

Electric Power Transmission Overview Markets, Operations and Planning

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IMA Workshop

Control at Large Scales: Energy Markets and Responsive Grids

Panel Discussion: Markets for Power Today and Tomorrow

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Outline

- Transmission systems background
- Decision making in operations and ops planning
- Market impacts and congestion management
- Planning aspects

Evolving Power System Structure



Key Transmission Features

- No time delays or storage: *instant transportation*
- Largely **non-routable flows** (flows follow Kirchoff's laws)
- Most transmission limits are *extrinsic* (violations are frequent)
- Meshed, *redundant* topology
- Planned to meet single/few utility needs, for *worst-case scenario*
- Currently supports regional trade
- High up-front costs and long development times
- Very long lifespan

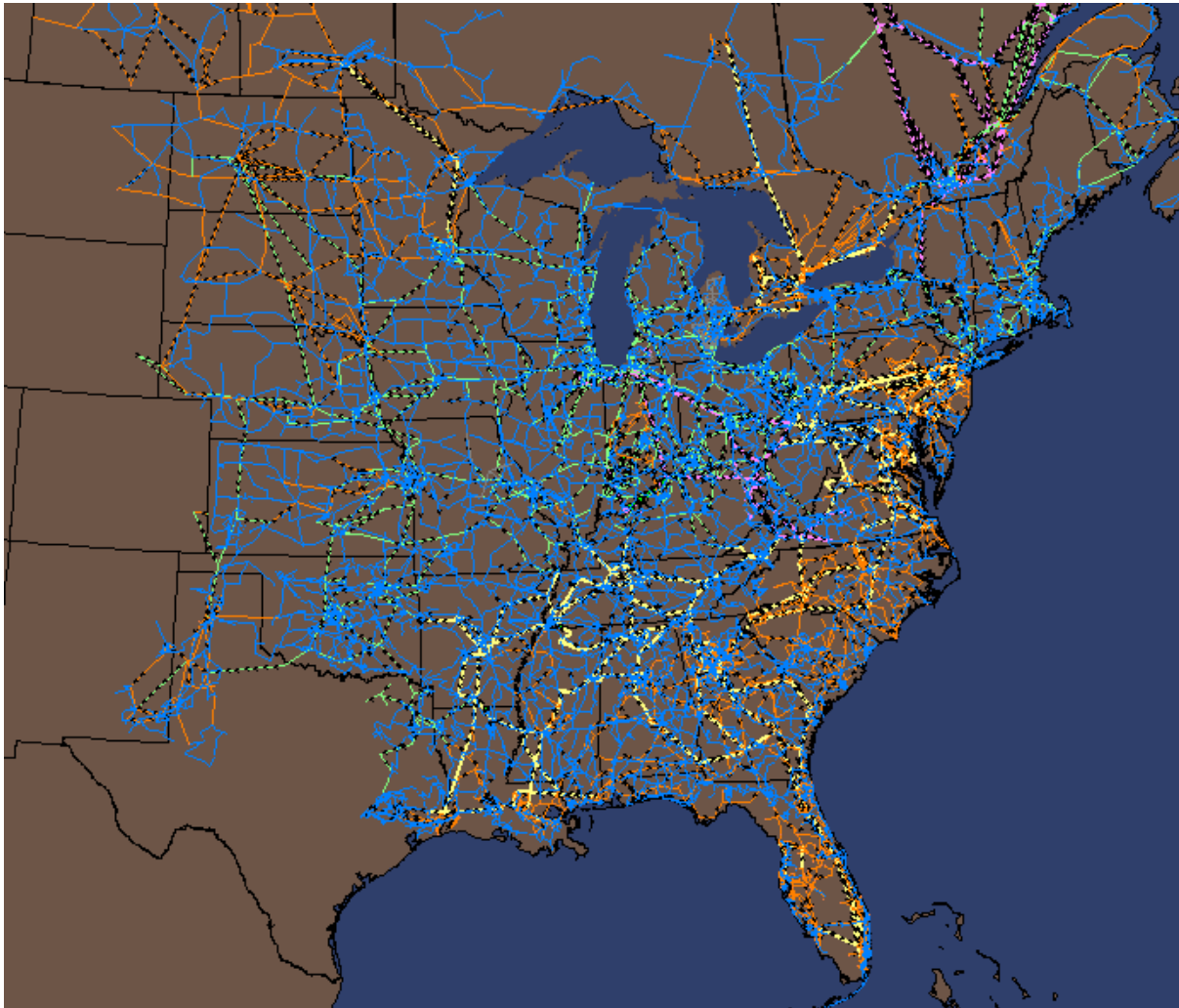


Source: eec-info.com



Source: www.burnsmcd.com

US Eastern Interconnection



