Production Cost Modeling

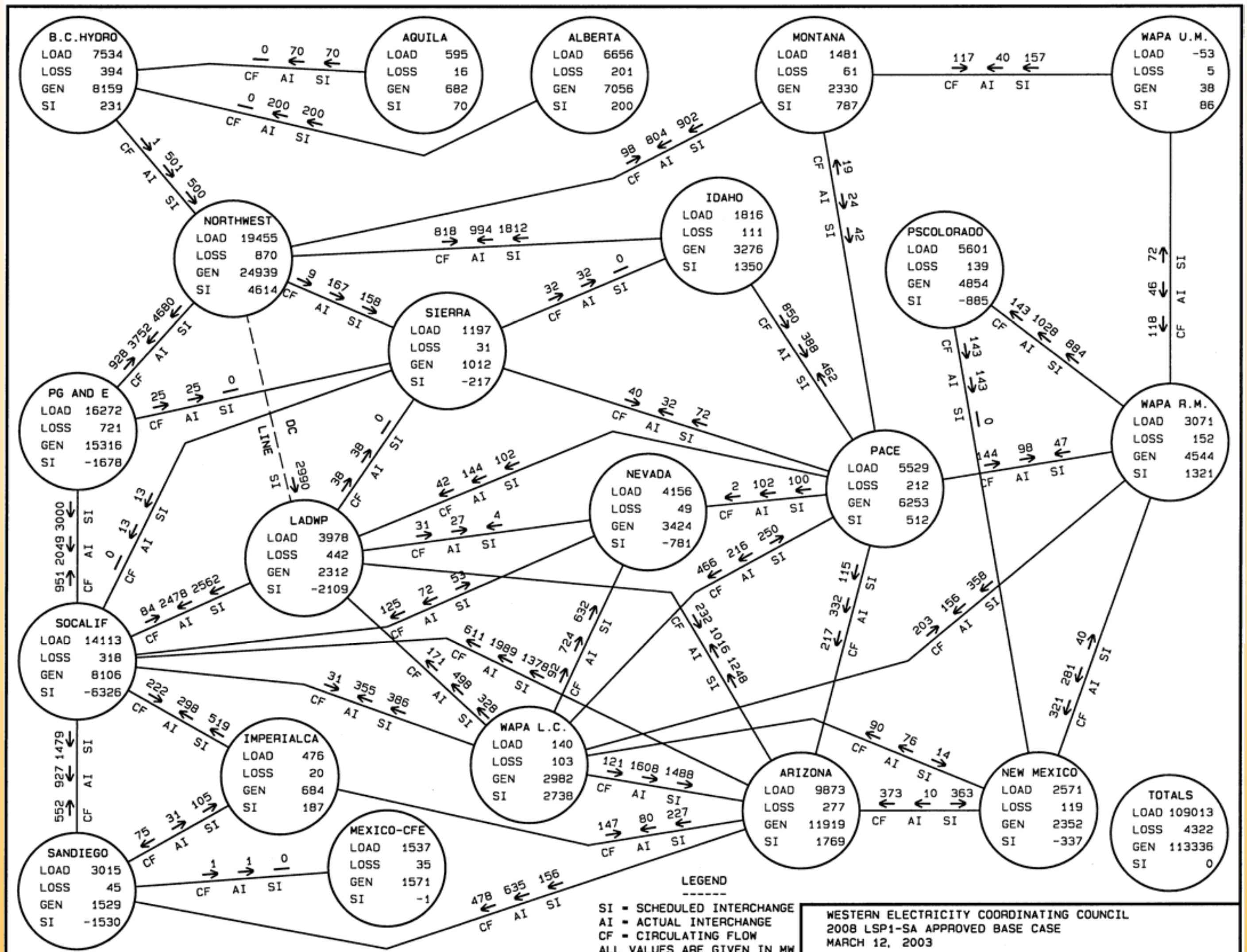
PacifiCorp

Session 2

Load Forecast Data & Load Modeling

Kurt Granat

Powerflow Areas



Load Forecast Data

- For each powerflow area
- Three types of load data:
  1. Monthly (or annual) peak and energy forecast
  2. Hourly shape of load (e.g. hourly forecast or FERC 714)
  3. A spatial distribution of the load in the powerflow area
- The data is needed for each powerflow area modeled

Peak & Energy Forecast

This sets the maximum MW peak and the total MWhs that the model needs to cover in a time period (typically a year).

- Depending on the model’s requirements may be
  - annual peak & energy
  - an annual growth rate from base
  - monthly peak and energy.

Hourly Load Shape

Transmission loadings vary with hourly loads. To get a reasonable hourly shape either

- Develop an hourly load forecast
- Use historic hourly loads (e.g. FERC 714 report)
  - Adjust to forecast by an Affine Transformation

Spatial Distribution of Loads

- Powerflows include a distribution of loads for the load condition modeled (e.g. Light Spring or Heavy Summer) based on the operators experience.
- Fixed percentages can be developed based on the powerflow data.
- If the total area load is 1000 MW in the powerflow, and 100 MW is at a bus, that bus gets 10% of the hourly load for the area for <u>all</u> modeled hours.
- Would like to bring in several load distributions –
  - E.g. Heavy Summer, Light Summer, Heavy Winter, etc

Sources of Forecast Data

- WECC Load & Resource Report
  - Regional Peak and Energy forecasts
- FERC 714 Reports
  - Historic hourly shapes by control areas or companies
  - Sometimes has forecast data included
- WECC Powerflow (FERC 715)
  - Distribution of loads across areas & grid

Problems with Data

Some errors cannot be helped, if only because collecting data and setting up the model takes time. By the time you're ready to start, things have changed.

- WECC data is for Summer peak, Winter peak, and annual energy for six regions not powerflow areas
  - Need peak/energy numbers for each powerflow area
  - Need to develop data & review
- Need for More Review of data
  - Some SSG-WI 2013 monthly forecasts were below the 2008 estimates on both peak and energy!
- Some regions might need more powerflow Areas
  - RMATS expanded the model to 33 areas.

Transmission Network and Constraint Modeling

Jamie Austin

Overview

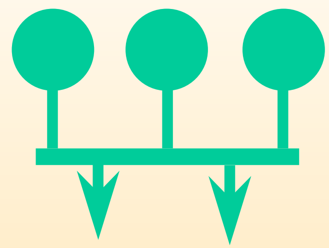
- Types of models
- Model Inputs
- Background and Terminology
  - What is the objective function of a typical model?
  - How paths/interfaces constraints are created?
  - What is a nomogram?
  - What is “security constrained”?

Source: ABB

Types of Models

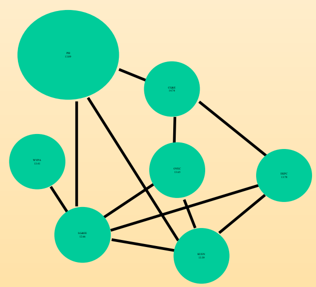
Supply Curve

- Ignores transmission
- OK for small control areas
- No congestion, no tariffs



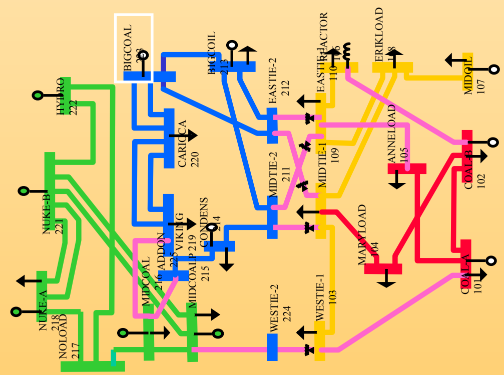
'Bubble' view

- Major interconnects only
- Transportation model
- Better, but…
- Power doesn't flow like that!



