Enhancing Reliability Unit Commitment with Robust Optimization

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ISO New England
Enhanced ISO and RTO unit-commitment models Conference
June 2-3, 2010

* The opinions expressed in this presentation are the authors' and not necessarily those of ISO New England

Outline

- Current Process for Market Operations
- Operational Challenges
- Managing Uncertainties in Unit Commitment
  - Deterministic UC
  - Stochastic Programming
  - Robust Optimization
- Two-Stage Robust Optimization Approach
- A Conceptual Five-Bus Example
- Conclusion

Current Process for Market Operations

- Day-head Market
  - A Financial Market
- Reliability Unit Commitment
  - Physical unit commitment to meet reliability needs
  - Commitment of units with long runtime
- Real-time Dispatch and Pricing
  - Commitment of fast-start units
  - Meeting the real-time load

Operational Challenges

- Real-time Challenges:
  - Increased penetration of intermittent resources
  - Increased frequency of interchange scheduling
  - Increased demand response participation
  - Real-time operating parameter re-declaration
  - Real-time performance of dispatchable resources
- Real-time Commitment/Dispatch
  - Rely on fast-start units : Increased production cost
  - Emergency procedure: Load reduction/shedding
- Is there a better unit commitment schedule to reduce the real-time operational risk?

The Unit Commitment Problem

- The mathematical formulation of the unit commitment problem in a compact form:

$$\min_{u,p} \sum_{i \in I, t \in T} \left(f_{it}(u_{it}) + f_{it}^{e}(p_{it}) \right)$$

$$s.t. \quad \sum_{i \in I} p_{it} = \sum_{n} d_{nt}, \forall t \in T$$

$$\sum_{i} r_{it} \geq \mathrm{Q}_t \quad \forall t \in T$$

$$(u, p, r) \in S$$

$f_{it}(u_{it})$ and $f_{it}^{e}(p_{it})$ are the startup and no-load cost, and the incremental cost

$u_{it} \in \{0,1\}$ is the commitment status for generator i at time t

p_{it}, $\mathrm{r}_{it} \geq 0$ are the energy and reserve output for generator i at time t

d_{nt} is the demand at bus n at time t

Q_t is the reserve requirement at time t

S is a feasible set

Uncertainties Parameters Affecting UC

- Type of uncertainties
  - Units' Initial Conditions
  - Load Forecast
    - Load Forecasting Errors
    - Demand Response
  - Resources' Generating Capabilities
    - Wind Power
    - Solar
  - Contingency Events
    - Generator's Forced Outages
    - Transmission Line Outages

Modeling of Uncertainty in UC

- Deterministic UC
  - Enforcing additional Reserve Requirements
- Stochastic programming
  - Minimizing the expected cost
- Robust optimization
  - Minimizing the cost for the worst case

Stochastic Programming

- A conventional way to model UC problem with real time uncertainties
- Require the knowledge of the probability distribution of the uncertain parameters
- Minimize the expected cost of the unit commitment problem
- The stochastic UC with demand uncertainty is the following:

$$\min_{u, p_\omega} \left\{ \sum_{i \in I, t \in T} f_{it}(u_{it}) + \sum_{\omega \in \Omega} \pi_\omega \left(\sum_{i \in I, t \in T} f_{it}^e(p_{it\omega}) \right) \right\}$$

$$s.t. \quad \sum_{i \in I} p_{it\omega} = \sum_n d_{nt\omega}, \forall t \in T, \forall \omega \in \Omega$$

$$\sum_i r_{it\omega} \geq Q_{t\omega} \qquad \forall t \in T \ \forall \omega \in \Omega$$

$$(u, p_\omega, r_\omega) \in S, \quad \omega \in \Omega$$

π_ω is probability for the scenario ω

$p_{it\omega}, r_{it\omega}$ are the power and reserve output for generator i at time t for scenario ω

Ω is the set of scenarios of the levels of demand d.

