DOE/OE Transmission Reliability Program

Dynamic Reserve Policies for Market Management Systems

Project Completion Report

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Overview

- Overall Project Objective, Scope
- Looking Back
- Need for Stochastic-Oriented Processes
- Looking Forward: Industry Practices, Movement
- Proposed Methodology: Enhanced Reserve Policies for Systems with Stochastic Resources
- Numerical Results: 2383-bus Polish Test System
- Concluding Remarks, Looking Forward

Overall Project Objective, Scope

- **Create smart, well-designed reserve policies for reserve and ramp products**
- **Design a multi-stage framework accounting for:**
  - A look-ahead stage prior to day-ahead (DA) market model
  - A DA market security-constrained unit commitment (SCUC) model
  - Adjustment period modifications (i.e., out-of-market corrections, OMCs)
- **Develop data-mining techniques to determine reserve policies**
- **Compare and contrast developed policies with stochastic programming approaches**

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Looking Back

- **Conference Publications/Presentations:**

[1] N. Li, N. G. Singhal, and K. W. Hedman, "An enhanced security-constrained unit commitment model with reserve response set policies," in *Proc. 50th Hawaii Int. Conf. on System Sciences*, pp. 3065-3074, Jan. 2017.

[2] S. Zhang, N. G. Singhal, K. W. Hedman, V. Vital, and J. Zhang, "An evaluation of algorithms to solve for do-not-exceed limits for renewable resources," in *Proc. 48th Hawaii Int. Conf. on System Sciences*, pp. 2567-2576, Jan. 2015.

- **Journal:**

[1] N. G. Singhal, N. Li, and K. W. Hedman, "A data-driven reserve response set policy for power systems with stochastic resources," *IEEE Trans. Sustain. Energy*, under review.

[2] N. G. Singhal, N. Li, and K. W. Hedman, "A reserve response set model for systems with stochastic resources," *IEEE Trans. Power Syst.*, under review.

Looking Back

- **Remaining Activities:**
  - Finalization of analysis regarding market implications of proposed methodology (planned *journal* submission)
  - Final reporting
  - Documentation, dissemination
- **Related Work / Industry Outreach and Presentations**
  - Leveraged separate ARPA-E project on related topic to engage with industry:

MISO	November 2016
ERCOT	January 2017
PG&E	April 2017
SPP	May 2017

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Need for Stochastic-Oriented Processes

- **Existing uncertainties**
  - Resource forced outages (contingencies)
  - Renewable resources (wind, solar)
  - Distributed energy resources
- **Combining uncertainty modeling with resource scheduling**
- **Stochastic programming**
  - Computational complexity
  - Market barriers

Increasing uncertainties and distributed resources call for stochastic-oriented processes and decision support tools – MISO

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Industry Practices, Movement

- **Existing market models**
  - Based on deterministic approaches that inadequately address uncertainty and variability
  - Numerous approximations to address the underlying stochastic program
- **Industry response, movement**
  - **MISO**: Zonal reserve deliverability constraints
  - **CAISO**: Generator contingency and remedial action scheme modeling (*proposed*), flexible ramping product
  - **ISO-NE**: Do-not-exceed (DNE) limits
  - **EPRI in collaboration with CAISO**: Dynamic reserve procurement
  - **Long-standing practice**: Participation factor modeling in real-time contingency analysis (RTCA)

Long-Standing Practice: Transmission Contingencies

Post-contingency transmission constraints for each modeled transmission contingency case, c

Post-contingency flow on line ℓ **=** *Pre-contingency* flow on line ℓ **+** ***Redistributed flow*** from contingency line c to line ℓ

Traditional practice

- **Explicit representation** of line contingencies
- **No** second-stage recourse decisions

MISO: Zonal Reserve Deliverability Constraints

MISO utilizes post-contingency transmission constraints to determine their zonal reserve requirements [1]

Post-contingency flow = *Pre-contingency* flow − Effect of ***generator contingency*** on flow + Effect of ***zonal reserve deployment*** on flow

Optimal nodal (zonal) reserve deployment factor

(Room for improvement)

Pre-determined ***zonal reserve deployment factor***

(Existing practice)

[1] Y. Chen, P. Gribik, and J. Gardner, "Incorporating post zonal reserve deployment transmission constraints into energy and ancillary service co-optimization," *IEEE Trans. Power Syst.*, vol. 29, no. 2, pp. 537-549, Mar. 2014.

