Dynamic Reserve Policies for Market Management Systems

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CERTS Annual Review

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Agenda

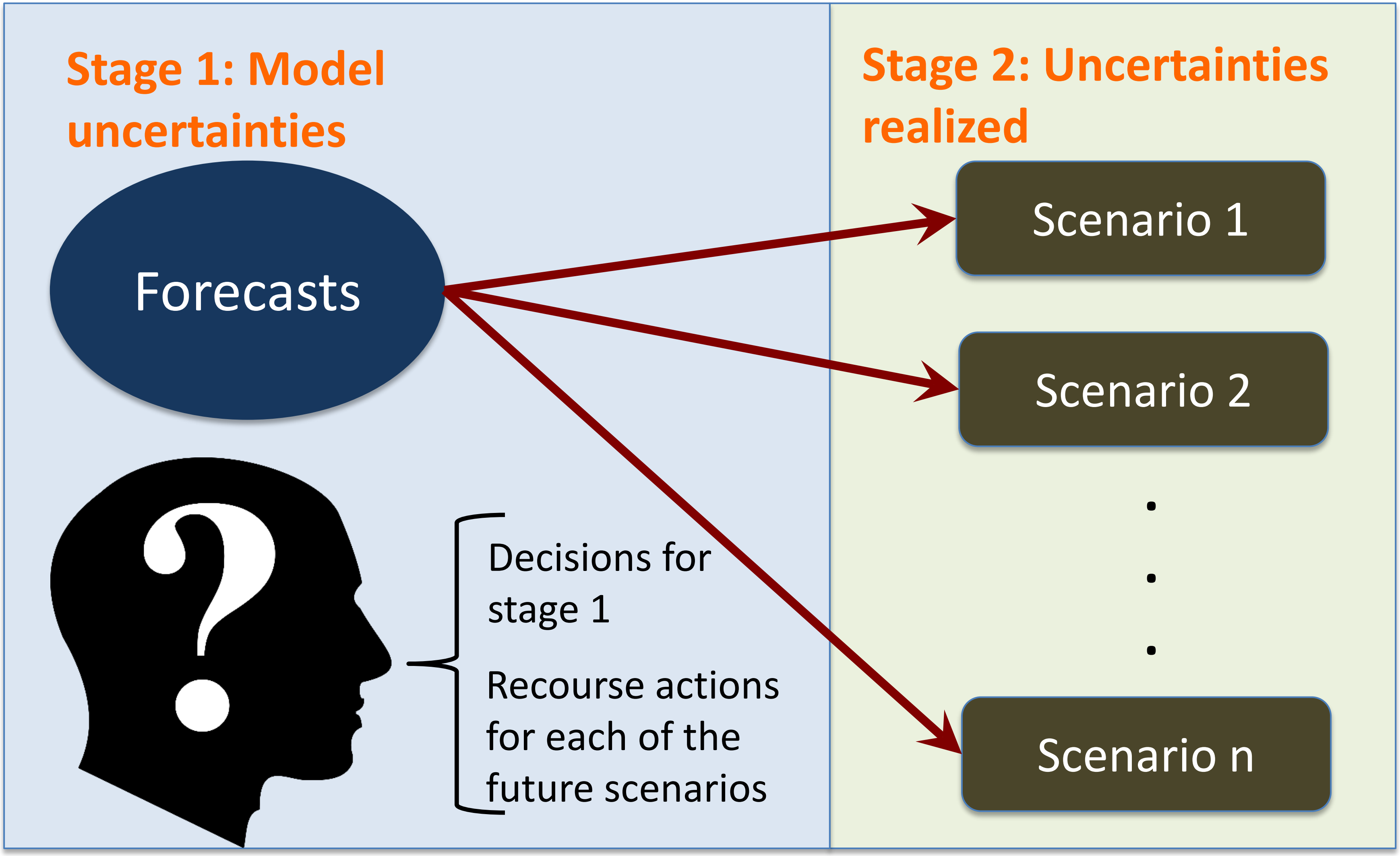
- Key Points
- Ongoing Debate: Deterministic vs. Stochastic
- Existing Industry Practices
- An Enhanced Reserve Policy Model for Market Management Systems
- Numerical Results: IEEE 118-bus and 2383-bus Polish Test Systems
- Conclusions and Future Work

Key Points

- Focus: Day-Ahead and Real-Time Markets
- Challenge 1: increasing uncertainty
- Challenge 2: existing market models inadequately handle reserve deliverability ***already***
- Ideal solution: model the uncertainty inside the optimization model (stochastic programming, robust optimization)
- Practical consideration: what will move stakeholders, industry?
  - Transparency? Minimal change?
- Practical consideration: scalability, market pricing
- Practical consideration: diminishing marginal returns
  - Let's start with something attainable that still makes a sizeable improvement *---- and then march in the direction of (and enhance) advanced stochastic optimization techniques*

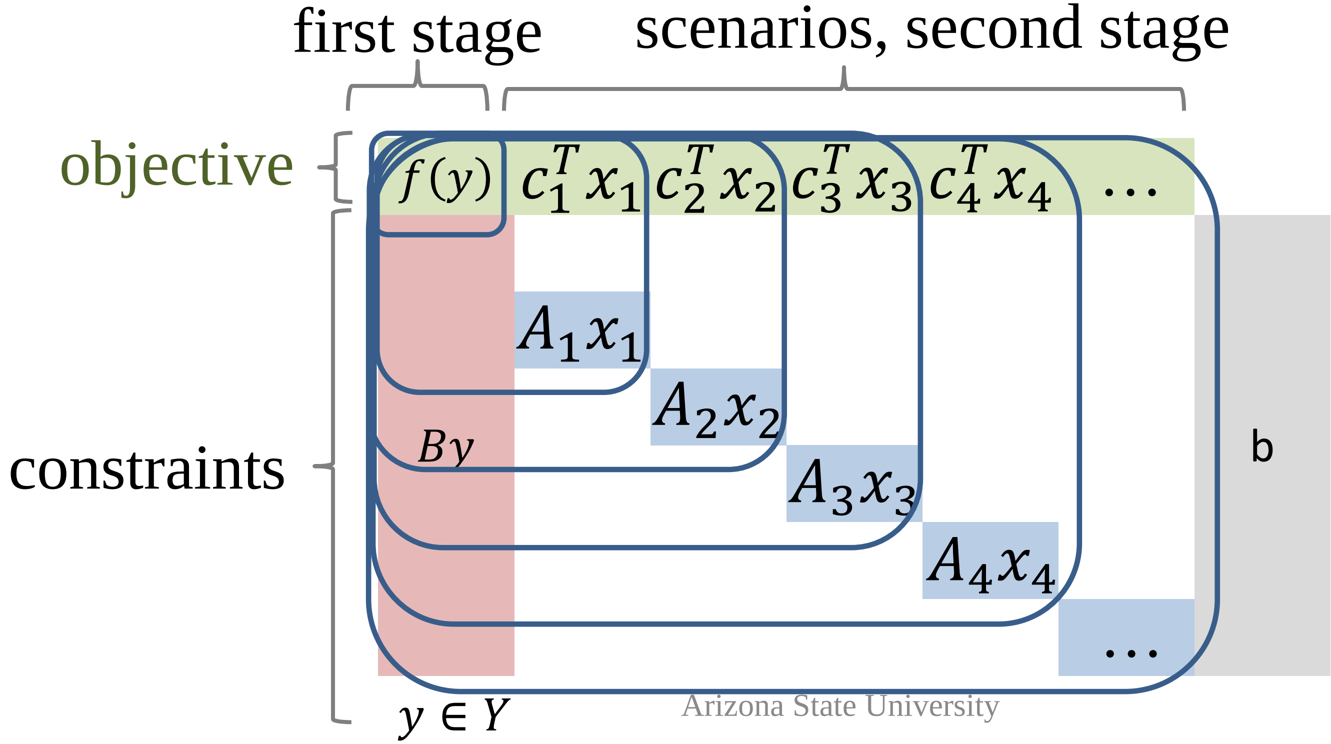
ONGOING DEBATE IN THE INDUSTRY AND ACADEMIA: HANDING UNCERTAINTIES

Two-Stage Scenario-Based Stochastic Programs



Block Diagonal Example

- Two-stage stochastic programs
  - **Stage one** (y): base-case decisions made here and now
  - **Stage two** (x): recourse decisions that can be deferred
- **Obstacle I – Computational Complexity**
  - Size of the problem: OPF × Scenarios



Stochastic Programs

- **Obstacle II – Market Barriers**
  - How to design the pricing mechanism
  - Price and dispatch depend on the corresponding uncertain realization
  - Guarantees: in expectation…
  - Market transparency

Stochastic Programs vs. Deterministic for Market Models

Increased robustness, increased complexity

Existing Deterministic Models

Explicitly model and simultaneously solve for multiple scenarios

Stochastic Programming

Better scalability, fewer technology and market barriers

Stochastic Programs vs. Deterministic for Market Models

Increased robustness, increased complexity

Existing Deterministic Models	Our Approach	Stochastic Programming

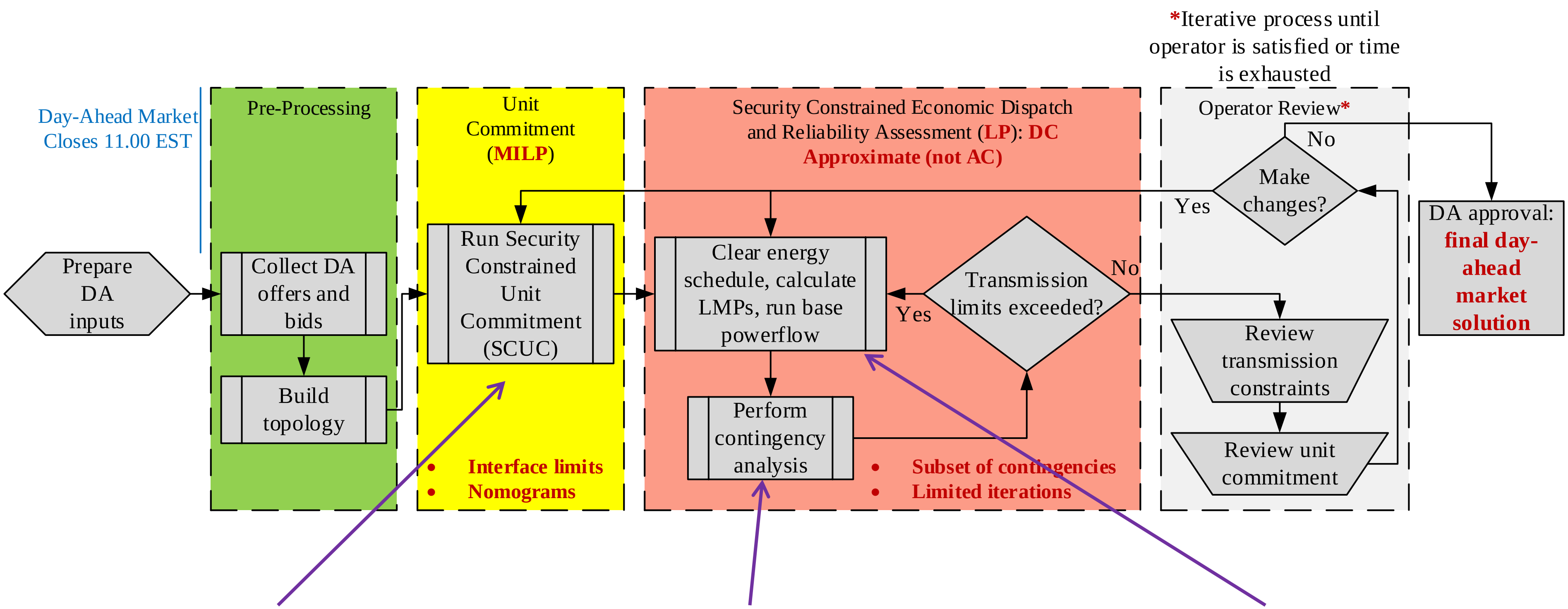
Better scalability, fewer technology and market barriers