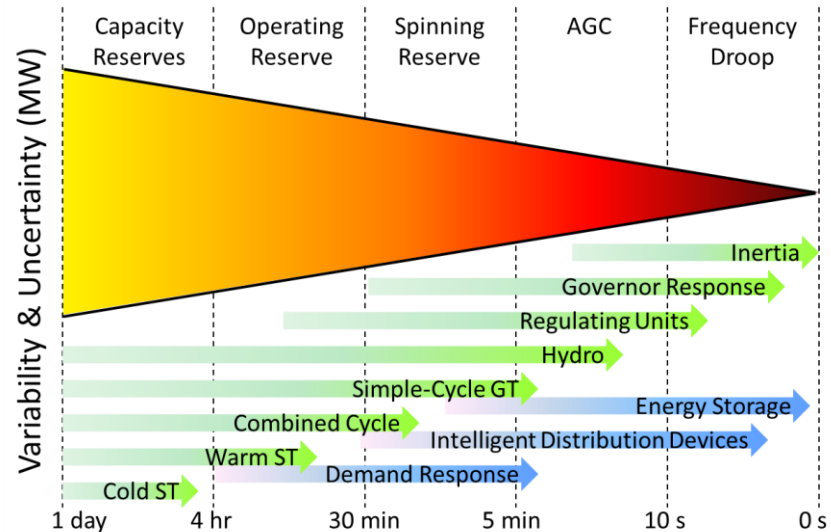
Source: Transmission Atlas

Operations Problems & Features

- Typical problem: congestion management (many different flavors)
- Decision variables
 - Transmission: breaker state, voltage set-points, tap settings
 - Non-transmission: generation dispatch and commitment
- Very limited optimization of *transmission variables*
 - Heavy reliance on operator knowledge and experience
 - Simulation-based decision making
 - Transmission variables assumed given in optimization
- Hybrid systems optimization – discrete and continuous variables
- Reliability constraints: system can withstand specified contingencies
- Nonlinearities – AC power flow equations
- Very large scale problems

Practical Decision Making

- Many approximations, as well as time-scale decomposition, are needed and applied in practical decision making and control
- System complexity and the practical approximations employed bring opportunities that the power systems and optimization and control science communities are addressing together



