	9900.00	1
4	6	6	1	Closed	150.94	9.99	1.04	YES	YES	150.00	500.00	-9900.00	9900.00	1
5	7	7	1	Closed	225.15	42.06	1.04	YES	YES	0.00	600.00	-99999.00	99999.00	0

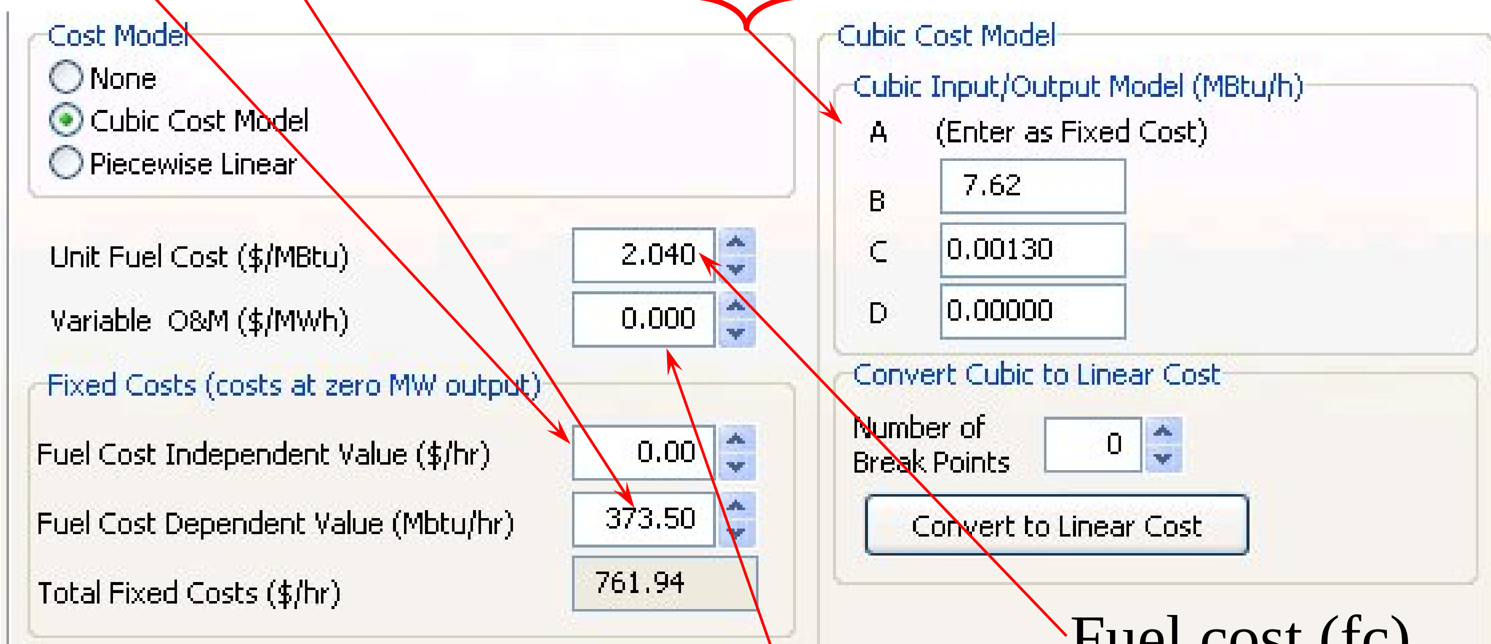
Change Gen MW field from this dialog to get change to occur in simulation; AGC field will change automatically when Gen MW field is changed manually.

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

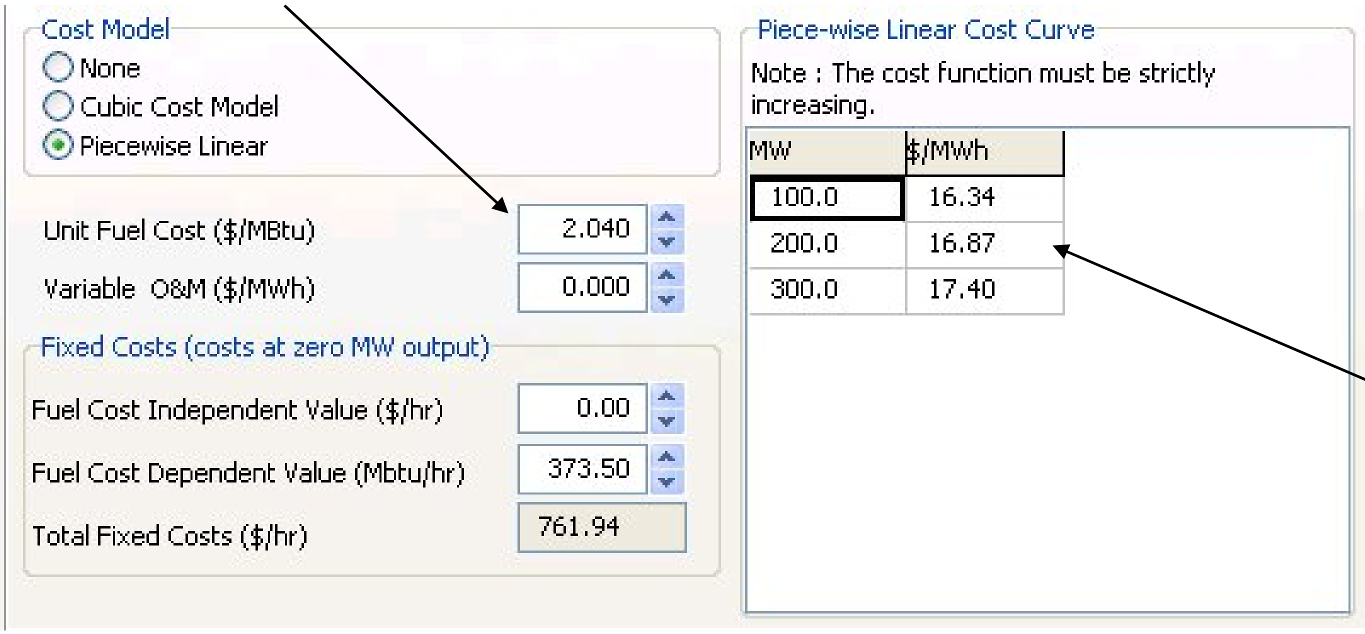
- Go to the Model Explorer and choose **Network → Generators → Cost Curves Cubic**
  - F, A, B, C, D Coefficients, Fuel Cost, and Variable O&M

Generators using Cubic Cost Models

	Number	Name	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	101.8	0.00	373.50	7.620	0.0013	0.00000	2.040	0.000	Unknown	UN (Unknown)
2	2	Two	Top	1	Closed	YES	170.0	0.00	403.61	7.519	0.0014	0.00000	2.061	0.000	Unknown	UN (Unknown)
3	4	Four	Top	1	Closed	YES	95.0	0.00	253.24	7.836	0.0013	0.00000	2.093	0.000	Unknown	UN (Unknown)
4	6	Six	Left	1	Closed	YES	200.3	0.00	388.93	7.573	0.0013	0.00000	2.139	0.000	Unknown	UN (Unknown)
5	7	Seven	Right	1	Closed	YES	200.6	0.00	194.28	7.771	0.0019	0.00000	2.574	0.000	Unknown	UN (Unknown)

