Tractable Transmission Topology Control

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Objectives

In this talk, we will discuss tractable control of the transmission network topology, to

- Increase the value extracted from existing transmission capacity
- Reduce the need for new transmission capacity
- Lower generation costs
- Increase system reliability
- Provide additional controls to manage congestion (especially that caused by variable generation)
Optimal Power Flow (OPF)

- Objective: select the production level of each scheduled generator for the single interval of interest so as to minimize the total operation costs

- Constraints
  - generation
  - transmission

- Model formulated so that all variables are continuous
OPF: No Transmission Constraints

- The optimal OPF solution employs the economic merit order: fully dispatch units starting from most economic 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.
OPF: Transmission-Constrained

- The economic merit order dispatch is not feasible,
- Some low-cost units have to decrease their production, while some high-cost units have to increase their generation,
- **US production costs** increase by several billion dollars annually due to congestion,
- Number of marginal units equals number of binding transmission constraints +1,
- Marginal cost becomes dependent on location.
Midwest ISO Real-Time Prices (3:30)

source: www.midwestiso.org
Midwest ISO Real-Time Prices (4:00)

source: www.midwestiso.org
Midwest ISO Real-Time Prices (4:30)

source: www.midwestiso.org
AC Power Flows

- Power flows distribute over the transmission network according to **Kirchoff’s Laws**: inversely proportional to path impedance
- To control flows, one needs to
  - re-dispatch generation
  - control effective impedances
- Few transmission branches have flow control devices
- All branches have switches which can connect or disconnect the branch
7-bus Example: All Lines Closed
7-bus Example: Line 3 – 4 Opened
Transmission Topology Control

- By switching transmission elements on or off, the network impedance can be discretely controlled so that the transfer capacity between low-cost resources and loads is maximized.
- The branch states can be added to the OPF as decision variables, converting the OPF into a MIP.
- Given the size of real systems and solution time requirements, MIP OPF formulations are computationally intractable.
Topology/Dispatch Requirements

- **OPF feasible**: all demand is supplied and there are no overloads
- **Cost-reduction**: transmission topology changes allow a lower out-of-merit cost dispatch
- **Reliability requirements**: redundant connections (system can withstand outages)
- **Connectivity requirements**: disconnecting transmission elements does not cause system separation (islanding)
Tractable Policies

- To significantly reduce the computational time while providing near-optimal savings, we employ sensitivity-based iterative heuristic policies for transmission topology control.

- These policies:
  - ensure feasibility
  - enforce security constraints
  - maintain system connectivity (no islanding)
IEEE 118-bus Test System
118-bus System Simulations

- Topology represents a portion of the AEP system circa 1962
- 118 buses, 54 generators, 194 branches (all connected)
- Monte-Carlo simulation, 100 samples of available wind power and fuel cost realizations
- **Congestion costs 9.49%** of the production costs with initial topology
Mean Congestion Cost

![Graph showing Mean Congestion Cost over max lines opened for different policies. The y-axis represents congestion cost (p.u.), and the x-axis represents max lines opened. The graph displays four policy curves: policy 1 (red), policy 2 (purple), policy 3 (blue), and policy 4 (green) with the optimal line (black). The initial topology is indicated by a dotted line at the beginning of the graph. The x-axis ranges from 0 to 40 max lines opened, and the y-axis ranges from 0 to 1 congestion cost (p.u.).]
# 118-bus System Simulations

<table>
<thead>
<tr>
<th>metric</th>
<th>initial</th>
<th>copper</th>
<th>optimal</th>
<th>policy 1</th>
<th>policy 3</th>
<th>policy 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>topology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>expected cost (k$)</td>
<td>129.7</td>
<td>117.4</td>
<td>120.5</td>
<td>126.9</td>
<td>121.2</td>
<td>120.6</td>
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<tr>
<td>expected savings (%)</td>
<td>n/a</td>
<td>9.3</td>
<td>6.9</td>
<td>2.1</td>
<td>6.4</td>
<td>6.6</td>
</tr>
<tr>
<td>min / max savings (%)</td>
<td>n/a</td>
<td>1.0 / 19.2</td>
<td>0.8 / 11.3</td>
<td>0.3 / 4.9</td>
<td>0.7 / 11.2</td>
<td>0.6 / 10.6</td>
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<tr>
<td>savings w/ 10% wind forecast error (%)</td>
<td>n/a</td>
<td>9.3</td>
<td>6.5</td>
<td>2.1</td>
<td>6.2</td>
<td>6.4</td>
</tr>
<tr>
<td>lines disconnected (median)</td>
<td>n/a</td>
<td>n/a</td>
<td>22</td>
<td>4</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>av. opened flow (%)</td>
<td>n/a</td>
<td>n/a</td>
<td>28%</td>
<td>58%</td>
<td>28%</td>
<td>26%</td>
</tr>
<tr>
<td>open lines in optimal topology</td>
<td>n/a</td>
<td>n/a</td>
<td>100%</td>
<td>36%</td>
<td>56%</td>
<td>52%</td>
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<tr>
<td>expected computation time (s)</td>
<td>0.004</td>
<td>0.003</td>
<td>3 - 3600</td>
<td>0.55</td>
<td>0.33</td>
<td>0.42</td>
</tr>
</tbody>
</table>
Summary

- Transmission congestion increases production costs
- Topology control can be effectively used to minimize these cost increments while maintaining reliability, but computational costs are high, due to integer variables
- We developed tractable algorithms that use sensitivity information to select promising candidate lines for switching
- The sensitivities employed indicate cost reductions while maintaining connectivity requirements
- Preliminary simulation results are very promising
Concluding Remarks

- Potential benefits of transmission topology control are very large
  - Production cost savings
  - Reduce transmission investment costs
  - Add flexibility in operations
  - Increase the ability to incorporate variable resources (wind, solar)
  - Increase reliability
Questions?

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