MISO: Zonal Reserve Deliverability Constraints

Post reserve deployment transmission constraint [1]

$$F^{P}_{i,t}(p_t, P_t) - E_{k,t} \cdot B^{TRIP}_{i,k,t} + D^{SPIN}_{k,t} \cdot \sum_{k' \in K} \{r^{SPIN}_{k',t} \cdot B^{SPIN}_{i,k',t}\}$$

$$+ D^{SUPP}_{k,t} \cdot \sum_{k' \in K} \{r^{SUPP}_{k',t} \cdot B^{SUPP}_{i,k',t}\} \le \bar{\bar{F}}_{i,t} \qquad \forall i \in I, k \in K$$

Pre-determined ***zonal reserve deployment factor***

(Existing practice)

Optimal zonal (nodal) reserve deployment factor ?

(Room for improvement)

[1] Y. Chen, P. Gribik, and J. Gardner, "Incorporating post zonal reserve deployment transmission constraints into energy and ancillary service co-optimization," *IEEE Trans. Power Syst.*, vol. 29, no. 2, pp. 537-549, Mar. 2014.

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CAISO: Generator Contingency and Remedial Action Scheme (RAS) Modeling

- **CAISO intends to update its market models to include [2]:**
  - Generator contingencies explicitly and pre-defined RAS
  - Combined transmission and generator contingencies explicitly
- **Post-contingency transmission constraints for each modeled generator contingency case [2]**
  - Explicit representation of generator contingencies
  - No second-stage recourse decisions

Post-contingency flow = *Pre-contingency* flow − Effect of ***generator contingency*** on flow + Effect of ***reserve response*** on flow

[2] CAISO, "Generator contingency and remedial action scheme modeling," Mar. 2017 [Online]. Available: http://www.caiso.com/Documents/RevisedStrawProposal-GeneratorContingencyRemedialActionScheme.pdf

CAISO: Generator Contingency and Remedial Action Scheme (RAS) Modeling

Post-contingency transmission constraints for each modeled generator contingency case [2]

Post-contingency flow $= F_{lt} - PTDF_{n(c),\ell} p_{ct} + \sum_{g:g \neq c} PTDF_{n(g),\ell} GDF_{gt}^{c} p_{ct}$

Where,

$$GDF_{gt}^{c} = \begin{cases} 0, & \forall g \notin G^{FREQ} \\ \dfrac{u_{gt} P_g^{max}}{\sum_{\forall g:g \neq c} u_{gt} P_g^{max}}, & \forall g \in G^{FREQ} \end{cases}$$

G^{FREQ}: Subset of generators with frequency response capability, $G^{FREQ} \subset G$.

Pre-defined ***generation loss distribution factors*** (Existing practice)

Determination of more appropriate participation factors (Room for improvement) ?

[2] CAISO, "Generator contingency and remedial action scheme modeling," Mar. 2017 [Online]. Available: http://www.caiso.com/Documents/RevisedStrawProposal-GeneratorContingencyRemedialActionScheme.pdf