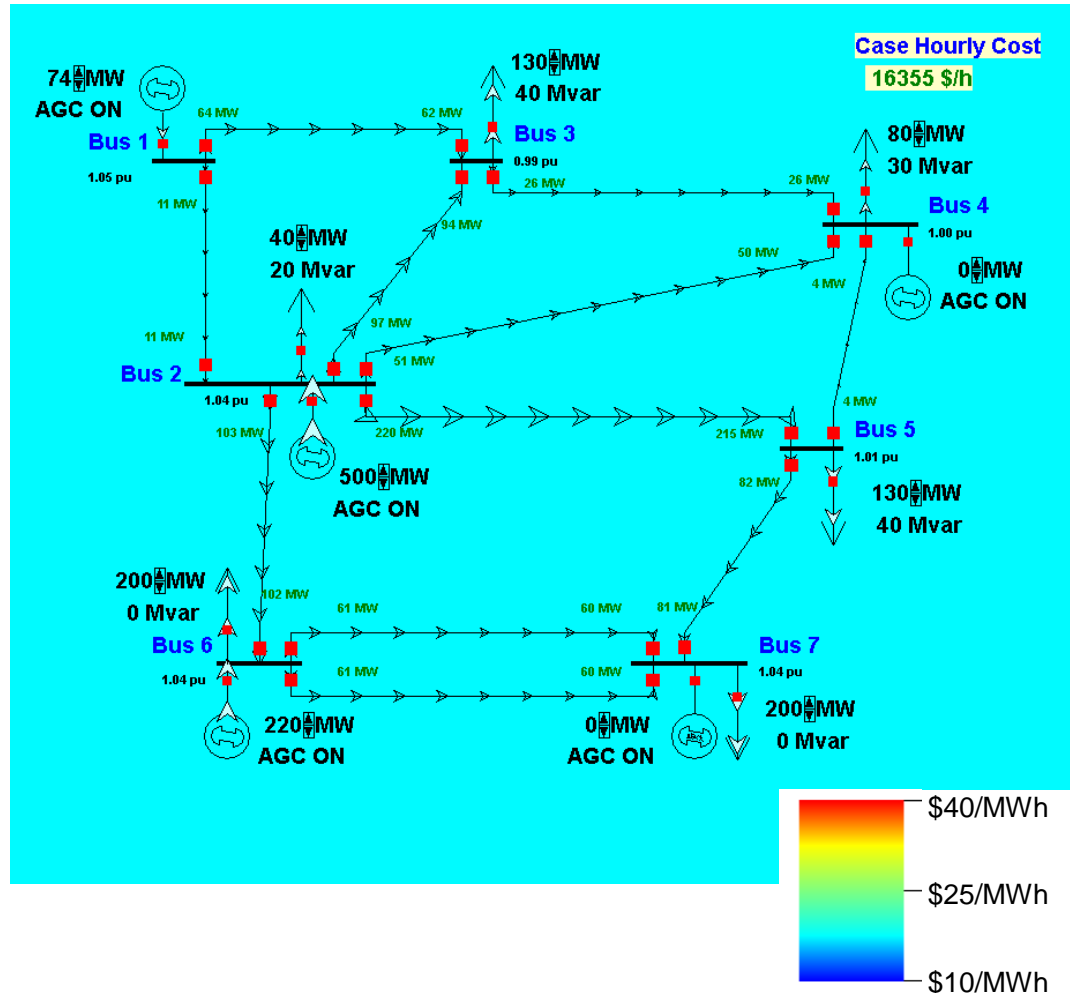
Source: Russ Philbrick, PES General Meeting, Detroit, July 2011

Optimal Power Flow (OPF)

- Objective: minimize the total operation costs for the single interval of interest
- Decision variables: production level of each scheduled generator and demand
- Constraints
 - supply = demand + losses
 - generation limits (capacity)
 - transmission limits (flow and voltage limits)
- Model formulated so that all variables are continuous

