PowerWorld Simulator OPF

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Presentation Goals

- Provide background on Optimal Power Flow (OPF) Problem
- Show how OPF is implemented in PowerWorld Simulator OPF
- Demonstrate how Simulator OPF can be used to solve small and large problems

"Ideal" Power Market

- Ideal power market is analogous to a lake. Generators supply energy to lake and loads remove energy.
- Ideal power market has no transmission constraints
- Single marginal cost associated with enforcing constraint that supply = demand

Real Power Market

- Different operating regions impose constraints that total demand in region = total supply
- Transmission system imposes constraints on the market
- Marginal costs become localized
- Requires solution by an optimal power flow

Optimal Power Flow (OPF)

- Minimize cost function, such as operating cost, taking into account realistic equality and inequality constraints
- Equality constraints
  - bus real and reactive power balance
  - generator voltage setpoints
  - area MW interchange

Optimal Power Flow (OPF)

- Inequality constraints
  - transmission line/transformer/interface flow limits
  - generator MW limits
  - generator reactive power capability curves
  - bus voltage magnitudes (not yet implemented in Simulator OPF)
- Available Controls
  - generator MW outputs

OPF Solution Methods

- Non-linear approach using Newton's method
  - handles marginal losses well, but is relatively slow and has problems determining binding constraints
- Linear Programming
  - fast and efficient in determining binding constraints, but has difficulty with marginal losses.

LP OPF

- Two approaches are possible
  - primal
    - take a feasible solution and make it optimal
  - dual
    - take an optimal solution and make it feasible
- PowerWorld Simulator OPF only includes a primal approach (currently)

Primal LP OPF Solution Algorithm

- Solution iterates between
  - solving a full ac power flow solution
    - enforces real/reactive power balance at each bus
    - enforces generator reactive limits
    - system controls are assumed fixed
    - takes into account non-linearities
  - solving a primal LP
    - changes system controls to enforce linearized constraints while minimizing cost

LP Solution

- Problem is setup to be initially feasible through the use of slack variables
  - slack variables have high marginal costs; LP algorithm will remove them if at all possible
- Slack variables are used to enforce
  - area/super area MW constraints
  - MVA line/transformer constraints
  - MW interface constraints

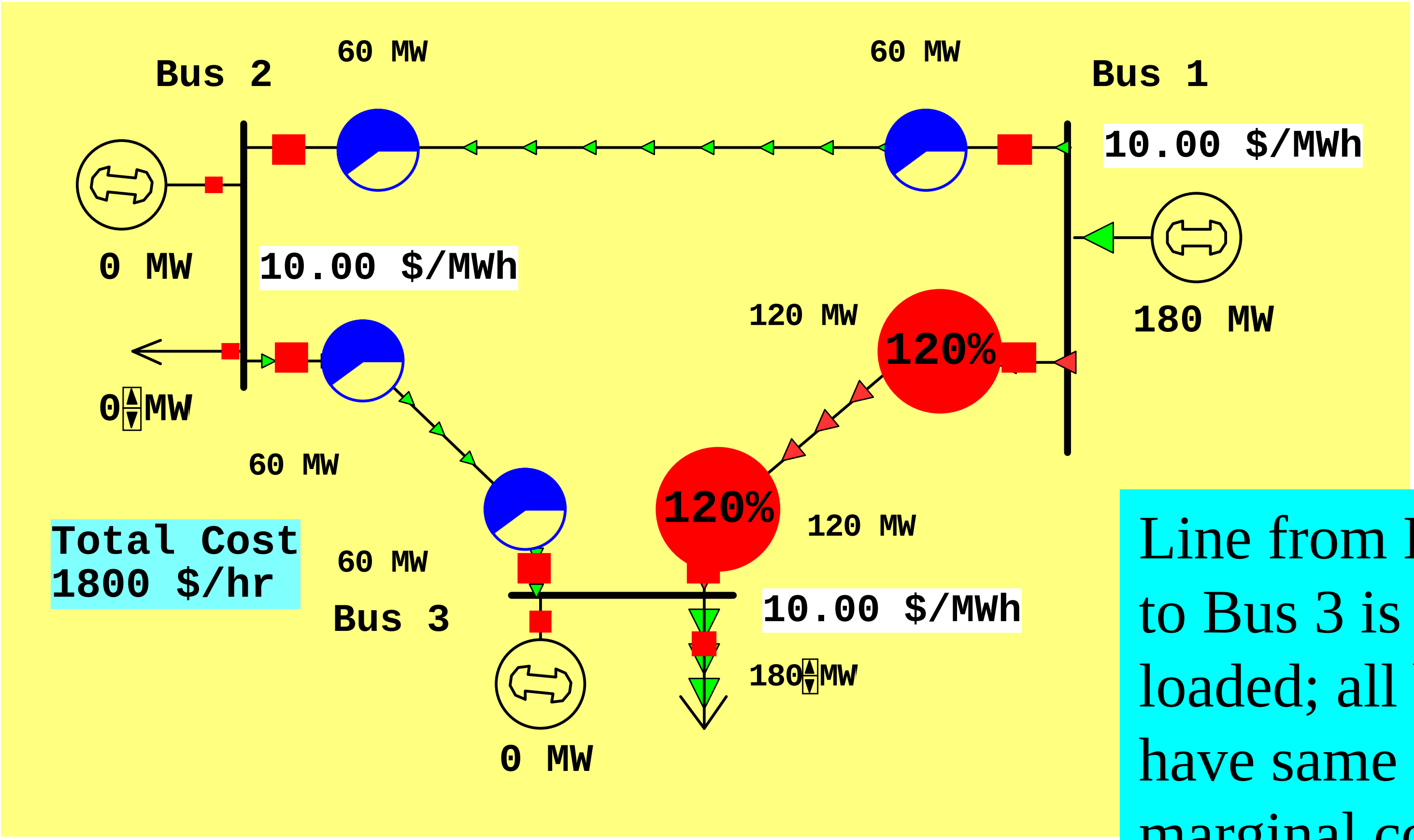
Three Bus (B3) Example

- Consider a three bus case (bus 1 as slack), with all buses interconnected through 0.1 pu reactance lines, each with a 100 MVA limit
- Let the generator marginal costs be
  - Bus 1: 10 $ / MWhr; Range = 0 to 400 MW
  - Bus 2: 12 $ / MWhr; Range = 0 to 400 MW
  - Bus 3: 20 $ / MWhr; Range = 0 to 400 MW
- Assume a single 180 MW load at bus 2

Solving the LP OPF

- All LP OPF commands are accessed from the LP OPF menu item.
- Before solving, we first need to specify what constraints to enforce
  - Select LP OPF, OPF Area Records to turn on area constraint; set AGC Status to "OPF"
  - Initially we'll disable line MVA enforcement; Select LP OPF, Options; check "Disable Line/Transformer MVA Line Limit Enforcement"

B3 with Line Limits Not Enforced



Line from Bus 1 to Bus 3 is over-loaded; all buses have same marginal cost

Line Limit Enforcement

- Previous LP tableau was

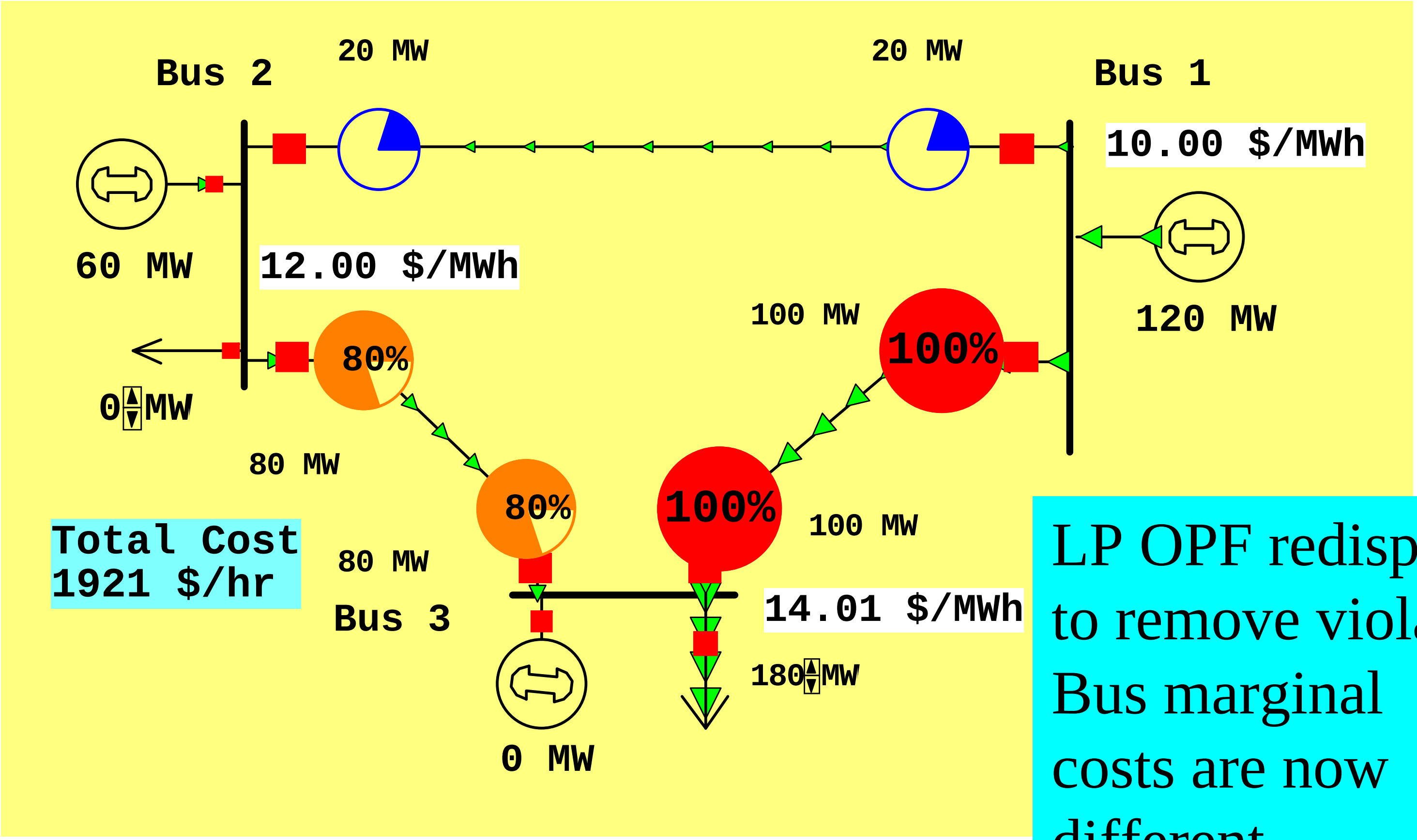
PG1	PG2	PG3	S1	b
1.00	1.00	1.00	1.00	0.00