More **effective** than existing deterministic models, more **scalable** than stochastic programs

Can **facilitate** the transition to future stochastic programs

INDUSTRY PRACTICES

Industry Practices: Day-Ahead Scheduling in MISO



Interface limits
Nomograms (e.g., COI)
Cut-off for PTDFs

Subset of contingencies

DC approximation
Not AC
Limited iterations

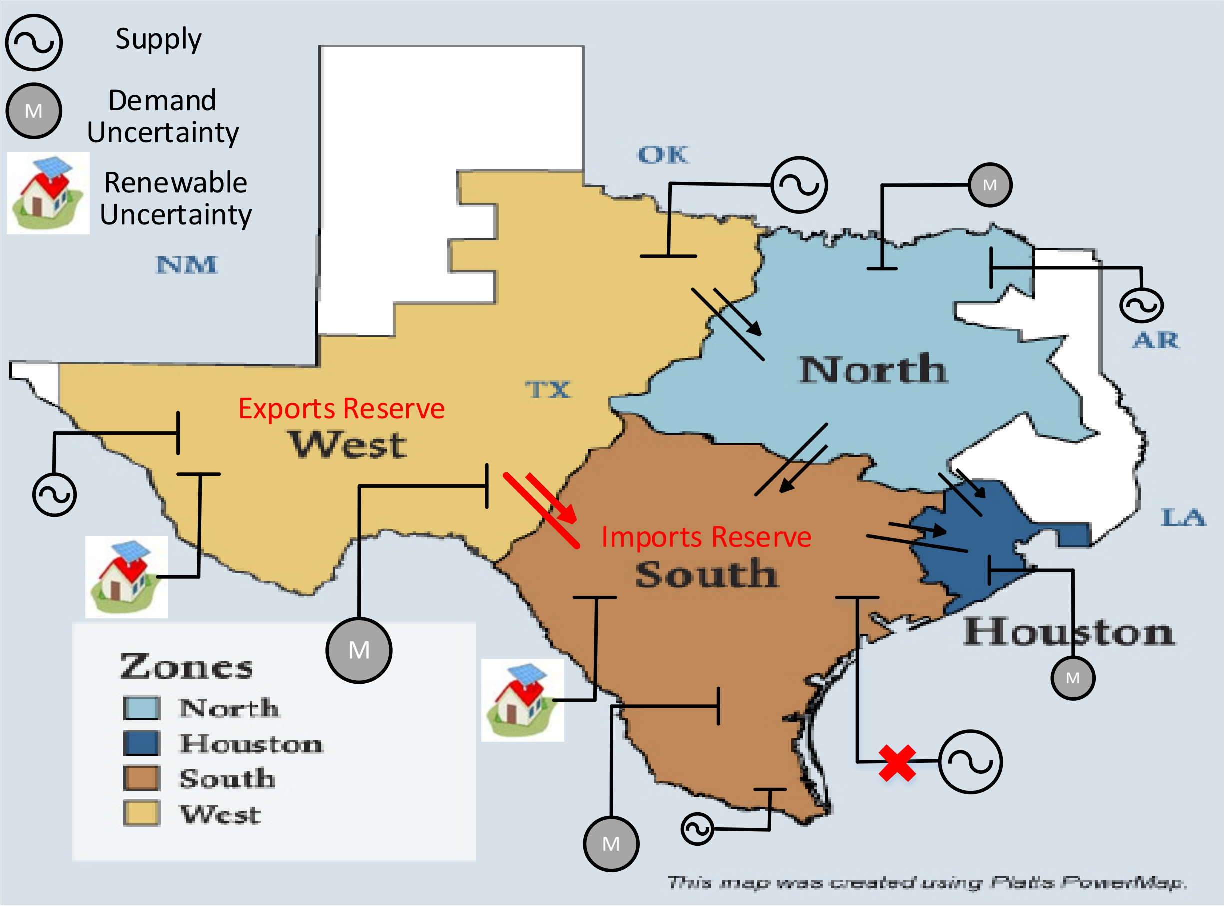
Industry Practices: Out-of-Market Corrections

- Market SCUC solutions do not guarantee *N*-1 reliability
  - Model approximations
  - Changing operating conditions
  - Deterministic structure
- Market operators adjust market solutions outside the market engine to create realistic, feasible solutions
  - Terms: uneconomic adjustments; supplement dispatch; out-of-sequence dispatch; reserve disqualification; reserve down-flags
  - **General term we will use:**
  - **Out-of-market corrections (OMC)**

Issues with present-day reserve policies

UNDERLYING DELIVERABILITY ISSUE

Reserve Deliverability Issue: Fictitious Example (ERCOT)



F_{lt}= Pre-contingency line flow

$\bar{F}_{lt}$= Emergency line rating (Rate C: post-contingency line limit)

An Enhanced Reserve Policy Model for Market Management Systems

PROPOSED METHODOLOGY

Analogous Approach

- ISOs use line outage distribution factors (LODF) to formulate transmission line contingencies (*T*-1) in SCUC
  - $-\overline{F}_{lt}^{emerg} \leq \underbrace{\boldsymbol{F_{lt}}}_{\text{Original flow on line L}} + \underbrace{\boldsymbol{LODF_{c,l}F_{c,t}}}_{\text{Portion of flow redistributed from line C to line L if line C is lost}} \leq \overline{F}_{lt}^{emerg}$

Original flow on line L + Portion of flow redistributed from line C to line L if line C is lost

= **Post Contingency Flow on line L**

  - Line contingencies are represented **explicitly**
  - But **NO** second-stage recourse decisions
- MISO uses post-zonal reserve deployment transmission constraints to determine zonal reserve requirements

Proposed Approach

- Existing line contingency modeling:
  - $-\overline{F}_{lt}^{emerg} \le \underbrace{\boldsymbol{F_{lt}}}_{\text{Original flow on line L}} + \underbrace{\boldsymbol{LODF_{c,l}F_{c,t}}}_{\text{Portion of flow redistributed from line C to line L if line C is lost}} \le \overline{F}_{lt}^{emerg}$

- **Proposed** gen contingency (or renewable resource deviation) modeling:
  - $-\overline{F}_{lt}^{emerg} \le \underbrace{\boldsymbol{F_{lt}}}_{\text{Original flow on line L}} - \underbrace{\boldsymbol{p_{ct}PTDF_{n(c),l}}}_{\text{Change in flow due to loss of gen}} + \sum_g \underbrace{\boldsymbol{PTDF_{n(g),l}\overline{\Gamma_{gt}^{c}}r_{gt}}}_{\text{Change in flow due to reserve activation}} \le \overline{F}_{lt}^{emerg}$

- Again, there are no recourse decisions
- Key issue: determine $\overline{\boldsymbol{\Gamma_{gt}^{c}}}$

$\sum_g \overline{\boldsymbol{\Gamma_{gt}^{c}}}\boldsymbol{r_{gt}} \ge p_{ct} + r_{ct}$

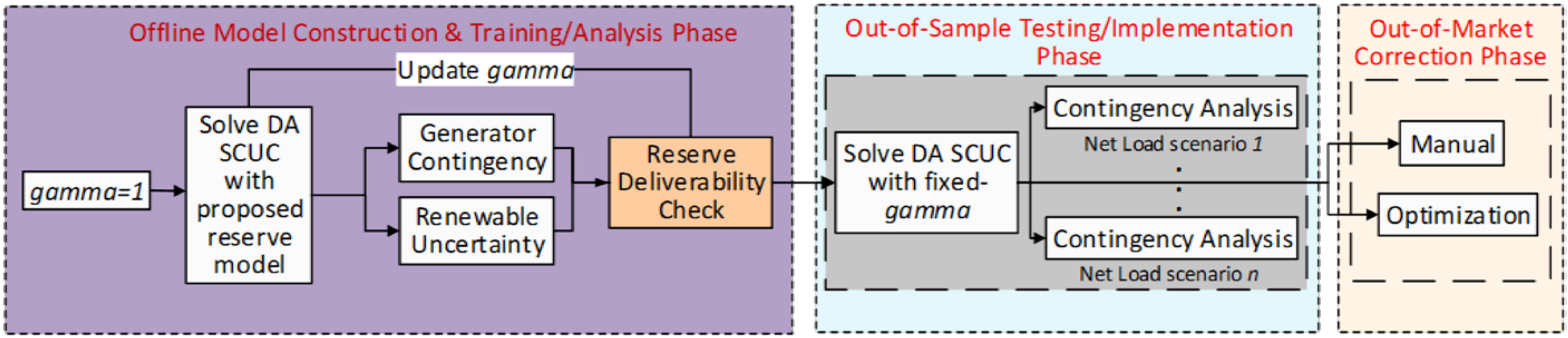
Reserve response set

How to Determine $\overline{\Gamma^{c}_{gt}}$?

