

Computational Issues of Optimization for Planning (5.2)

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Research Goals

Improved computational methods for long-term resource planning under uncertainty:

- Efficiently and effectively reduce the number of scenarios considered in stochastic program for generation expansion planning
- Multi-level models for transmission planning, generation expansion, and market operations
 - Solve tri-level model for transmission plans
 - Include uncertainty in bi-level model for transmission and generation expansion

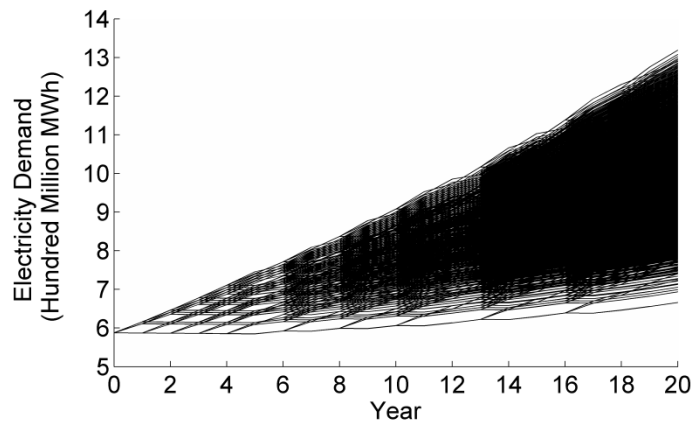
Generation Expansion Planning under Uncertainty

- Stage 1: investment plan over long time horizon
- Stage 2: for realized scenario paths of load and natural gas price
 - Energy generated by each unit, in each load duration curve (LDC) segment, each year
 - Unserved energy in each LDC segment, each year
- Minimize investment plus operational cost
 - Expected value
 - Conditional Value at Risk = expected cost in the α -fraction of worst cases

Scenario **Generation** and **Reduction**

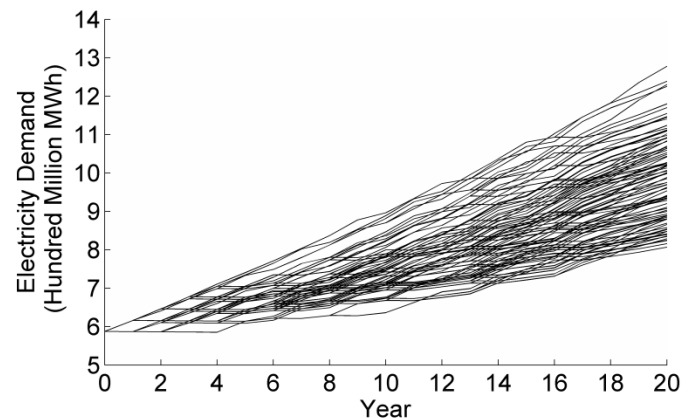
Correlated processes for demand and fuel prices

- Match historical properties: mean, variance, skewness, cross-correlation
- Scenario tree for conditional evolution
- 3 branches per period * 10 periods



Forward Selection in Wait-and-See Clusters (FSWC)

1. Solve subproblem for each scenario path
2. Cluster scenarios based on similarity of investment decisions and total costs
3. Apply *Forward Selection* within each cluster