- Line limit tableau is

PG1	PG2	PG3	S1	S2	b
1.00	1.0	1.00	1.00	0.00	0.00
0.00	-0.33	-0.66	0.00	1.00	-0.20

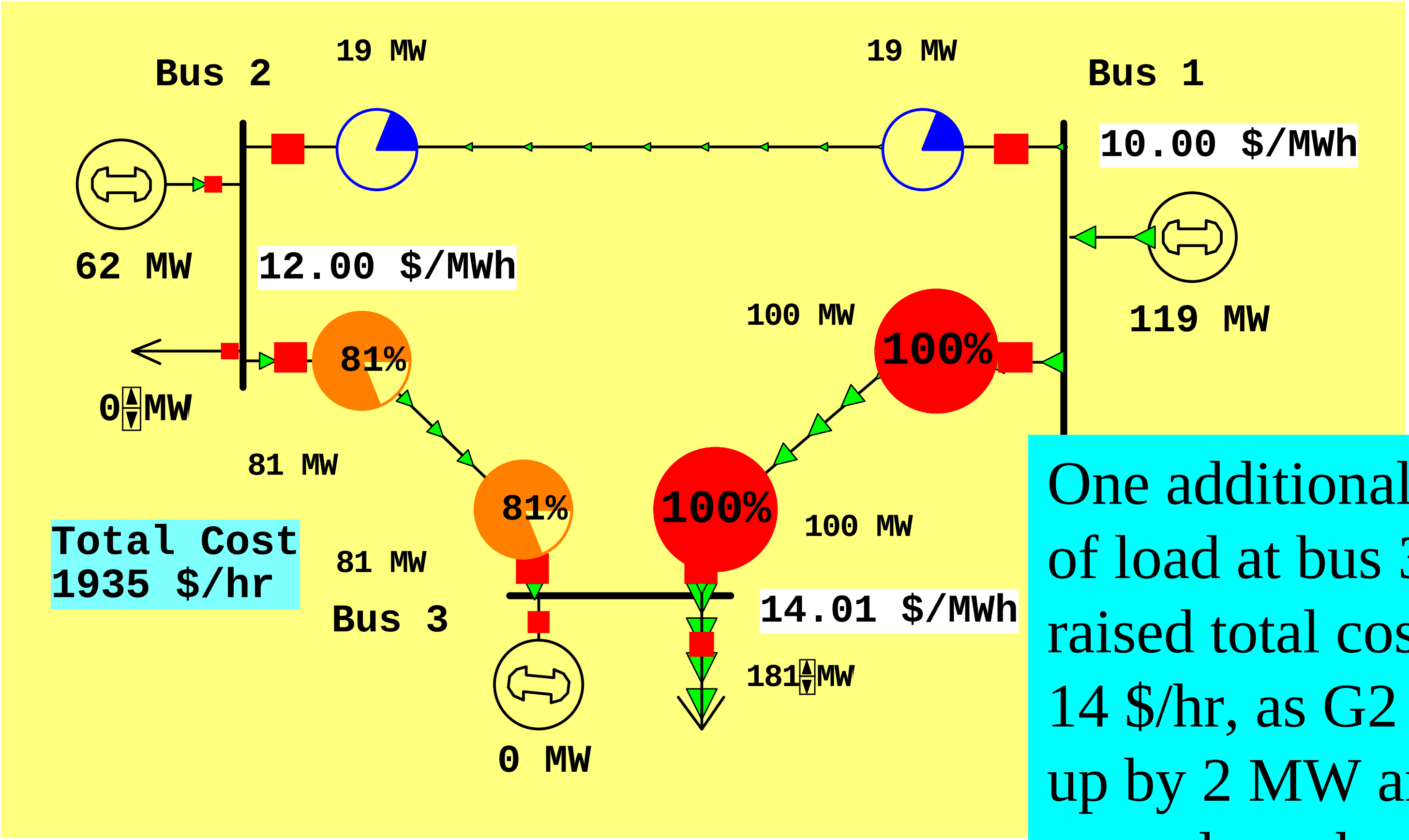
- Second row is from enforcing the line flow MVA constraint

B3 with Line Limits Enforced



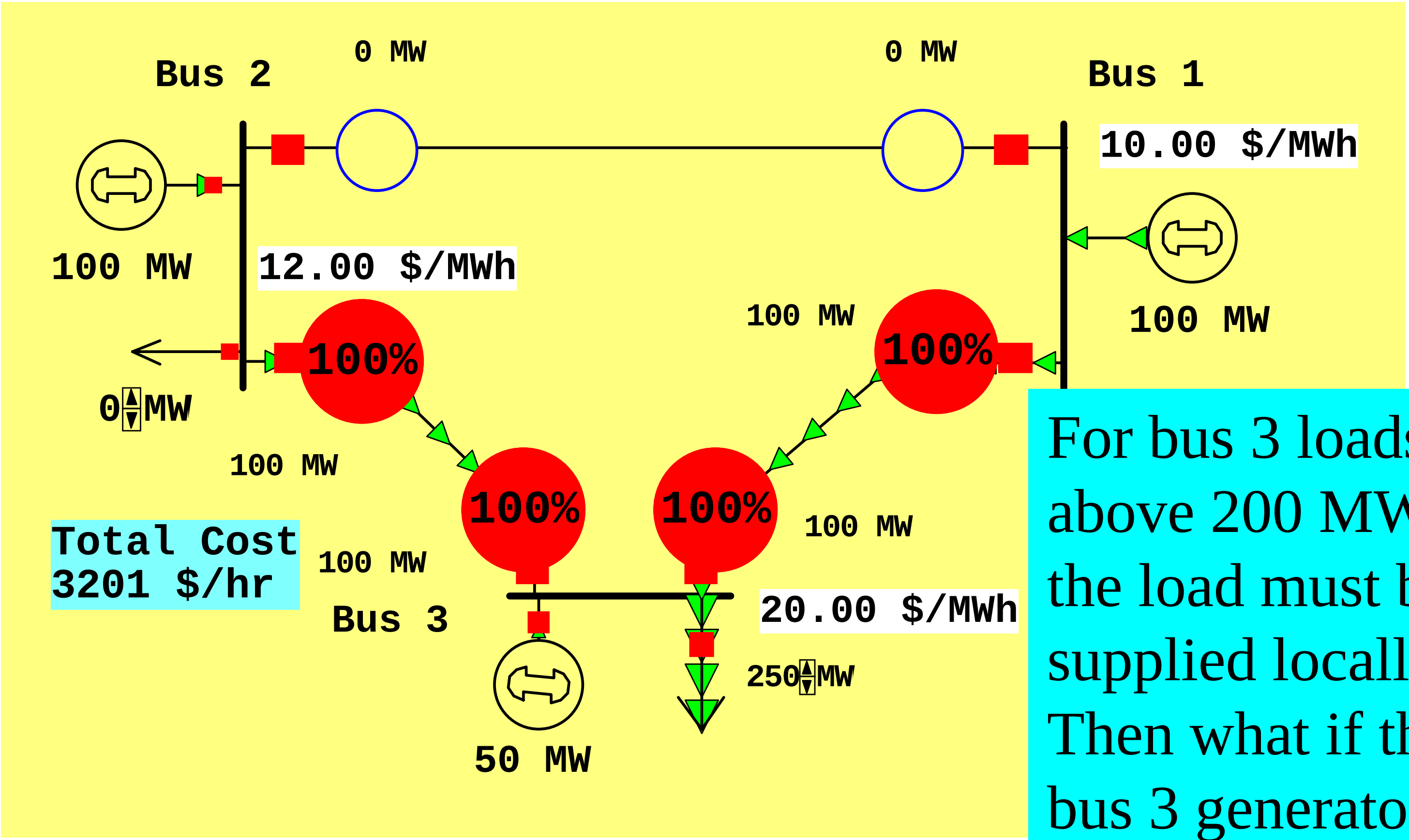
LP OPF redispatches to remove violation. Bus marginal costs are now different.