- Analogous existing approach: real-time contingency analysis (RTCA)
  - Uses participation factors for gen contingencies to estimate post-contingency operating state
  - Potential participation factors: inertia, available reserve
- Proposed approach: analyze historical data; data mining
- To replace (missing) historical data: we create an offline stochastic simulation methodology
- Generate hypothetical data
- Then analyze performance of **gamma**
- Test chosen **gamma** against various operational states and scenarios (out-of-sample testing)

Offline Methodology for $\overline{\Gamma_{gt}^{c}}$

- The method (offline) utilizes a knowledge discovery process from historical data analogous to contemporary data-mining techniques



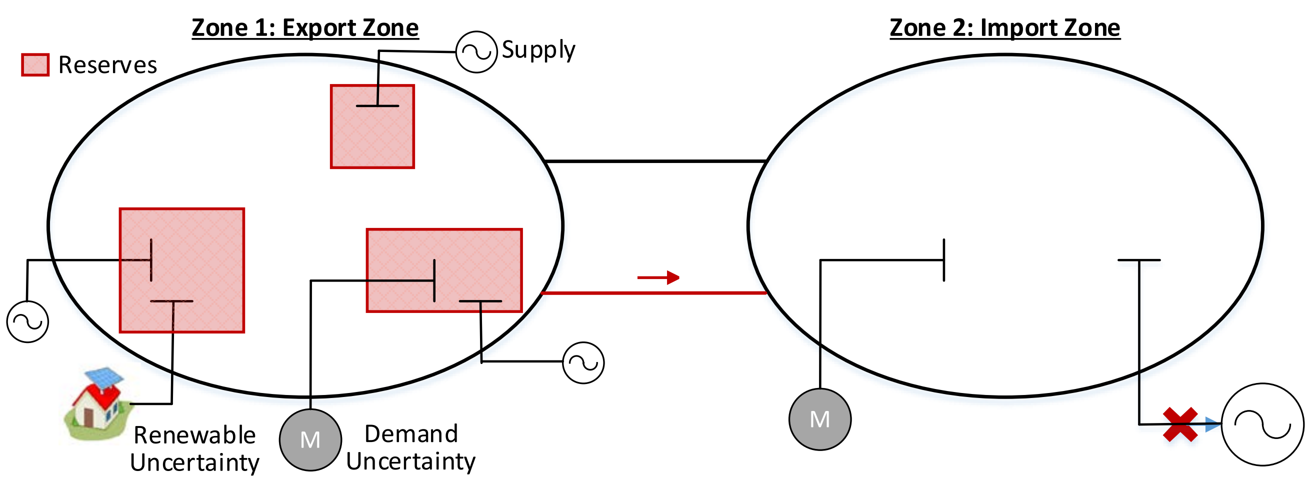
- SCUC formulation enhances determination of reserve regarding both ***quantity and location***
- Improve reserve deliverability on ***critical links***

Comparison: Base Case Reserve Model

- A zonal reserve model
- Allows reserve sharing between zones: $'\alpha'$ policy defined in relation to the available headroom
- Illustration: Pre-contingency flow: 50 MW; Limit (Rate C): 100 MW

Case 1 (liberal policy): $\alpha = 1$

Case 2 (conservative policy): $\alpha = 0.75$



Reserve sharing limit from zone 1 to zone 2:

$= 1 \times 100 - 50 = 50$ MW

$= 0.75 \times 100 - 50 = 25$ MW

P

Message:

- Enhance reserve deliverability
- Stakeholder acceptance (transparency)
- Diminishing marginal returns
- Enhance stochastic programming

- Proposed gen contingency (or renewable resource deviation) modeling:
  - $-\overline{F}_{lt}^{emerg} \leq \underbrace{\boldsymbol{F_{lt}}}_{\text{Original flow on line L}} - \underbrace{\boldsymbol{p_{ct} PTDF_{n(c),l}}}_{\text{Change in flow due to loss of gen}} + \underbrace{\sum_g \boldsymbol{PTDF_{n(g),l} \overline{\Gamma_{gt}^{c}} r_{gt}}}_{\text{Change in flow due to reserve activation}} \leq \overline{F}_{lt}^{emerg}$

Original flow on line L

Change in flow due to loss of gen

Change in flow due to reserve activation

- Again, there are no recourse decisions
- Key issue: determine $\overline{\boldsymbol{\Gamma_{gt}^{c}}}$

$\sum_g \overline{\boldsymbol{\Gamma_{gt}^{c}}} \boldsymbol{r_{gt}} \geq p_{ct} + r_{ct}$

Reserve response set

Preliminary Results on a Small-Scale Test System

Test for Robustness of the Proposed Approach: Implementation on Multiple Days

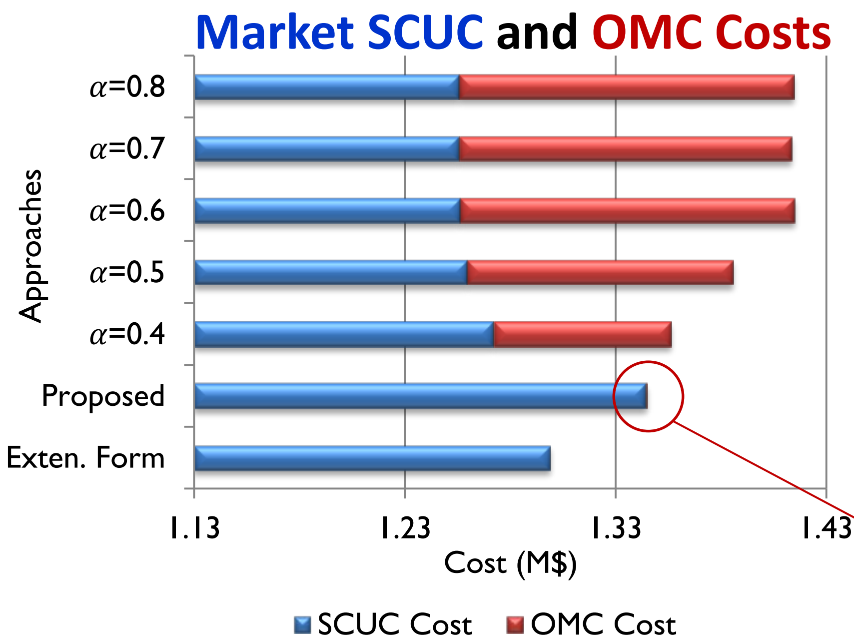
NUMERICAL RESULTS: IEEE 118-BUS TEST SYSTEM

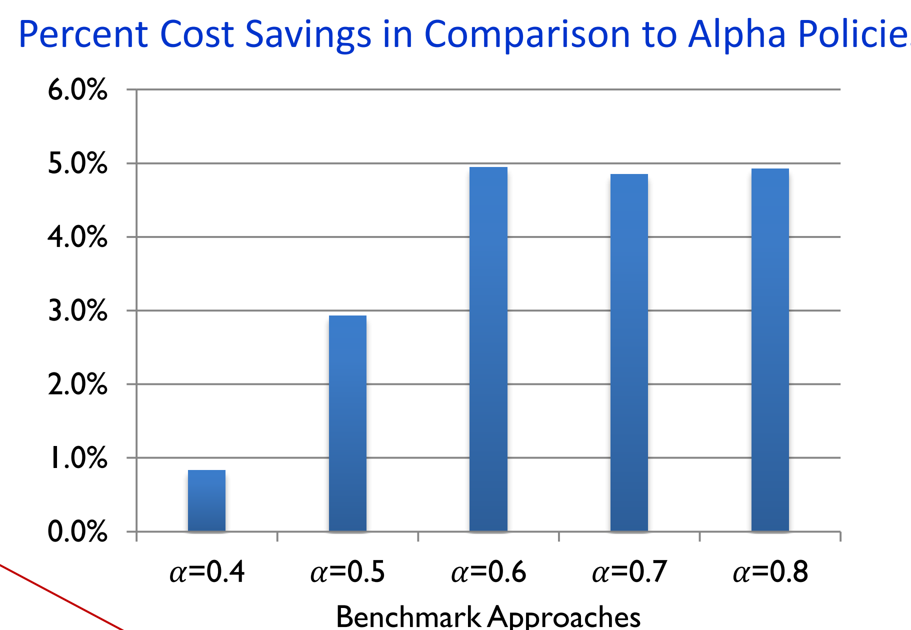
Out-of-Market Corrections (OMC)

- Approximate market models, stochastic programs (with limited scenarios, i.e., *all*): produce unreliable solutions
  - Out-of-sample testing: may have load shedding
- Often, a value of lost load (VOLL) is assumed to **estimate the cost of load shedding**
  - Subjective results
- Our analysis simulates dispatch operator out-of-market correction procedures to better estimate actual costs
  - All solutions are reliable, no load shedding
- **OMC terms:** uneconomic adjustments; supplement dispatch; out-of-sequence dispatch; reserve disqualification; reserve down-flags

Results: 118-Bus System, Day 1

- Comparison of the proposed reserve model with a contemporary reserve model with varying reserve sharing policies ($\boldsymbol{\alpha}$)
- System partitioned into three reserve zones
- 1 inter-zonal link post-contingency line flow constraint



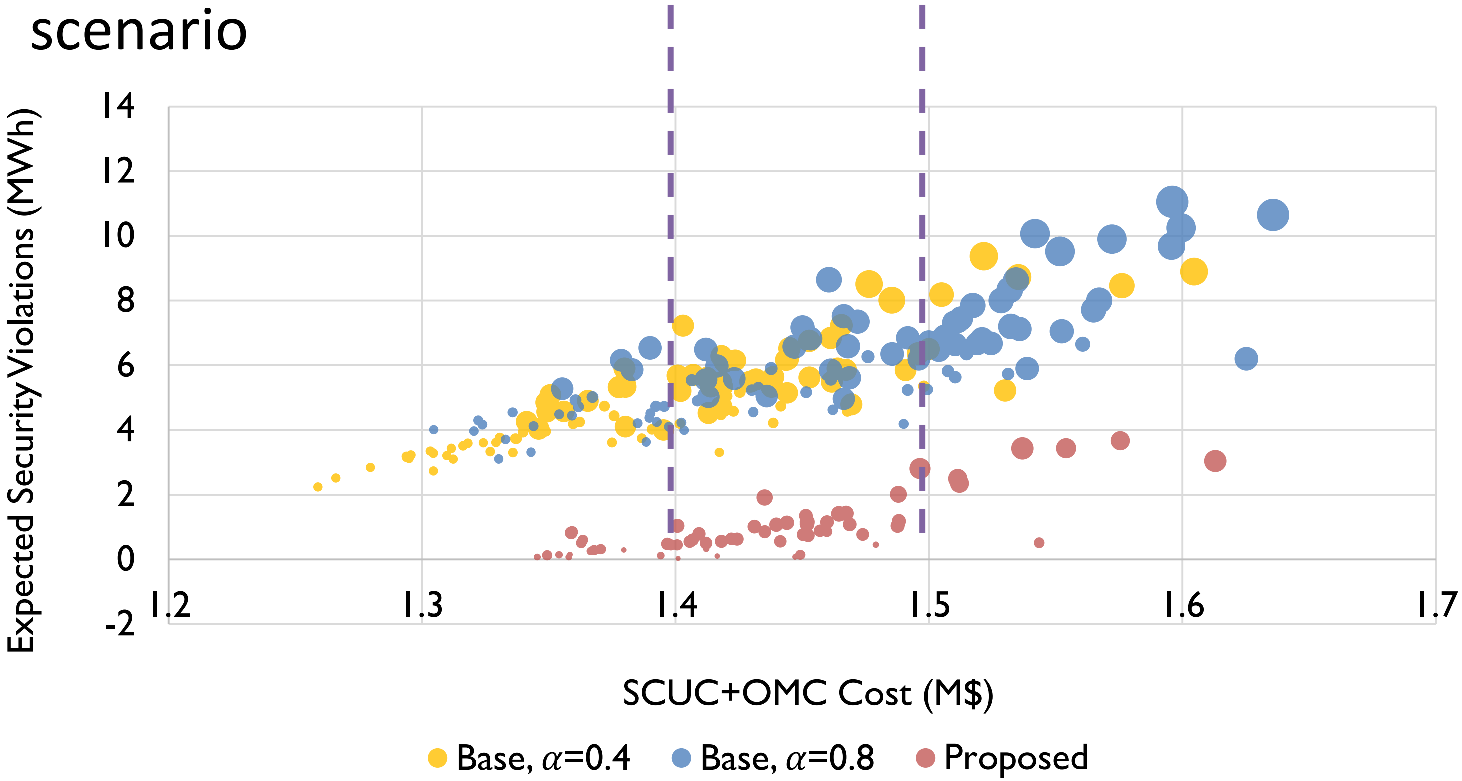


(Extensive form final optimality gap: *0.16%*)

The market solution is close to a *N*-1 reliable solution!