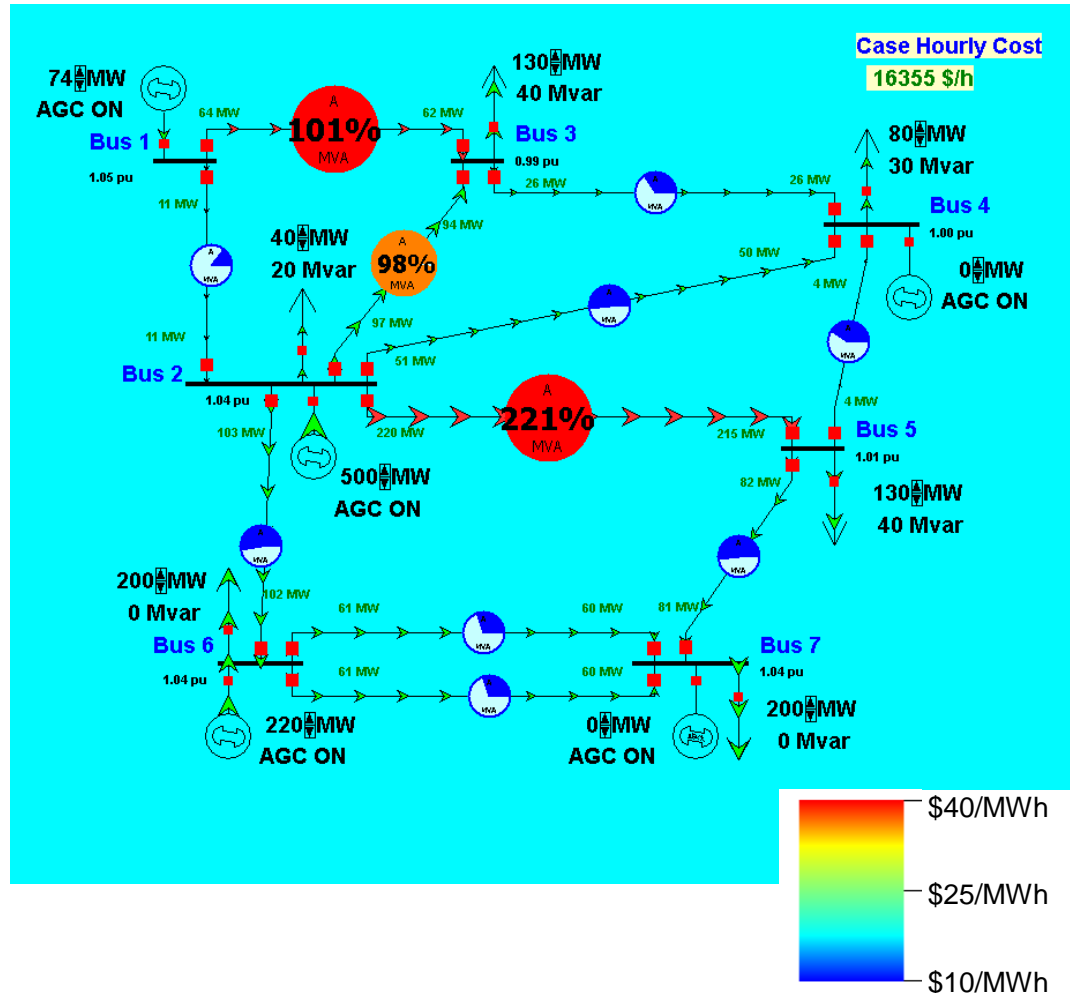
OPF: No Transmission Constraints

- The OPF solution uses the economic merit order: fully dispatch units starting from most to least economic, until supply equals demand
- There is a single unit not at a capacity limit (marginal unit), whose cost sets the system-wide marginal price