Verify Bus 3 Marginal Cost



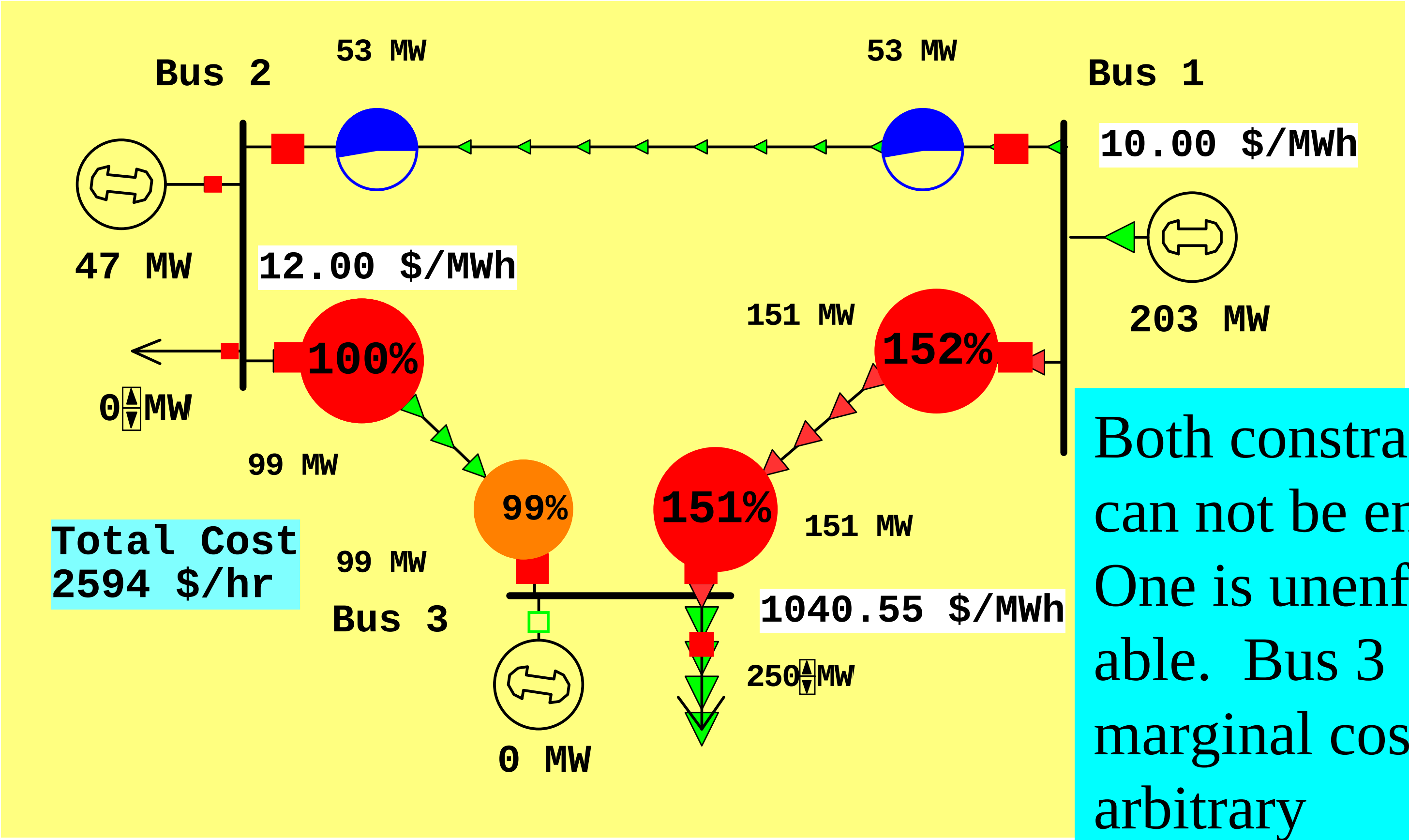
One additional MW of load at bus 3 raised total cost by 14 $/hr, as G2 went up by 2 MW and G1 went down by 1MW

Both lines into Bus 3 Congested



For bus 3 loads above 200 MW, the load must be supplied locally. Then what if the bus 3 generator opens?

Case with G3 Opened Unenforceable Constraints

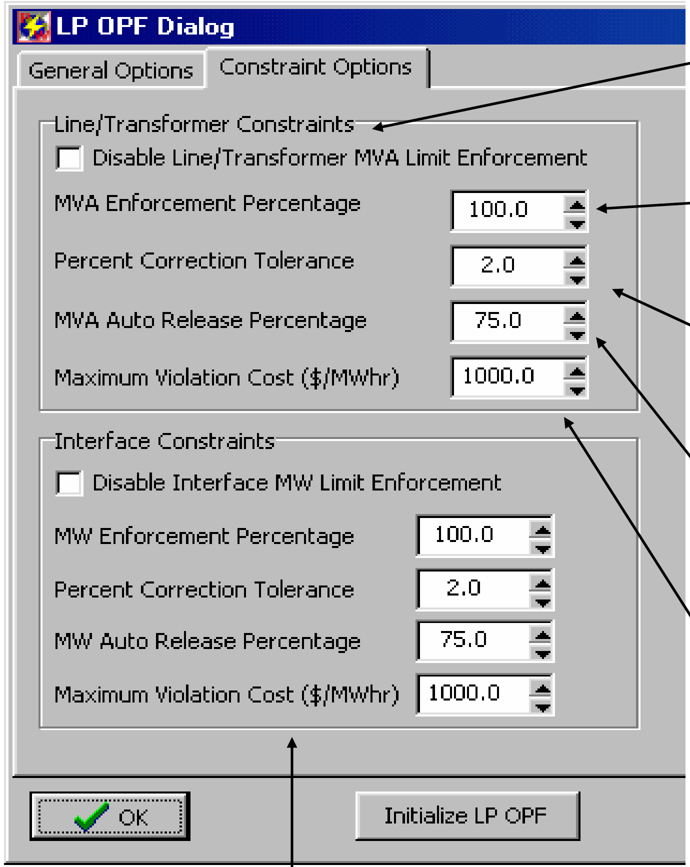


Both constraints can not be enforced. One is unenforceable. Bus 3 marginal cost is arbitrary

Unenforceable Constraint Costs

- If a constraint can not be enforced due to insufficient controls, the slack variable associated with enforcing that constraint can not be removed from the LP basis
  - marginal cost depends upon the assumed cost of the slack variable
  - this value is specified in the Maximum Violation Cost field on the LP OPF, Options dialog.

LP OPF, Options Dialog



Disables enforcement of line constraints

Lines with a percentage loading above this amount are enforced

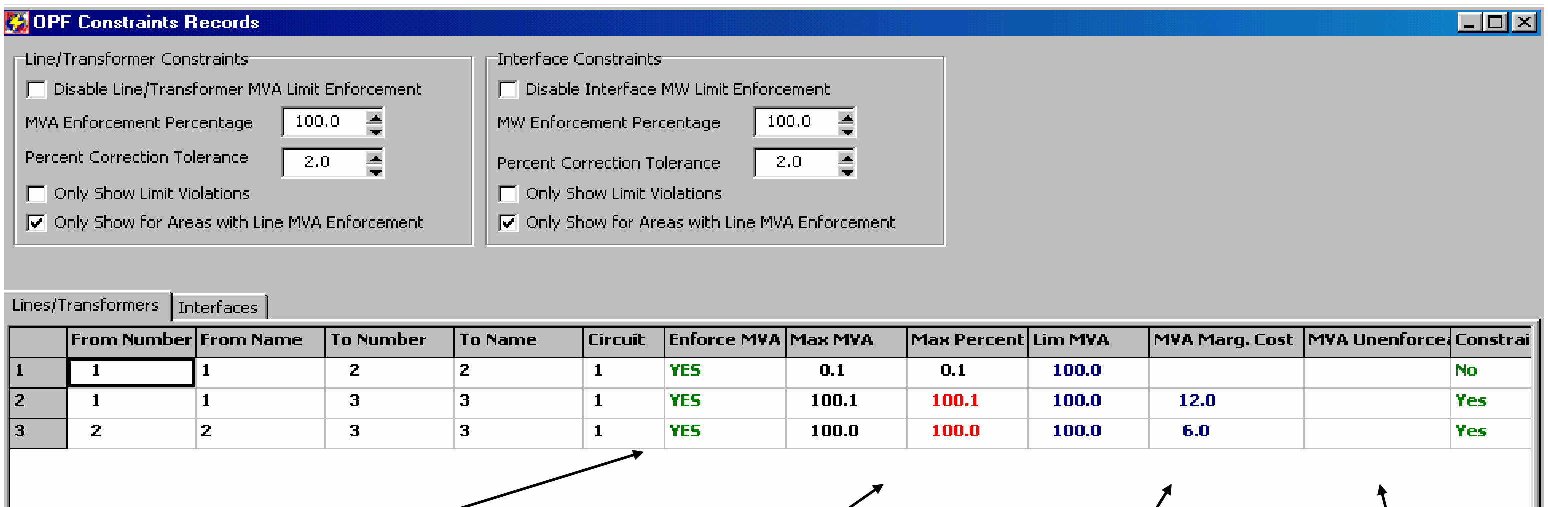
Enforcement tolerance deadband; needed because of system non-linearities

Previously binding line constraints with loadings above this value remain in tableau

Cost of unenforceable line violations

Similar fields for interfaces

OPF Line/Transformer MVA Constraints Display



	From Number	From Name	To Number	To Name	Circuit	Enforce MVA	Max MVA	Max Percent	Lim MVA	MVA Marg. Cost	MVA Unenforcea	Constrai
1	1	1	2	2	1	YES	0.1	0.1	100.0			No
2	1	1	3	3	1	YES	100.1	100.1	100.0	12.0		Yes
3	2	2	3	3	1	YES	100.0	100.0	100.0	6.0		Yes

