FirstRate™ Generator Cost Models

PowerWorld Client Conference

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Outline

- Motivation and Background
- FirstRate^{TM} Cost Model Source Data
- FirstRate^{TM} Limitations
- Demo

Motivation and Background

- Automatic Generation Control (AGC) is a Simulator feature with several variants:
  - Participation Factor
  - Injection Group
  - Optimal Power Flow
  - Economic Dispatch
  - Area Slack
- Most of these can be applied to an Area, Super Area, or entire Island

AGC

- Power flow assumes constant frequency and balance between load and generation
- The key role of AGC (as a software feature) is to satisfy the Area Control Error (ACE) constraint for Islands, Areas, or Super Areas
- ACE = Generation – (Load + Losses + Scheduled Exports)
- Ideally ACE = 0 for all Areas and Super Areas on control
- ACE must be zero for all Islands (Island Slack or “Swing Bus” enforces this constraint)

Areas

- Defined with the power flow case
- Every bus, generator, and load is assigned to exactly 1 area
  - Generators and loads are typically assigned to the same area as their terminal buses, but may differ
- Every Area on AGC has 1 ACE constraint

Super Areas

- Simulator object for aggregating Areas
- Each Area can belong to at most one Super Area
- Useful for ISO modeling
- ACE constraints for individual Areas that are part of a Super Area are ignored
  - Replaced with a single ACE constraint for the Super Area
  - Transactions (imports/exports) between Areas that are part of the Super Area and external Areas or Super Areas are aggregated

Area Slack Control

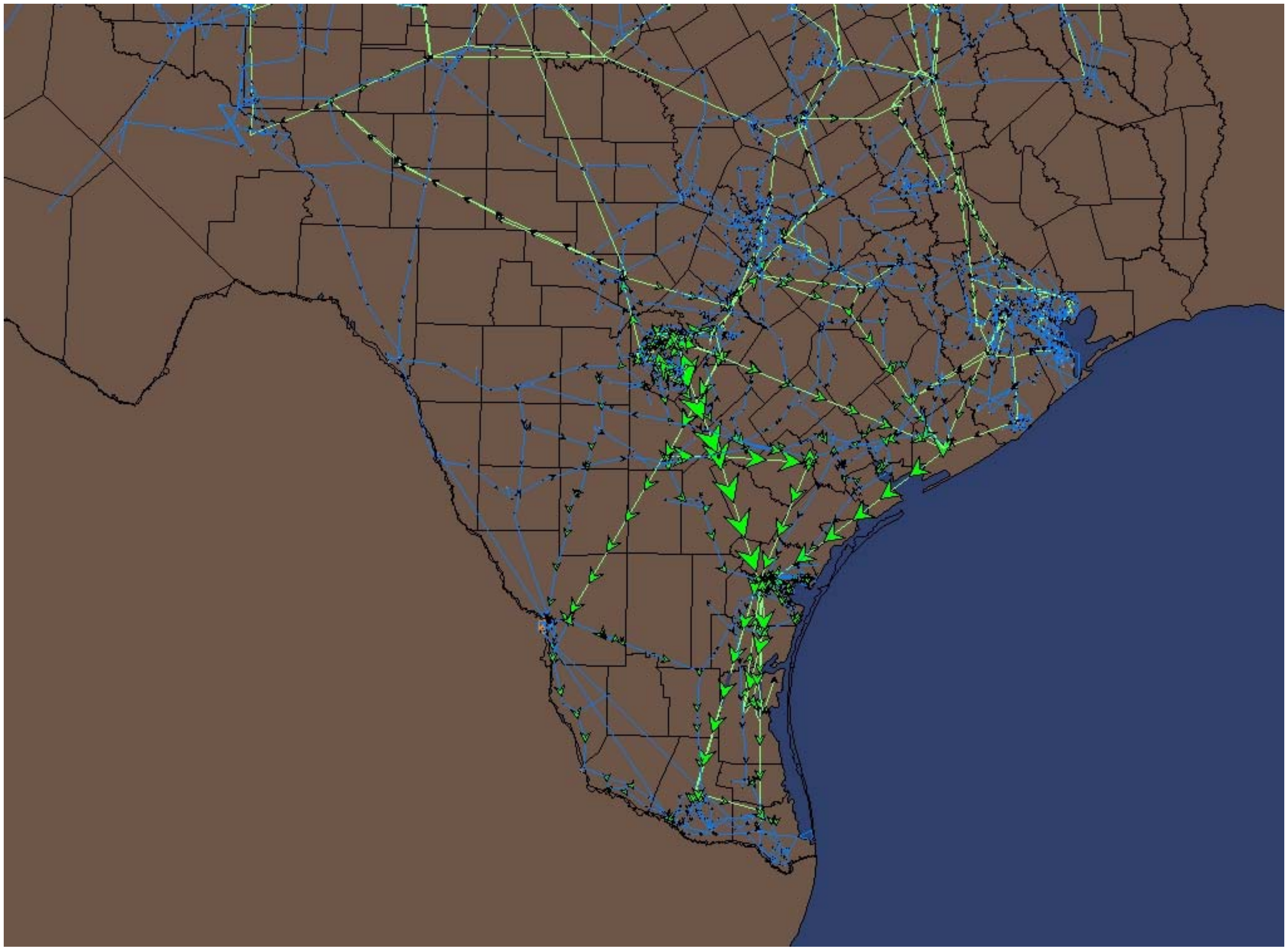
- Area Slack is commonly used in other software, but often degenerates to manual control
- If you make an adjustment to the case that affects ACE and the Area Slack generator moves too much, you manually adjust one or more other generators
- With other AGC methods, the software typically adjusts multiple generators and enforces limits

