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

Source: DOE ARPA-E
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.

Electric Power Transmission: Markets, Operations and Planning
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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

Source: www.misoenergy.org, 8 Sep 2015, 13:20
Add Transmission Variables! (e.g., Topology)

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

<table>
<thead>
<tr>
<th>Unit</th>
<th>Line 3-4 Closed</th>
<th>Line 3-4 Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus 1</td>
<td>80 MW</td>
<td>0 MW</td>
</tr>
<tr>
<td>Bus 2</td>
<td>220 MW</td>
<td>296 MW</td>
</tr>
<tr>
<td>Bus 4</td>
<td>6 MW</td>
<td>0 MW</td>
</tr>
<tr>
<td>Bus 6</td>
<td>188 MW</td>
<td>220 MW</td>
</tr>
<tr>
<td>Bus 7</td>
<td>291 MW</td>
<td>270 MW</td>
</tr>
<tr>
<td>Total</td>
<td>785 MW</td>
<td>786 MW</td>
</tr>
</tbody>
</table>
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.

Panel Discussion...