Generator Cost Model Piecewise Linear

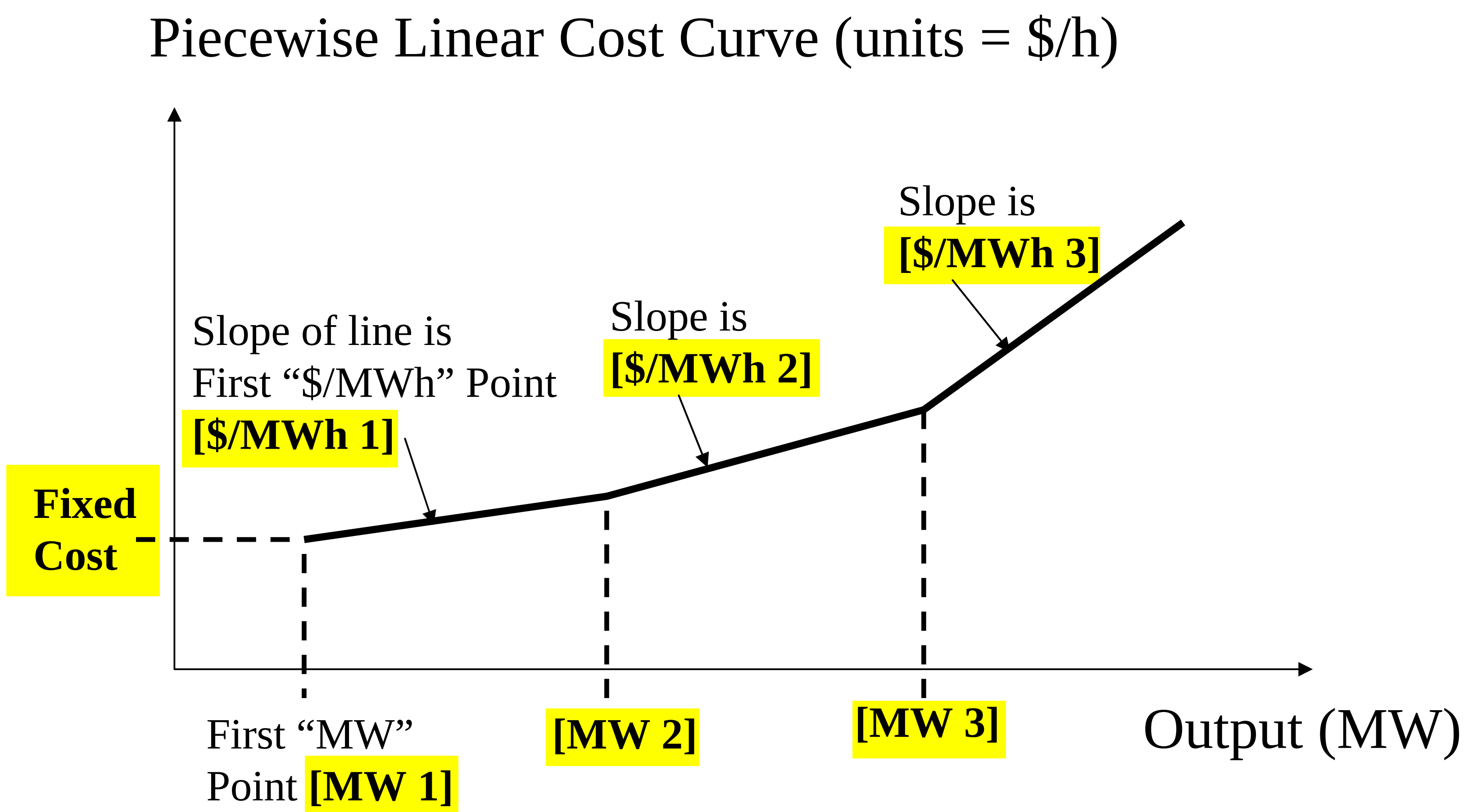
Fuel Cost



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

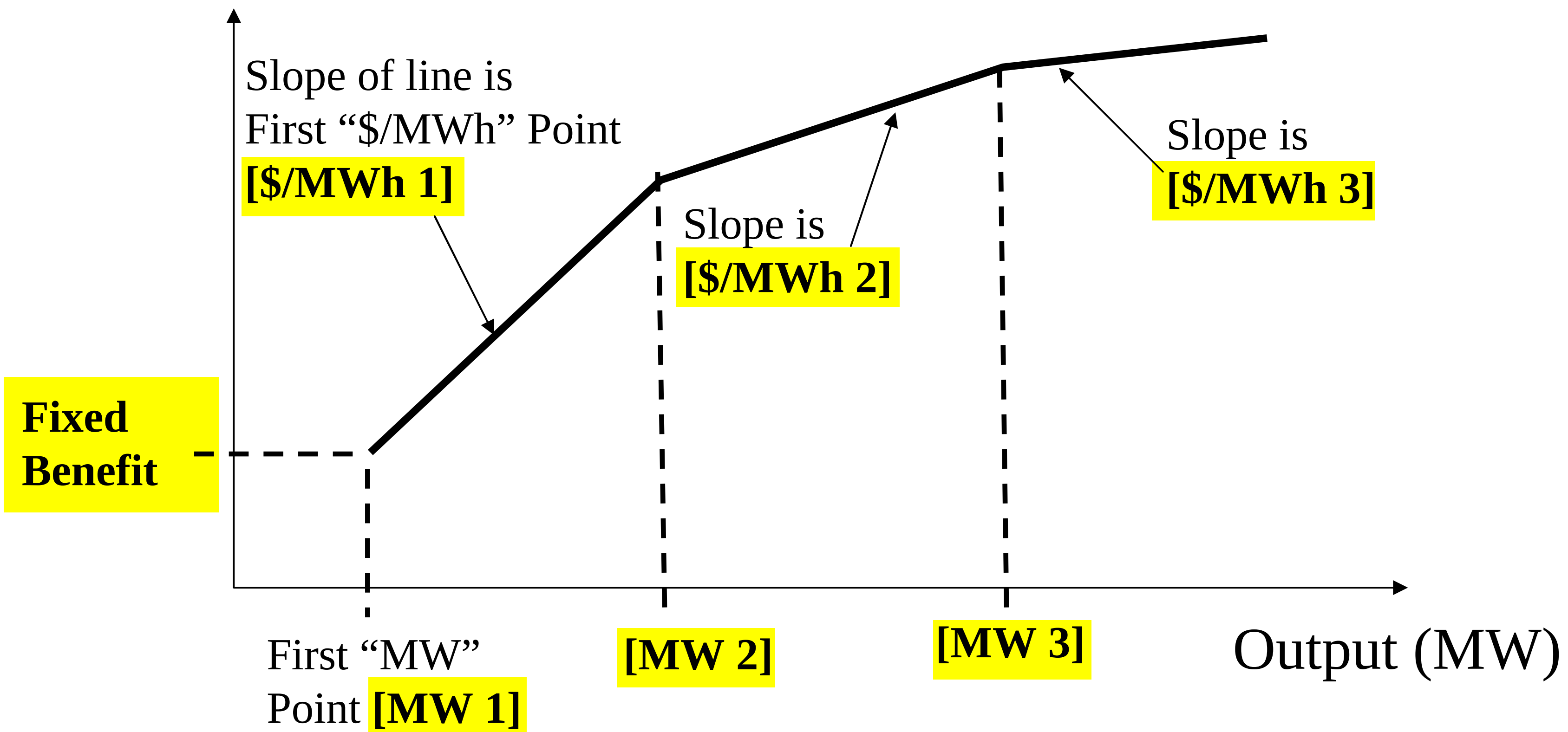
Piecewise Linear Cost Curve Input



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

Generators using Linear Cost Models

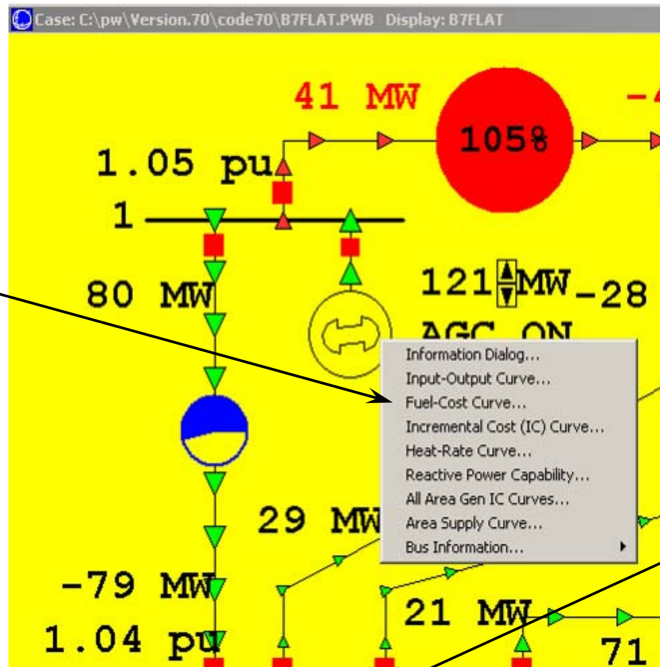
	Number	Name	Area Name of Gen	ID	Fuel Cost	Fixed Cost($/hr)	Fixed Cost(Mbtu/hr	MW Break1	MWh Price1	MW Break2	MWh Price2	MW Break3	MWh Price3	MW Break4	M
1	1	One	Top	1	1.300	0.00	0.00	100.00	16.34	200.00	16.87	300.00	17.40		
2	2	Two	Top	1	2.061	0.00	403.61	150.00	15.50	300.00	16.50				
3	4	Four	Top	1	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				