Participation Factor Control

- Participation Factor Control is a means of allowing many generators in an Area, Super Area, or Island, to adjust to maintain ACE
- Individual units must have AGC=YES and a non-zero participation factor to contribute
- ERCOT Example: transfer 200 MW from area 905 to area 908 (CPS Energy → AEP Texas Central Company)

Difference Flows:

200 MW Transfer



Optimal Power Flow

- Optimal Power Flow (OPF) seeks to meet ACE with minimal cost, subject to transmission constraints
- Can be applied to Area or Super Area
- Most significant cost component is usually generation cost
- Generator Cost Models are needed as OPF inputs
- PowerWorld can provide basic cost model parameters from public sources, formatted to import directly to FERC 715 planning models
  - Sold as “FirstRate” subscription service through Energy Visuals, Inc. (a PowerWorld affiliate)
  - http://www.energyvisuals.com/products/firstrate.html

FirstRate Cost Models

- Updated monthly with issue of US Energy Information Administration (EIA) generator data
  - Survey-Level Detailed Data Files at http://www.eia.gov/electricity/data/detail-data.html
- Formats for use with PowerWorld Simulator
  - Microsoft Excel spreadsheet
  - Simulator auxiliary file format
- Source Data mapped to power system key fields
  - Bus Number + Generator ID
  - Bus Name_NominalKV + Generator ID (not a strict key)