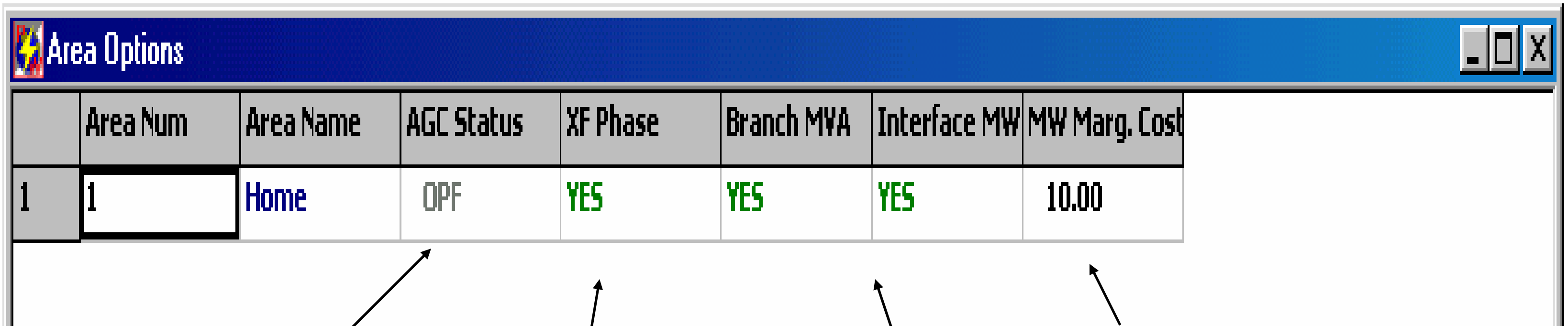
Set to specify enforcement of individual lines

Line loadings

Marginal costs are non-zero only for lines that are active constraints

Indicates if line is unenforceable

OPF Area Records Display



AGC (automatic generation control) status must be set to “OPF” to include this are in the OPF objective function

Phase shifter control is still under development

Set to indicate if branch and/or interface constraints in an area should be enforced

Interpreting this value is difficult in areas with congestion

OPF Generator Records Display

OPF Gen Records Data

	Number	Name	ID	Area Name	AGC	OPF MW Control	Gen MW	MW Marg. Cos	Initial MW	Delta MW	Min MW
1	1	1	1	Home	YES	If Agcable	99.9	10.0	99.9	-0.0	0.0
2	2	2	1	Home	YES	If Agcable	99.9	12.0	99.8	0.1	0.0
3	3	3	1	Home	YES	If Agcable	0.3	20.0	0.3	-0.0	0.0

The OPF Generator Records display is similar to the Generator Records display, except it contains several LP OPF specific fields

Current MW marginal cost

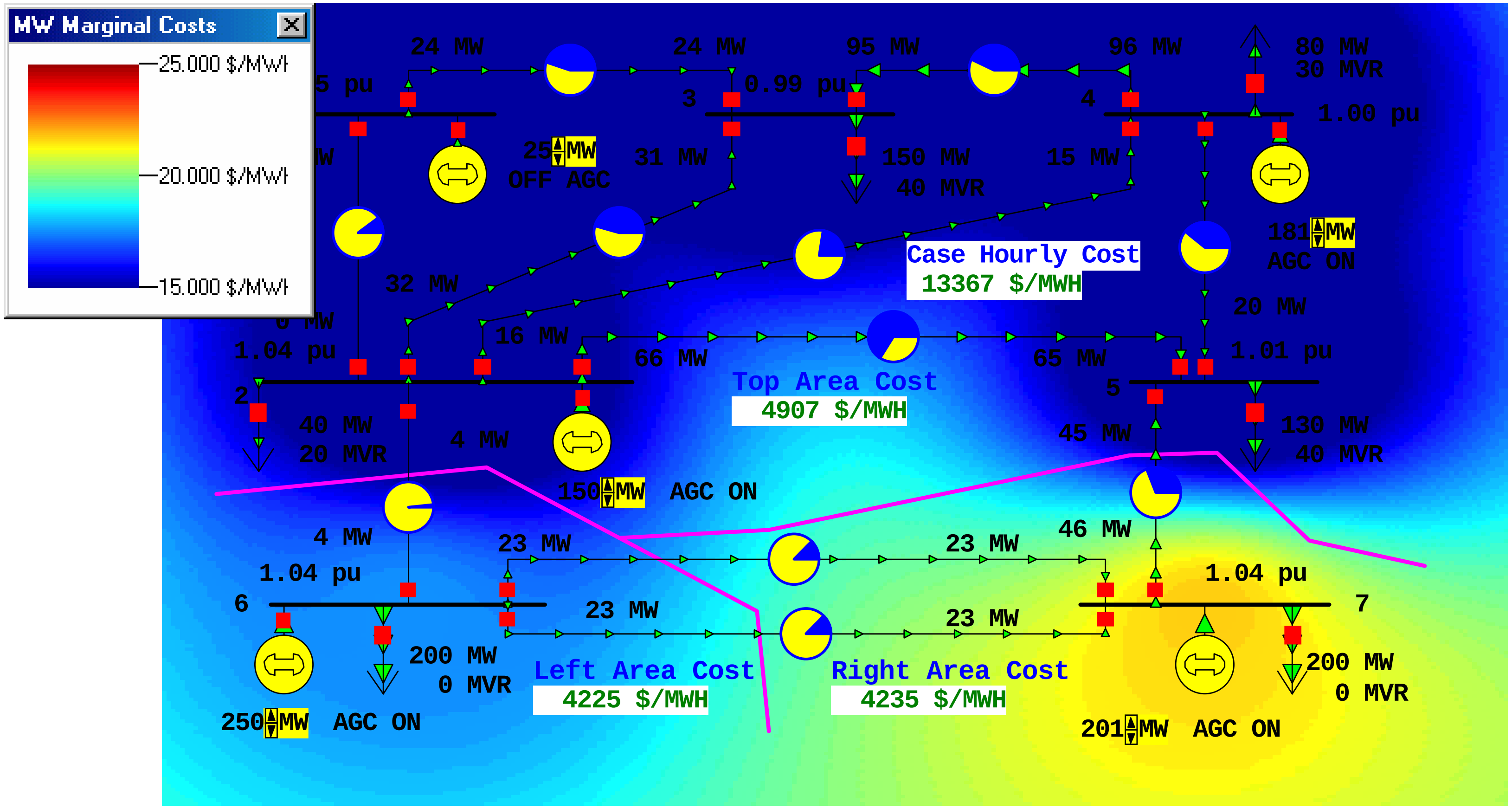
Amount of change in MW during last OPF solution

OPF MW Control specifies whether a particular generator is available for control

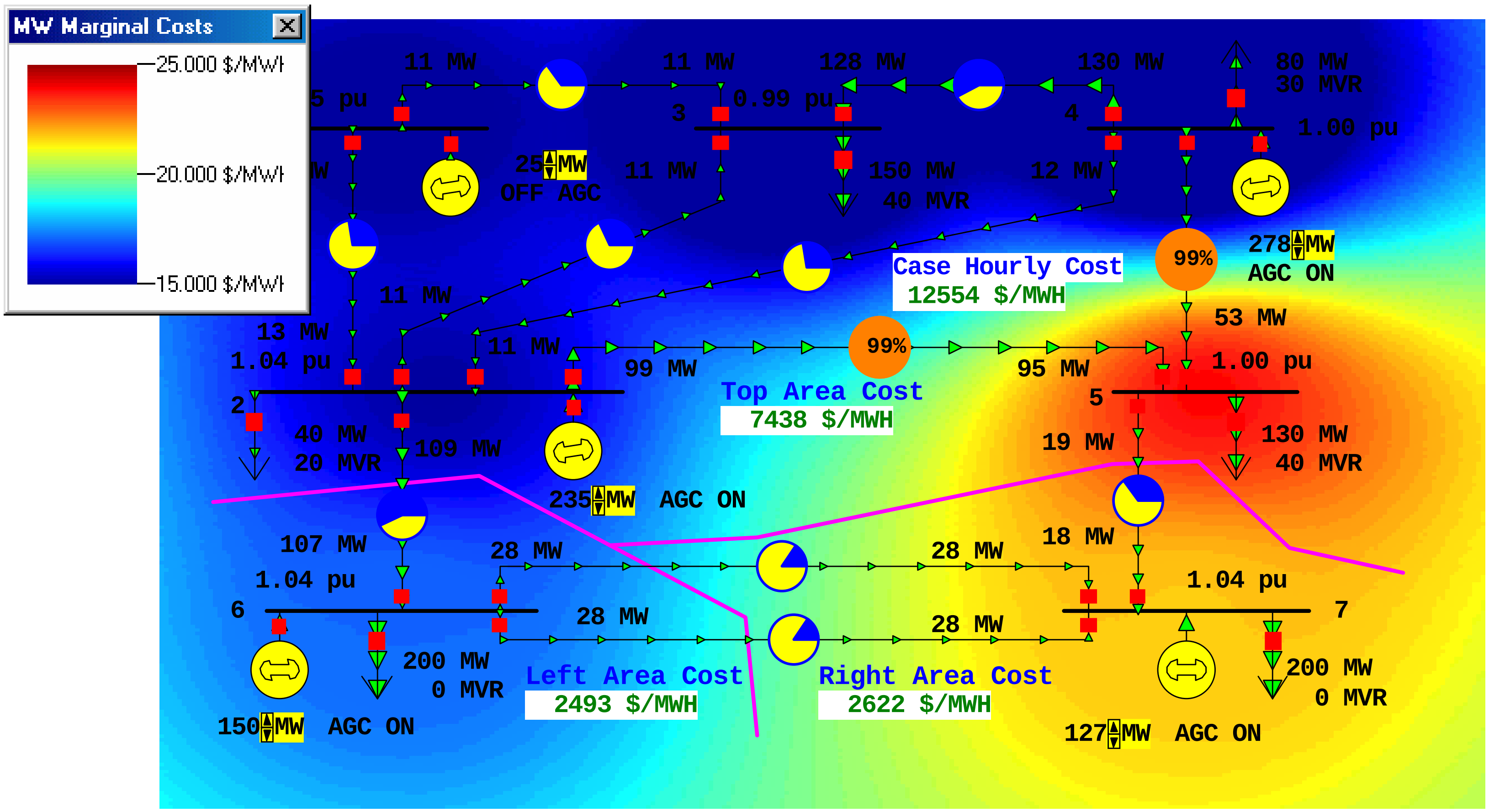
Super Areas

- Super areas are a record structure used to hold a set of areas
- Using super areas a number of areas can be dispatched as though they were a single area
- For a super area to be used in the OPF, its AGC Status field must be "OPF"