Robust Optimization

- Robust optimization models random demand using uncertainty sets rather than probability distributions.
- Minimize the worst-case cost in that set.
- The robust optimization counterpart of the original problem is the following:

$$\min_{u}\left\{\sum_{i\in I,t\in T} f_{it}\left(u_{it}\right)+\max_{d\in U}\left(\min_{p}\sum_{i\in I,t\in T} f_{it}^{e}\left(p_{it}(u,d)\right)\right)\right\}$$

$$s.t.\quad \sum_{i\in I} p_{it}=\sum_{n} d_{nt},\forall t\in T,d_{nt}\in U$$

$$\sum_{i} r_{it}\geq \mathrm{Q}_{t}\qquad \forall t\in T$$

$$(u,p,r)\in S$$

$p_{it} \geq 0$ is the power output for generator i at time t

U is the uncertainty set of the real-time nodal demand d.

Stochastic Programming vs. Robust Optimization

	Stochastic Programming	Robust Optimization
Data	Random variables	Uncertainty sets
Information required	Distributions	Convex hull of data realization
Advantage	Able to quantify expectations such as evaluating probability of outcomes	•Distribution free •Computationally tractable for many classes of optimization
Disadvantage	•Computationally challenging •How to obtain exact distribution?	•Unable to provide probability measure such as expectations •How to choose the right uncertainty set?

Risk Management

- Risk is inevitable. It would be desirable to set up a corporate risk management policy.
- What is the right risk metric?
  - LOLP, EUE, etc..
  - Chance Constraints
- What is the N-1 protection criterion? – worst case
- Can we find the least cost unit commitment schedule that sustain any of the credible events? --- robust unit commitment.
- No risk has been quantified by these methods. Monte Carlo simulation can be used to quantify the risk.

The Uncertainty Set in Robust UC

- Choosing uncertainty sets that yield a good trade-off between performance and conservatism is central to robust optimization.
- Bertsimas, Sim and Thiele proposed the concept of "budget of uncertainty" to model the trade-off.
- In order to not overprotect the system, the random demand d_{nt} at node *n* at time t can be modeled as,

$$d_{nt} = \bar{d}_{nt} + \hat{d}_{nt} z_{nt}, \quad |z_{nt}| \leq 1$$

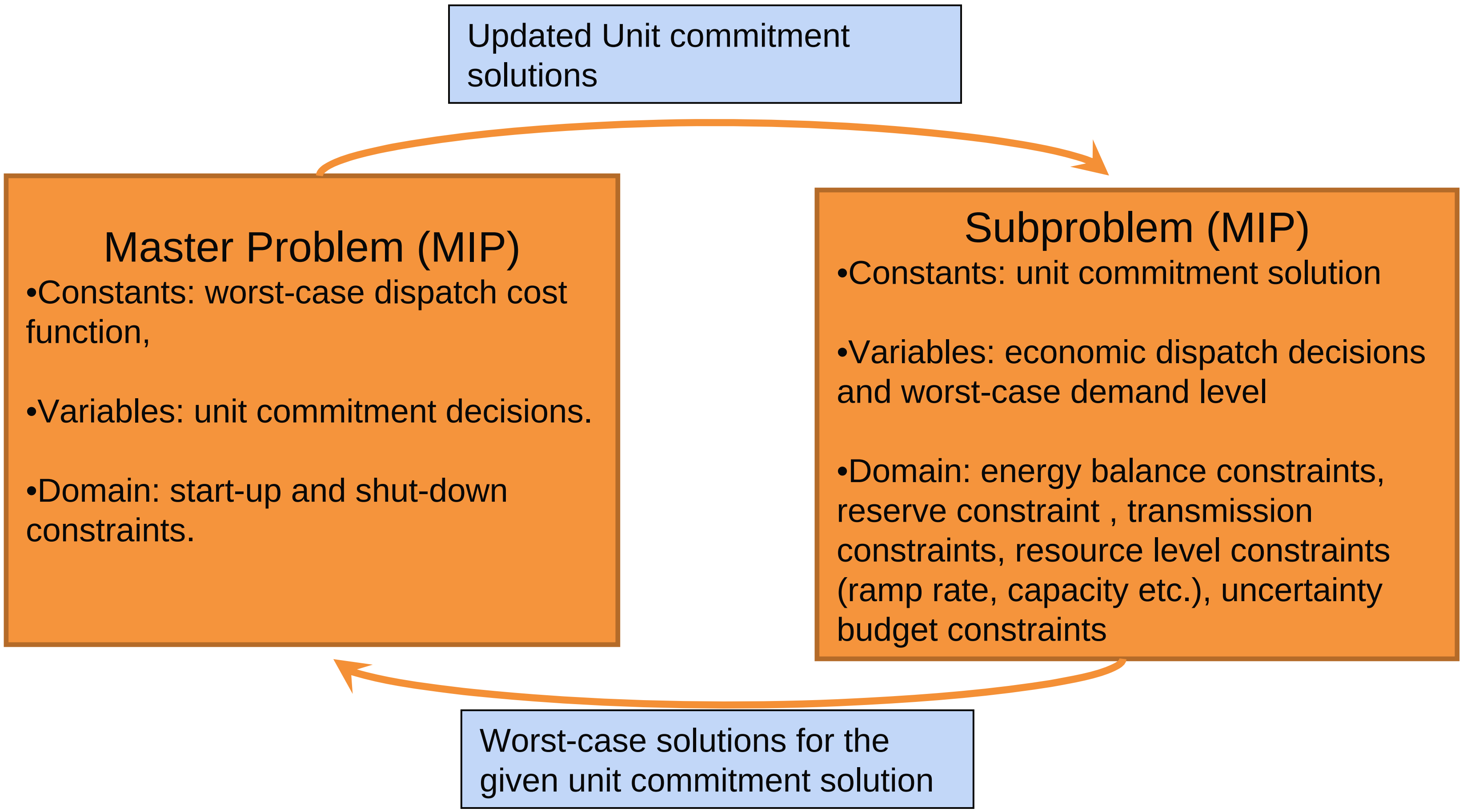
$$\sum_{n=1}^{m} |z_{nt}| \leq \Gamma_t, \text{ for each time interval } t$$