EIA Sources

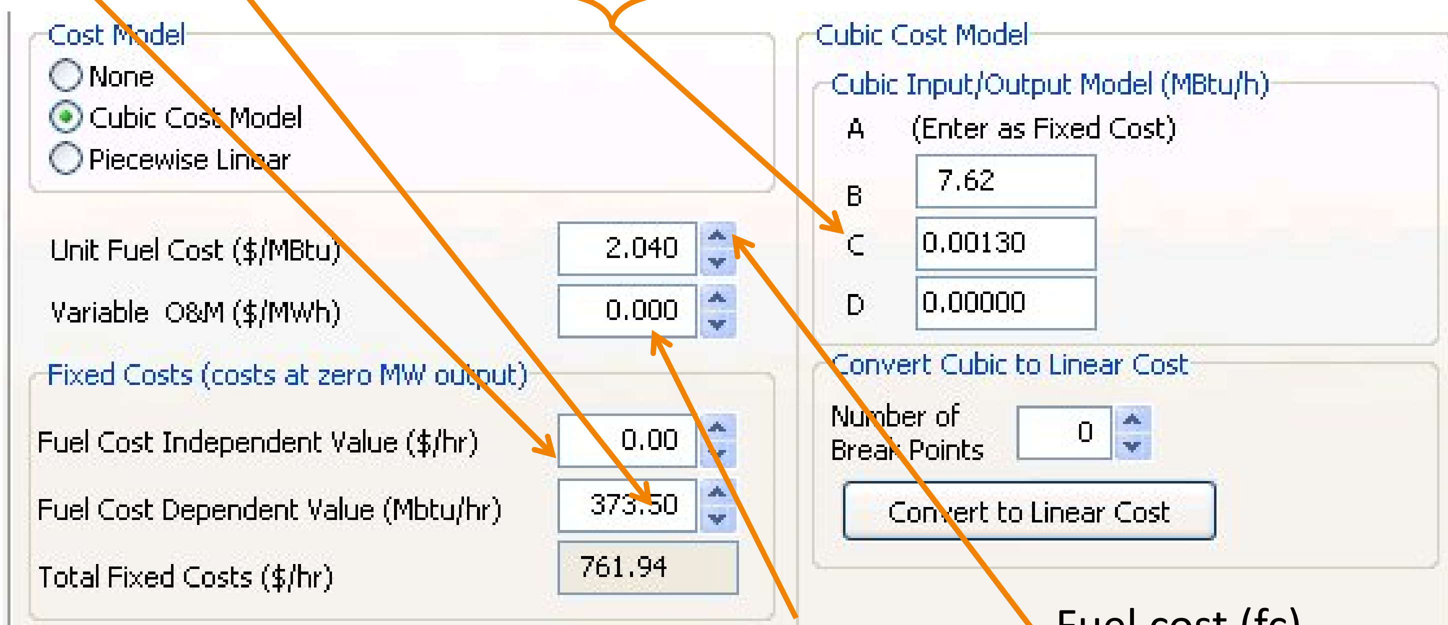
- Form 923
  - Average heat rate
  - Cost and quantity of fuels
- Electric Power Monthly
  - Summary-level information to help estimate withheld cost information
  - Planned additions and retirements
- Form 860
  - Unit-level fuel and prime mover
  - Geo-coordinates

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

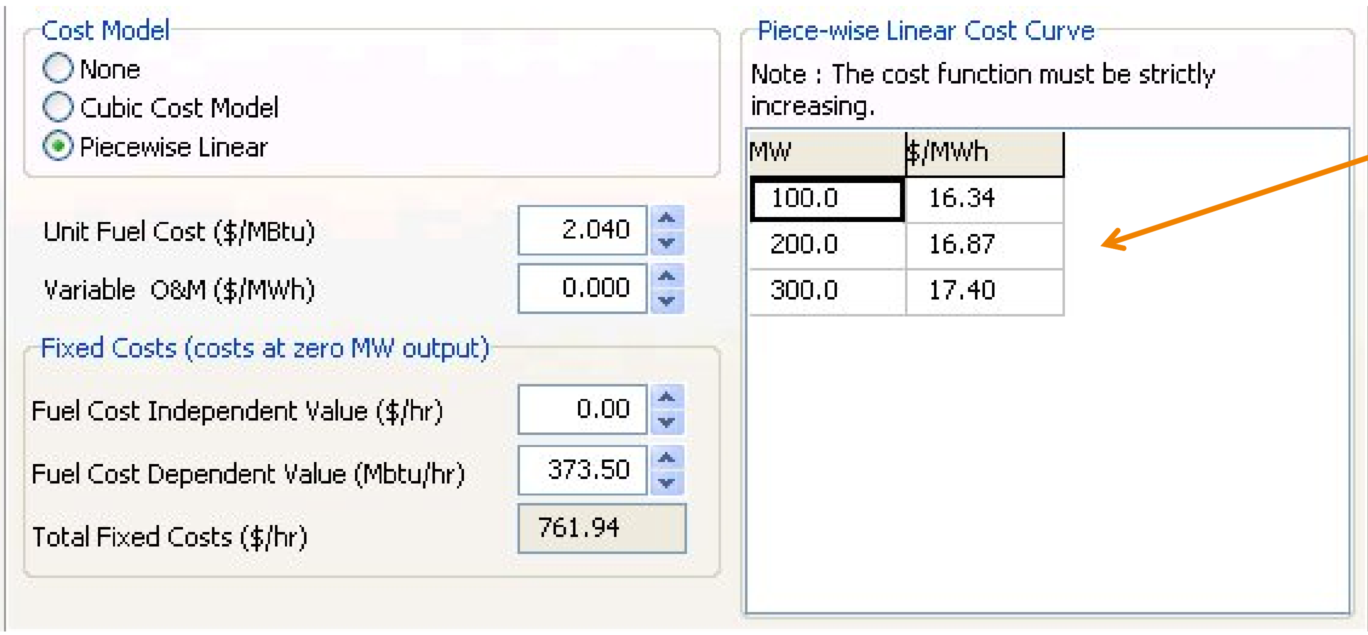


Fuel cost (fc)