Result - 118-Bus System, Day 1

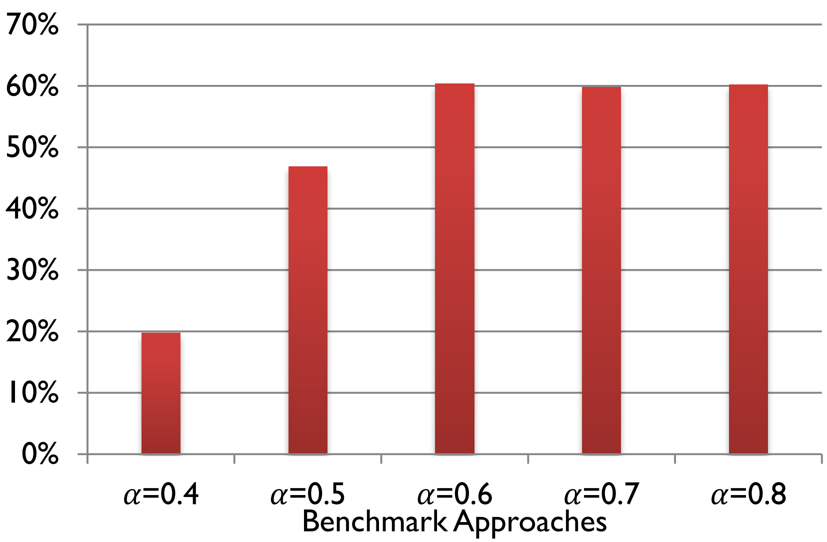
- Expected security violations for the day-ahead market solution compared against the cost of the final N-1 reliable solution
- Size of the bubble represents the number of violations in each scenario



Results: 118-Bus System, Day 1

- Relative performance measures the percentage of the highest potential cost savings that the proposed approach can achieve
- $RltP_i\% = \frac{C_\alpha - C_{our}}{C_\alpha - C_{stoch.}} \cdot 100\%$

Relative Performance



Average Time to Solve Day-ahead SCUC (s)

Approaches	Day 1	Day 2	Day 3
Proposed	9.6	3.6	6.6
α=0.4	23.5	25.8	31.8
α=0.5	22.4	15.6	14.5
α=0.6	15.2	12.5	23.9
α=0.7	19.3	17.2	20.5
α=0.8	9.4	15.5	20.4

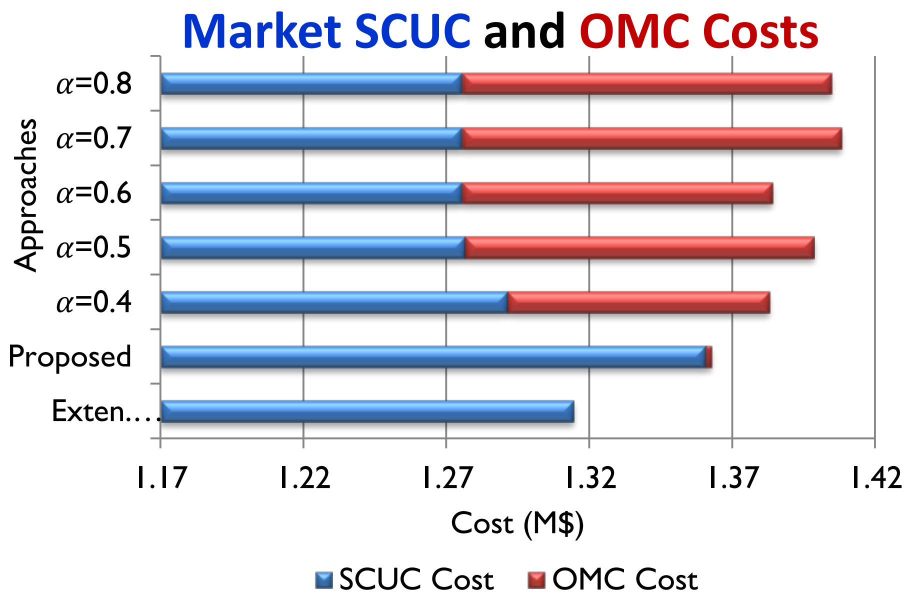
Results: 118-Bus System

- Potential drawback of the proposed approach:
  - Performance over time
  - Robustness

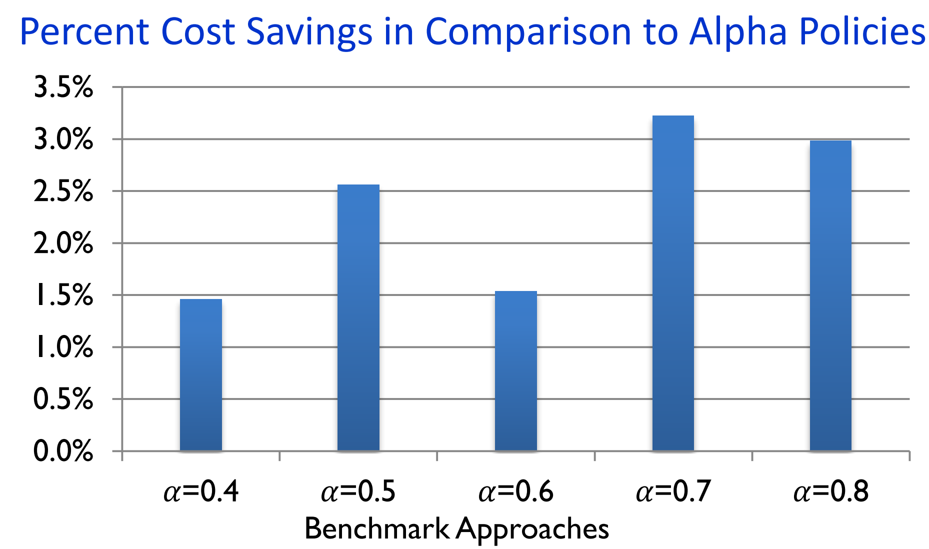
- Testing process: take offline Gamma and test against multiple day types
  - Next few slides
  - Investigation needs to continue

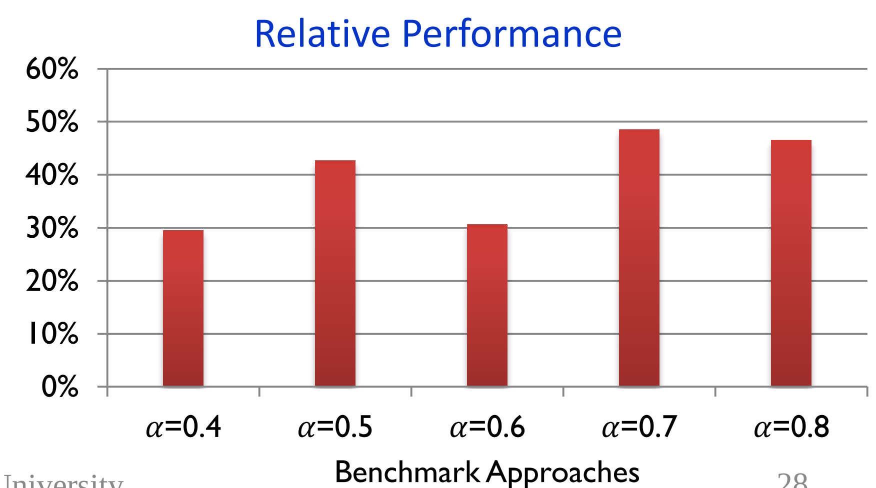
Results: 118-Bus System, Day 2

- Tested using scenarios from a different day



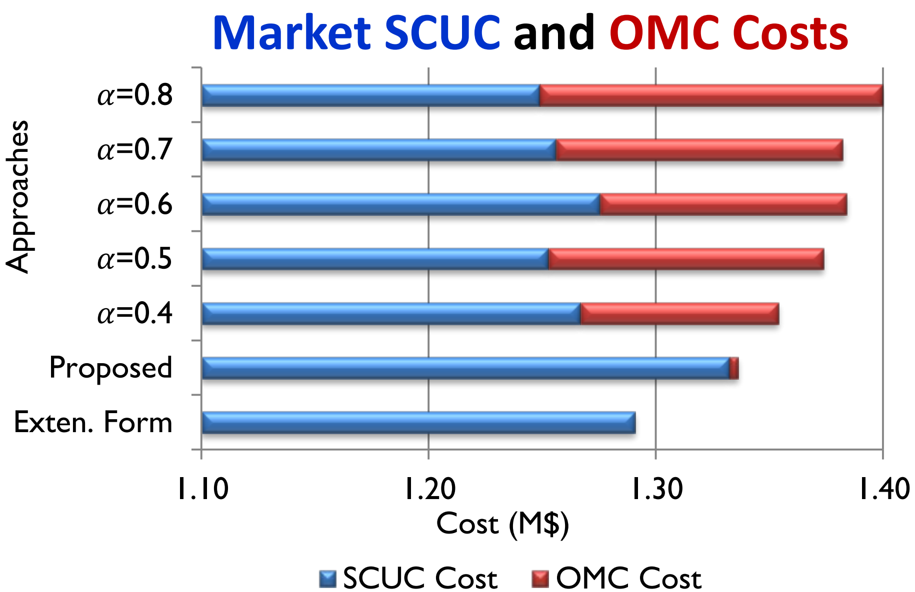
(Extensive form final optimality gap: *0.17%*)