Detailed view

- Very complex
- Only way to track line flows



Poor

Accuracy

Good

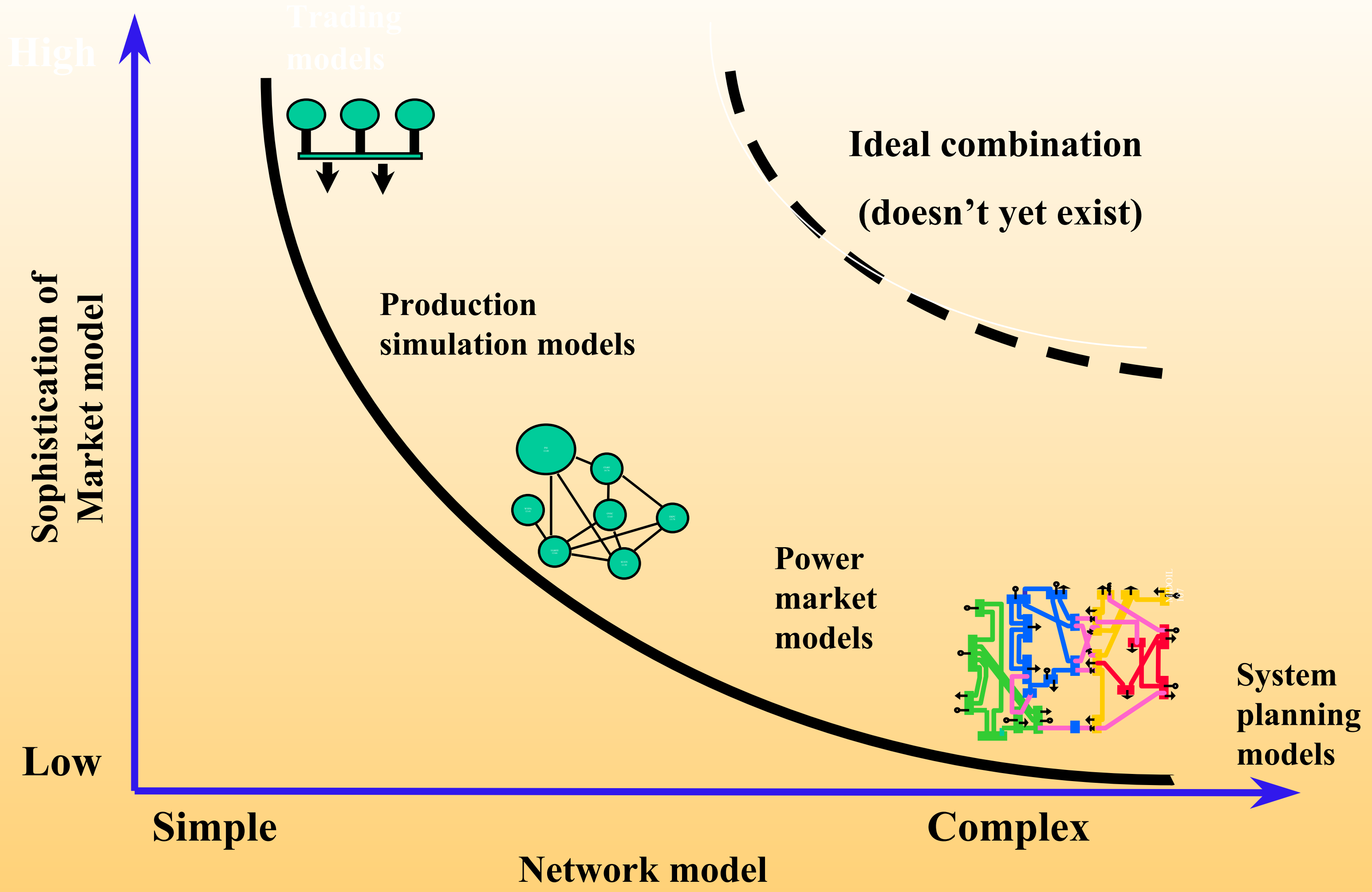
Simple

Ease

Difficult

Source: ABB

Trade-off in Market vs Network modeling



Source: ABB

DC OPF: Transmission network and constraint modeling

DC Optimal Power Flow: What is it?

Transmission constrained economic dispatch w/ linearized power flow model

Why Linearize?

- *Speed:* Enables fast Linear Program (LP) formulation
- *Convergence:* LP always a convex problem
- *Accuracy:* Flows on HV circuits modeled well

AC OPF is ideal, but may not solve

Data Inputs

Transmission Data Required (1)

- Transmission facility (buses, lines, transformers, etc) thermal limits using normal ratings
- Transmission facility limits considering (N-1) contingencies using emergency ratings
- Paths and nomograms limits due to voltage and stability problems
- Paths and nomograms limits considering (N-2) contingencies
- Data is obtained from solved power flow cases

Source: ABB

Transmission Data Required (2)

AC Transmission Lines

- Location: Bus connections
- Reactance: for Flow Model
- Resistance: for Losses
- Thermal Capacity
- Same for transformers

Powerflow Data (14K bus)

Data format: PSS/E, PowerWorld, GE, Others

Data source: User model or FERC 715

Transmission Data Required (3)

HVDC

- DC lines are modeled as matched pair of withdrawal (or load) MWs and injection (or generation) MWs taking place at fixed points on the grid. The model doesn't see any lines or control devices, only MWs in and matched MWs out. The model will simply move the MWs to minimize costs (moving the power to higher LMPs) and assumes that what we enter will work.
  - Act like valved flow
  - Capacity
  - Losses
  - Operating Schedule

Transmission Data Required (4)

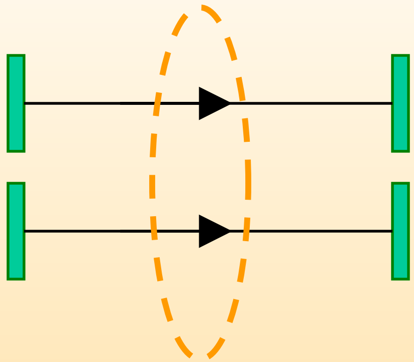
Phase Shifting Transformers (Phase Shifters)

- Reactance
- Thermal Capacity
- Angular Limits
- Schedule
- ‘Cost for moving’

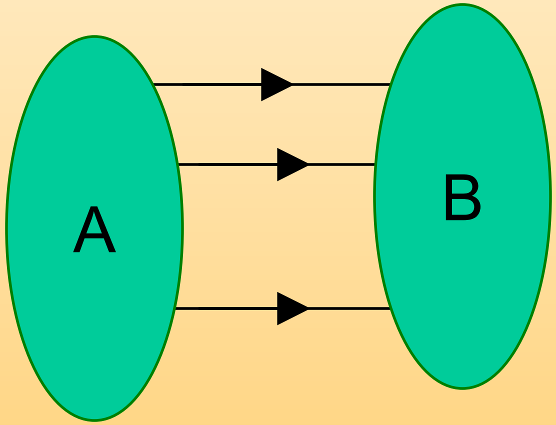
Transmission Data Required (5)

Path (Interface, TOT) Definition

- Which Lines (AC, DC, and/or PS)
- What Direction



Example: WECC Path Rating Catalog



Background and Terminology

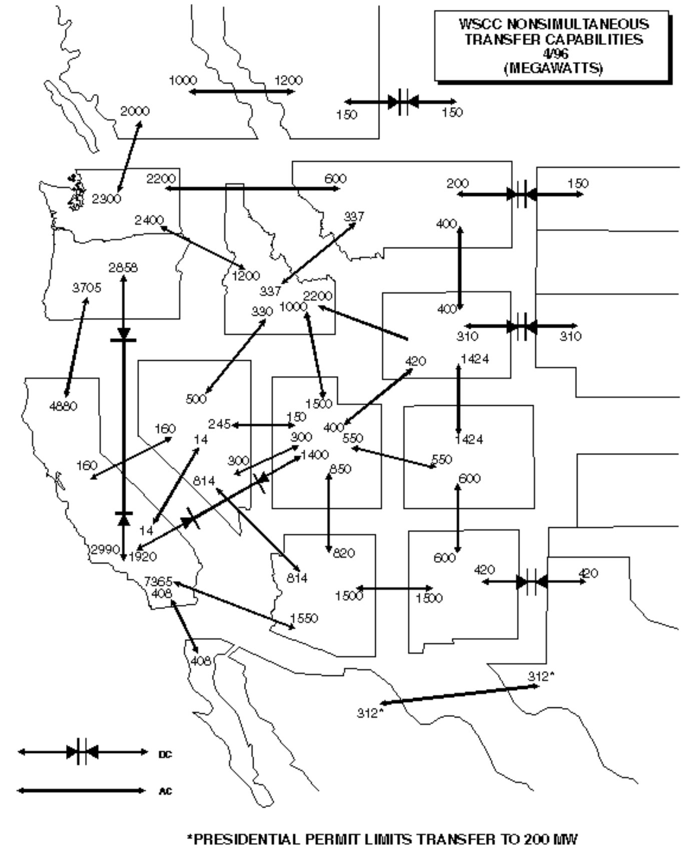
What is the Optimization Objective of a Typical Model?

- **Minimize production costs**
- **Subject to**
  - DC load flow
  - Generation constraints
  - Line limits
  - Transmission path limits
  - Limits for Phase Shifters, DC lines
- **Solution yields**
  - Lowest production costs, and
  - Spot prices, shadow prices

How are Transmission Constraints Developed?

- Generation dispatch
- Magnitude and distribution of load
- Reliability measures
- Level of system security
- Angular Stability
- Voltage Stability
- Area interchange limits
- Treaties
- Imposed TTC limits

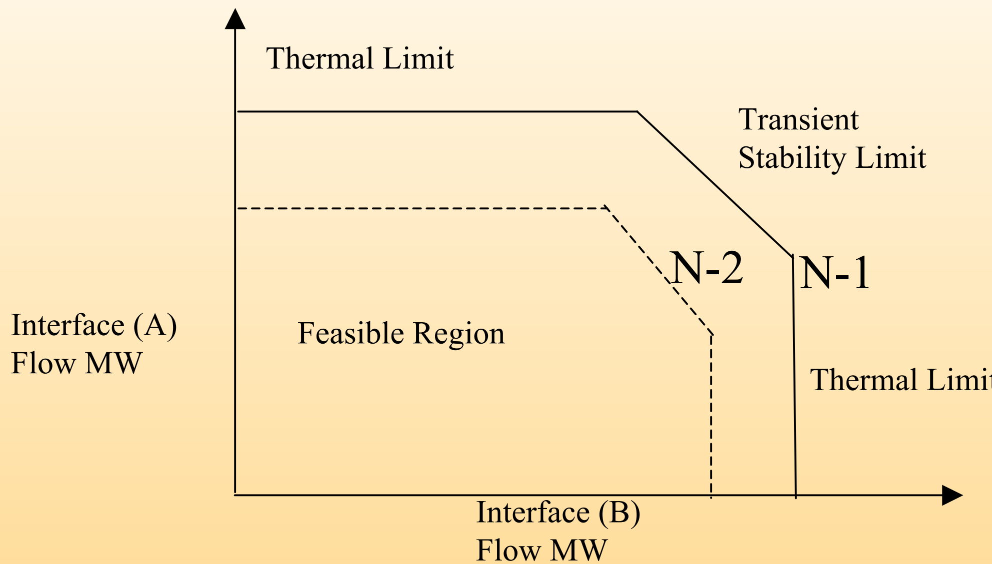
WECC Security Constraints



What is a Nomogram?

Nomograms define the operating limit of transmission system:

- Simultaneous transfer limits across two interfaces (i.e., interfaces A & B)
  - Thermal limits
  - Voltage Security
  - Voltage Stability
  - Inertial limits
  - N-1 and relevant N-2 contingencies
- Transmission access impacts each limit and is addressed using appropriate analysis (i.e., Power Flow analysis, Transient Stability, Voltage Stability.)