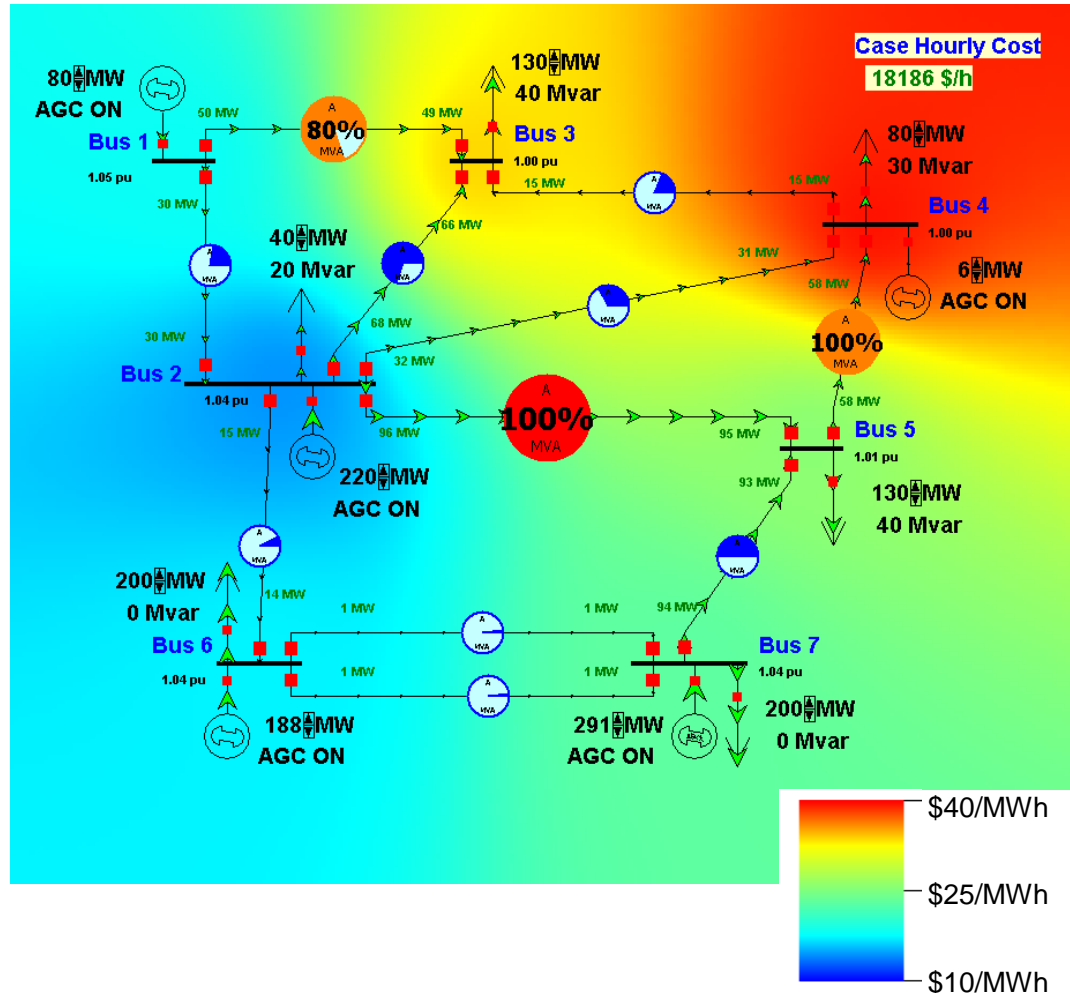
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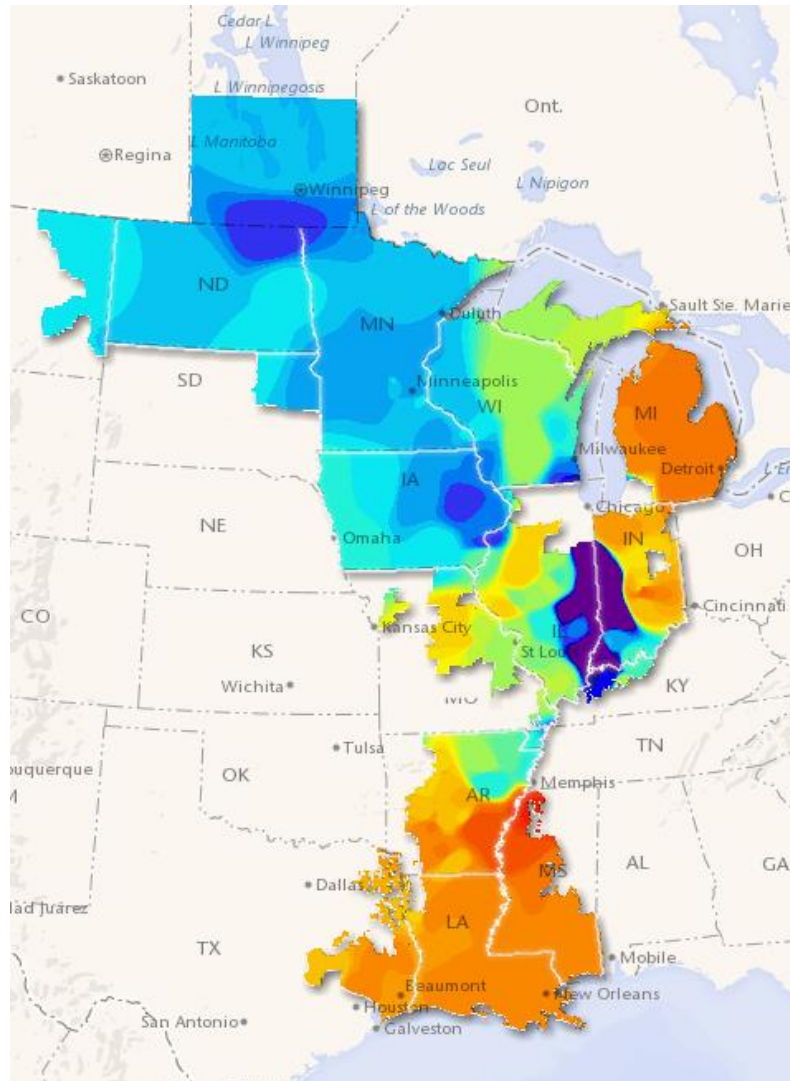
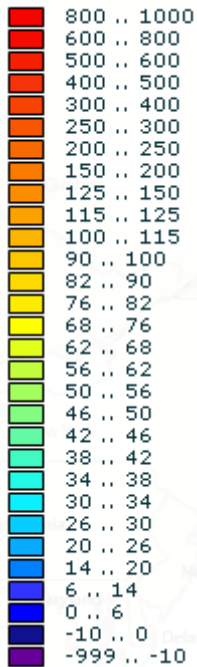
OPF: Transmission-Constrained