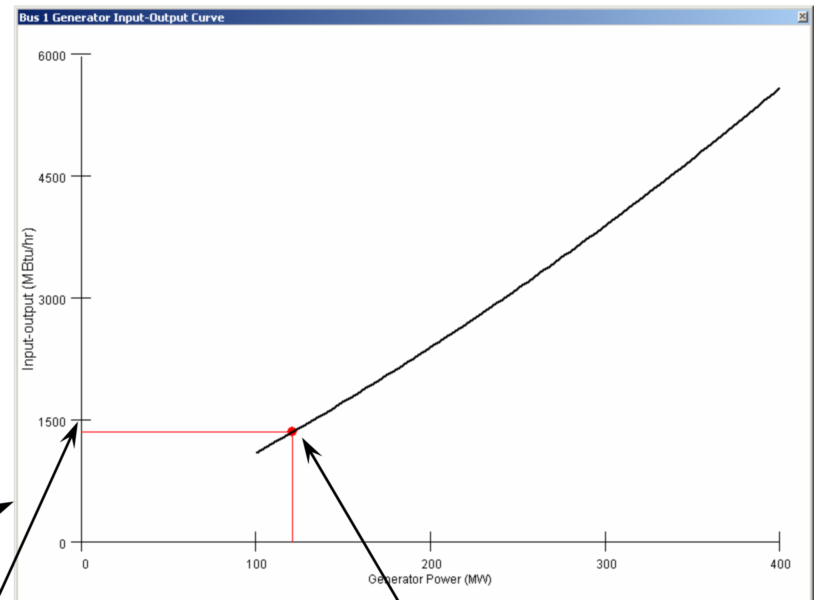
- Note: when you change the Fuel Cost value, Simulator will prompt you asking if you want to change the bid curve points as well
  - If you double the fuel cost, it will double the bids

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

Current 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 use oneline local menu.

Area Records

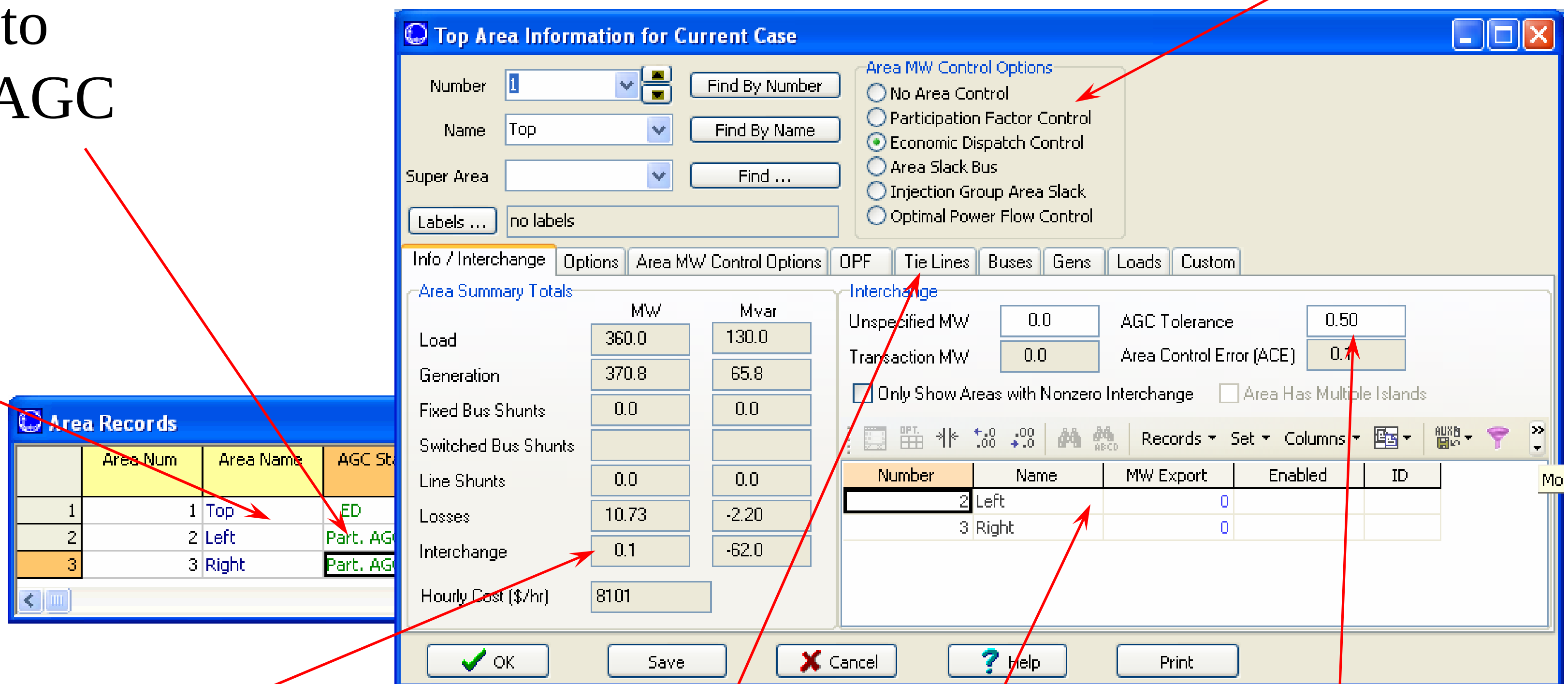
- In the Model Explorer select **Aggregations → Areas** to view the Area Records display.
- Display shows summary information about all areas in case.
- Entries can be sorted by clicking on the column labels.
- Right-click in the row of a desired area and select Show Dialog to view the area's information