Seven Bus Example - Dispatched as Three Separate Areas



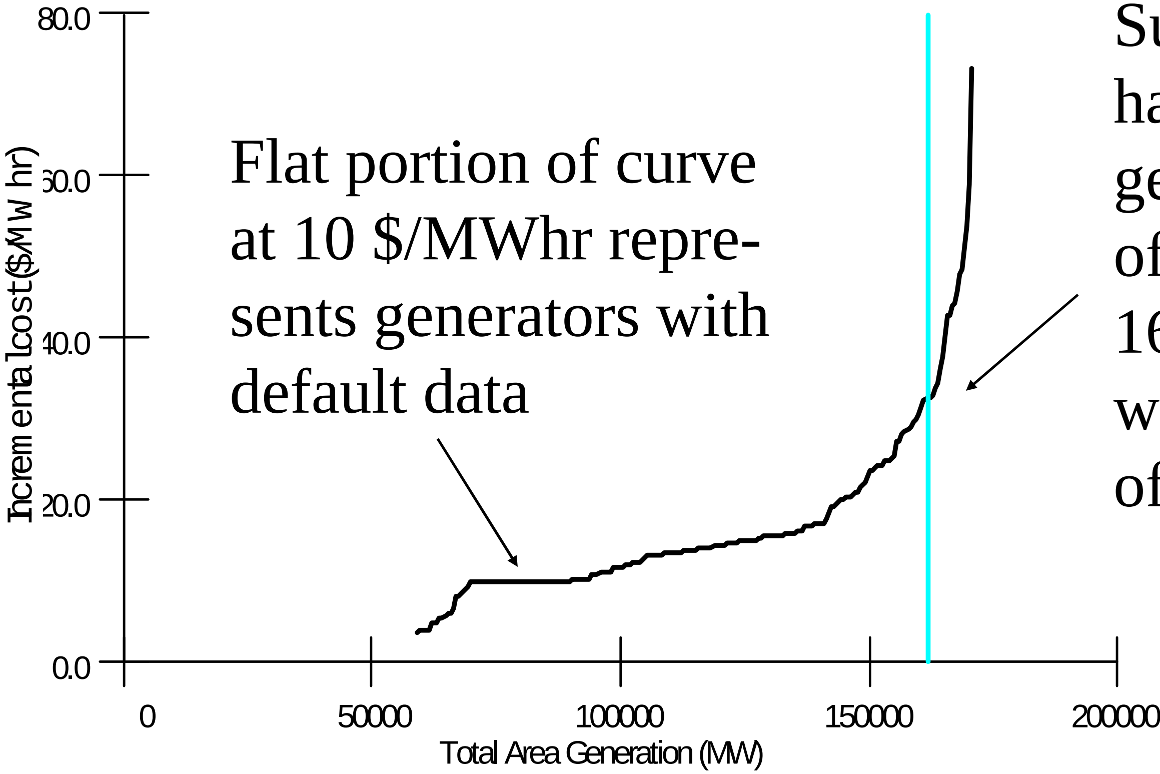
Seven Bus Case Dispatched as One Super Area



New England FERC 1997 Case

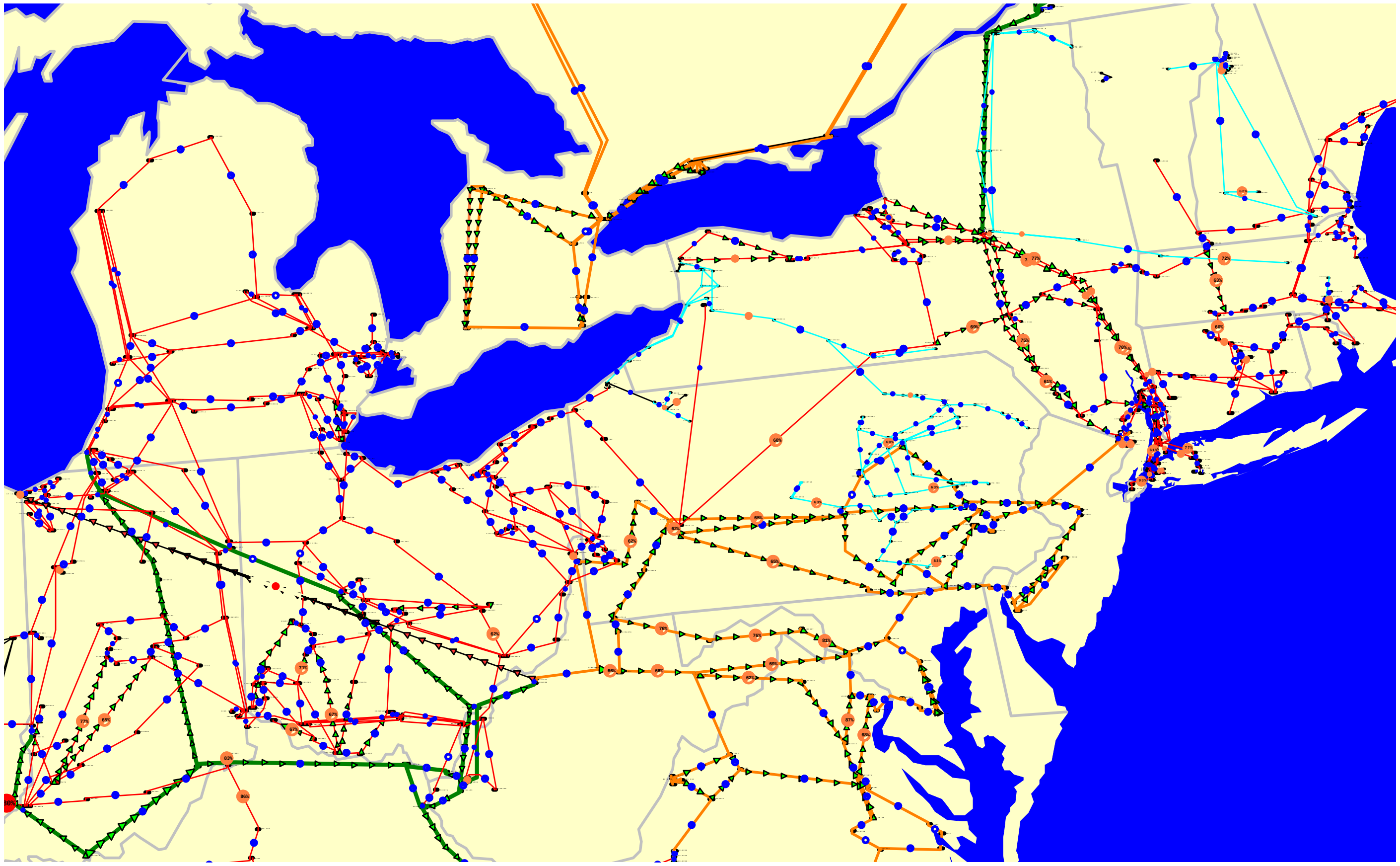
- Next case is based upon the FERC Form 715 1997 Summer Peak case filed by NEPOOL
  - case has 9270 buses and 2506 generators, representing a significant portion of the Eastern Interconnect transmission and generation
  - estimated cost data for most generators in NEPOOL, NYPP, PJM, ECAR supplied by EIA
  - these regions were modeled as a super area