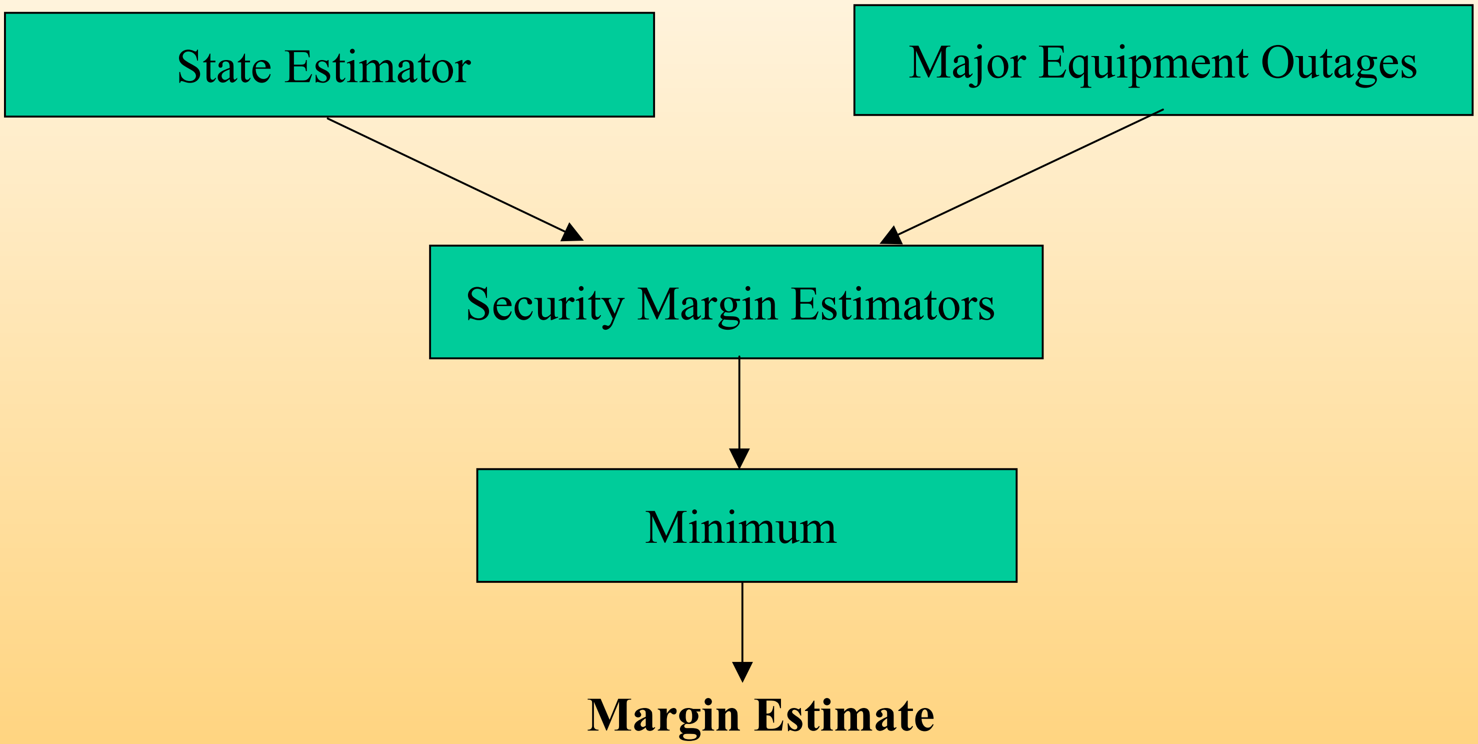
What is Security Constrained?

- Optimal Power Flows (OPF) have been used in planning real time operation for active and reactive power dispatch (1) to minimize generation costs and system loses (2) to improve voltage profile. Traditionally, these two problems have been assumed decoupled and thus treated independently.
- As systems operate closer to its stability limits (i.e., closer to the voltage collapse point) due to market pressures, the decoupling assumption become obsolete
- OPF formulations that “optimize” a system considering both costs and voltage stability criteria to minimize operating costs and losses while maximizing the “distance” to voltage collapse conditions

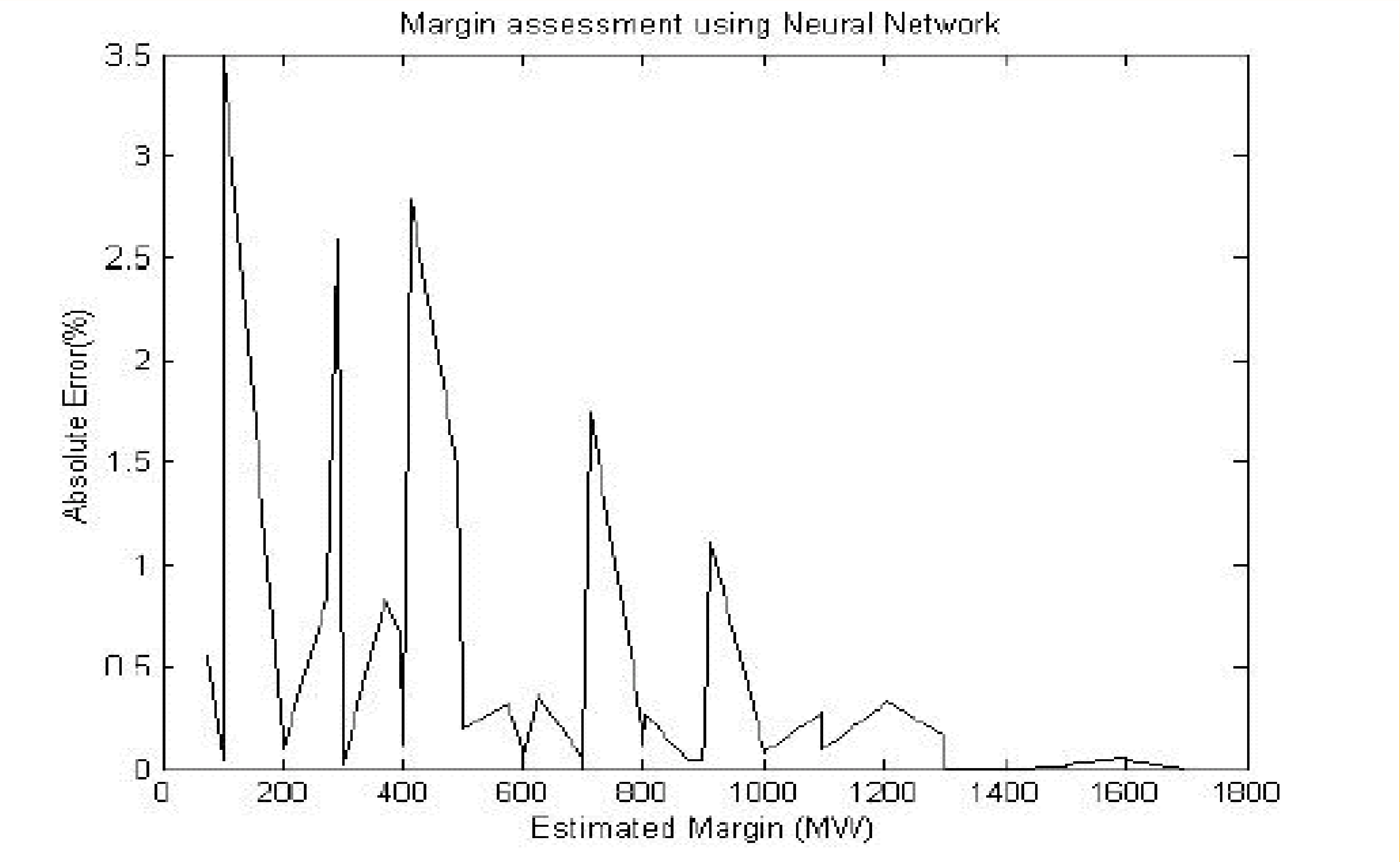
Security Tools

- Power system model
- Network reduction
- SCADA
- Power Flow
- State Estimation
- Static contingency analysis
- Security constrained dispatch
- Optimal Power flow (OPF)
- Security constrained OPF
- Voltage/VAR dispatch
- Transient stability analysis
- Mid-term stability analysis
- Long-term stability analysis
- Eigenvalue analysis