Results: 118-Bus System, Day 3

- Tested using scenarios from a different day



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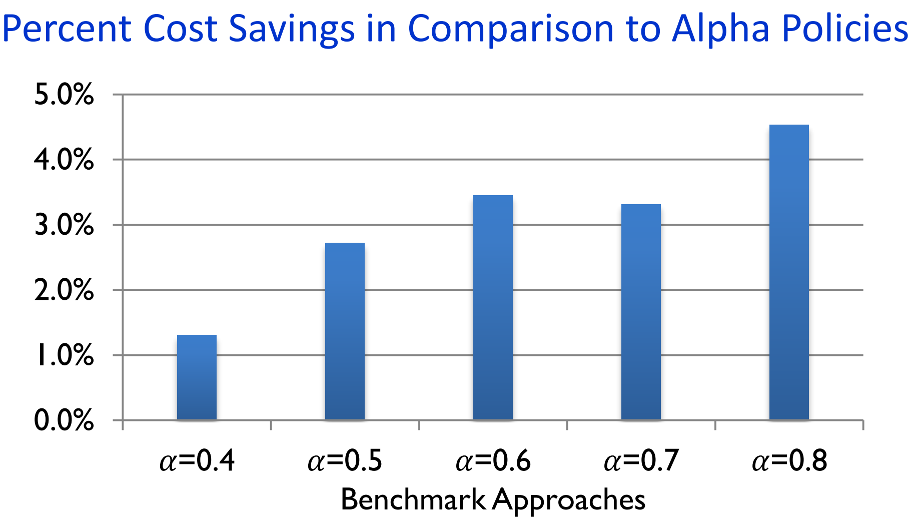
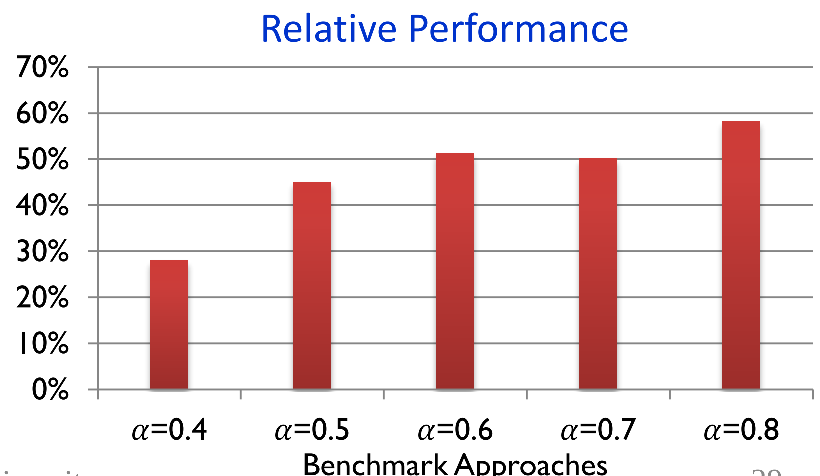




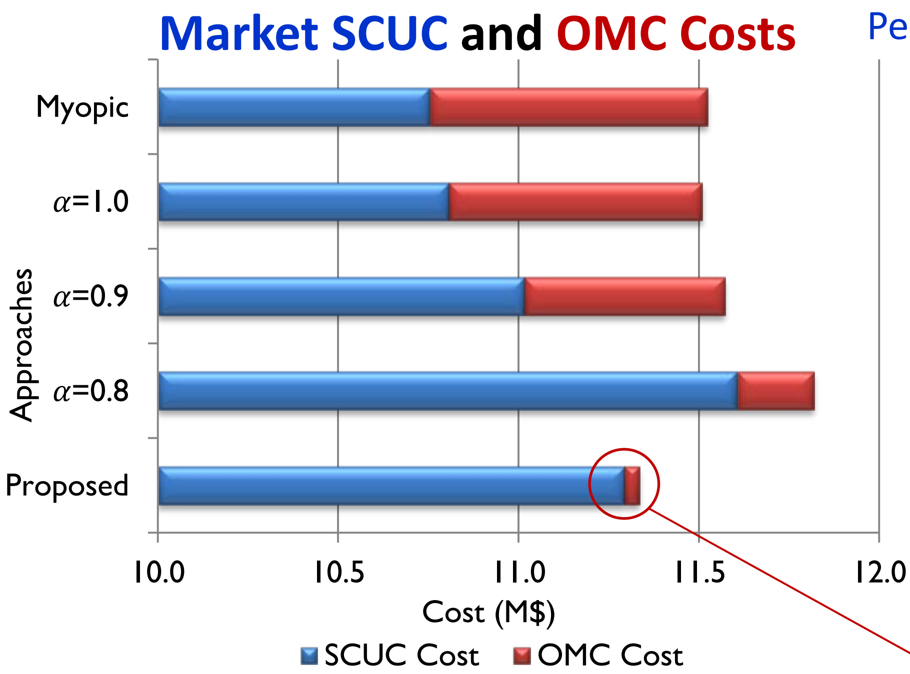
Test for Scalability of the Proposed Approach: Large-Scale Implementation

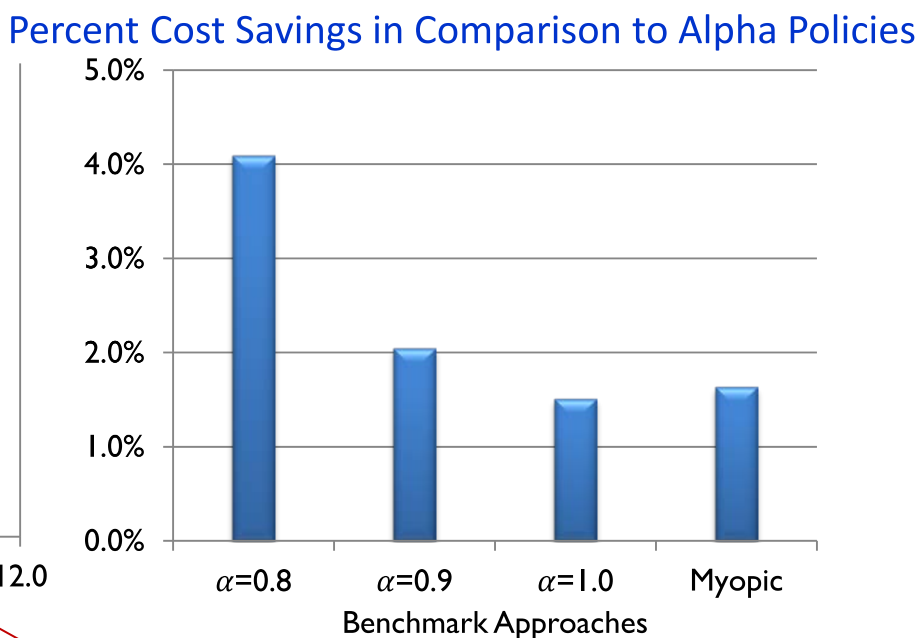
Tested on Two Versions of OMC

NUMERICAL RESULTS: POLISH TEST SYSTEM

Results: 2383-Bus Polish System, Day 1, OMC version 1

- Comparison of the proposed reserve model with contemporary reserve models: 1) single-zone reserve model (myopic) and 2) reserve model with varying reserve sharing policies ($\boldsymbol{\alpha}$)
- System partitioned into three reserve zones
- 3 inter-zonal links formulated with the post-contingency line flow constraint

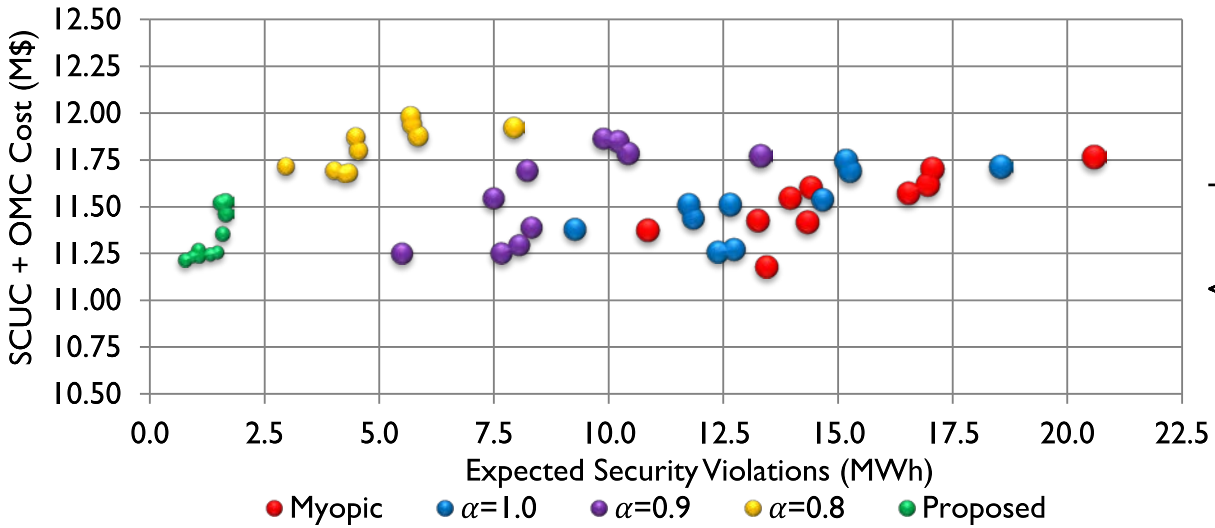


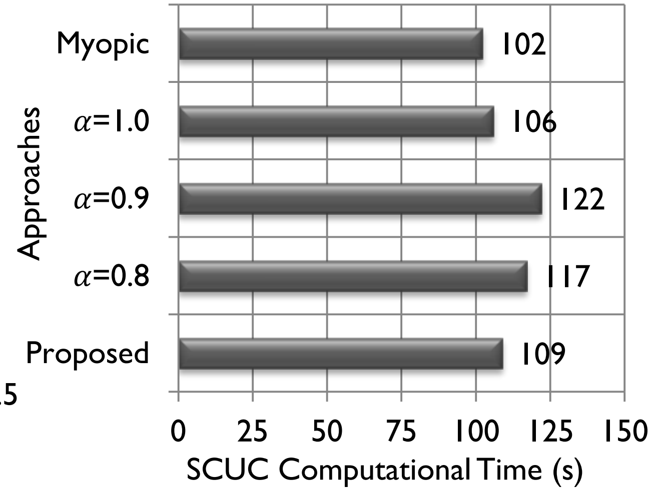


Market solution close to an *N*-1 reliable solution

Results: 2383-Bus Polish System, Day 1, OMC version 1

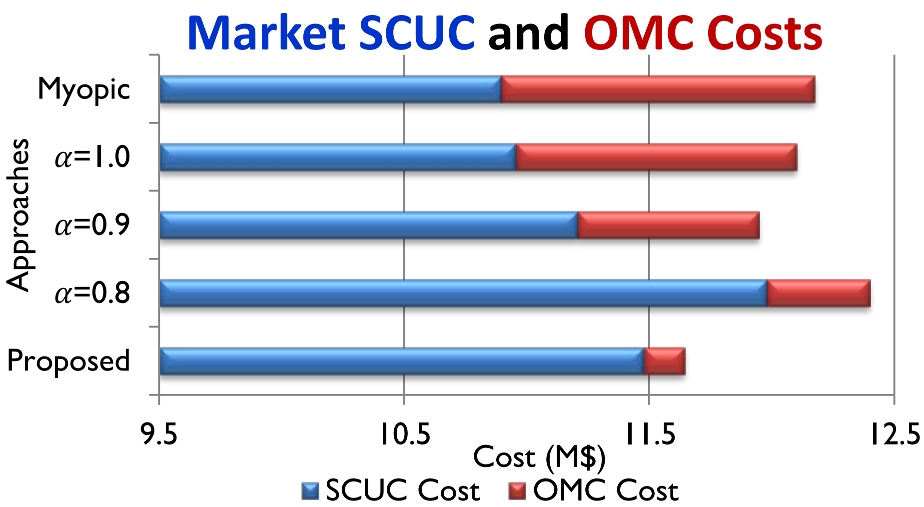
- Bubble chart comparing the cost of the final *N*-1 reliable solution against the expected security violations for the day-ahead market solution for each scenario
- Size of the bubble represents the number of violations in each scenario
- Computational time comparison