Variable O&M (V_{OM})

Generator Cost Model: Piecewise Linear

- Formulated like bids, with one or more breakpoints and associated costs



Linear cost curve breakpoints and costs

FirstRate Sample Model

- Uses Simulator's Cubic form, with only the linear term populated
- Fuel Cost and Variable O&M are also included

$$C_i(P_{gi}) = (B_i * fc + V_{OM}) * P_{gi}$$

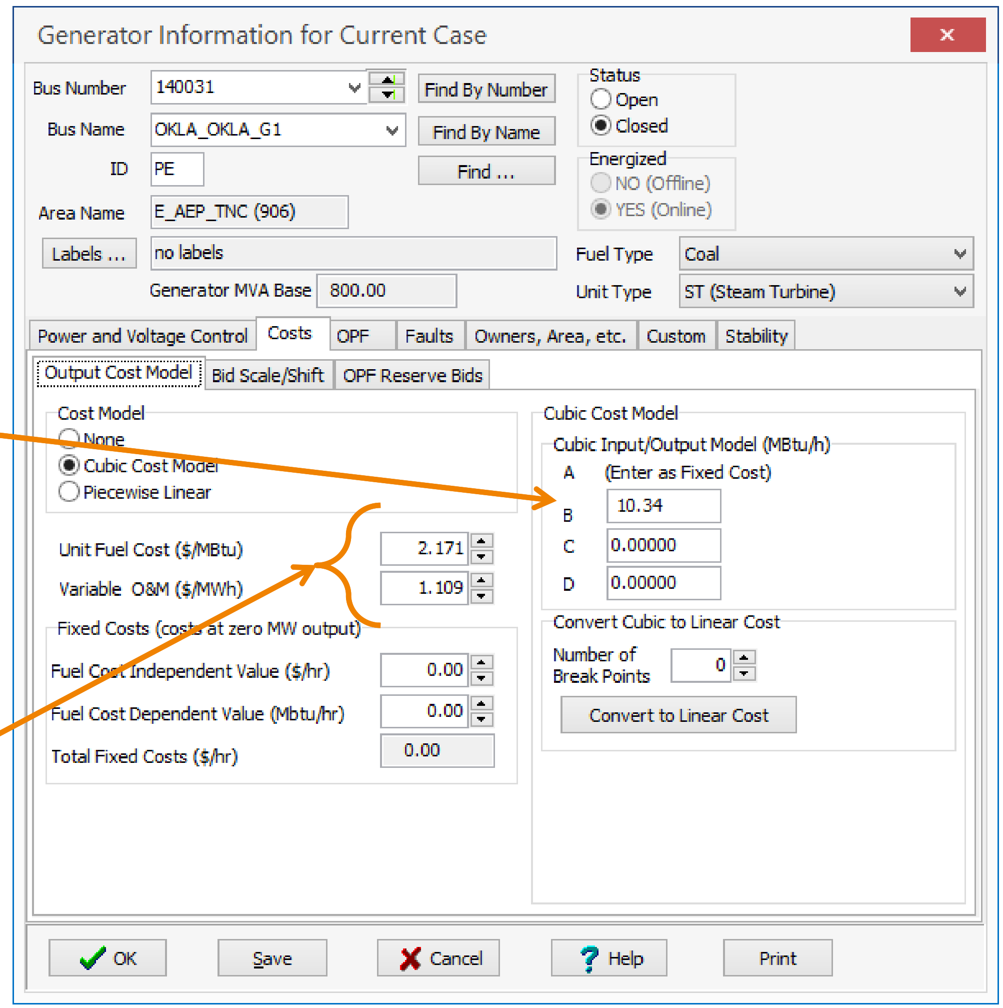
Average Heat Rate (MBtu/MWh)

Fuel Cost ($/MBtu)

Variable O&M ($/MWh)

FirstRate Sample Model

- Oklaunion Unit 1, Wilbarger County, TX
- Average Heat Rate: 10.34 MBtu/MWh
- Other Cubic Model terms are zero
- Fuel Cost and Variable O&M