Area Interchange Control

Double-click on field to change AGC status

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

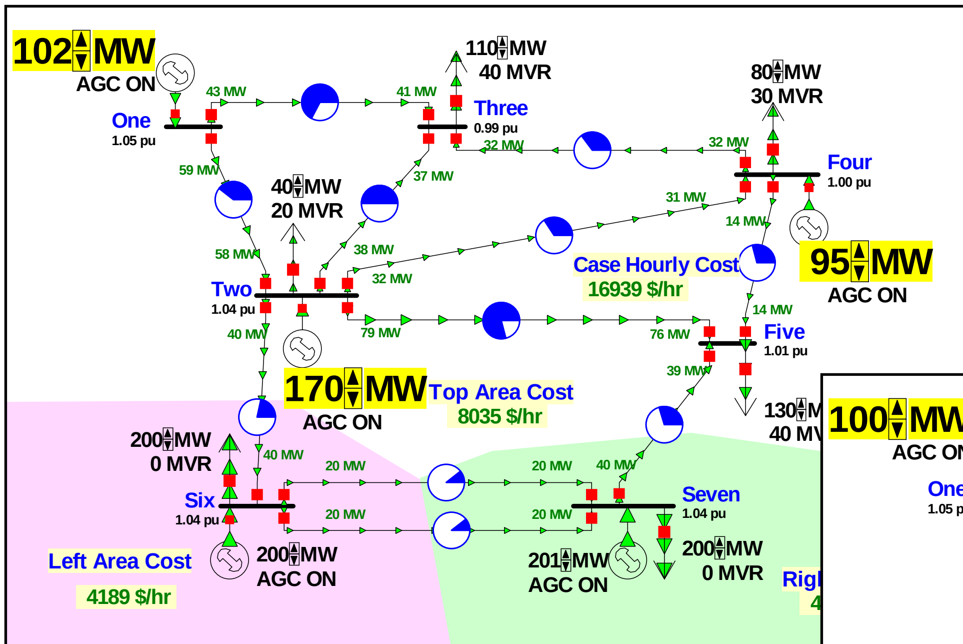
- For B7FLAT Case, verify that all three areas are on economic dispatch control.

Area Records

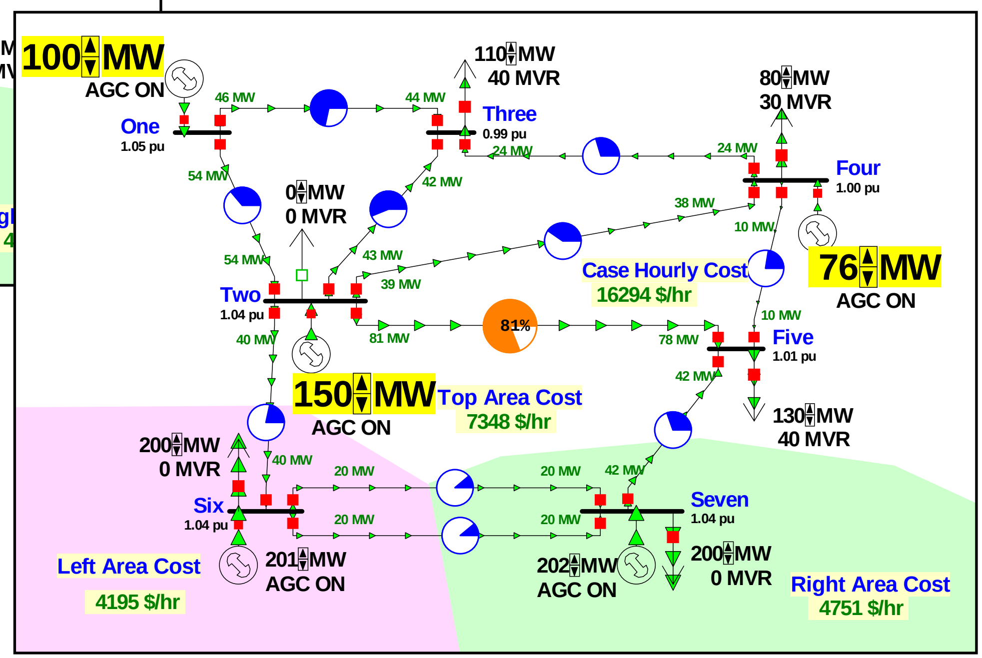
	Area Num	Area Name	AGC Status	Gen MW	Load MW	Tot Sched MW	Int MW	ACE MW	Lambda	Loss MW	Auto Shunts	Auto XF
1	1	Top	ED	366.96	360.00	0.00	0.00	0.00	16.90	6.96	YES	YES
2	2	Left	ED	200.33	200.00	0.00	0.00	0.00	17.22	0.33	YES	YES
3	3	Right	ED	200.65	200.00	0.00	0.00	0.00	22.01	0.65	YES	YES

- 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



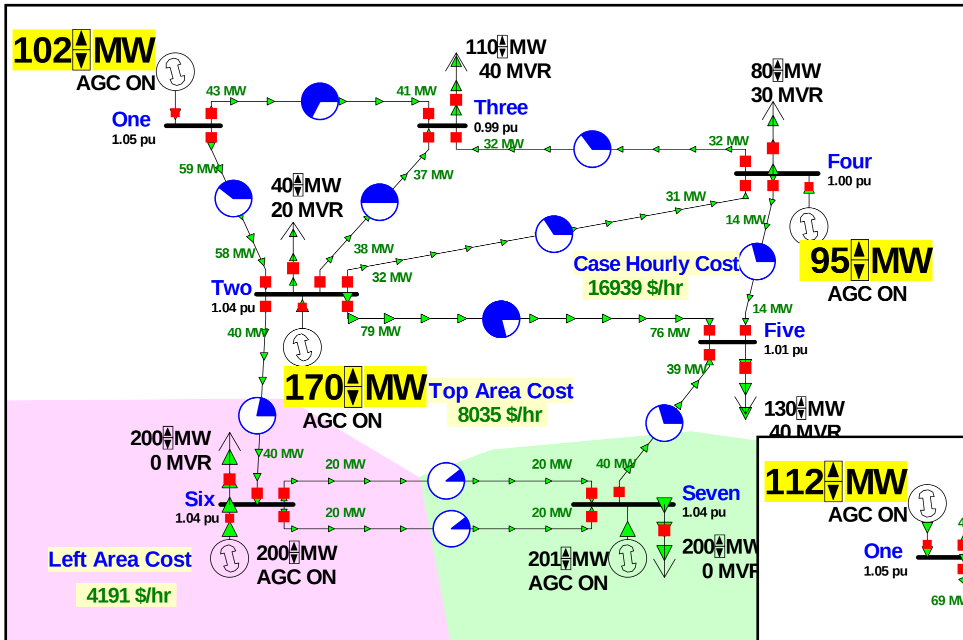
Load goes out of service – All generators respond to reduce generation cost in top area



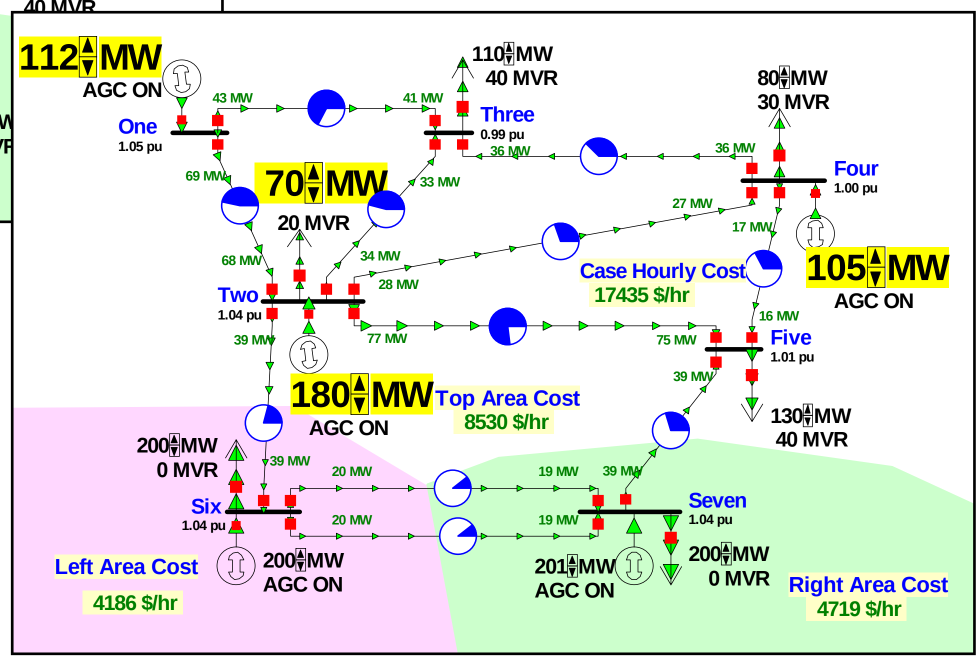
Participation Factor Example

- 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". 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