Results: Accuracy and Computation Time

- 100 scenarios selected by two heuristics

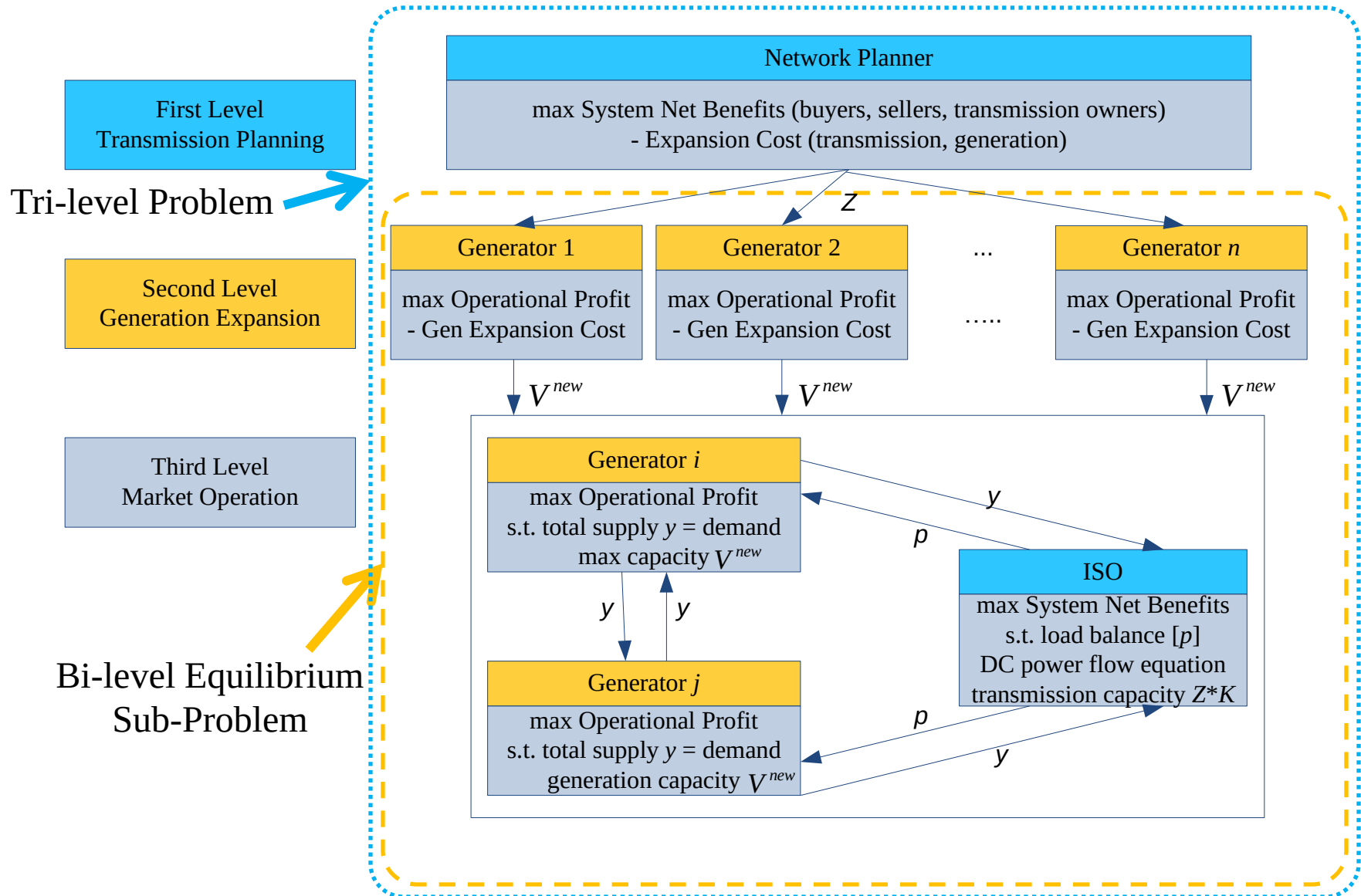
Performance	Forward Selection	FSWC
Investment Cost (\$B)	99.42	99.61
Generation Cost* (\$B)	81.31	81.53
Unserved energy** (MWh)	ϵ	1.6 ϵ
Total Cost* (\$B)	224.61	253.73
Scen. Red. (CPU seconds)	1.067E6	1.11E5
Solution (CPU seconds)	1672	1534
Total time (CPU seconds)	1.068E6	1.12E5

* Expectation across *all* scenarios

** Total over 20 year time horizon

- Order of magnitude time reduction, similar results

Transmission and Generation Expansion in Market Environment



Solution Approach

Iterative process

- Complementarity reformulation: convert 3-level optimization problem to 1-level master problem
 - Binary and continuous variables
 - Linear, nonlinear, and complementarity constraints
 - Necessary, but not sufficient, conditions for equilibrium of generator expansions and market operations
- Evaluate candidate transmission plan by diagonalization to find “true” equilibrium
- Send cuts back to master problem based on bounds and feasibility

Results in IEEE Test Systems

- Modified 30-bus system
 - 10 candidate lines: 1,024 possible expansion plans

Major Iteration	MINLP Master Problem A			EPEC Sub-problem B	Adding Constraints to Master Problem A	
	Status	Transmission Plan	Net Surplus	Net Surplus	Lower Bound	Cut Point
1	Feasible	None	13235.34	13038.62	13038.62	None
2	Feasible	B	13057.90	12727.90	13038.62	B
3	Feasible	E	13216.10	12957.11	13038.62	E
4	Feasible	H	13246.07	13066.56	13066.56	H
5	Infeasible					

- Computation time: 1.55 hours
- 118-bus test system, 4 candidate lines
 - Optimal transmission plan found in first iteration

Multiple Scenarios in Bi-Level Model

- Upper level – investments in transmission and generation capacity
- Lower level – wholesale market equilibrium
- Deterministic version can be reformulated as a mixed integer program
- Multiple scenarios for lower level result in stochastic mixed integer program
 - Changing hourly conditions
 - High- and low-frequency uncertainties
- Ongoing: customize and apply FSWC scenario reduction heuristic in this context

Accomplishments

- New scenario reduction heuristic for two-stage stochastic programs works much faster than current one on very large scenario trees
 - Incorporates cost and constraint information in addition to scenario probabilities
- Iterative method to search among, not just test, alternative transmission plans anticipating generator expansions and market operation
 - Allows exploration of a variety of conditions

Benefits and Applications

- Reducing the computational burden of long-term planning under uncertainty can
 - Allow inclusion of more operational, spatial, or temporal detail
 - Identify plans that avoid risks of under- or over-expanding
- Multi-level model of transmission planning
 - Understand how follower decision-makers may respond to planning decisions
 - Better transmission plans can expand use of renewables, equalize locational prices, and prevent or mitigate undue market influences

References

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