Other FirstRate Information

Plant Name and Operator, Fuel Type, and Unit (prime mover) Type

Generators (Filter:Quick) | Cost Curves Cubic | Buses

	Number of Bus	Name_Nominal kV of Bus	ID	Sta	Plant Name	Plant Operator	Fuel Type	Unit Type
322	160121	COL_COLETOG1_24.00	L1	Closed	Coleto Creek	Coleto Creek Power LP	Coal	ST (Steam Turbine)
323	160131	SAN_SANMIGG1_24.00	L1	Closed	San Miguel	San Miguel Electric Coop, Inc	Coal	ST (Steam Turbine)
324	160141	VAL_VALEROG1_13.80	P1	Closed	Valero Refinery Corpus Christi West	Valero Refining Co	Coal	ST (Steam Turbine)
325	160142	VAL_VALEROG2_13.80	P2	Closed	Valero Refinery Corpus Christi West	Valero Refining Co	Coal	ST (Steam Turbine)
326	160151	INGLCOS_CTG1_18.00	PE	Closed	Ingleside Cogeneration	Ingleside Cogeneration LP	Natural Gas	CT (Combined Cycle Combustion Turbine Part)
327	160152	INGLCOS_CTG2_18.00	PE	Closed	Ingleside Cogeneration	Ingleside Cogeneration LP	Natural Gas	CT (Combined Cycle Combustion Turbine Part)
328	160153	INGLCOSW_STG_18.00	PE	Closed	Ingleside Cogeneration	Ingleside Cogeneration LP	Natural Gas	CA (Combined Cycle Steam Part)
329	160161	KOC_KOCHUPG1_12.40	P1	Closed	Corpus Refinery	Flint Hills Resources Corpus Christi LLC	Natural Gas	GT (Gas Turbine)
330	160171	FRO_FRONTEG1_18.00	C1	Closed	Frontera Energy Center	Frontera Generation Limited Partnership	Natural Gas	CT (Combined Cycle Combustion Turbine Part)
331	160172	FRO_FRONTEG2_18.00	C2	Closed	Frontera Energy Center	Frontera Generation Limited Partnership	Natural Gas	CT (Combined Cycle Combustion Turbine Part)
332	160173	FRO_FRONTEG3_18.00	C0	Closed	Frontera Energy Center	Frontera Generation Limited Partnership	Natural Gas	CA (Combined Cycle Steam Part)
333	160181	REYSHR_G1_13.80	P1	Closed	Sherwin Alumina	Sherwin Alumina Company	Other	ST (Steam Turbine)
334	160191	DUK_DUKE_GT1_18.00	C1	Closed	Hidalgo Energy Center	Calpine Corp - Hidalgo	Natural Gas	CT (Combined Cycle Combustion Turbine Part)
335	160192	DUK_DUKE_GT2_18.00	C2	Closed	Hidalgo Energy Center	Calpine Corp - Hidalgo	Natural Gas	CT (Combined Cycle Combustion Turbine Part)
336	160193	DUK_DUKE_ST1_18.00	C0	Closed	Hidalgo Energy Center	Calpine Corp - Hidalgo	Natural Gas	CA (Combined Cycle Steam Part)
337	160201	LGE_LGE_GT1_18.00	PE	Closed	Gregory Power Facility	DPS Gregory LLC	Natural Gas	CT (Combined Cycle Combustion Turbine Part)
338	160202	LGE_LGE_GT2_18.00	PE	Closed	Gregory Power Facility	DPS Gregory LLC	Natural Gas	CT (Combined Cycle Combustion Turbine Part)
339	160203	LGE_LGE_STG_13.80	PE	Closed	Gregory Power Facility	DPS Gregory LLC	Natural Gas	CA (Combined Cycle Steam Part)
340	160211	OXY_OXY_CCG1_13.80	PE	Closed	Corpus Christi	Equistar Chemicals LP	Natural Gas	GT (Gas Turbine)

EIA Form 923: Fuel Cost

- Oklaunion coal purchases in January 2015, from the EIA source spreadsheet:

U.S. Department of Energy, The Energy Information Administration (EIA)
Fuel Receipts and Cost Time Series File, 2015 October
Sources: EIA-923 and EIA-860 Reports

	YEAR	MONTH	Plant Id	Plant Name	Plant State	Purchase Type	Contract Expiration Date	ENERGY_SOURCE	FUEL_GROUP	QUANTITY	Average Heat Content	FUEL_COST
56	2015	1	127	Oklaunion	TX	C	115	SUB	Coal	29,383.0	17.050	215.4
57	2015	1	127	Oklaunion	TX	C	115	SUB	Coal	364.0	17.056	210.9
58	2015	1	127	Oklaunion	TX	NC	1215	SUB	Coal	14,867.0	17.622	227.1
59	2015	1	127	Oklaunion	TX	S	.	SUB	Coal	121.0	17.336	221.9
60	2015	1	127	Oklaunion	TX	S	.	SUB	Coal	134,392.0	16.672	224.9

Page 5 Fuel Receipts and Costs | Page 6 Pl ...