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Proposed Methodology

- **Proposed gen contingency (or renewable resource deviation) modeling:**

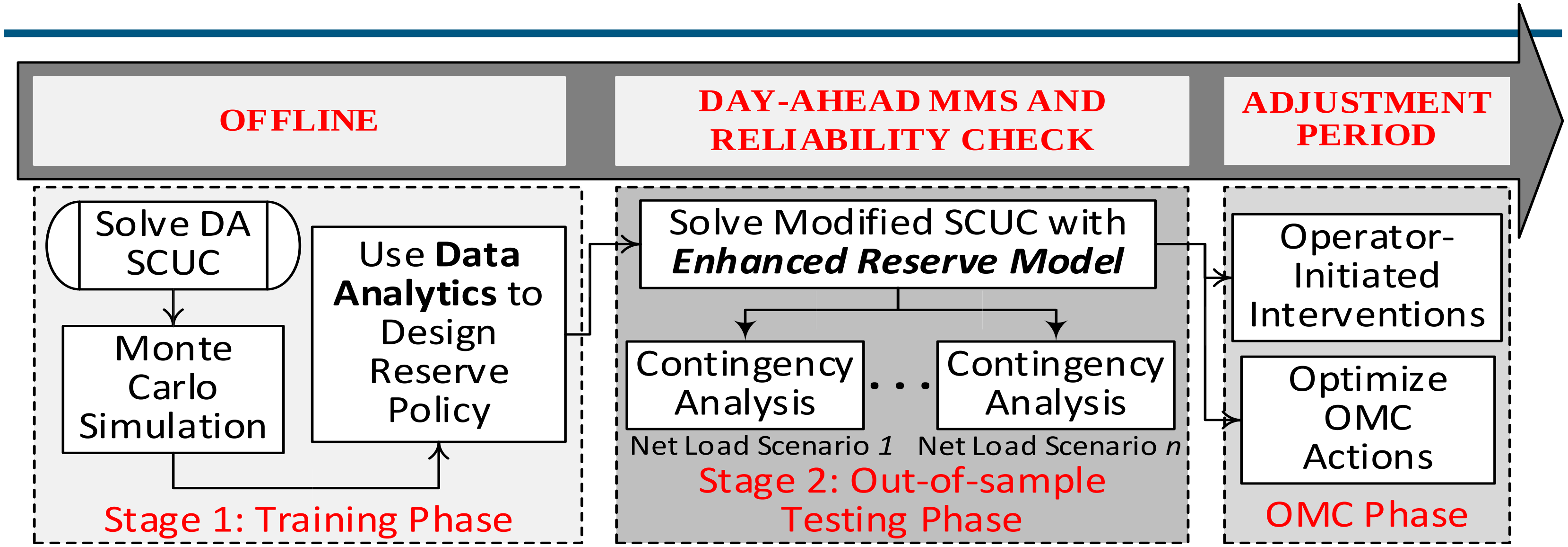
$$-\bar{F}_l^{RateC} \le \underbrace{F_{lt}}_{\text{Pre-contingency flow on line } l} - \underbrace{P_{ct} PTDF_{n(c),l}}_{\text{Change in flow due to loss of generator } c} + \underbrace{\sum_{g:g\neq c} r_{gt} \bar{\beta}_{g,l,t}^{c}}_{\text{Change in flow due to reserve response}} \le \bar{F}_l^{RateC}$$

- **Reserve response factors: interpreted as a factor that defines the average impact of a responsive generator; weighted PTDF**
- **Again, no recourse decisions**

Determination of Reserve Response Factors

- **Data mining model: Support Vector Machines for regression and function estimation (or Support Vector Regression with linear kernels)**
  - Target: post-contingency flow due to activated reserve
  - Attributes: activated reserve quantities from responsive generators
  - Instances: net load scenarios (uncertainty); historical data or generate hypothetical data
- **Goal: determine a regression function that approximates the post-contingency flows due to nodal reserve deployment**
- **Test the obtained reserve response factors $\left(\beta^{c}_{g,l,t}\right)$ against various operational states (*out-of-sample* testing)**

Simulation Setup



- **The method (*offline*) uses a data-mining algorithm**
  - Offers augmentation with minimal added computational burden
- **The modified SCUC formulation enhances reserve determination (both quantity and location)**
  - Improves reserve deliverability on critical links
  - Approximately captures uncertainty (between scenarios)

Out-of-Market Corrections (OMC)

- **Approximate market models, stochastic programs (with limited scenarios): 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**
  - Results: subjective
- **Our analysis simulates dispatch operator out-of-market correction procedures to better estimate actual costs**
  - All solutions are ***reliable***, no load shedding
- **Other OMC terms: uneconomic adjustments; supplement dispatch; out-of-sequence/out-of-merit dispatch; reserve disqualification; reserve down-flags**