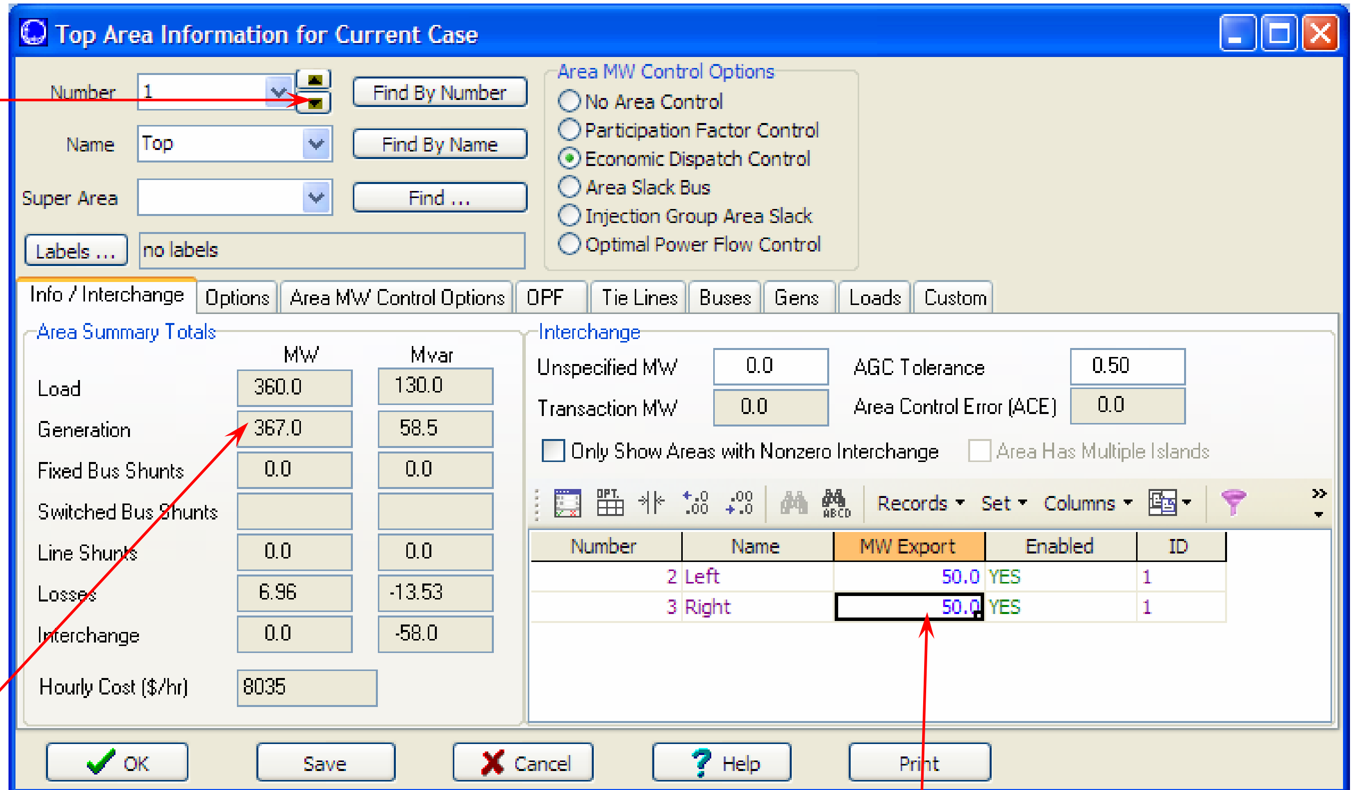
- Used to quickly set up transactions between an area and
  – another specific area
  – unspecified areas
- Cost and start/stop times are not specified
- Transaction areas must be on area control (Participation Factor, OPF, ED, Area Slack)

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



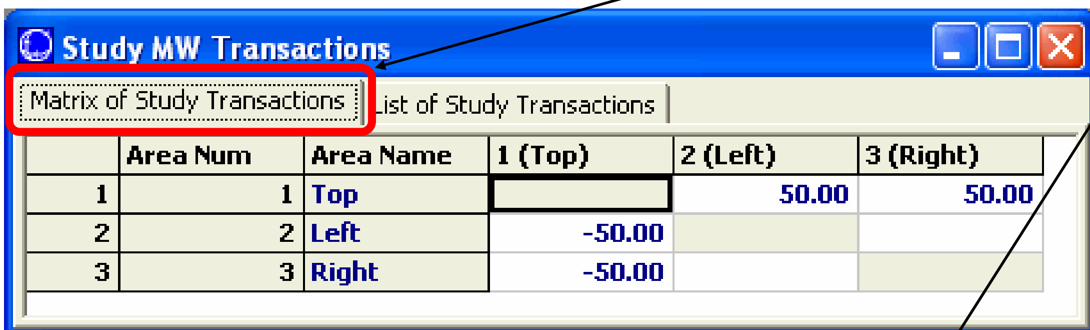
Load + losses + interchange is equal to generation

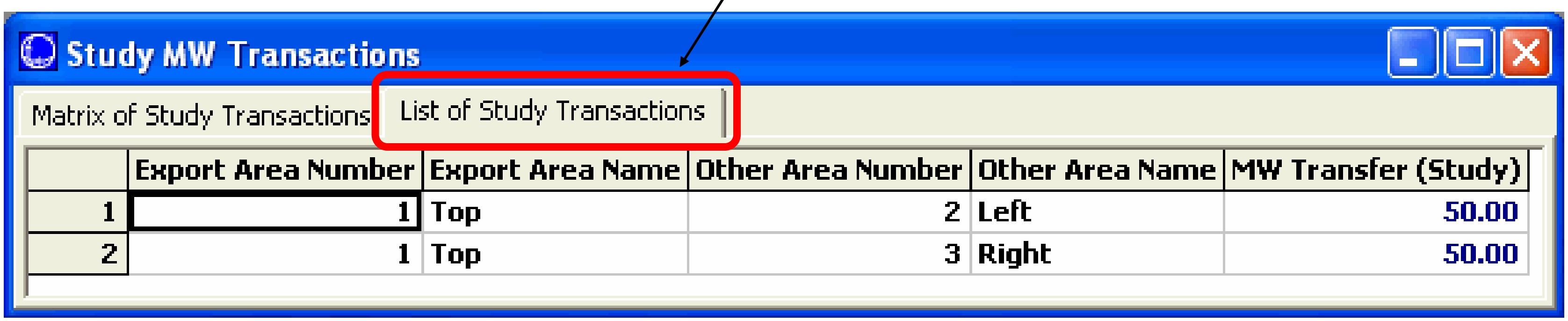
Algebraic sum of actual flow is equal to scheduled