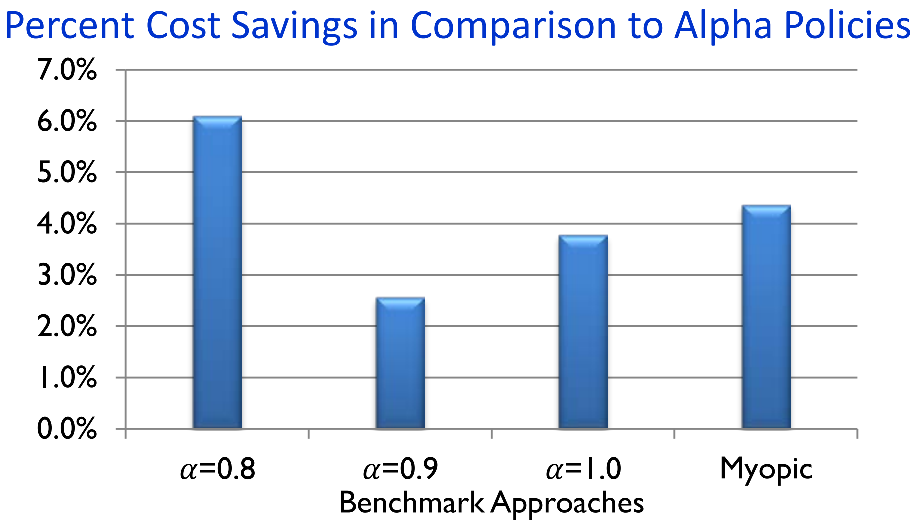


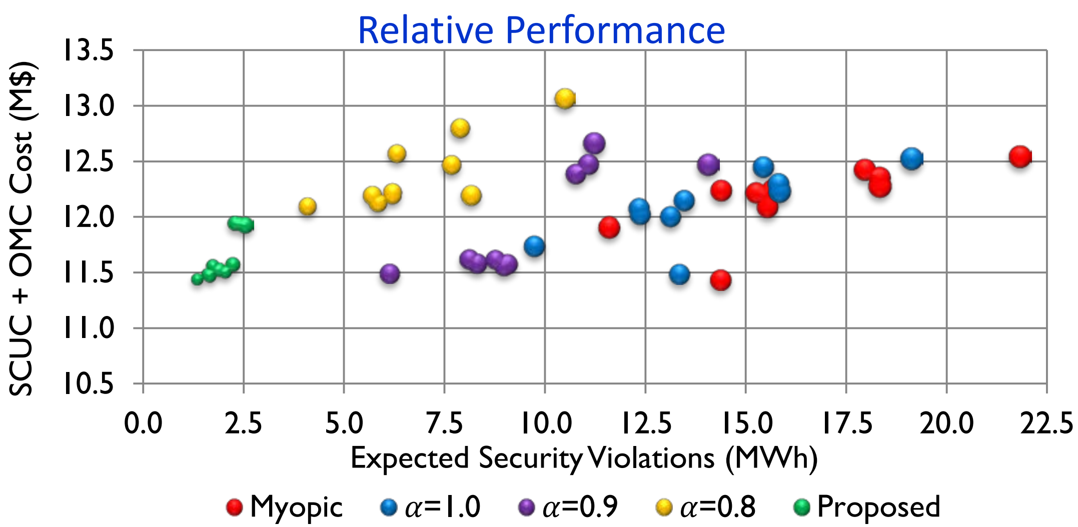


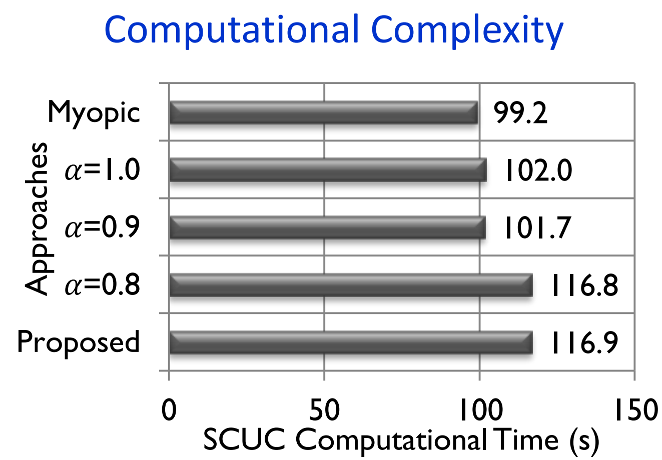
Results: 2383-Bus Polish System, Day 2, OMC version 1

- Tested using scenarios from a different day





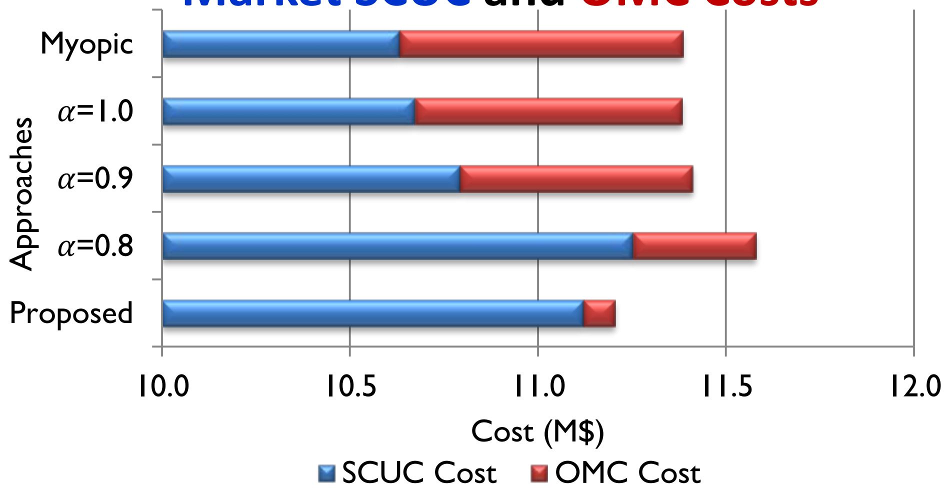




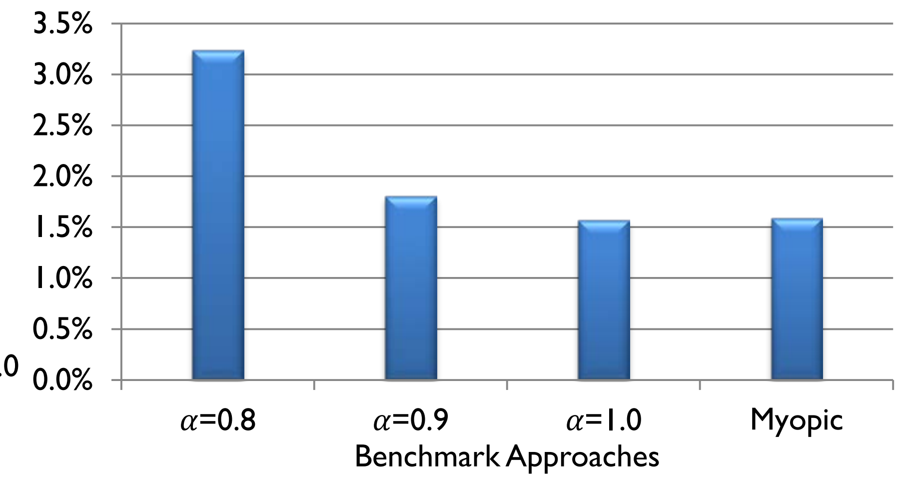
Results: 2383-Bus Polish System, Day 3, OMC version 1

- Tested using scenarios from a different day

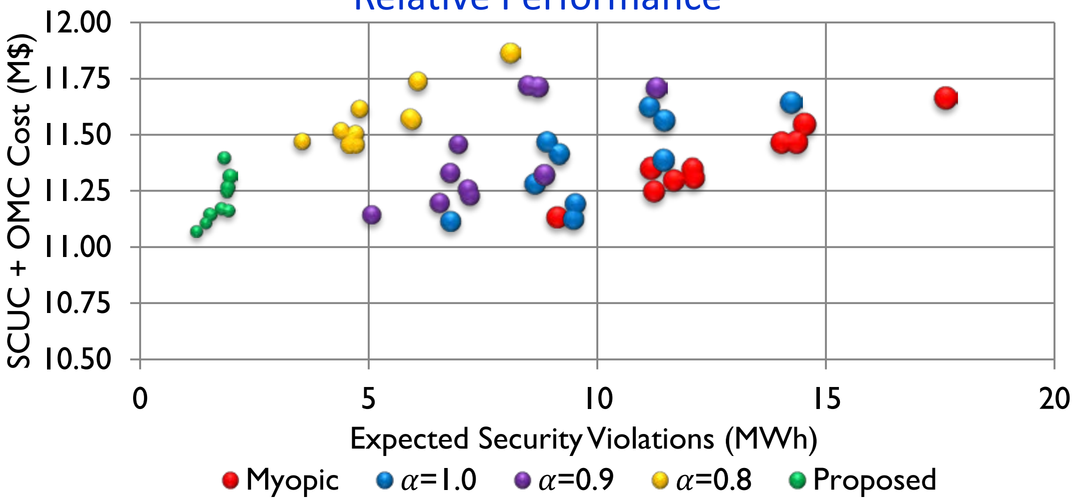
Market SCUC and OMC Costs



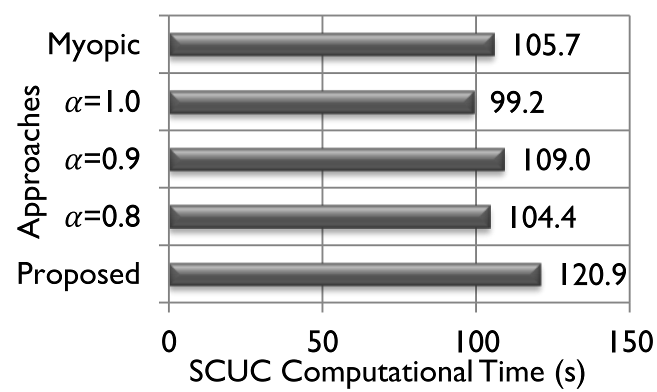
Percent Cost Savings in Comparison to Alpha Policies