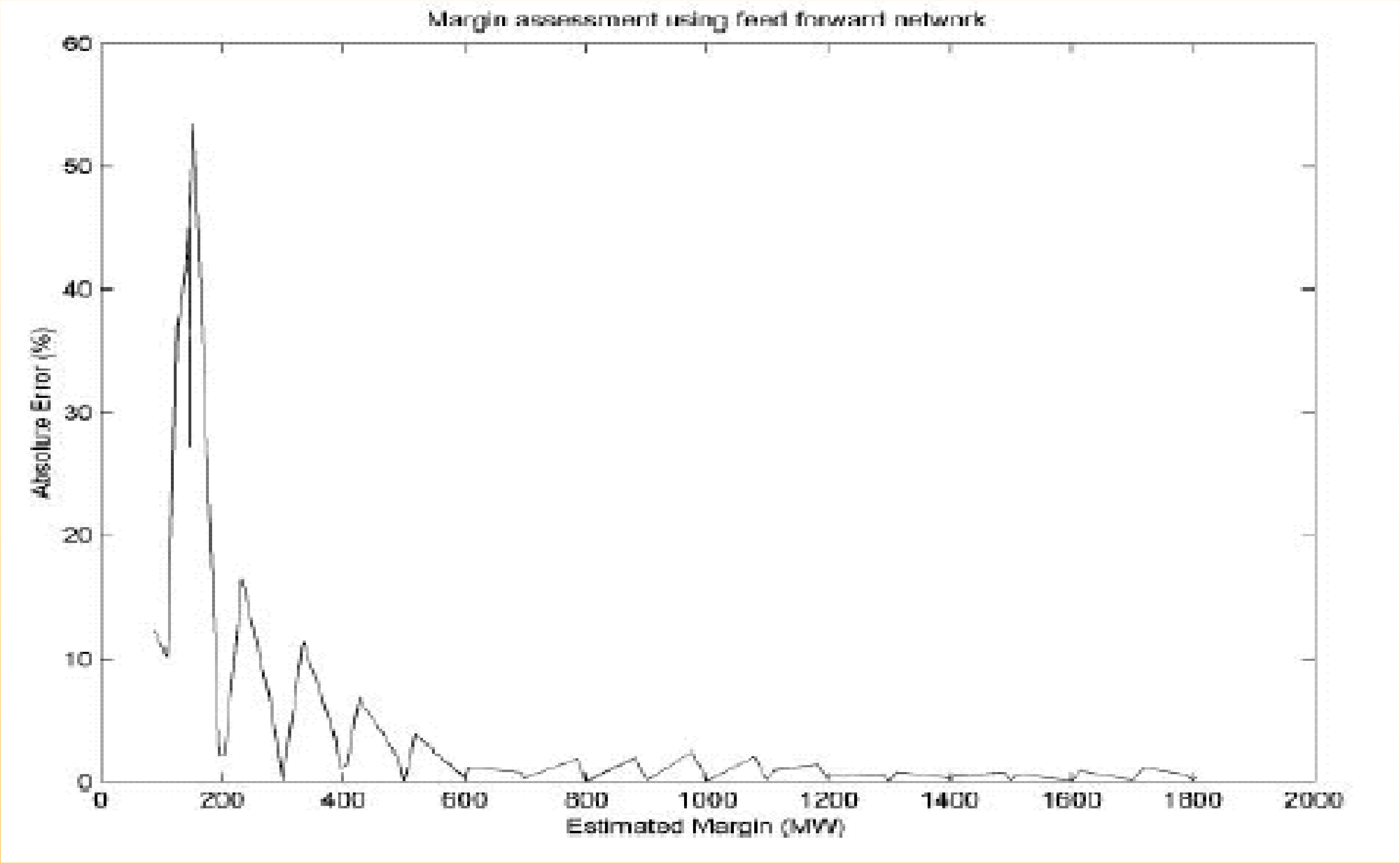
Security Margin Estimation



Voltage Security Margin Results (WECC)



Dynamic Security Margin Results (WECC)



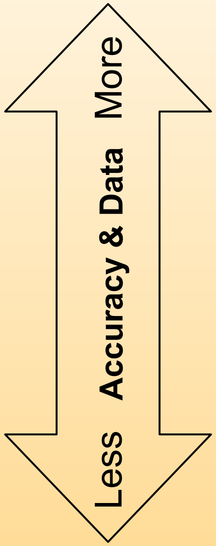
Thermal Generation Modeling

James Gall

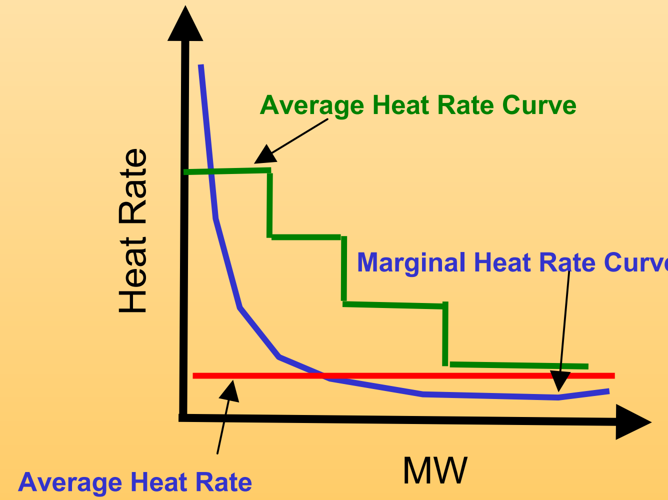
Key Data Inputs

- Plant Characteristics
  - Location (bus/area)
  - Start/end dates
  - Nameplate/maximum dependable operating capacity (and minimum dispatch)
  - Fuel/plant type
  - Heat rate
  - Commitment logic
  - Planned outage schedule
  - Forced outages
  - Reserve capability (spinning and/or non-spinning)
- Cost/Pricing
  - Fuel cost ($/MMBtu)
  - Variable O&M ($/MWh)
  - Startup cost or MMBtu for cycling plants
  - Environmental adders ($/MWh)
  - Fixed costs

Heat Rates



- Three different types of ways to input heat rates- this will depend on the model and its level of accuracy
  1. Marginal Heat Rate Curve
     - Heat Rate for each MW of dispatch
  2. Average Heat Rate Curve
     - Piece-wise curve: usually 2 – 4 estimates for dispatch levels.
  3. Average Heat Rate
     - Single estimate for all dispatch. Average of normal plant dispatch levels



Commitment Logic

- Depending on the model's area of focus, the level of commitment logic varies
- Required Inputs for Commitment Logic
  - *Initial state*: plants status for the hour before the first hour of the model simulation
  - *Minimum down/up time*: controls how much the plant can cycle; coal plants have longer down times than a gas fired plant
  - *Must run:* plants that must run not matter if economic or not; such as a QF or plant under contract
  - *Ramp Rate*: controls how fast a unit can move from one dispatch level to another; coal plant: 4-5MW/min, CCCT: 2.5MW/min, SCCT: 2.5 – 5MW/min

Plant Outages

- Planned maintenance
  - Manually entered schedule a plant will be out for maintenance
- Forced outages, the outages range from 1-10% depending on plant type and age
- Two ways to model forced outages
  1. *Derate*: percent of maximum capacity withheld from production; The problem with this methodology is that transmission implications are not shown when all plants are operating at full capacity.
  2. *Monte Carlo*: Random outages based upon percent of time per year with an unplanned outage

Simple Example: Need 50MW to serve load

- Two plants with available generation:
  1. Cold start gas single cycle unit with a fuel price of $6.00 MMBtu and the heat rate of 11,000; start up cost of $120
  2. Ramp up a gas combined cycle with a fuel price of $6.25 MMBtu, heat rate is 7,500
- Program will choose lowest cost plant that has available transmission to dispatch
- Cost to serve load
  1. simple cycle: $3,420
  2. combined cycle: $2,344

Single Cycle Calculation

$$\left(\left(\frac{\$6.00}{\text{MMBtu}} \times \left(\frac{11{,}000\ \text{MMBtu}}{\text{KWh}} \times \frac{1}{1000}\right)\right) \times 50\ \text{MW}\right) + \$120$$

Combine Cycle Calculation

$$\left(\frac{\$6.25}{\text{MMBtu}} \times \left(\frac{7{,}500\ \text{MMBtu}}{\text{KWh}} \times \frac{1}{1000}\right)\right) \times 50\ \text{MW}$$

Modeling Hydro and Wind Generation

Kurt Granat

Hydro Modeling

Some hydro is run of river, some has pondage, some has considerable storage (years of river flow)

- Limited energy plant (optimize on revenue)
  - Hard to do with a large number of plants
- Peak shaving algorithm
  - Max MW for time period
  - Total MWh for time period
  - Min MW for period (run-of-river portion)
- Fixed dispatch
  - Need to create a dispatch or load history