Schedules are also Automatically set for areas LEFT and RIGHT

Case Information, MW Transactions

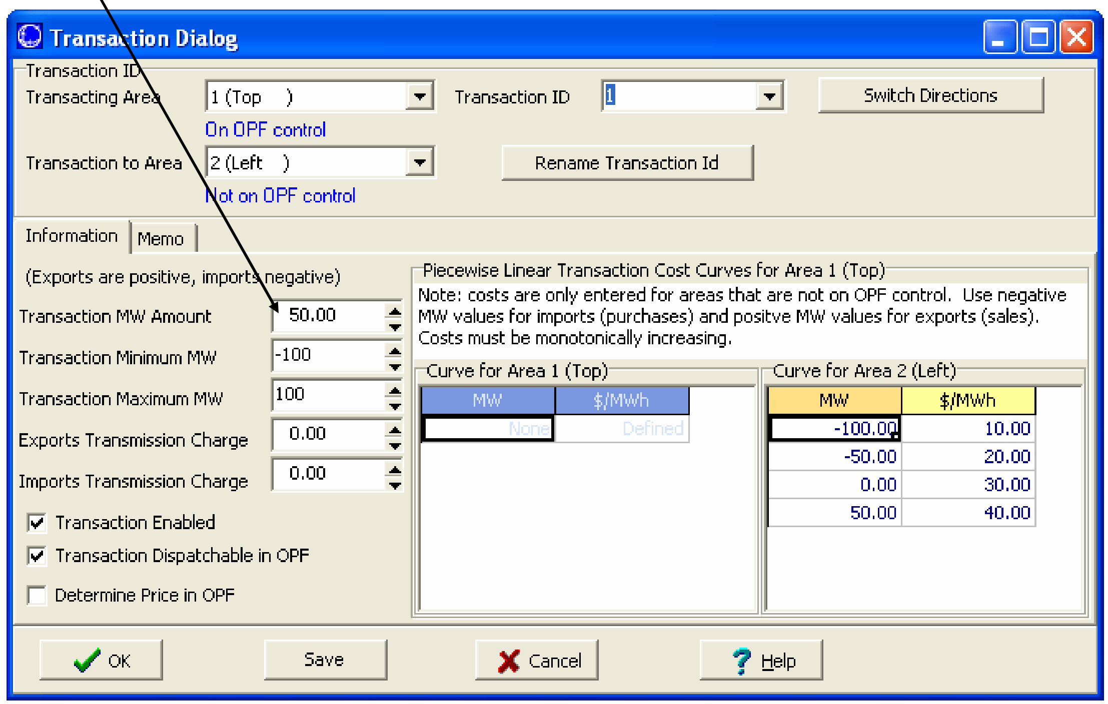
- You can also bring up a summary of all the transactions in the case
  - Can show in a Matrix or in a List





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.



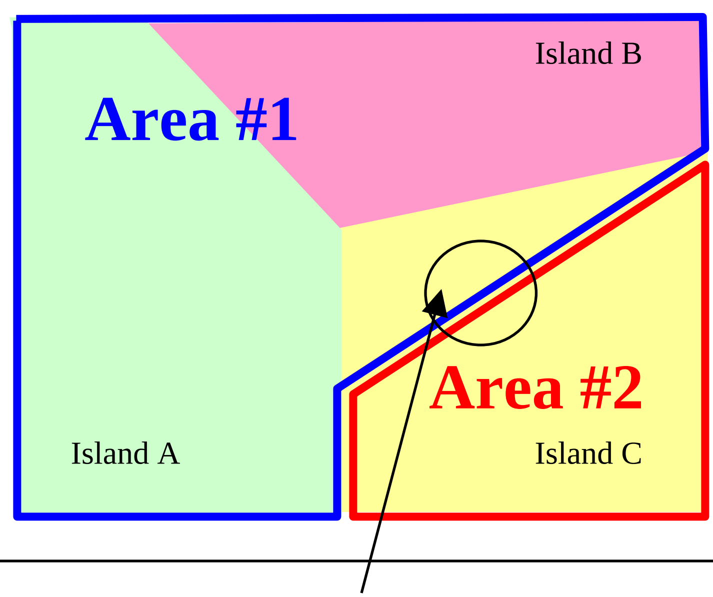
Area control across multiple islands

- 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

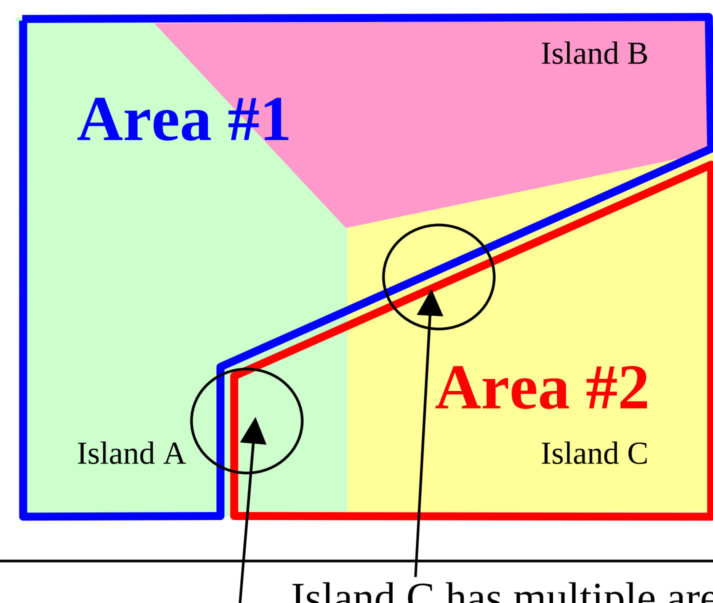
Only Island C has multiple areas



Island C has multiple areas

Control NOT Allowed

Island A and Island C have multiple areas



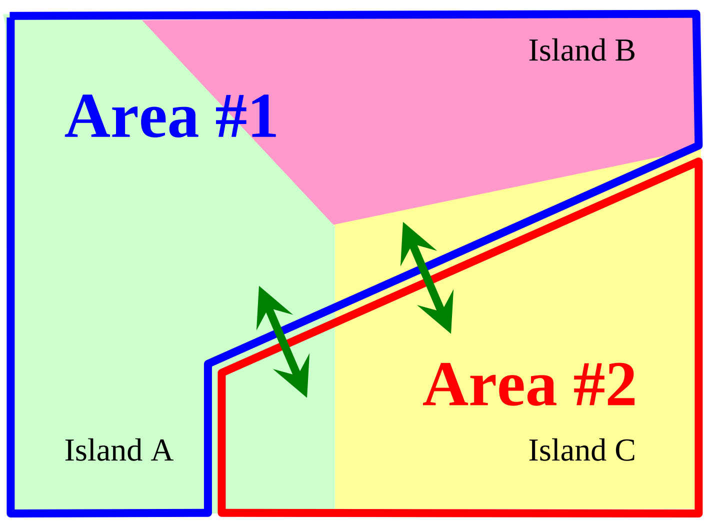
Island C has multiple areas

Island A has 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 [MBtu/(MWhr) vs. MW]
  - Fuel Cost [$/MBtu]

- Output Information
  - Total Cost Curve [$/hr vs. MW]