- FirstRate incorporates the last 12 months of available data (rolling, with each update)

EIA Form 923: Heat Rate

- Oklaunion fuel consumption and MWh output

U.S. Department of Energy, The Energy Information Administration (EIA)
EIA-923 Monthly Generation and Fuel Consumption Time Series File, 2014 Final Release
Sources: EIA-923 and EIA-860 Reports

					Year-To-Date		
	Plant Name	Operator Name	Reported Prime Mover	Reported Fuel Type Code	Elec Fuel Consumption MMBtu	Net Generation (Megawatthours)	YEAR
152	Oklaunion	Public Service Co of Oklahoma	ST	DFO	65,362	6,012	2014
153	Oklaunion	Public Service Co of Oklahoma	ST	SUB	33,194,079	3,210,629	2014
154	Cross	South Carolina Public Service Authority	ST	BIT	117,580,391	11,870,582	2014
155	Cross	South Carolina Public Service Authority	ST	DFO	219,019	21,998	2014

Page 1 Generation and Fuel Data | Page 2 Stocks Data ...

- FirstRate incorporates the last calendar year of available data

Non-Regulated Plants

- Fuel consumption and net generation are generally available
- Cost of fuels is not publicly available
  - FirstRate compiles averages from the most complete set of comparable characteristics for each: fuel type, prime mover, plant state, fuel source state, mine type, purchase type (contract vs. spot market), etc.
  - If these are not available, use state, regional, or national average by broad fuel class (coal, natural gas, petroleum, etc.)

EIA Electric Power Monthly

- Provides broad national, state, and regional-level averages for utility and non-utility plants

Table 4.10.A. Average Cost of Coal Delivered for Electricity Generation by State, November 2015 and 2014
(Dollars per MMBtu)

Census Division and State	Electric Power Sector			Electric Utilities		Independent Power Producers	
	November 2015	November 2014	Percentage Change	November 2015	November 2014	November 2015	November 2014
West South Central	2.04	2.08	-1.9%	2.25	2.18	1.79	1.97
Arkansas	W	W	W	2.25	2.45	W	W
Louisiana	W	W	W	3.85	3.20	W	W
Oklahoma	W	W	W	1.98	1.94	W	W
Texas	1.88	1.98	-5.1%	2.07	2.01	1.75	1.96

Non-Regulated Plant Example

- Martin Lake Unit 1
  - Sub-bituminous purchased from WY on contract
  - Lignite purchased from TX on contract and spot market
- Compare to average price paid by Texas utility plants with similar source characteristics:

FuelType	PlantState	MineState	MineType	Contract	AvgCost	QuantityReceived	Samples
LIG	TX	TX	S	C	2.662	75,359,682	24
SUB	TX	WY	S	C	2.016	442,344,283	191

Non-Regulated Plant Example

- Also incorporate ratio of average non-utility price paid to utility price paid to estimate
- Compute weighted average cost of all types of coal purchases

PlantCode	FuelType	PlantStat	MineState	MineType	Contract	HeatContent	MBtuReceived	Cost
6146	DFO	TX	All	All	S	5.8	66300	17.17
6146	LIG	TX	TX	S	C	13.891	34564122	2.409
6146	LIG	TX	TX	S	S	13.723	67757342	2.409
6146	SUB	TX	WY	S	C	16.73	15170562	1.824

- Distillate fuel oil is a secondary source
  - Used for les that 1% of MWh output
  - Ignored by FirstRate

Data Processing

- Removal of statistical outliers
  - Could be caused by data entry errors, misplaced decimals, wrong units, etc.
  - Averages and standard deviations are considered for each fuel and prime mover type, and within each plant