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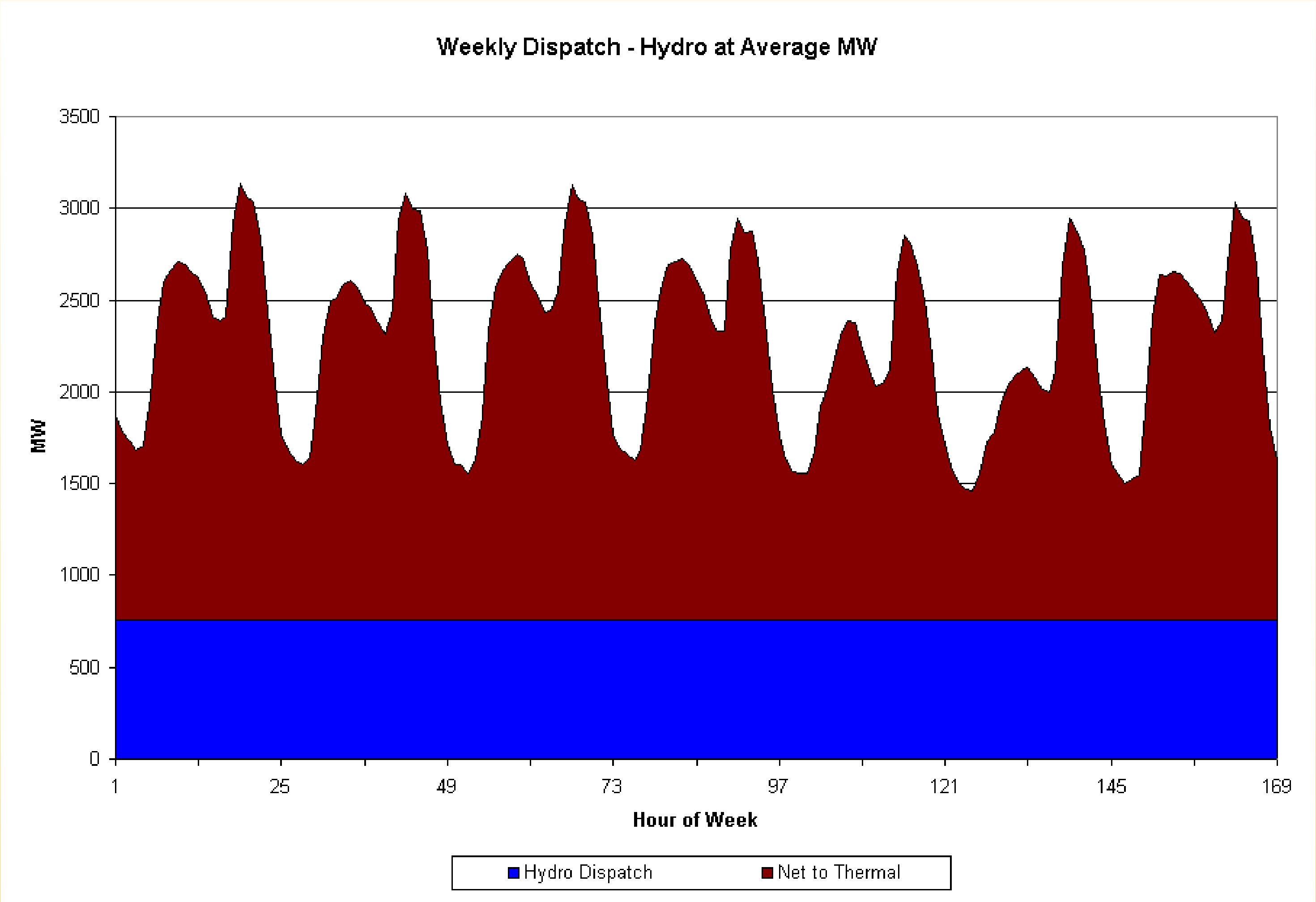
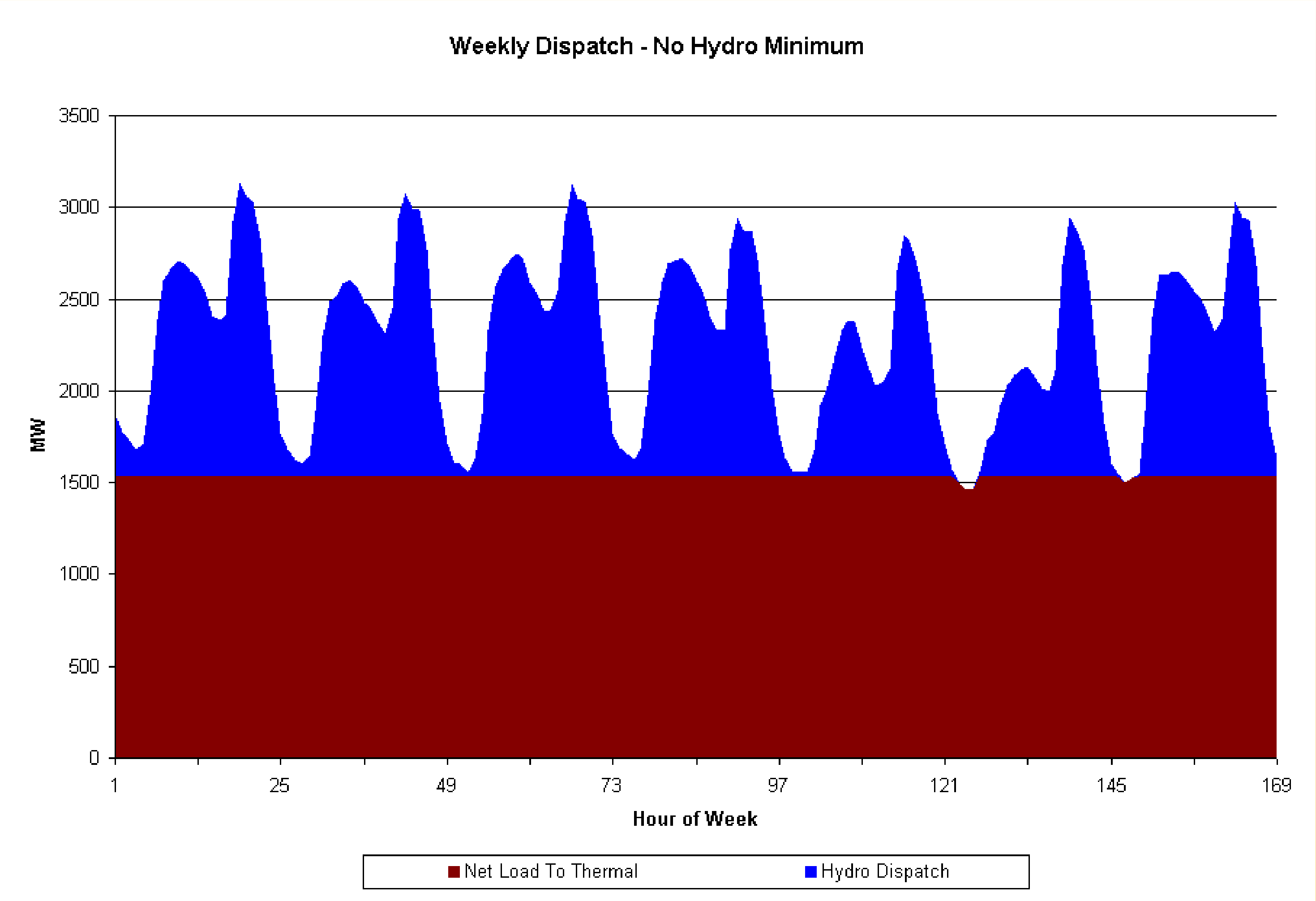
Run of River Hydro



Peak Shaving Hydro



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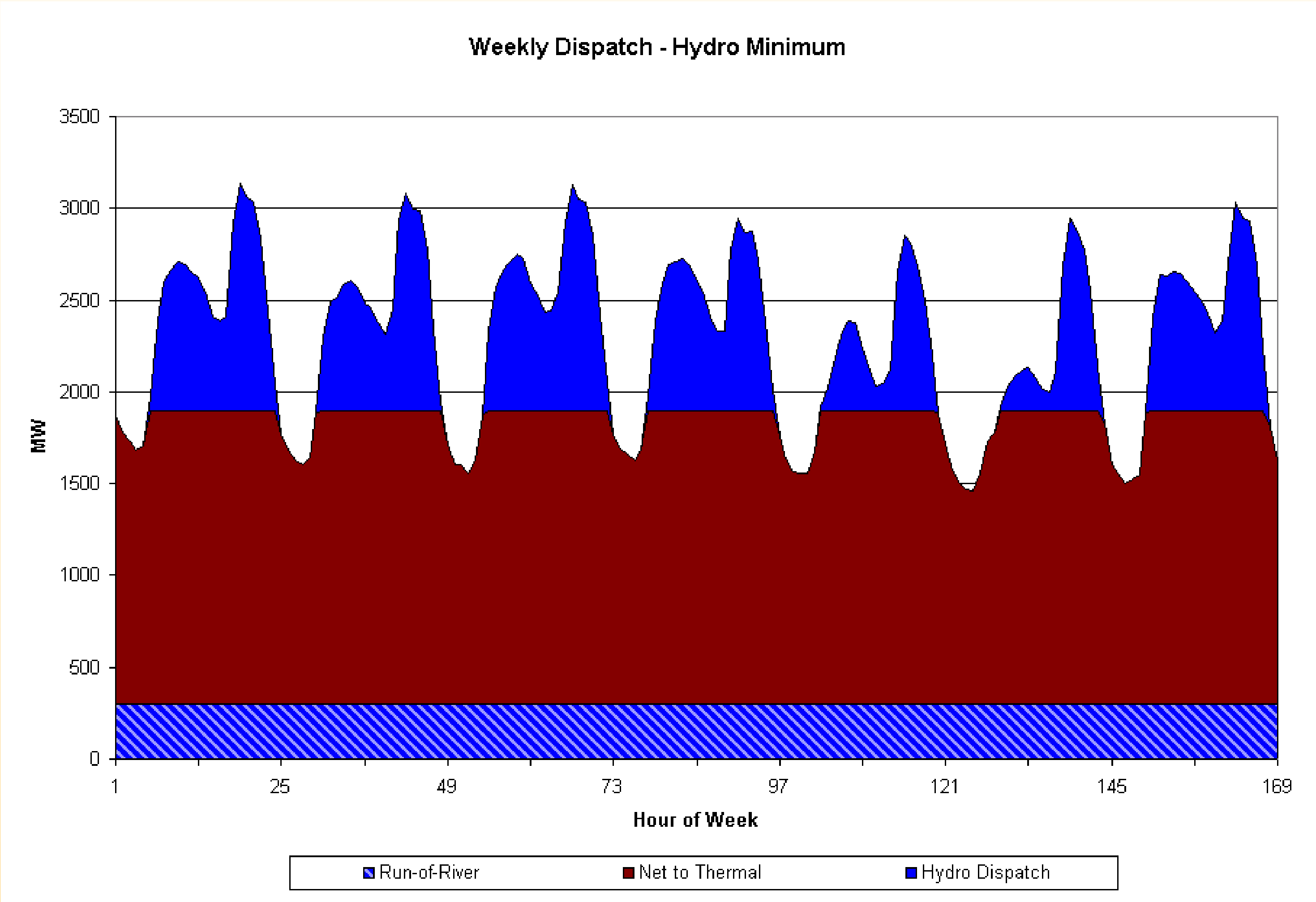
Peak Shaving with Minimum Flow Requirement



