Large-Scale Stochastic Programming to Cooptimize Networks and Generation in the Face of Long-Run Uncertainties: What Lines Should We Build Now?

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Overview

1. Introduction
2. Method Overview
3. Four Questions
   Q1: What is the value of stochastic planning?
   Q2: Is it practical?
   Q3: What approximations affect the solutions?
   Q4: What is the value of transmission-generation cooptimization?
**Method: JHSMINE (Johns Hopkins Stochastic Multi-stage Integrated Network Expansion)**

**Stage 2014:** “Today’s Choices”
- Choose Yr 10 Investments in:
  - Transmission
  - Generation
- Choose Yr 20 Investments in trans / gen
- Operations

**Stage 2024:** “Tomorrow’s Choices”
- Choose Yr 10 investments in:
  - Transmission
  - Generation
- Scenarios of:
  - $ Fuels
  - Load growth
  - Technology
  - Policies
- Choose Yr 20 investments in trans / gen
- Operations

**Uncertainty (Multiple Study Cases)**

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**Deterministic Approach:**
One model for each study case

**JHSMINE:** Solve all cases at once in one model

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**JHSMINE Structure: Mixed Integer linear program**

**Optimize the objective:**
Minimize (probability-weighted, present worth) of cost over 40 yrs

**By choosing values of decision variables:**
- Transmission investment (0-1)
  - 10 yr “portal” (optional) lines (in addition to Common Case lines)
  - 20 yr lines
  - Gen investment (*co-optimized*)
- Gen dispatch

**Respecting constraints:**
- Kirchhoff’s laws (linear OPF)
  - Load by hour
- Generator operating constraints
  - Variable renewable availability by hour
- RPS
- Siting restrictions

**Accounting for uncertainties:**
- load/renewable conditions (hourly variability)
- **IN STOCHASTIC MODEL:** long-run study cases
Mathematical structure

\[
\begin{align*}
\text{MIN} & \quad C_1 X_1 + \sum_{\text{scenarios } S} P_S \cdot C_2 X_{2,S} \\
A_{1,1} X_1 & \quad \leq B_1 \\
\{A_{2,1,S} X_1 + A_{2,2,S} X_{2,S}\} & \quad \leq B_{2,S}, \quad \forall S
\end{align*}
\]

JHSMINE cooptimizes transmission and generation

- “Anticipative” transmission planning:
  - Where will generation build in response to line additions?
  - How will it operate?
Two versions of JHSMINE–WECC

21 TEPPC Zone “Pipes-&-Bubbles”

300 bus network: Both Linearized DC OPF & “Pipes-&-Bubbles” versions

- Preserve WECC paths between regions
- 244 preserved monitored lines
- 282 equivalenced unmonitored lines
- 26 hubs for new thermal plants
- WREZs for renewable development

Question 1: What can we learn from stochastic transmission planning?

Q1.1 What transmission expansion best balances:

- Value of tomorrow’s flexibility
  vs.
- Today’s investment costs?

... Recognizing how generation siting, operations react
(“anticipative planning”/“cooptimization”)

Q1.2 Are those plans different, and cheaper on average, than traditional deterministic plans?

Q1.3 Are any high-value lines identified by stochastic programming that are missed by deterministic planning?

- Which add flexibility, optionality to system

Q1.4 Are stochastic plans more robust against scenarios not considered?
Alternative Study Case/Scenario Sets: 1, 5, and 20

- Three groups of uncertain parameters (24 parameters):
  - $P_{\text{Carbon}}$, $P_{\text{Gas}}$, Energy growth
  - RPS, Renewable capital cost
  - Peak growth, storage

Example: Optimal “Portal” 10 yr Transmission (21 Zone model)

Optimal under just Base Case (100% probability)

Heuristically combine deterministic results: Optimal in $\geq 3$ of 5 2013 Study Case models

Stochastic Optimum under 5 (and also 20) study cases (equal chance of each scenario)

Expected PW cost under 20% chance of each of 5 study cases:

- $681.4B$
- $680.3B$
- $678.5B$ (optimal)
Example: Optimal “Portal” 10 yr Trans (21 Zone) for Heuristics that Combine Deterministic Study Case Results

Optimal in all 5 2013 Study Case models

Optimal in ≥3 of 5 2013 Study Case models

Optimal in ≥1 of 5 2013 Study Case models

Expected PW cost penalty under 20% chance of each of study cases:

$5.2B

$1.9B

$3.2B

Comparison of Yr 10 Lines Under Alternative Scenario Sets (300 bus case)

Optimal under Base Case

Optimal under 5 Scenarios (20% Probability Each)

Optimal under 20 Scenario Case (5% Probability each)

Expected suboptimality cost penalty under 5% chance of each of 20 scenarios:

$14.2B

$2.0B

$0B Optimal
Does a stochastic solution based on the “wrong” scenarios do better against other scenarios?