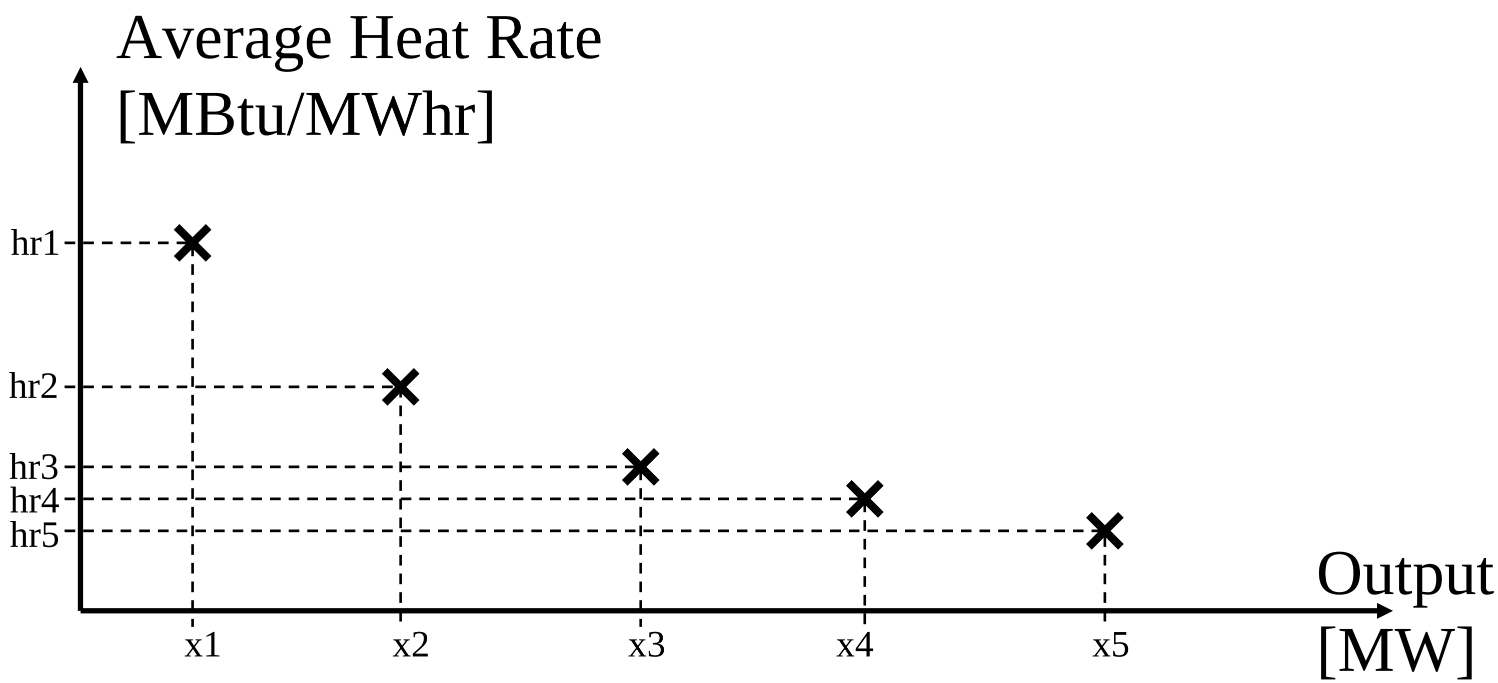
Input Data

- 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

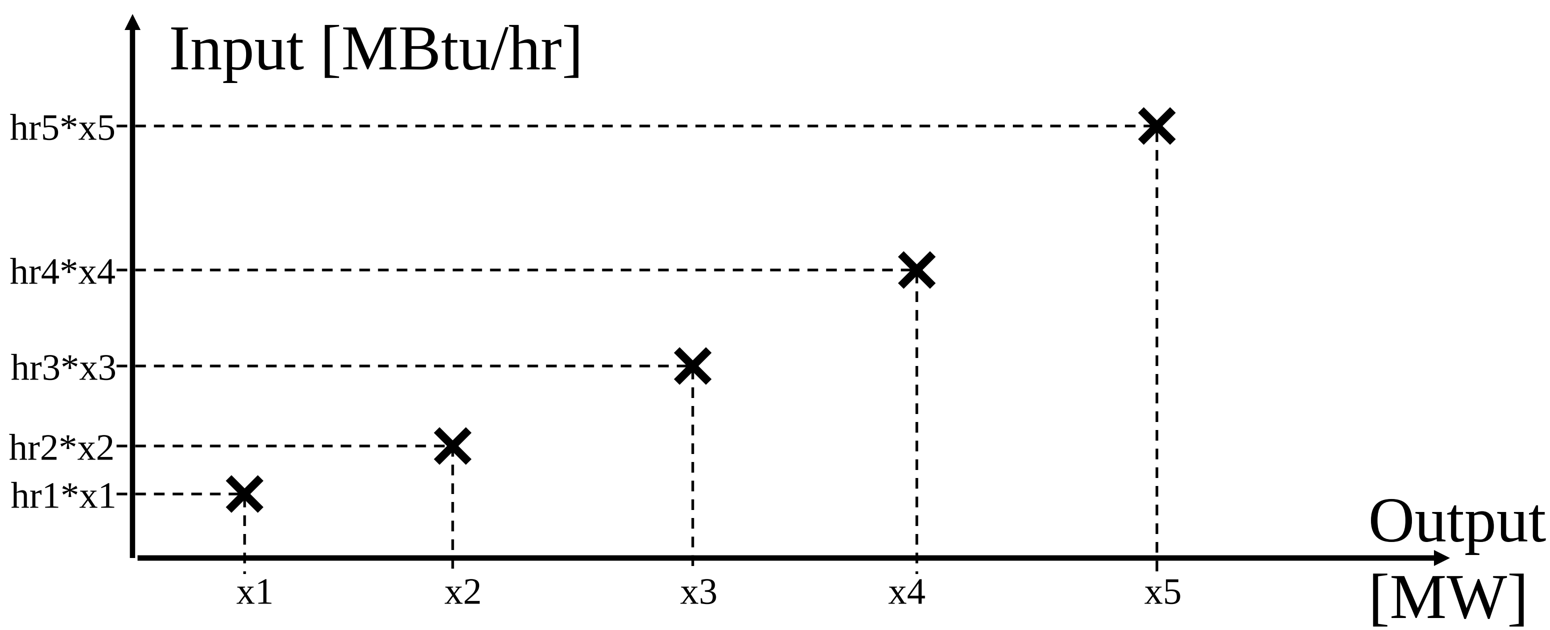
Average Heat Rate Curve Graphically

- 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

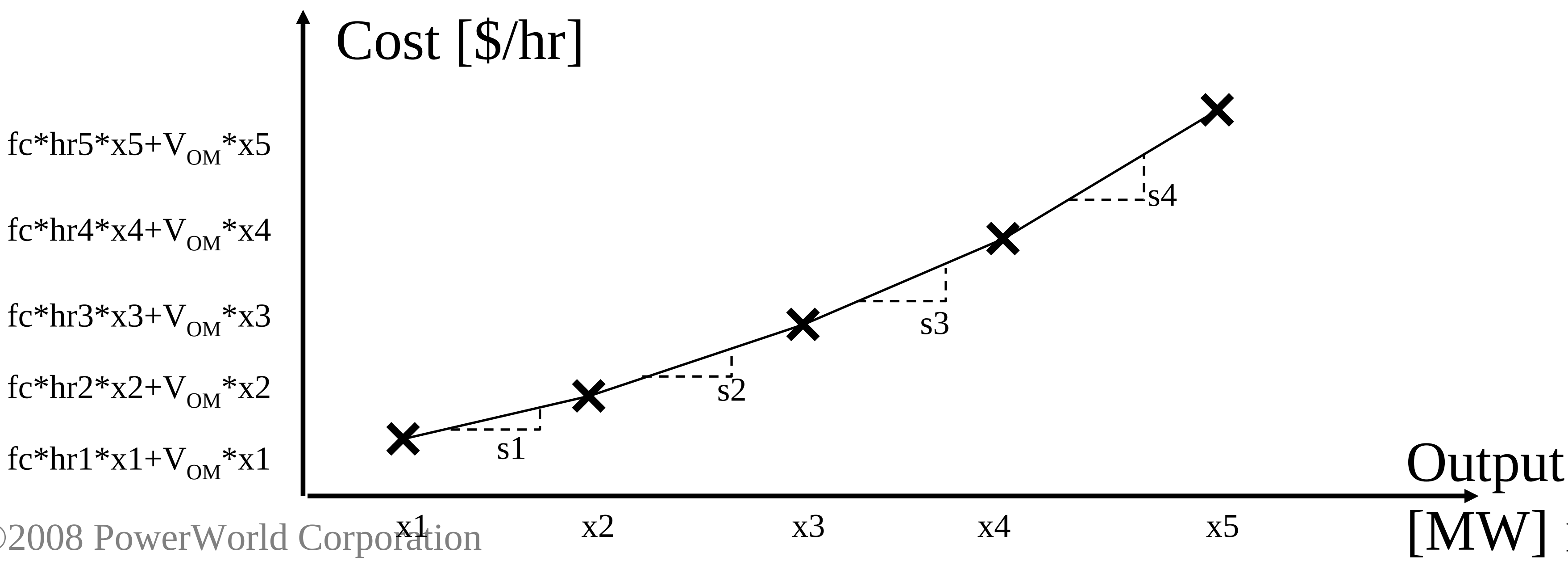
- Input-Output shows the power going into the generator versus the power coming out
  - MBtu/hr = Input Power = fuel being used per hour
  - MW = Output Power