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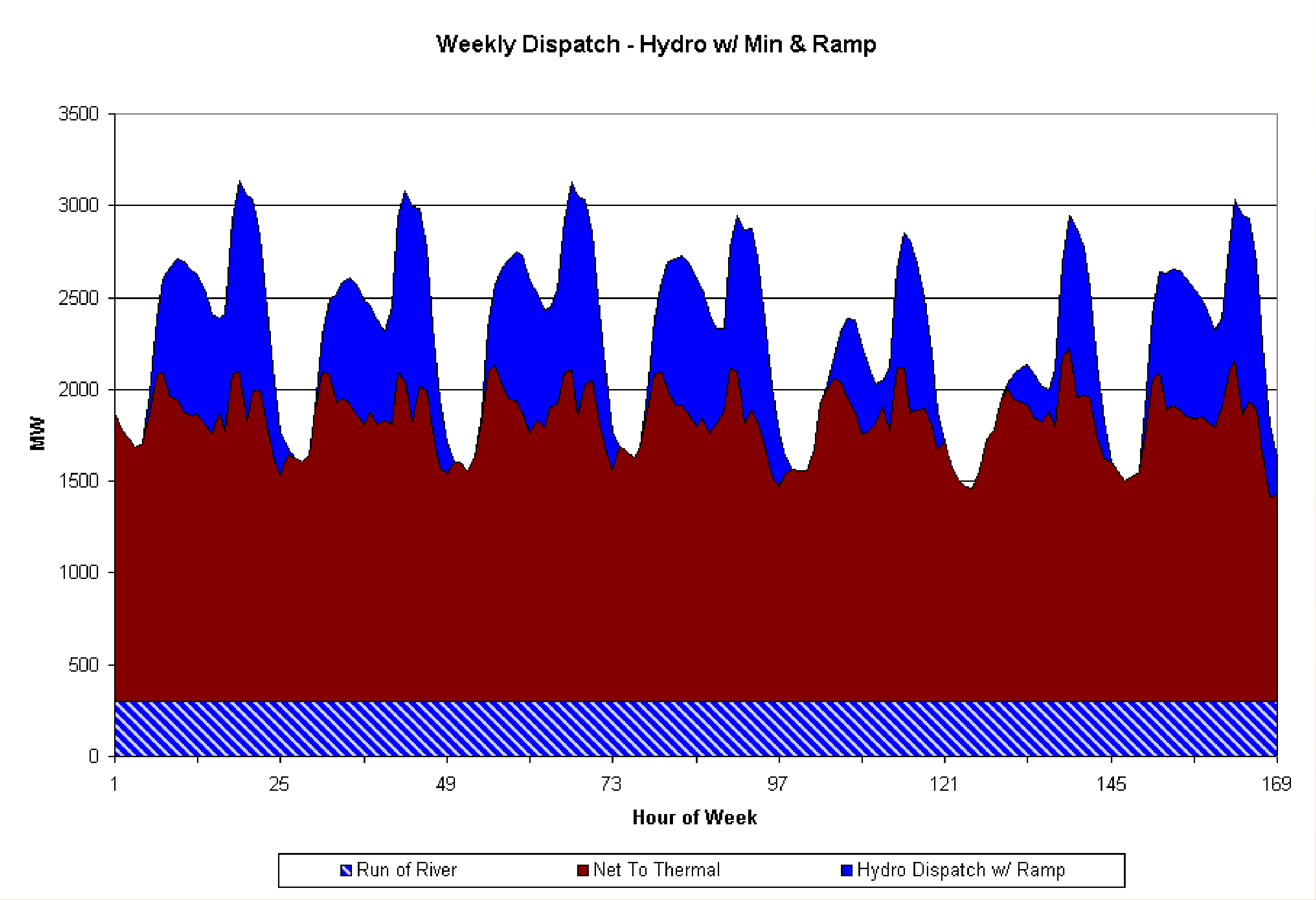
Peak Shaving w/ Min Flow and Ramp Rate Limit

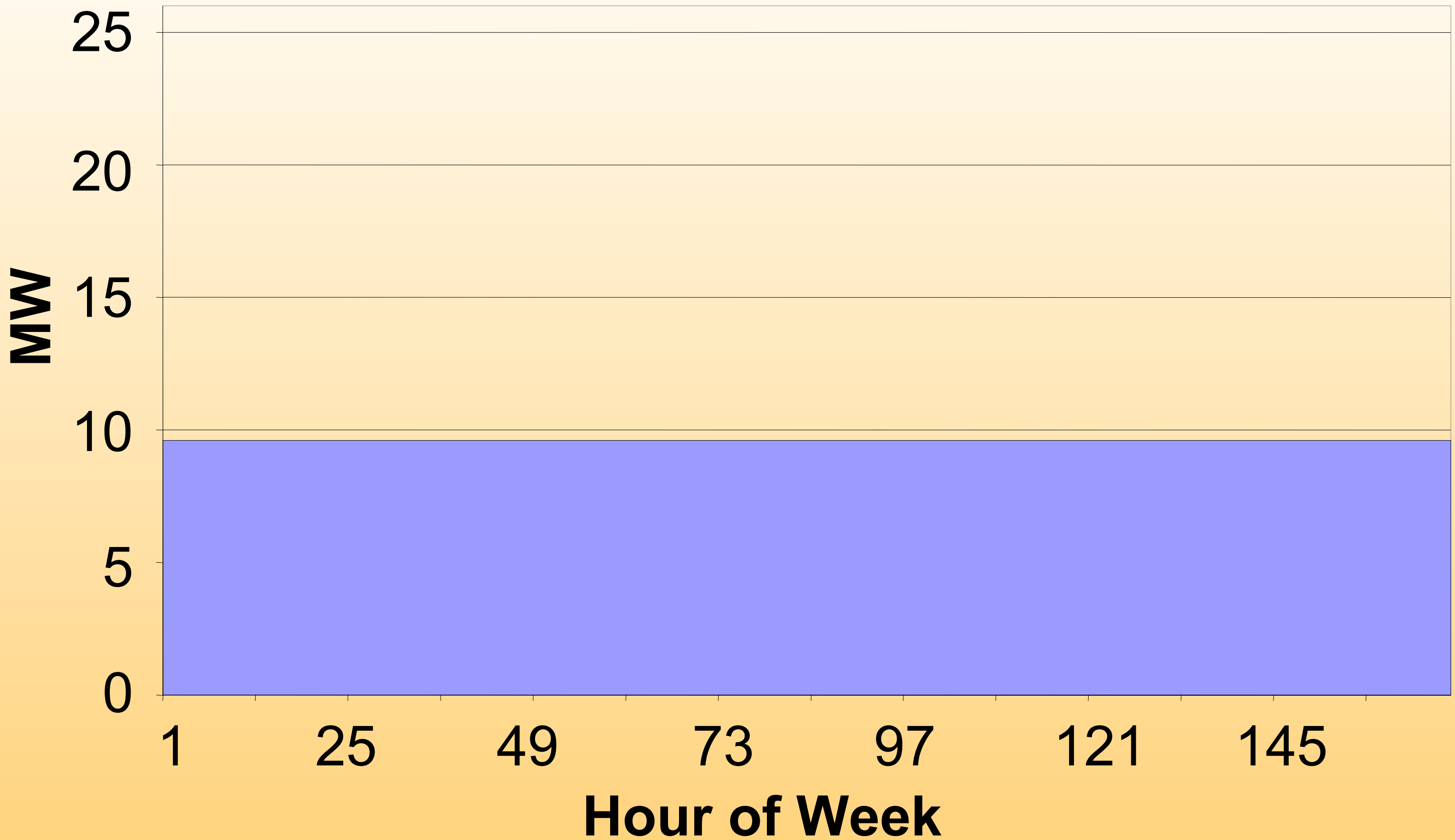


Wind Modeling

Depending on model capabilities & data availability

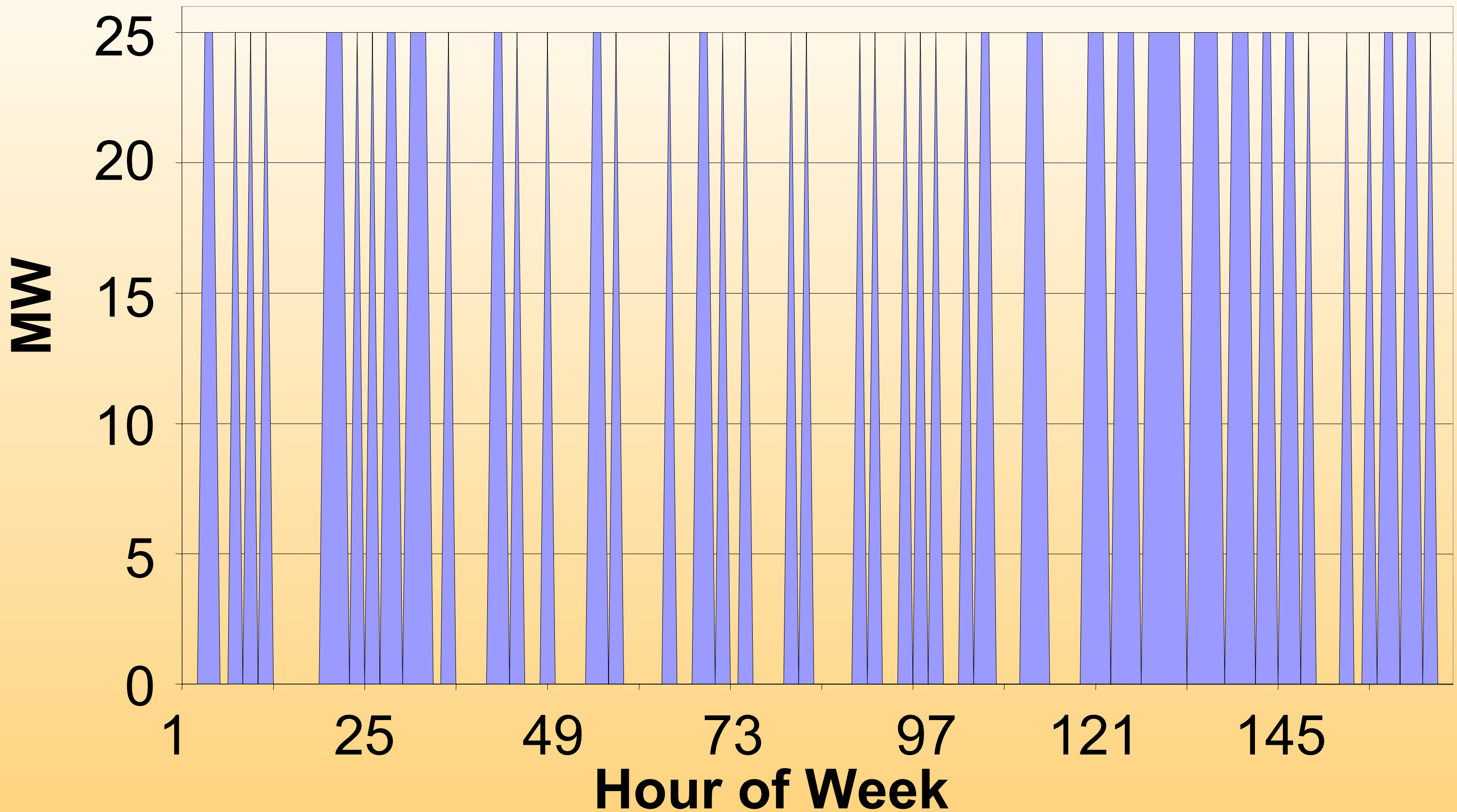
- Average energy
  - Often used, but can miss transmission limitations
  - Ignores need for shaping wind output
- Thermal plant with a high forced outage rate
  - Can overstate transmission limits
  - Overstates need for shaping
- Input pattern
  - Used in SSGWI and RMATS effort, but hard to get data
    - SSGWI data from grnNRG, while RMATS was by NREL
- State matrix
  - Also hard to get this data