- Γ is called the "budget of uncertainty".
- $\Gamma = 0$ yields the normal deterministic problem.
- $\Gamma = m$ leads to the most conservative case.

Three Random Loads

Budget of Uncertainty	Load 1 (MW)	Load 2 (MW)	Load 3 (MW)
$\Gamma = 0$	150	250	350
$\Gamma = 1$	[150-15,150+15]	250	350
	150	[250-25,250+25]	350
	150	200	[350-35,350+35]
$\Gamma = 2$	[150-15,150+15]	[250-25,250+25]	350
	[150-15,150+15]	250	[350-35,350+35]
	150	[250-25,250+25]	[350-35,350+35]
$\Gamma = 3$	[150-15,150+15]	[250-25,250+25]	[350-35,350+35]

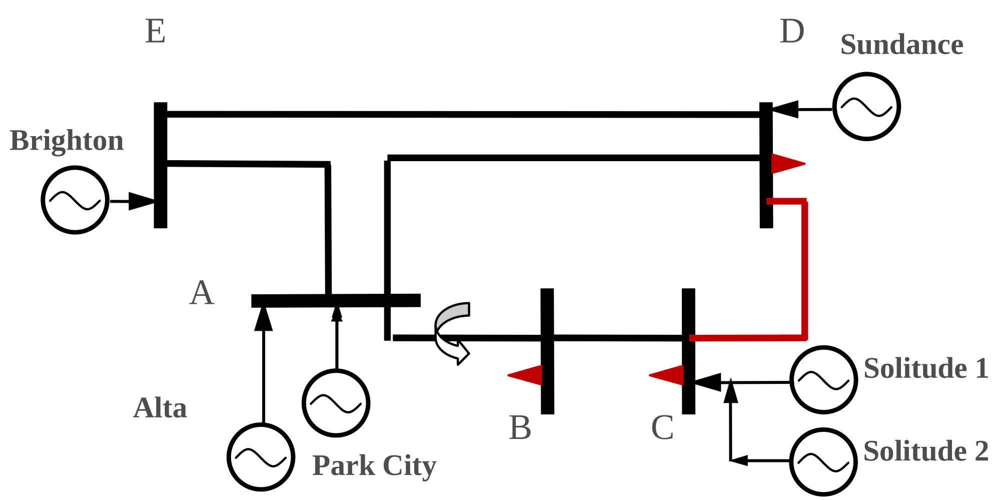
Bender’s Decomposition Algorithm for RO Two-Stage UC Problem