Relative Performance

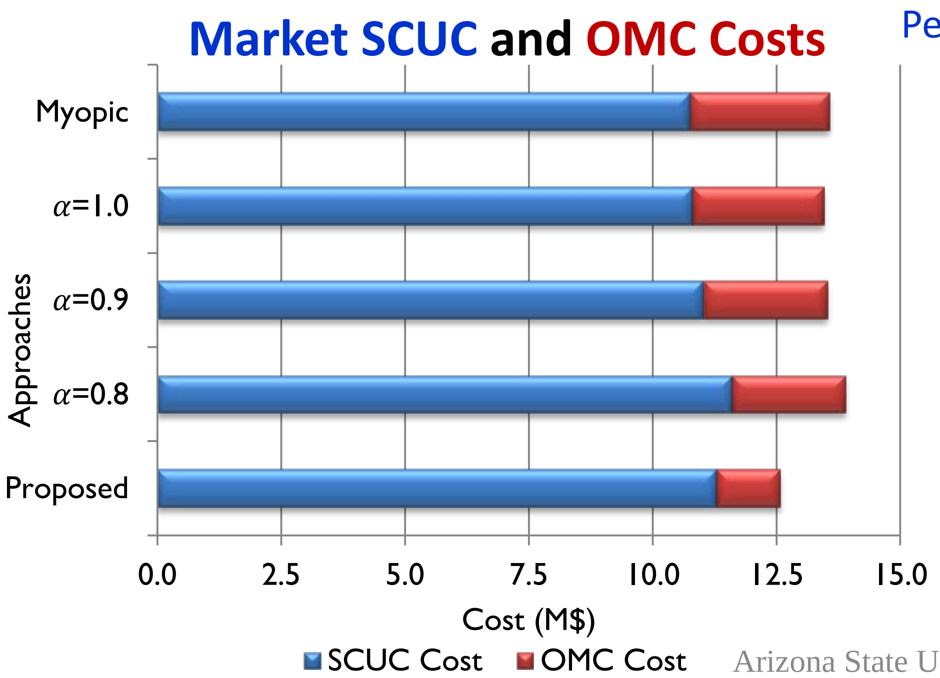


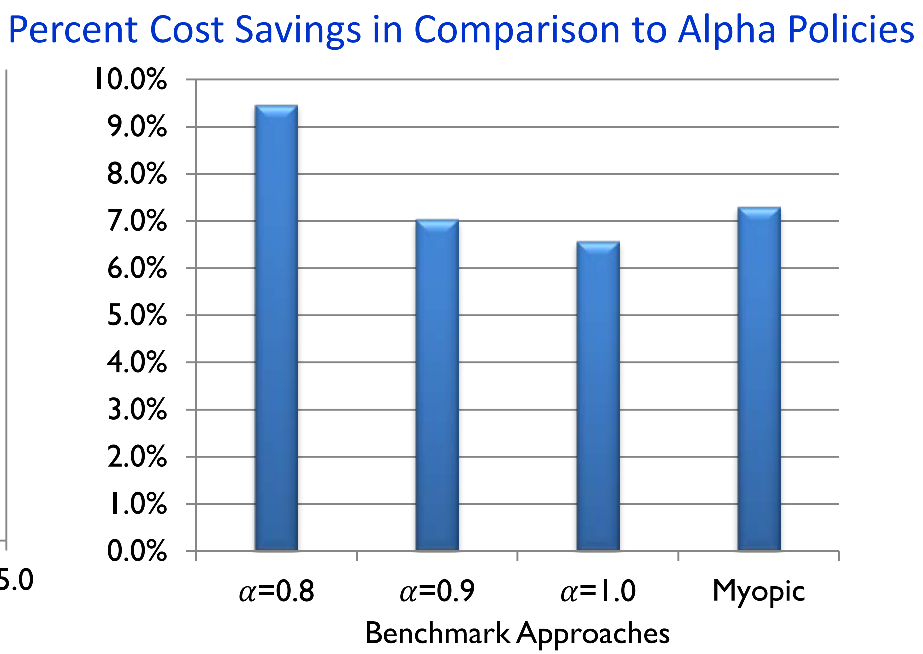
Computational Complexity



Results: 2383-Bus Polish System, Day 1, OMC version 2

- Comparison of the proposed reserve model with contemporary reserve models: 1) single-zone reserve model (myopic) and 2) reserve model with varying reserve sharing policies ($\boldsymbol{\alpha}$)
- System partitioned into three reserve zones
- 3 inter-zonal links with post-contingency line flow constraint





Results: 2383-Bus Polish System, Day 1, OMC version 2

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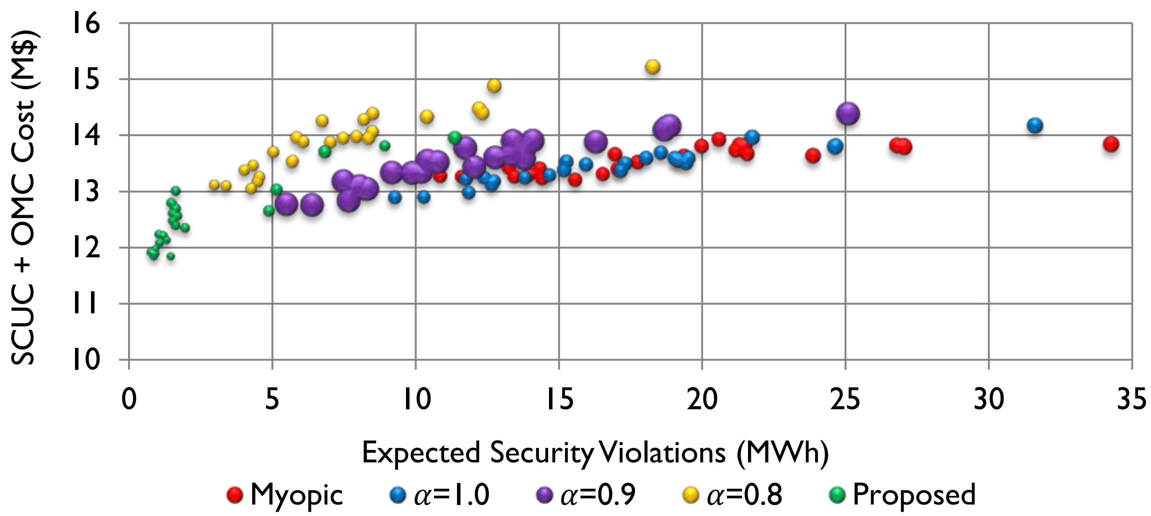
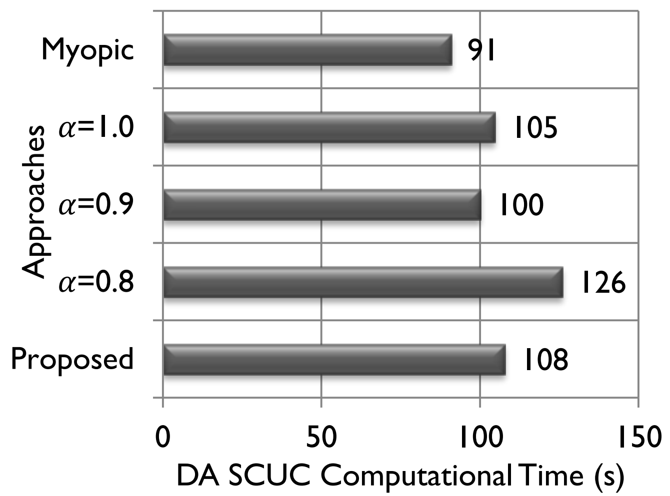
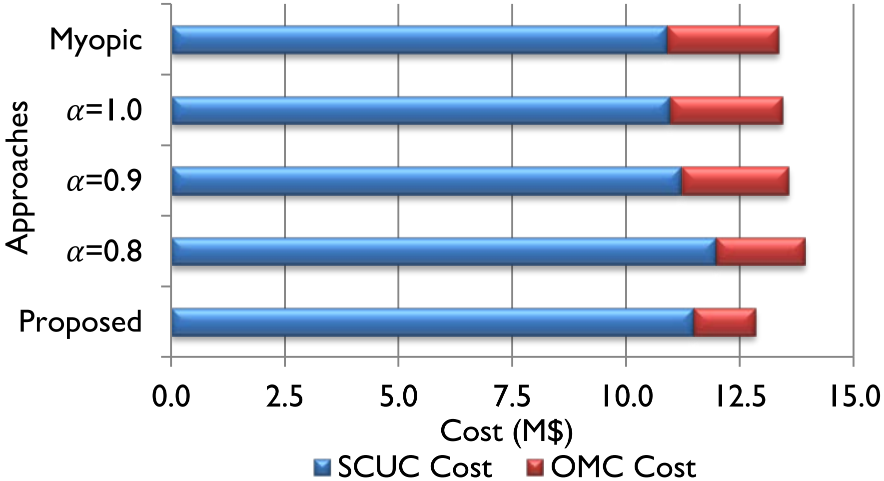




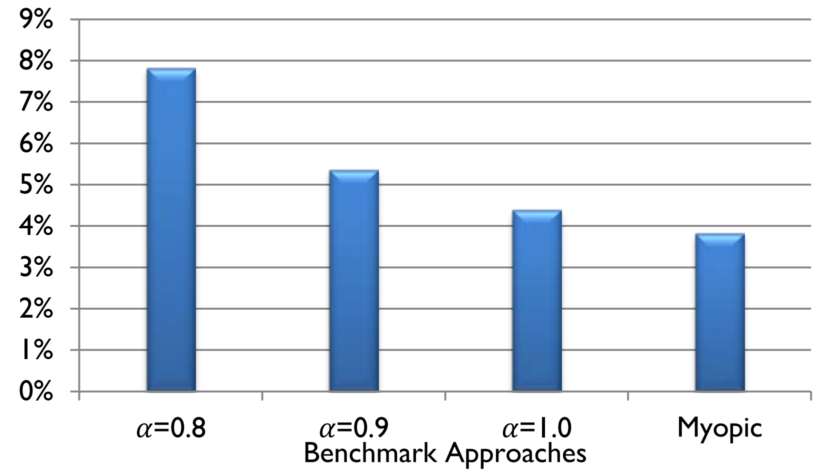
Results: 2383-Bus Polish System, Day 2, OMC version 2

- Tested using scenarios from a different day

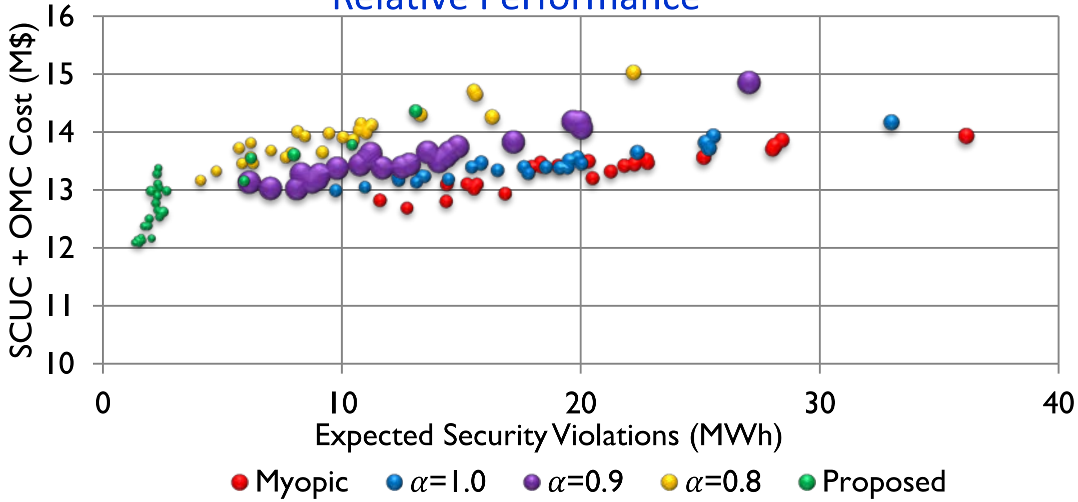
Market SCUC and OMC Costs



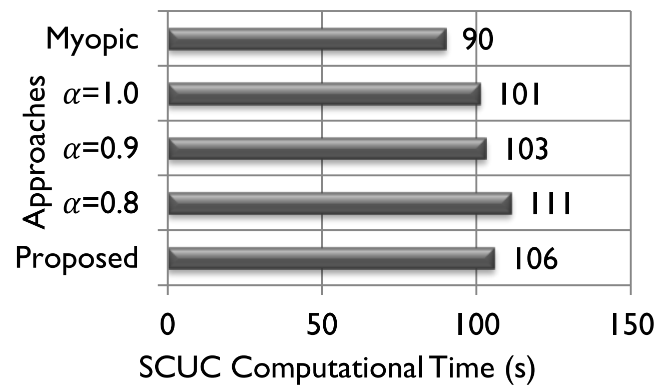
Percent Cost Savings in Comparison to Alpha Policies