25 MW Windfarm as Average Output



Average will not pick up transmission limits for peak outputs

25 MW at 62% Forced Outage



Too much exposure to Transmission Limits
as Output is either at Maximum or Zero

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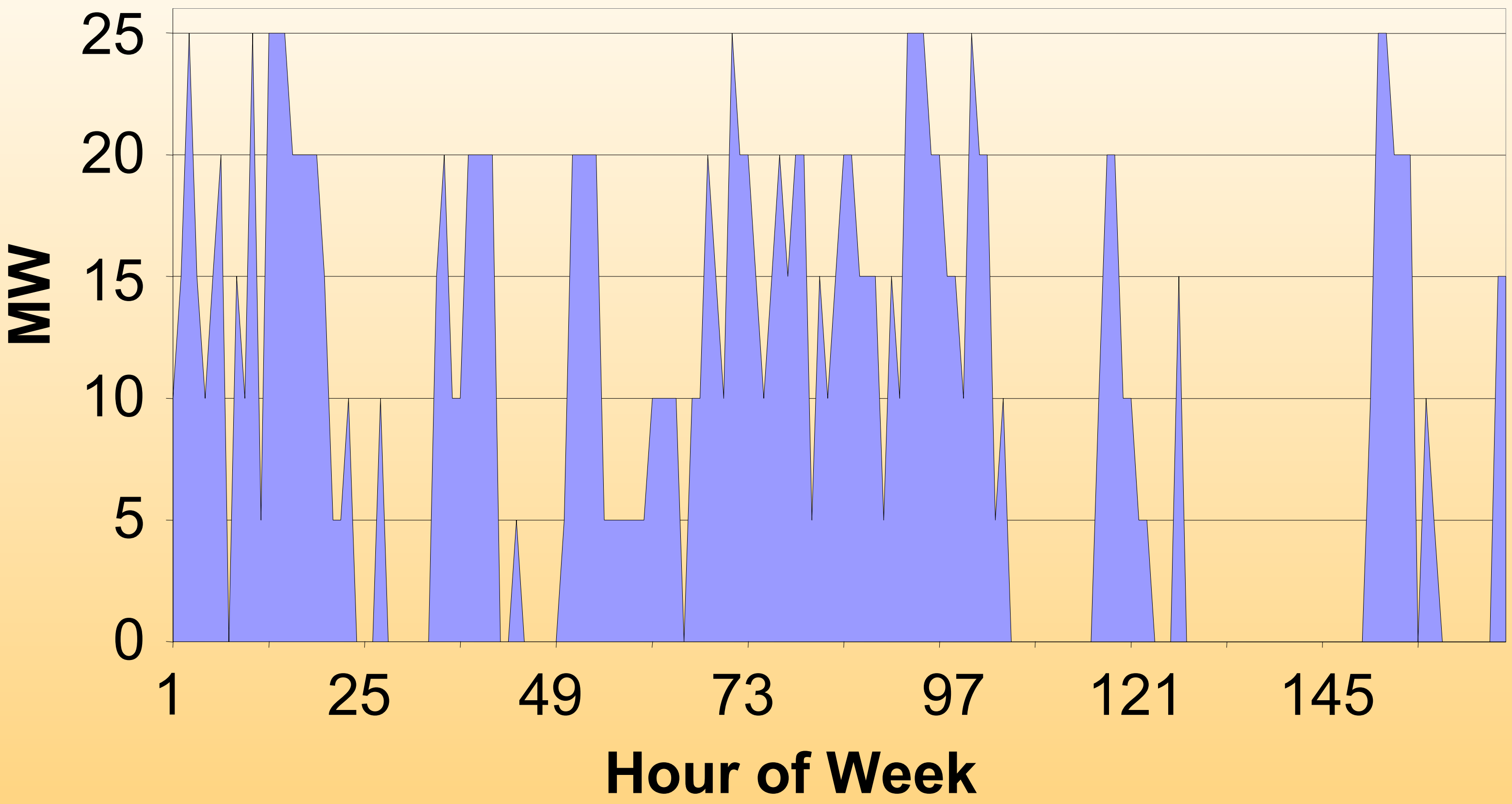
25 MW with a Pattern



More Reasonable reflection of output and interaction with limits

Market Simulation Outputs

James Gall

Typical Model Outputs

- Production costs
- Generation dispatch
- Locational Marginal Prices (LMP) and average area prices
- Generator Revenue and Load Cost
- Transmission shadow prices (opportunity costs)
- Transmission utilization

Production Costs & Generation Dispatch

Production Costs

- *Fuel Costs*: The total dollars of fuel burned for each hour for each unit/plant, including start up costs
- *Other VOM*: incremental costs associated with plant operation that are not fixed. May include environmental costs
- *Available Reports*: Hourly – Annual by plant/unit, area/zone, fuel type

Generation Dispatch

- *Dispatch*: hourly- annual by plant/unit, area/zone, fuel type
- *Capacity Factors*: dispatch as a percent of maximum dispatch
- *Outage Rates*: percent time on maintenance/forced outages
- *Fuel Burn*: quantity of fuel burned
- Environmental Emissions: quantity of CO_2, SO_2, NO_x, and Hg

Locational Marginal Prices (and Area Averages)

- LMP is the price to access one additional MW at a bus; shadow price of load at a bus
- Model outputs a marginal price at each bus you specify for each hour.
- Models also allow you to average the LMP based on the area the bus resides, so that you can get a general price for each area
- Some models segregate the LMP into three pieces; energy, congestion, and losses

Generator Revenue and Load Cost

- Usually compiled by area:
  - ***Generator Revenue*** is the LMP at each generator bus multiplied by the total MW dispatched- summed for a period of time
    - To arrive at ***Generator Gross Margin***; production costs must be subtracted from revenues
  - ***Load Cost*** is the LMP at each load bus multiplied by the total MW served- summed for a period of time
- Assumes a perfectly competitive market, with all costs and revenues priced at the marginal cost

Transmission Shadow Prices (Opportunity Costs)

- For each line or interface that is monitored, the model indicates the savings if you increase a path by 1MW for an entire year
- In other words, Transmission Shadow Prices are the opportunity cost of not increasing a path by 1 MW for the entire year
- These values help indicate which paths to further study for expansion projects

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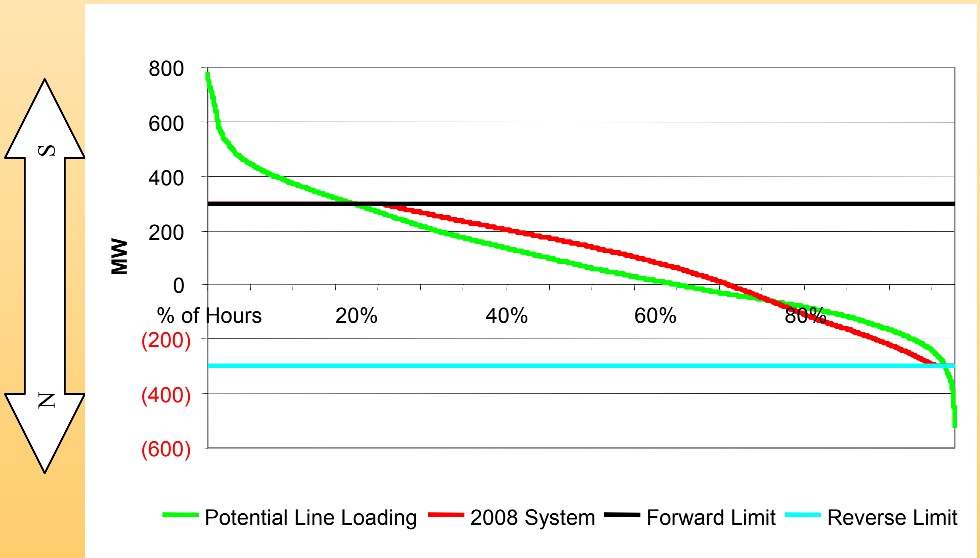
Transmission Utilization

- Models indicate for each line or interface monitored the amount of line loading/utilization
- Available outputs are:
  - Percent of time at path capacity
  - Min, max and average line utilization
  - Annual duration curves