- The economic merit order dispatch is not feasible
- Some low-cost units have to reduce their outputs, while some high-cost units have to increase them
- US production costs increase by \$4-8 billion due to congestion annually
- Marginal cost varies by location/node



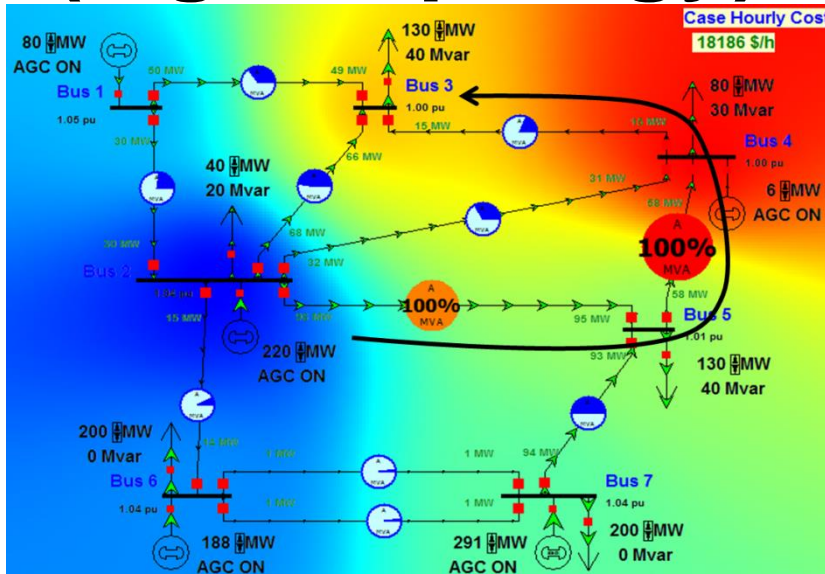
Midcontinent Market Price Contour

LMP (USD)



Source: www.misoenergy.org, 8 Sep 2015, 13:20

Add Transmission Variables! (e.g., Topology)



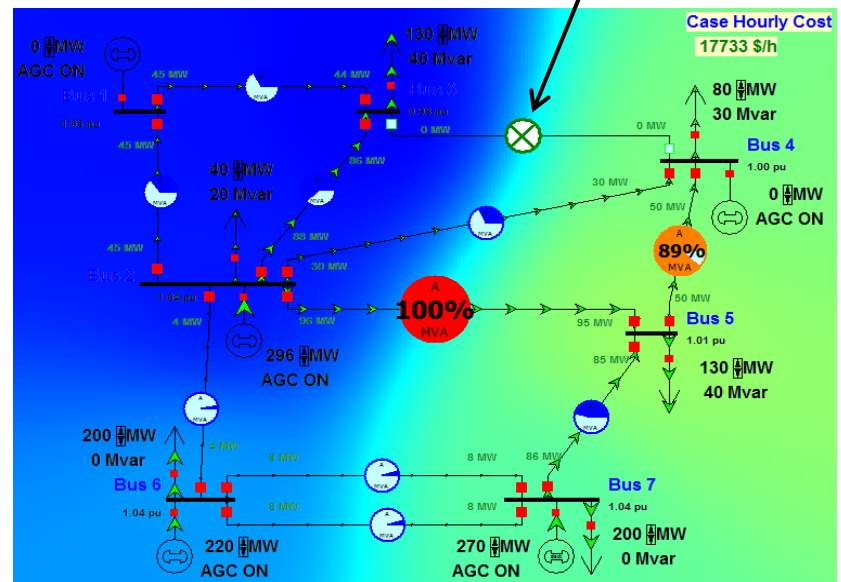
\$40/MWh



\$10/MWh

... and reduce the cost of congestion by half!
(Friday lecture)