NEPOOL/NYPP/PJM/ECAR Supply Curve

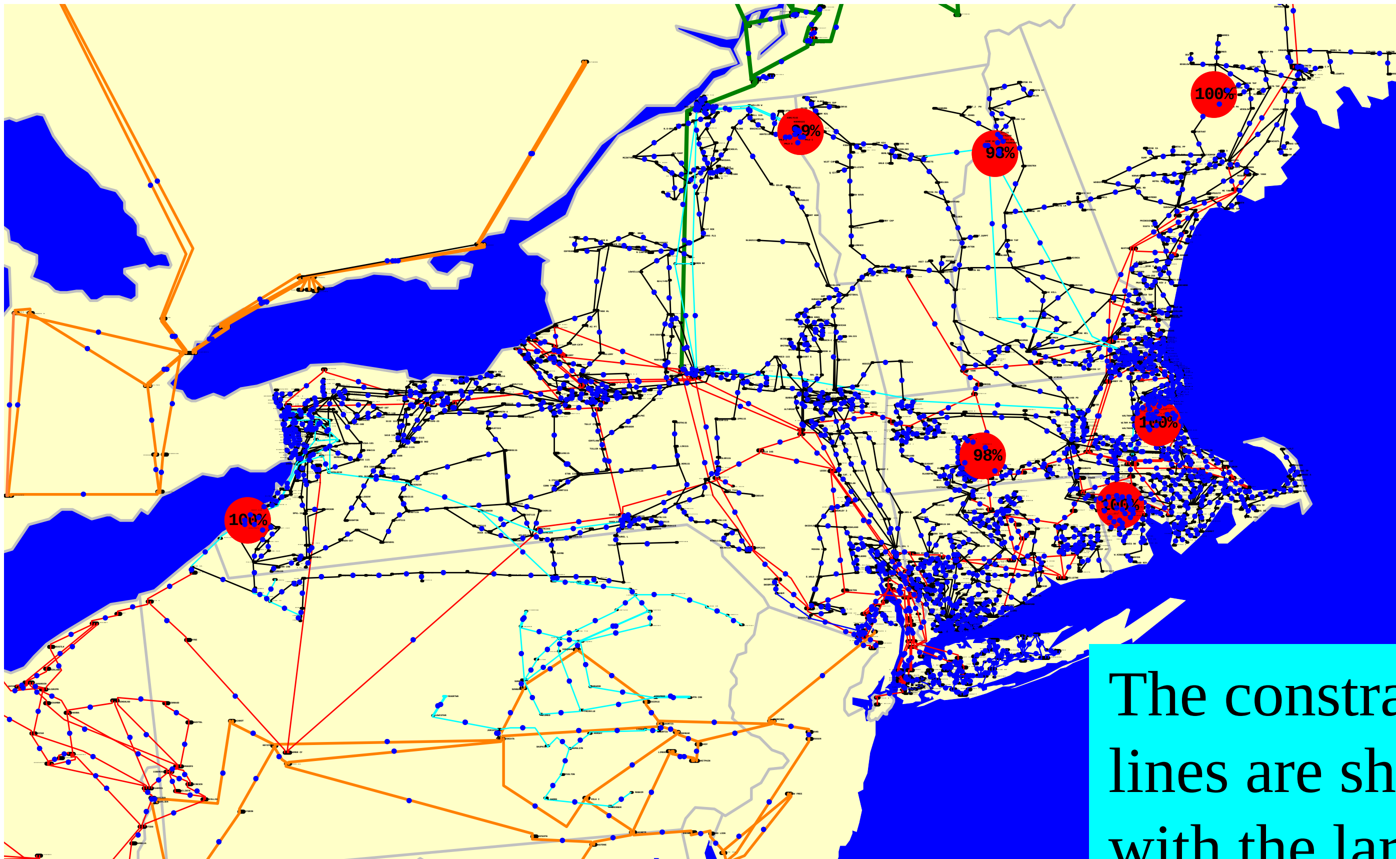


Super area has total generation of about 160 GW, with imports of 2620 MW

Case HEV Transmission

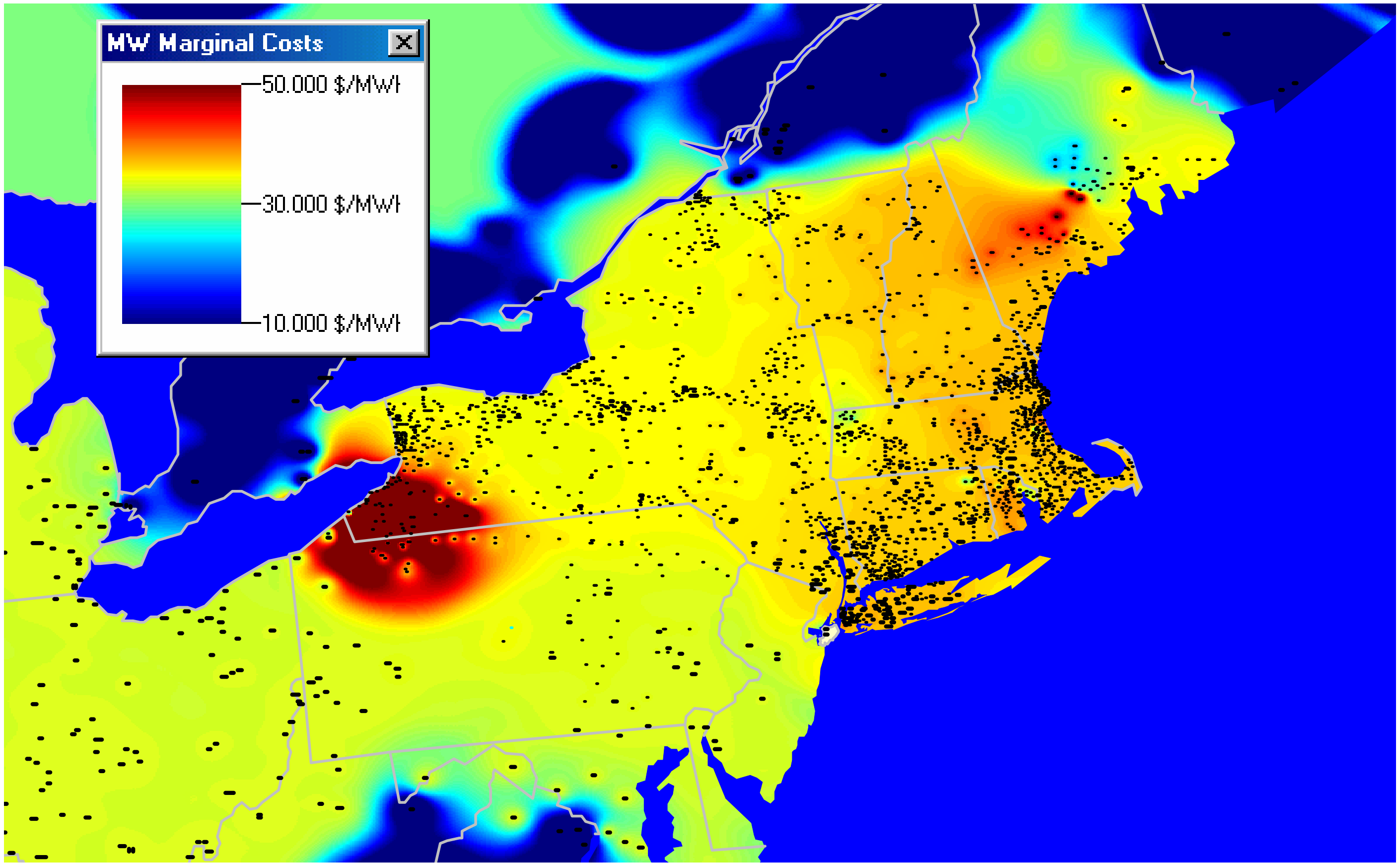


NYPP/NEPOOL Lower Voltage Transmission - Optimal Solution



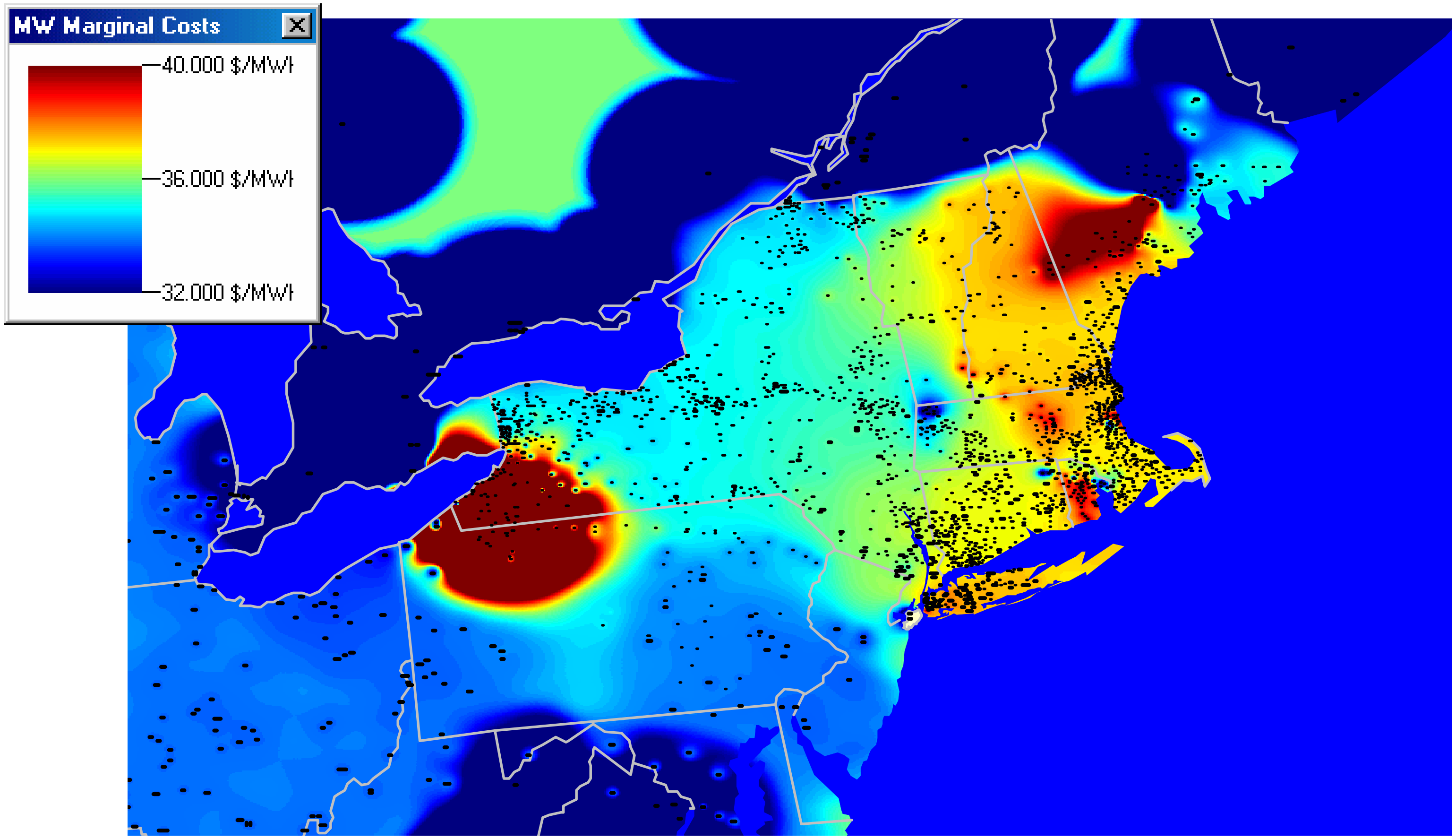
The constrained lines are shown with the large red pie charts

