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Stochastic Generation Expansion Planning

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Introduction

- The GEP

- Stochastic GEP

- CVaR

- Chance Constraints

- Computational Results
The GEP

- Determination of the type, quantity, and timing of power plant construction.

- Two main cost components in GEP: investment (first stage) and generation (second stage).

- Minimize cost, with important constraints...

- Must meet “anticipated” demand for electricity.
Notation: Sets, Indices, and Parameters

Sets:

- \( g \in \mathcal{G} \): Types of generators.
- \( y \in \mathcal{Y} \): Years in planning horizon.
- \( t \in \mathcal{T} \): Load duration curve sub-periods.
- \( T_y \): Set of sub-periods \( t \) in year \( y \).
- \( Y_t \): Year \( y \) to which sub-period \( t \) belongs.
- \( \omega \in \Omega \): Scenario paths representing parameter uncertainties.

Parameters:

- \( c_g \): Cost per MW capacity to build a generator of type \( g \), discounted to the beginning of the construction period. Units are $/MW.
- \( m_g^{\text{max}} \): Maximum output capacity of installed generators of type \( g \). Units are MW.
- \( h_t \): Number of hours in sub-period \( t \).
- \( n_g^{\text{max}} \): Maximum output rating of generators of type \( g \) per hour. Units are MW.
- \( u_g^{\text{max}} \): Maximum number of generators of type \( g \) that can be constructed over the planning horizon.
- \( u_g \): Existing number of generators of type \( g \) at the beginning of the planning horizon.
- \( p_u \): Penalty cost for unserved energy. Units are $/MWh.
- \( r \): Annual interest rate, for cost discounting purposes.

The following parameters are defined for each scenario \( \omega \in \Omega \):

- \( l_{gt\omega} \): Generation cost per MW hour for generators of type \( g \) in sub-period \( t \), for scenario \( \omega \). Units are $/MWh.
- \( d_{t\omega} \): Demand per hour in sub-period \( t \) for scenario \( \omega \). Units are MW.
- \( \pi_\omega \): Probability that scenario \( \omega \) is realized; \( \sum_{\omega \in \Omega} \pi_\omega = 1 \).

Decision Variables:

- \( U_{gy} \in \mathbb{Z}^+ \): (Investment) Number of generators of type \( g \) to be built in year \( y \).
- \( L_{gt\omega} \geq 0 \): (Operations) The power generated by generators of type \( g \) per hour in sub-period \( t \) for scenario \( \omega \). Units are MW.
- \( E_{t\omega} \geq 0 \): (Operations) The unserved load per hour in sub-period \( t \) for scenario \( \omega \). Units are MW.
Constraints:

\[ \sum_y U_{gy} \leq u^\max_g \quad \forall g \in \mathcal{G} \quad (1) \]

\[ \sum_g L_{gt\omega} + E_{t\omega} = d_{t\omega} \quad \forall t \in \mathcal{T}, \omega \in \Omega \quad (2) \]

\[ L_{gt\omega} \leq n^\max_g (u_g + \sum_{y \leq Y_t} U_{gy}) \quad \forall g \in \mathcal{G}, t \in \mathcal{T}, \omega \in \Omega \quad (3) \]
Minimization of Expected Cost

\[
\min_{U_{gy}, L_{gt\omega}, E_{t\omega}} \sum_{y \in Y} \sum_{g \in G} \frac{c_{gy} \max g{U_{gy}}}{(1+r)_{y-1}} + \sum_{\omega \in \Omega} \pi_{\omega} \xi_{\omega} \tag{4}
\]

where the per-scenario operational costs \( \xi_{\omega} \) are defined as:

\[
\xi_{\omega} = \frac{\sum_{y \in Y} \sum_{t \in T_{y}} \left( \sum_{g \in G} h_{tg_{\omega}} L_{tg_{\omega}} + p_{u} h_{t} E_{t\omega} \right)}{(1+r)_{y-1}} \quad \forall \omega \in \Omega \tag{5}
\]
Stochastics

- Extended time horizon, so there is uncertainty represented by scenarios.

- Use expected cost and/or CVaR

- Cost uncertainty, demand uncertainty modeled using GBM to generate scenarios

- Data from MISO and Korea

- (In Korea, demand uncertainty has historically been very low)

- Nuke uncertainty??? (e.g., upper bounds on Nukes)
Mean versus Risk? A Matter of Taste!

*Conditional Value-at-Risk (CVaR) is a linear approximation of TCE*
As a practical matter:

- CVaR is an expectation and can be optimized using the same machinery used for the expected value.

- CVaR solutions are often viewed as excessively costly, so CVaR is often combined with expected-cost minimization in a weighted multi-objective scheme (or the tail probability can be varied).

- CVaR gives a bound on VaR, so a VaR frontier can be obtained from the same process.
How Many Scenarios?

- For MISO data with uncertain price and demand: Hundreds.

- We looked at both confidence intervals and solution differences.
Chance Constraints

- With the advent of the smart grid, the thinking is that if generation capacity is inadequate, price signals will reduce demand.

- So from a long term planning perspective, some probability of “load shedding” might be OK.

- (but it must be limited)
A bit of notation

• $ST$: Service Threshold. Fraction of demand that must be satisfied when there is “load shedding.”

• $CC$: Probability of load shedding.
Conclusions

• Various forms of the 2-stage stochastic GEP are computationally tractable for full-scale data to support policy analysis.


Figure 1: The expected total costs over the planning horizon for the South Korean GEP, as a function of the probability of load shedding $CC$. Each point represents the average over 3 replicates. Each line represents costs for a different value of the service level threshold $ST$. 
Figure 2: The expected total costs over the planning horizon for Midwest ISO GEP, as a function of the probability of load shedding $CC$. Each point represents the average over 2 replicates. Each line is for a different value of the service threshold $ST$. 