20 Scenarios

- The stochastic (5) plan does better in 10/15 of the unconsidered scenarios
- Not necessarily the case; but stochastic plans tend to build more in more places

**Question 2: Practical to Optimize Economic Planning of Regional Transmission?**

- Yes: Can rapidly screen, define, and assess performance of alternative plans
- After initial model set-up, ~0.5-2 hours to optimize a single stochastic WECC plan for a particular set of assumptions (single server)
  - If multiple servers, can quickly generate & evaluate many plans under various:
    - study cases (climate, regulations, technology...)
    - objectives (least-cost, least-emissions, least land use,...)
- Far faster than manual assembly & evaluation of plans
- You should always subject plans to detailed production costing!
If Kirchhoff's voltage law enforced (DC OPF), 1 hr solution time on a workstation with a 0.5% optimality gap →
~100 candidate lines
~100,000 combinations of:
- Generation types
- X Buses/zones
- X Sample hours (load/renewable output)
- X Decision stages (in-service dates)
- X Long run regulatory/economic/technology study cases
→ Tradeoffs! (more detail on one aspect → less on another)

Pipes-&-bubbles model
~100 candidate lines
~2,000,000 combinations

Problem size examples solved here

Pipes-&-bubbles:
- 8 Generation types
- X 21 TEPPC zones
- X 20 Sample hours (load/renewable output)
- X 2 Decision stages (2024, 2034)
- X 20 Long run regulatory/econ/tech scenarios

KVL (DC OPF):
- 10 Generation types
- X 300 Buses
- X 6 Sample hours (load/renewable output)
- X 2 Decision stages (2024, 2034)
- X 3 Long run regulatory/econ/tech scenarios
Question 3: What affects transmission decisions?

- **What strongly matters?**
  - More lines recommended if:
    - Consider several study cases/scenarios at once (cf. 1 study case at a time)
    - Consider KVL (parallel flows)
  - Considering a range of load/renewable operating conditions
  - Considering KVL (parallel flows) → more lines
  - Unit commitment, if significant coal generation (low C cost)

- **What matters less?**
  - Going from 5 to 20 study cases/scenarios
    - No difference in 21 zone case, differences in 300
  - Precise probabilities of study cases/scenarios
  - Unit commitment, if low coal penetration
  - Consideration of “failure to launch” for planned lines—few additional lines are justified in Yr 10 as “insurance”

Question 4: What is the value of cooptimization? (“Anticipatory Planning”)

<table>
<thead>
<tr>
<th>Traditional Planning</th>
<th>Iterative Cooptimization</th>
<th>Simultaneous Cooptimization</th>
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<tbody>
<tr>
<td>Generation Planning</td>
<td>Optimize Generation</td>
<td>Optimize Generation &amp; Transmission Investment Together</td>
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<td>Generation Siting/Mix Scenario</td>
<td>Transmission Plan &amp; Consistent Generation Siting/Mix</td>
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<tr>
<td>Transmission Planning</td>
<td>Optimize Trans</td>
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<td>Optimize Generation</td>
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<td>Etc.</td>
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Eastern Interconnection Case Study: Comparison of Three Approaches (Johnson et al. 2015)

JHU Model (M.I.L.P.): JHSMINE
- 27 EI regions
- Pipes & Bubbles
- 20 years of annual transmission & generation investment

US-Wide Hypothetical Example (Liu et al., 2013)

JHSMINE Model:
- 13 US regions
- Build & dispatch gen; build transmission

Results:
1. Gen-Only (with existing grid): $1846B PW
2. Trans-Only (with Gen-Only generation): $1766B
   • $19B/$35B trans investment 2010-20/20-30
3. Co-op Iterate: $1716B
   • $26B/$45B trans
4. Co-op Simultaneous: $1679B
   • $73B/$44B trans

Savings: $88B Fuel, $62B Gen Capacity
**Conclusions**

Q1: Stochastic plans are different & likely better  
Q2: Stochastic planning is practical  
Q3: Other approximations can be important as assuming certainty  
Q4: “Anticipatory planning” (cooptimization) captures not only fuel cost savings, but generation capital cost savings

**Next:**  
- detailed regional study for BPA  
- Improved decomposition methods for solving huge problems

**Questions?**

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Bibliography