Relative Performance

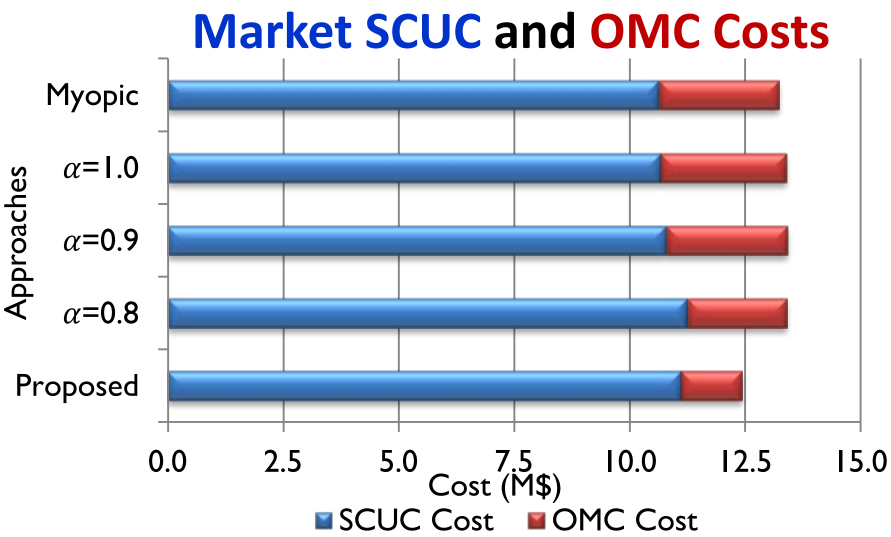


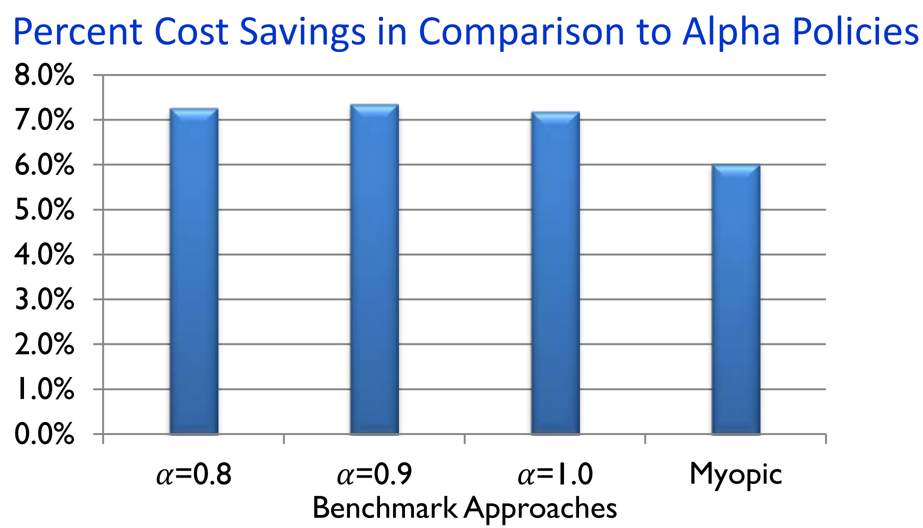
Computational Complexity

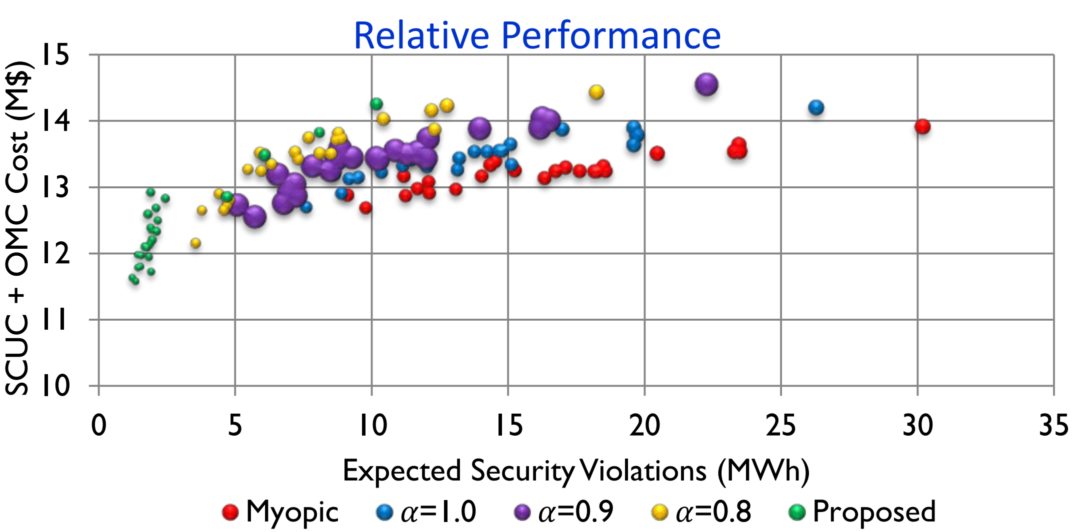


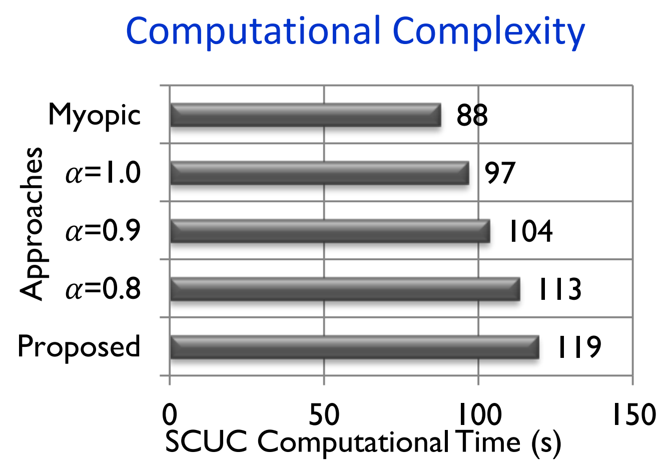
Results: 2383-Bus Polish System, Day 3, OMC version 2

- Tested using scenarios from a different day









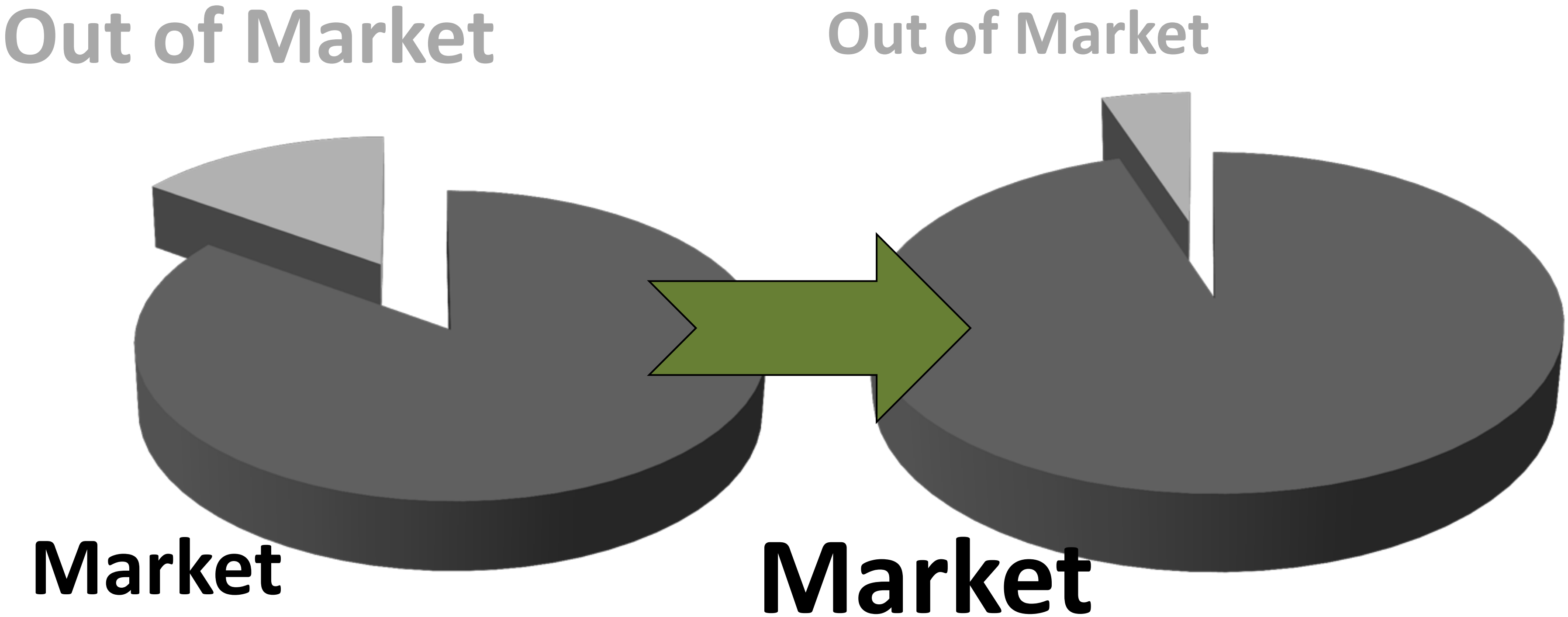
Concluding Remarks and Lessons Learned

CONCLUSIONS AND FUTURE WORK

Conclusion

- Model complexity comes with model accuracy
- Smart, well-designed reserve policies can improve existing deterministic models and facilitate the transition to stochastic programs
- The offline knowledge discovery approach:
  - Enhances reliability of the market solution while also reducing overall operational costs
  - Requires fewer out-of-market corrections by market operators (*fewer discretionary changes*)
  - More transparent than stochastic programs
  - Scalable

- Existing:
- Proposed:



Philosophy: Enhance reserve modeling to capture more requirements in market models to improve efficiency, enhance price signals (LMPs), maintain scalability and transparency

Future Work

- Investigate the market implications of the proposed approach
- More sophisticated and more systematic ways to identify the response set for each contingency event
- Scalability
- Stochastic program implemented for large-scale systems to provide a benchmark
- Hybrid dynamic reserves with stochastic programs

- **Assumption:** do the cost savings obtained by the proposed market SCUC carry through to actual operations when we ignore other factors (e.g., AC)?

Questions?

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Thanks to:

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