line 3 – 4 open

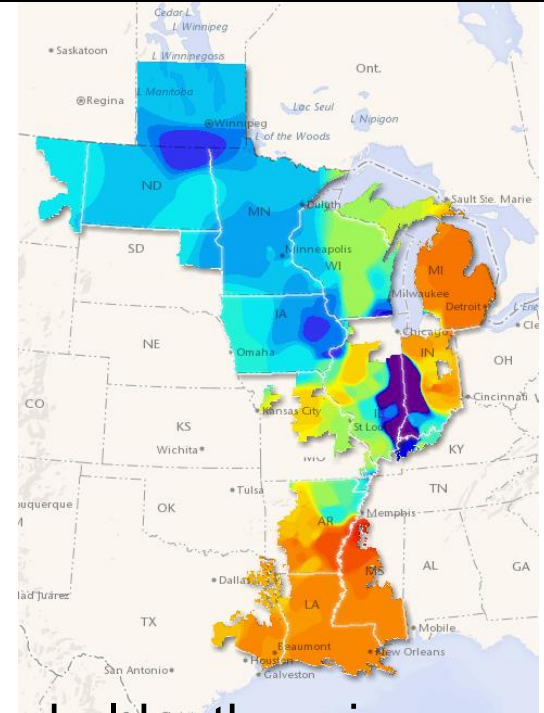


Unit	Line 3-4 Closed	Line 3-4 Open
Bus 1	80 MW	0 MW
Bus 2	220 MW	296 MW
Bus 4	6 MW	0 MW
Bus 6	188 MW	220 MW
Bus 7	291 MW	270 MW
Total	785 MW	786 MW



Markets Aspects

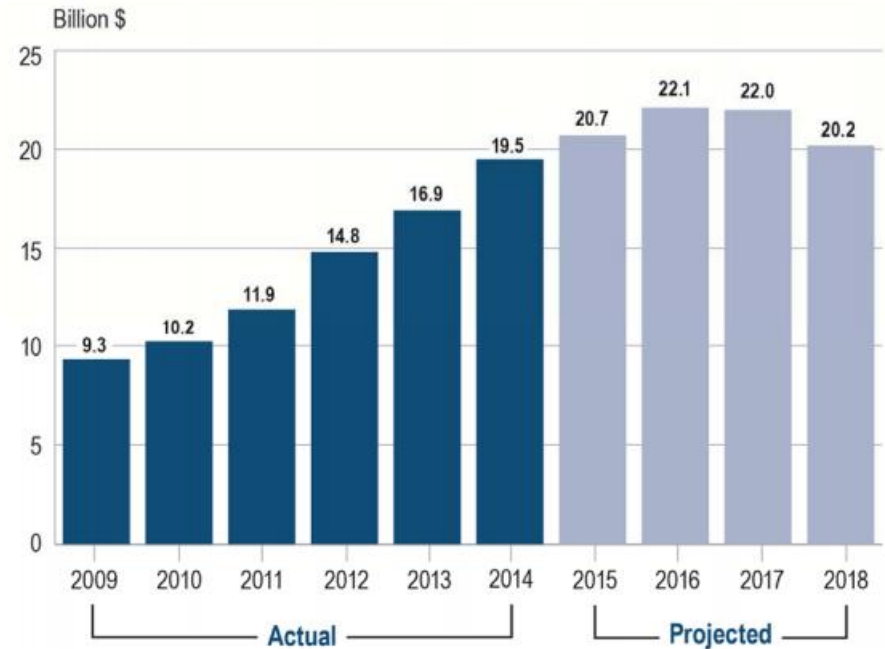
- Market prices can vary very significantly
- Congestion risk hedging is critical – (\$ billions at stake)
- (Congestion Rent) = (Load Payments) – (Generator Revenues)
- Financial Transmission Rights (FTR) give the holder the price difference (congestion component) between two specified nodes
 - Medium term financial instrument (1 month to 1 year duration)
 - Purchased in FTR auctions
 - FTR auction proceeds given to holders of transmission rights
- FTR holders: load serving entities and financial entities
- FTR profits ~50% (\$960M costs vs \$450M profits in PJM in 2015)



Planning

- Regional Transmission Organizations lead and coordinate regional planning
- Transmission expansion in the US have been driven by renewables development
- The transmission industry remains largely regulated
- Most transmission projects serve multiple purposes, are centrally approved, owners earn regulated rate of return, paid by loads
- *Very few* (usually small) projects have been developed purely to address a market opportunity – developers get FTRs

Historical and Projected Transmission Investment (Nominal Dollars)



Source: EEI Actual and Planned Transmission Investment by Investor-Owned Utilities (2009 – 2018)

Panel Discussion...