Bus Marginal Prices - Large Range

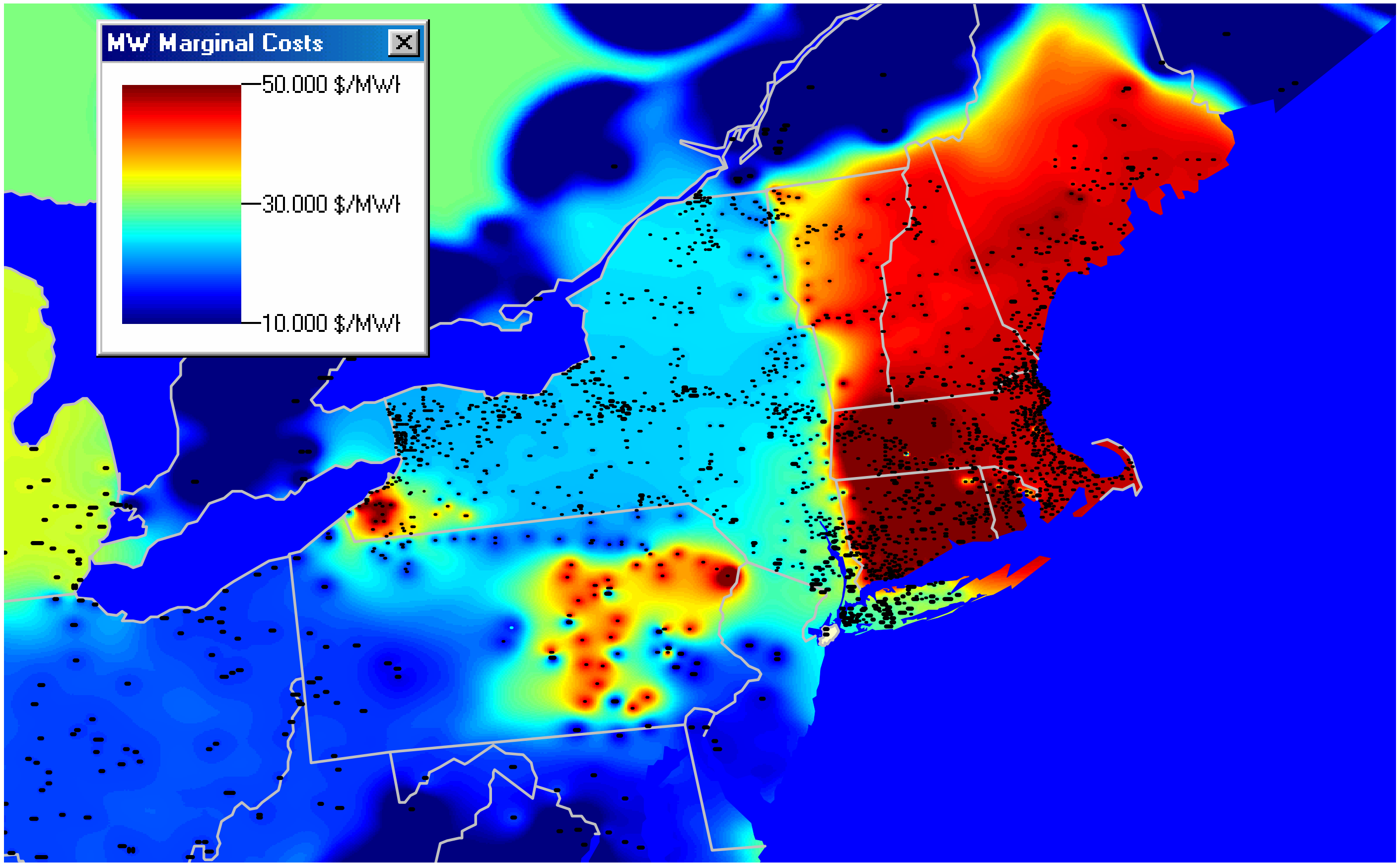


Total operating cost = $ 4,445,990 / hr

Bus Marginal Prices - Narrow Range

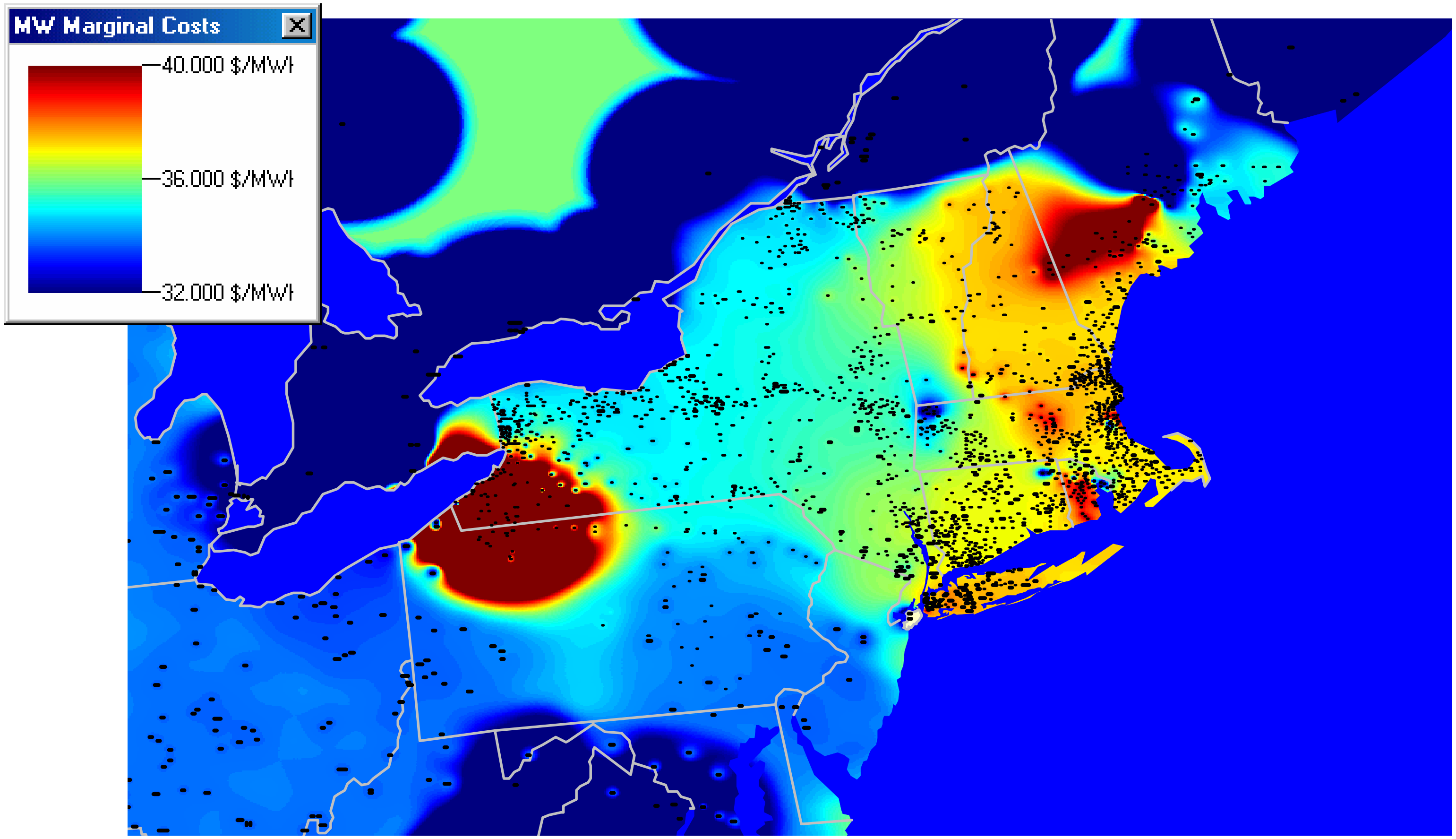


Bus Marginal Costs -- Individual Areas with Basecase Interchange

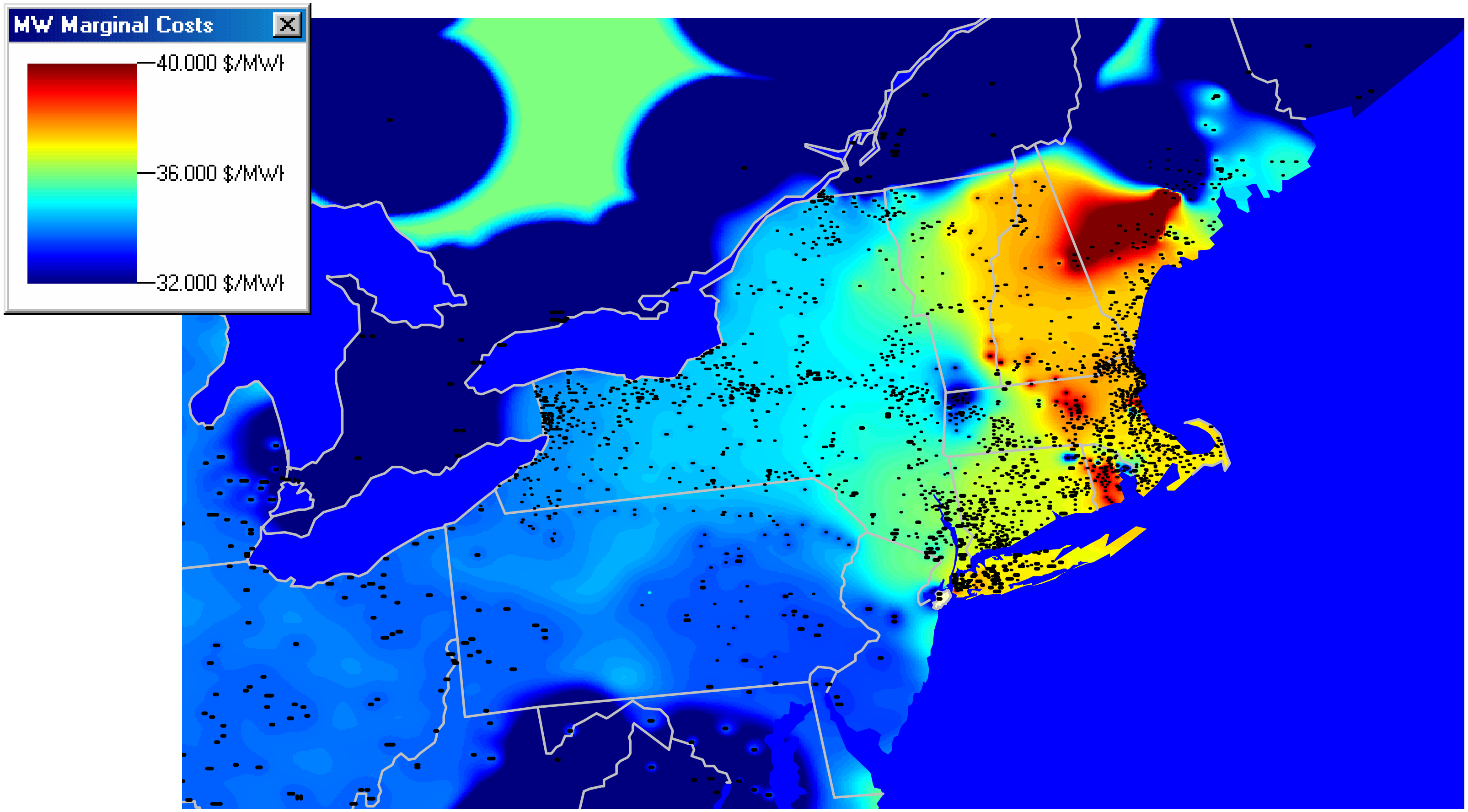


Total operating cost = $4,494,170 / hr, an increase of $48,170 / hr