A Five-Bus Example

Unit Name	[EcoMin, EcomMax] (MW)	Offer Price ($/MWh)	Start-up Cost ($/MWh)	No-load cost ($/MWh)	Initial Status
Alta	[10,150]	25	1000	0	ON
ParkCity	[50,350]	30	1000	10	ON
Solitude 1	[50,300]	60	1000	30	ON
Solitude 2	[10,300]	140	1600	60	OFF
Brighton	[180,400]	20	2000	20	ON
Sundance	[100,300]	50	1500	16	ON

	Level (MW)
Load B	[400-25,400+25]
Load C	[370-10,370+10]
Load D	[325-15,325+15]



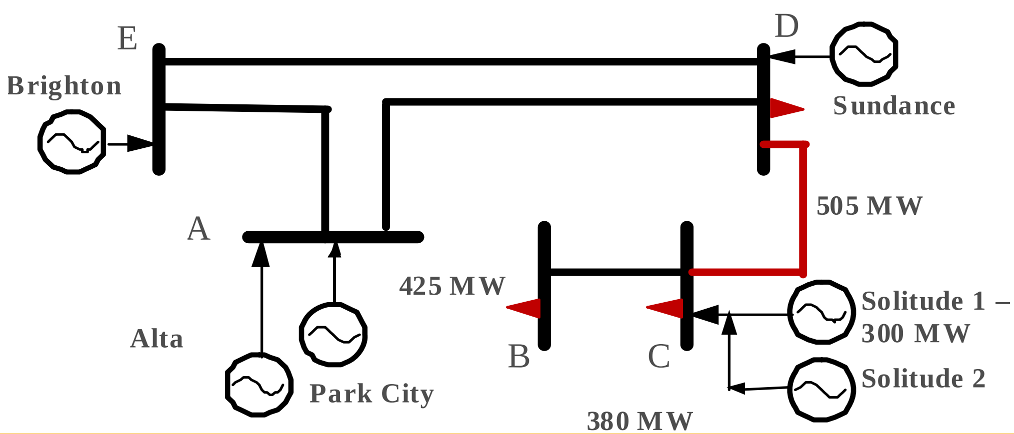
Line	Normal (MW)	LTE (MW)
AB	800	800
AD	300	400
AE	425	525
BC	400	500
CD	400	500
DE	350	450

A Five-Bus Example with Deterministic UC

- Case D1:
  - Use expected load level (400+370+325 =1095 MW)
  - Reserve requirements:
    - 10-min spinning = 50 MW
    - 10-min total = 100 MW
    - 30-min operating = 200 MW.
- Case D2:
  - Use expected load level (1095 MW)
  - Additional Reserve requirements (total load variation 50MW):
    - 10-min spinning = 100 MW
    - 10-min total = 150 MW
    - 30-min operating = 250 MW.

A Five-Bus Example -- Deterministic UC

- For both cases
  - All units except Solitude 2 are committed (total cost is $38,255)
  - Line CD is binding at 500 MW after contingency AB loss.
- Is such commitment good for any load realization?
  - What if the loads at B and C are increased by 25 and 10 MW respectively?
    - Under line AB contingency, line CD flow will be 505 MW, which is higher than its emergency limit 500 MW.
    - We failed to protect the system from such contingency.



A Five-Bus Example Robust UC

- Case R1 – with one load variation
- Case R2 – with two load variations
- Case R3 – with three load variations
- All reserve requirements are the same as case D1.
- The robust UC solution always finds load variation at the extreme point.

Case	Solitude 2	All other units	Worst Load Variation	Worst Cost ($)
R1	Off	On	LoadB	39,755
R2	On	On	LoadB and LoadC	42,416
R3	On	On	LoadB, LoadC and LoadD	42,866

Conclusion

- With the increased penetration of renewable resources and demand response, a robust unit commitment to cover the “worst” case scenario is needed in the reliability commitment process.
- Compared to the deterministic unit commitment, it is more efficient in identifying the proper commitment needed for the worst case scenario.
- Compared to the stochastic unit commitment, the robust unit commitment :
  - More consistent with the N-1 protection criterion (the worst case)
  - Do not require the knowledge of probability distribution
  - Requires less computational efforts

QUESTIONS?