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
  - V_{OM} = variable O&M
  - a, b, c, d = coefficients
- The generation cost is then defined as

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

- 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

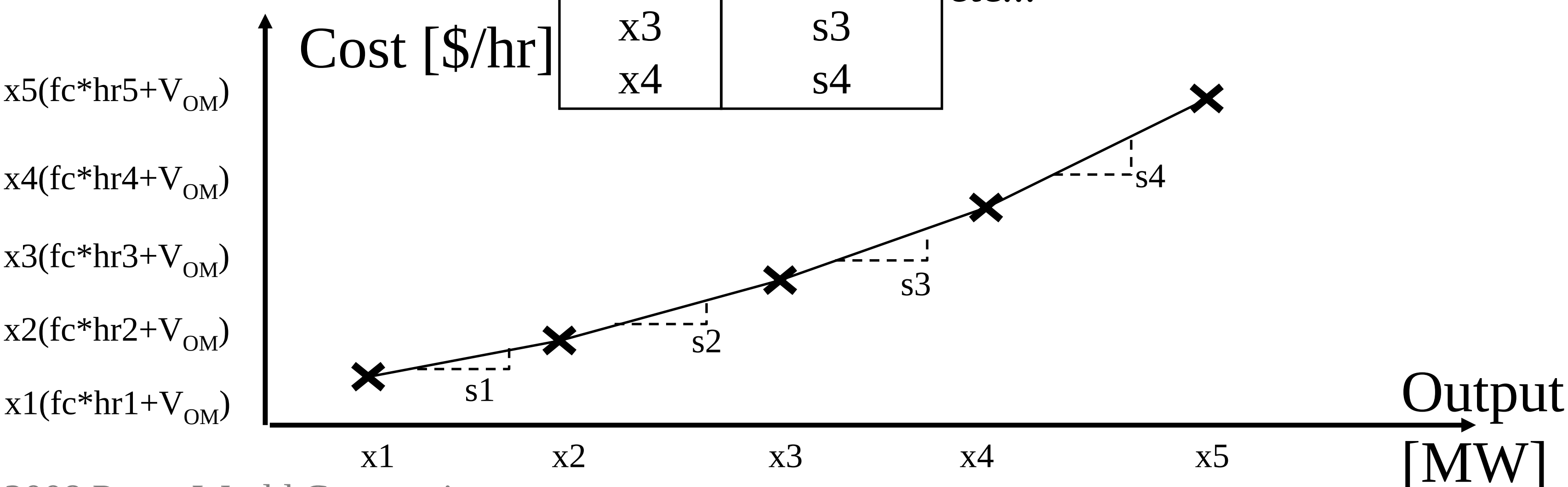
- Fixed Cost = $x1(fc*hr1+V_{OM})$
  - Cost at lowest output specified by the pairs entered
- Enter pairs of (output, slope) as follows
  - Mimics a “bid”

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

where

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

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

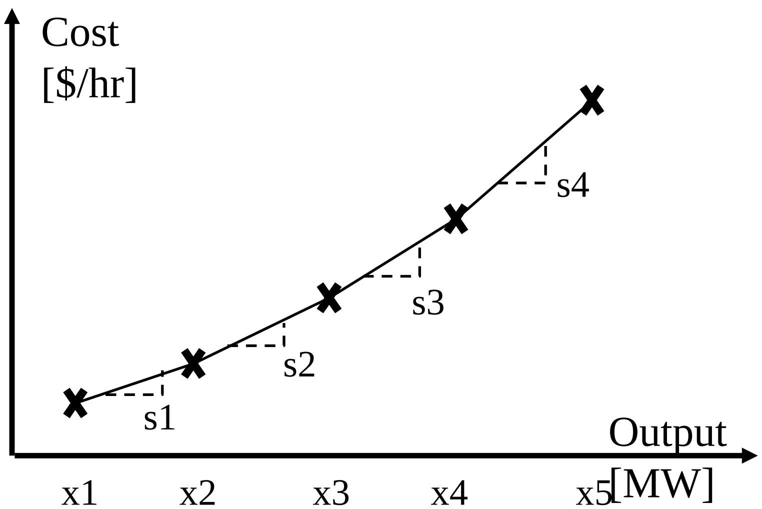
Convex Requirement

- 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

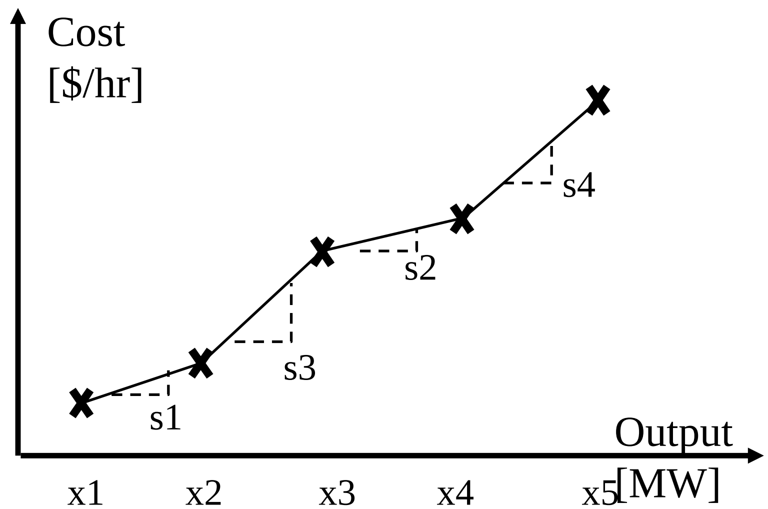
Output [MW]	Slope [$/MWhr]
100 MW	20 $/MWhr
200 MW	24 $/MWhr
300 MW	26 $/MWhr
400 MW	28 $/MWhr



Unacceptable Curve

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

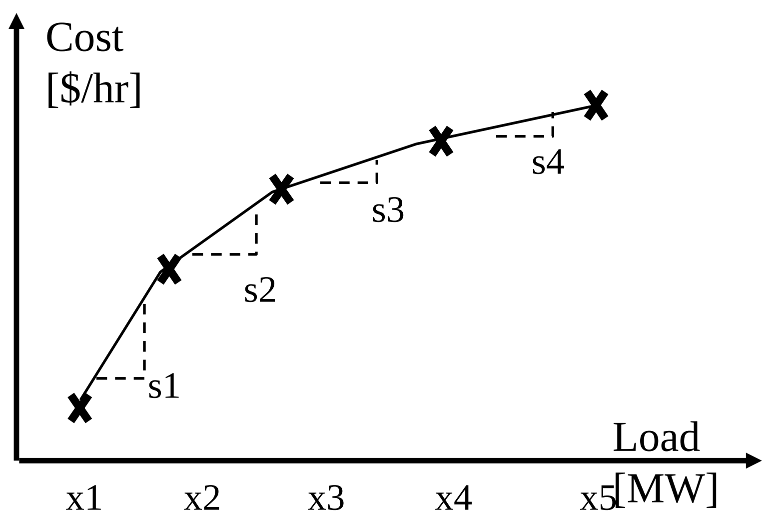
Decrease in slope



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