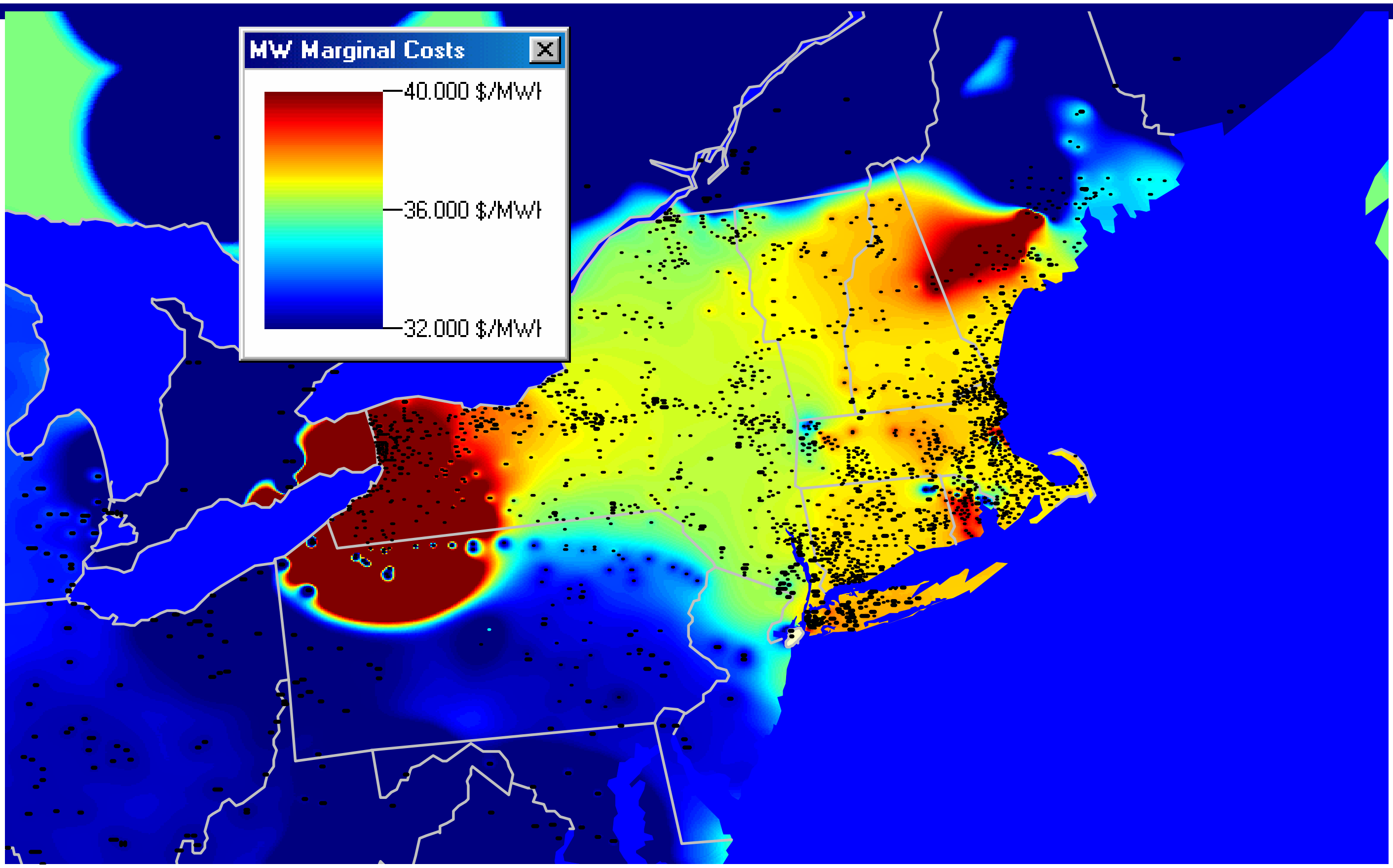
Superarea Case Again
85 MW Gen at 6642 is off



Superarea Case
85 MW Gen at 6642 is On

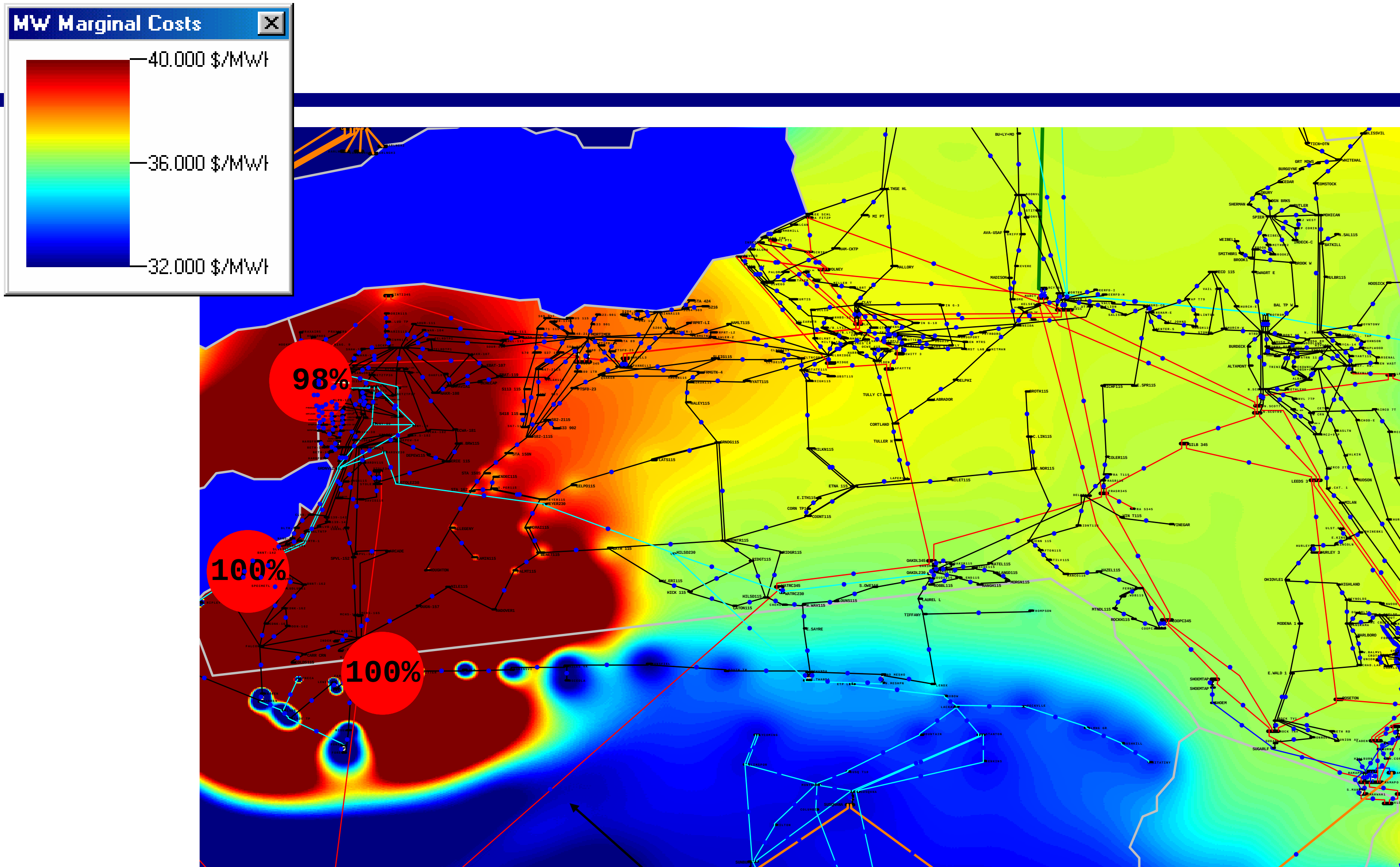


Contingency - Loss of 345 kV line from 5407 to 20379 with 500 MW



Total operating cost = $4,448,750 / hr

Western New York Detail



Outaged line (5407 to 20379)

With 85 MW of Generation at 6642