Model Limitations

Kurt Granat

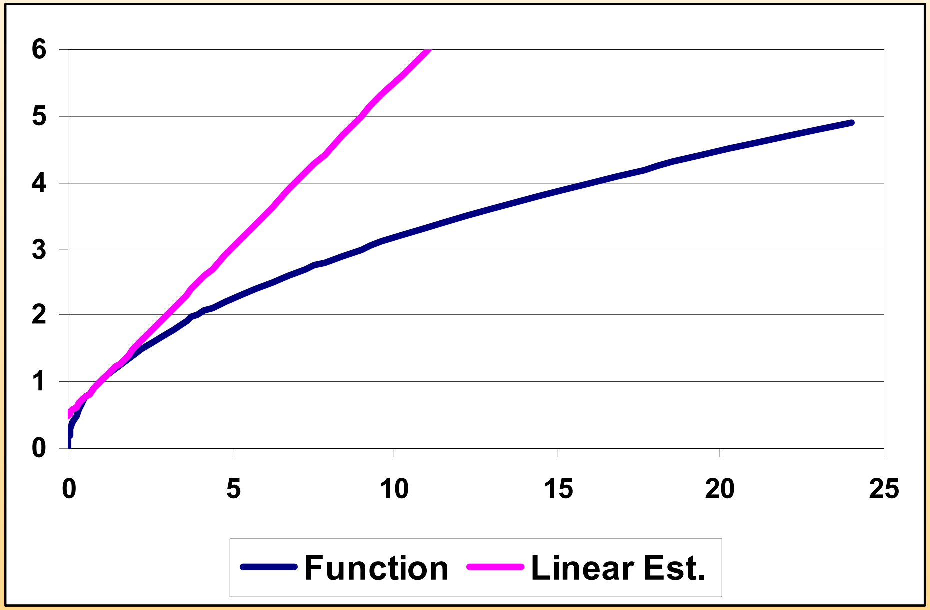
Model Assumptions & Simplification

The whole point of a model is to help people gain insight about a system that is too complex to comprehend at a glance

- Model assumption of Loads and Load behavior
  - Hard to capture load uncertainties (weather, economy)
- Model assumptions on generator plant behavior
  - How to price peaking & cycling units
  - Hydro dispatch & bidding behavior
- Degree of foresight in model
  - Many optimization routines have perfect foresight
- Single Market Dispatch
  - How to model ownership or contract rights
- Simplification for Mathematical Solutions
  - Modelers set up problems that can be solved

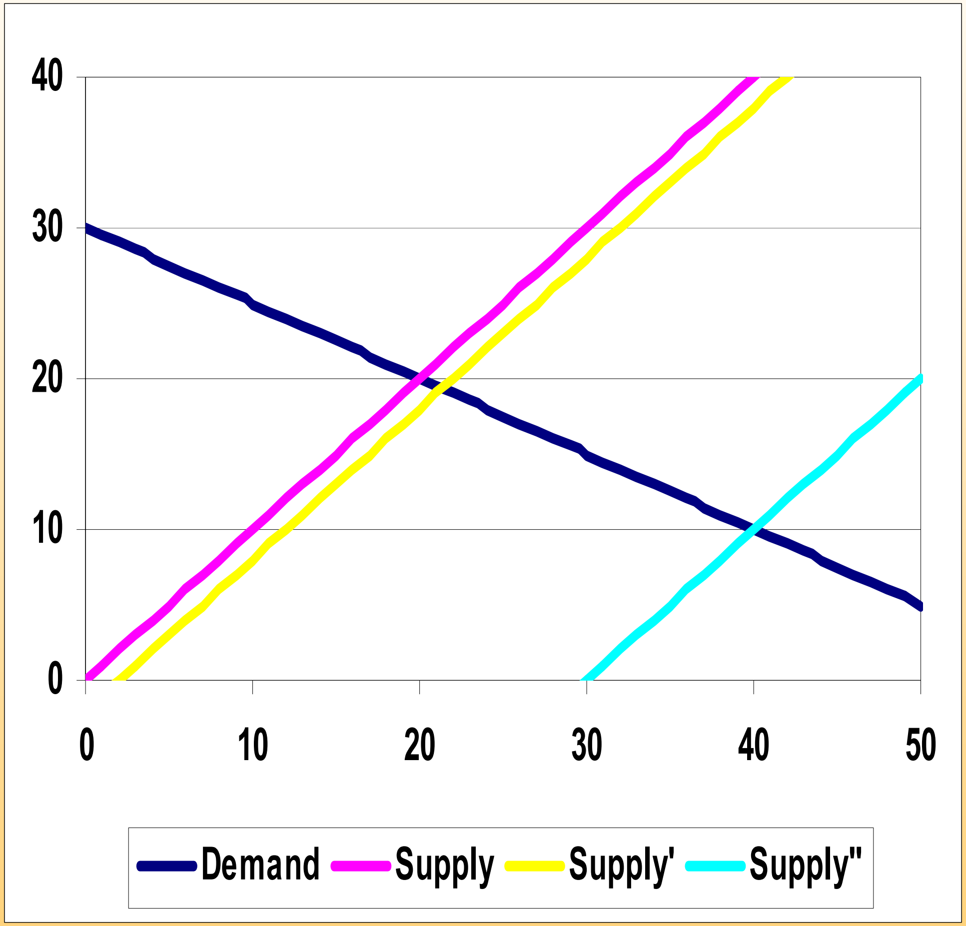
Linear Programming Issues

- System only approximately linear
- Shadow prices fall out of the solution for constraints
  - Reflects the marginal benefit of relaxing the constraint by one unit
  - Good for rough screening, but poor approximation for lumpy capital additions



Lumpy Additions

- Shadow cost (opportunity cost) of constraint is for next unit. Transmission lines often come in big increments.
  - Need to consider how the incremental capacity compares to the existing total capacity. Is it a moderate capacity addition or a huge addition?
  - 100 MW addition is 1% of West-of-River (Path 46), but over 500% of Silver Gate to Control (Path 52)!



Low Voltage Transmission & Distribution

- Powerflow has simplified grid by equivalencing selected low voltage transmission & distribution elements
- There are additional parts of the system that are manually switched to different configurations in certain conditions (e.g. low load or high load seasons)
- Operators sometimes make changes to low voltage elements rather than re-dispatch generation (may have no choice on their system). Local impact on flows
- Many models run all year with one transmission configuration and modifications are difficult
- Not monitoring low voltage elements can approximate these local or seasonal changes.

Odd Results

- These are the most informative outputs!
  - Either you have a modeling error (data or code)
  - Or the model is working and you have gained insight into how the system works – or how the system might be improved!

It is a Model Result

The best of these are but shadows and the worse, no worse, if imagination is applied. (BS)

- A model is supposed to be simple!
  - Need to remember what was simplified & why
  - Need to consider if more details & data would be available, would be solvable, or would help with decisions!
- The best modeling still leaves considerable uncertainty.
- Both action & inaction can be expensive & risky
  - Inaction implies gas generation near load – at some price

Fixed Cost Modeling

Jamie Austin

Data Required to Model Capital Costs

- Initial capital investment requirements
  - Transmission & customized equipment
  - Generation
  - Grid integration costs
- Annualized capital investment costs and other incremental costs associated with the investment, such as;
  - Capital charge,
  - Fixed O&M,
  - Plant wear & tear,
  - Opportunity costs/savings
- Change in production costs from simulation model

Initial Investment Example from RMATS

RMATS

Initial Generation Capex

Initial Transmission Capex

		Initial Investment
1	**Production Costs (Fuel & Other VOM)**	
2	Change from All Gas Case [Column A]	
3	Change from IRP- Based Case [Column B]	
4		
5	**Resource Costs:**	
6	**RM Resource Additions Capex**	
7	Wind	3,766
8	Gas thermal	373
9	Coal thermal	7,857
10	Incremental Transmission Integration Capex	311
11	**RM Resource Capex Sub Total**	**12,306**
12	**Adj. Outside RM Resource Additions Capex**	(2,257)
13	**Other RM Costs**	
14	Incremental Capital Charge @ 10%	
15	Incremental Fixed O&M	
16	Wind "wear and tear"	
17	**Subtotal Other RM Costs**	
18	Adj. Other Costs Outside RM	
19	**Total Resource Costs**	
20		
21	**Transmission Costs:**	
22	Incremental Line Capex	3,872
23	Customized Equipment Capex	393
24	**RM Transmission Capex Sub Total**	**4,265**
25		
26	Incremental Fixed O&M	
27	Incremental Capital Charge @ 10%	
28	**RM Transmission Costs**	**4,265**
29		
30	**Annualized Costs**	
31		
32	**Total Initial Investment**	**14,315**
33	**Annual Net (Savings)/Cost from All Gas Case**	
34	**Annual Net (Savings)/Cost from IRP- Based Case**	

Annualized Costs Example from RMATS

Change in Production Costs

		Representative Year
1	**Production Costs (Fuel & Other VOM)**	**18,458**
2	Change from All Gas Case [Column A]	(2,560)
3	Change from IRP- Based Case [Column B]	(1,588)
4		
5	**Resource Costs:**	
6	**RM Resource Additions Capex**	
7	Wind	
8	Gas thermal	
9	Coal thermal	
10	Incremental Transmission Integration Capex	
11	**RM Resource Capex Sub Total**	
12	**Adj. Outside RM Resource Additions Capex**	
13	**Other RM Costs**	
14	Incremental Capital Charge @ 10%	1,231
15	Incremental Fixed O&M	245
16	Wind "wear and tear"	94
17	**Subtotal Other RM Costs**	**1,570**
18	Adj. Other Costs Outside RM	**(254)**
19	**Total Resource Costs**	**1,316**
20		
21	**Transmission Costs:**	
22	Incremental Line Capex	
23	Customized Equipment Capex	
24	**RM Transmission Capex Sub Total**	
25		
26	Incremental Fixed O&M	85
27	Incremental Capital Charge @ 10%	427
28	**RM Transmission Costs**	**512**
29		
30	**Annualized Costs**	**1,828**
31		
32	**Total Initial Investment**	
33	**Annual Net (Savings)/Cost from All Gas Case**	**(986)**
34	**Annual Net (Savings)/Cost from IRP- Based Case**	**(525)**

Incremental Costs

Incremental Costs