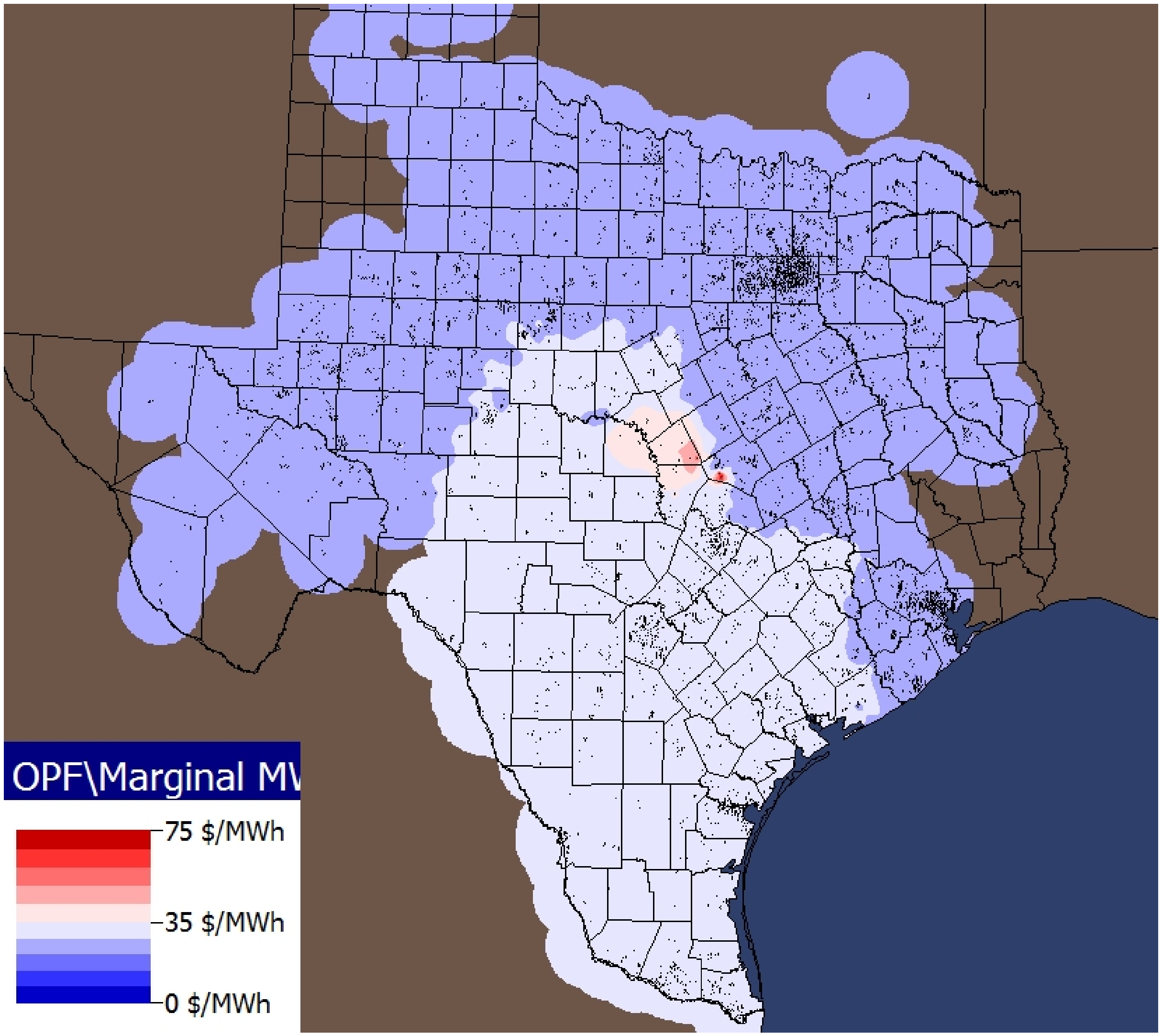
Limitations

- Wind, solar, and hydro units
  - do not have fuel costs or heat rates
  - *Cost Model* field is set to "None" in FirstRate
- Combined cycle units have uniform figures for all components
  - Simulator does not have algorithm to coordinate dispatch of combustion turbine and steam units
  - Key result for OPF is total output of all units
- No explicit source for plant-level Variable O&M in public EIA databases
  - Could be partially estimated from emissions
  - FirstRate uses industry averages
- Generally available only for FERC 715 planning models; maintenance challenges with other models
  - No persistent key fields
  - Generator information obscured or redacted

Demo: ERCOT Model

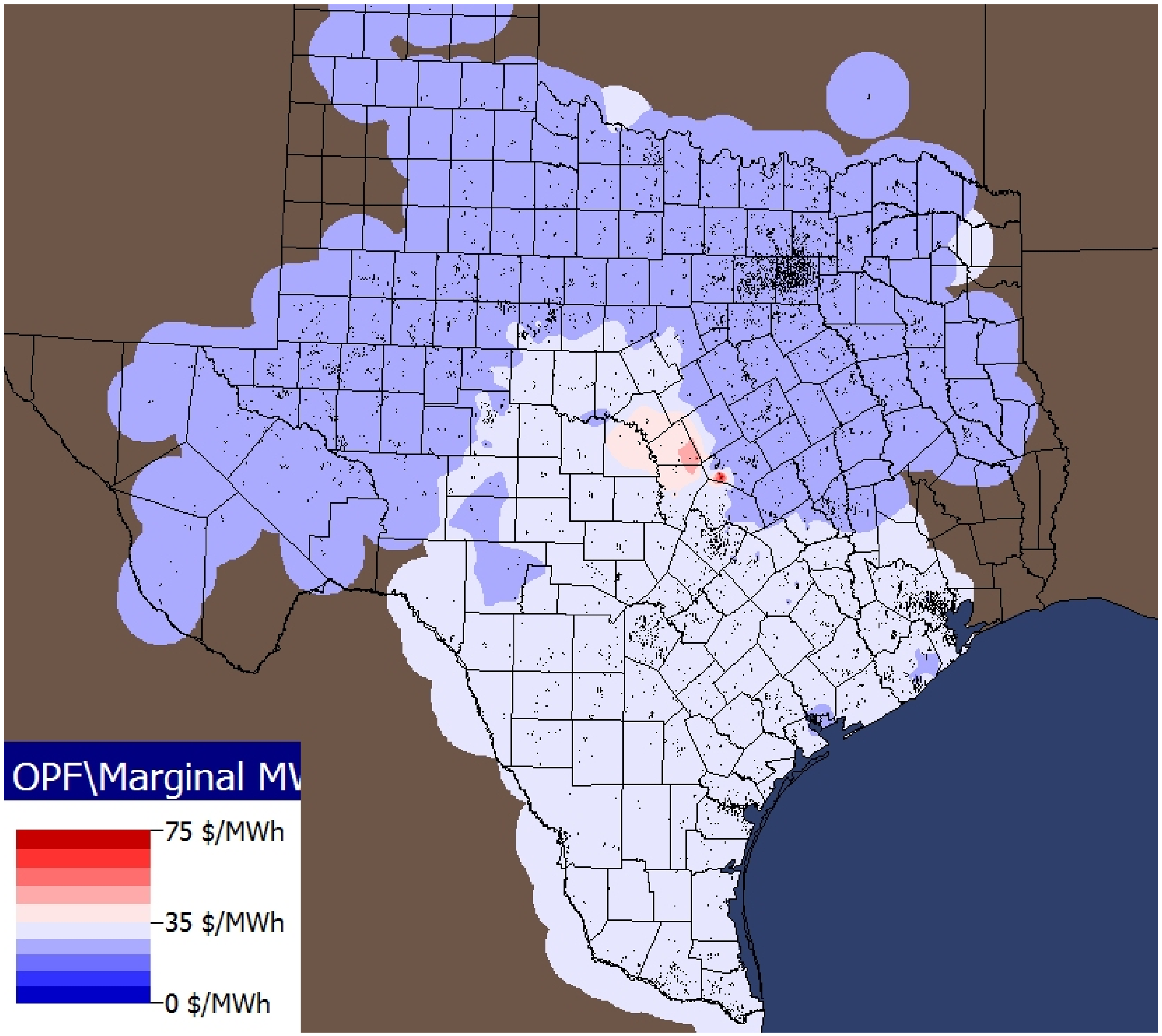
- 15DSA_2016_WIN1_TPIT_Final_10152014 (2016 Winter Peak)
- OPF solutions without and with contingency constraints

OPF Solution: Base



OPF Solution:

Contingency Constraints



More Information

- Download sample files and other documentation at

  http://www.powerworld.com/services/generator-cost-models