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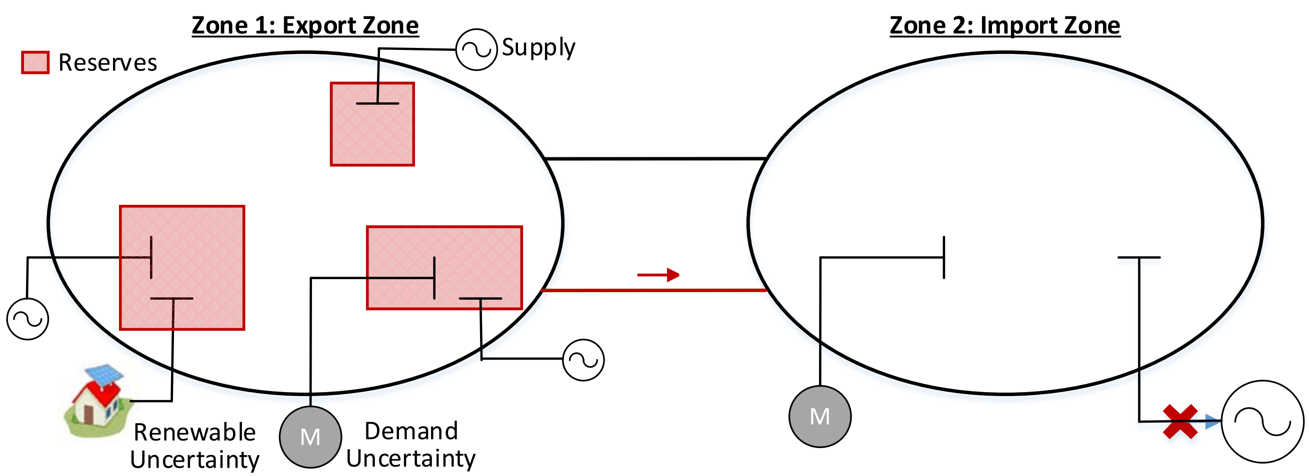
Comparison: Base Case Reserve Model

- **A zonal reserve model**
  - Reserve sharing between zones: 'α' policy defined in relation to the available headroom
- **Illustration:** Pre- and post-contingency limits: 50 MW and 100 MW

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

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



Reserve sharing limit from zone 1 to zone 2:

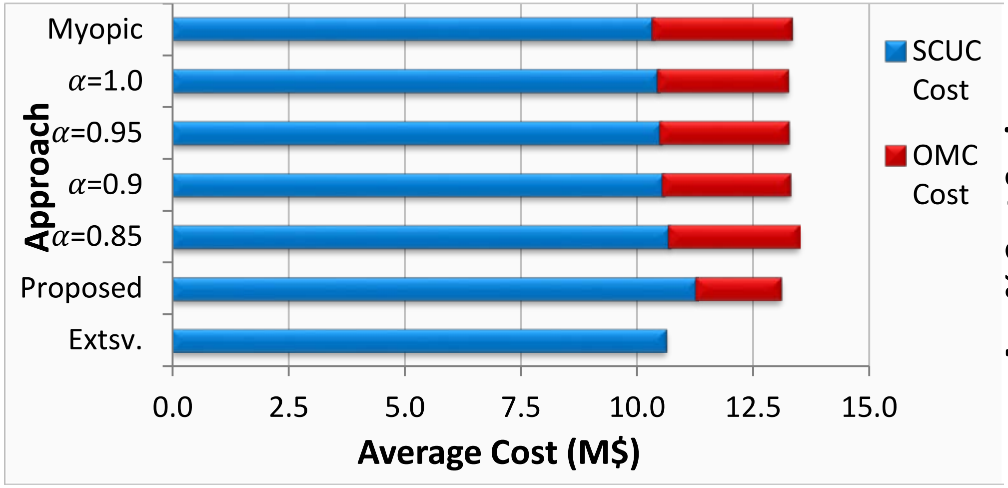
$= 1 \times 100 - 50 = 50$ MW

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

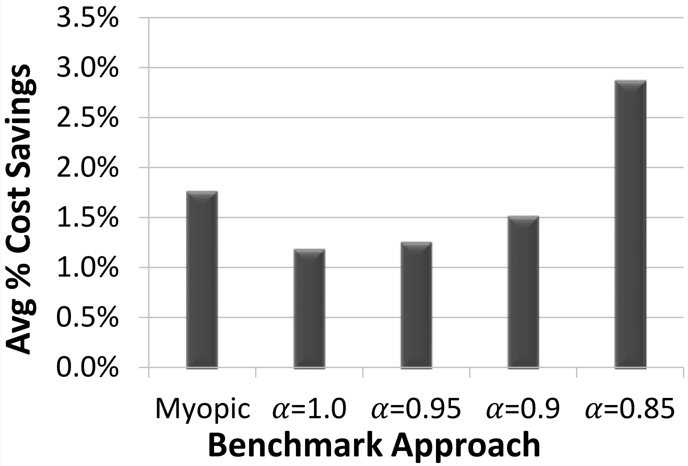
Results: 2383-Bus Polish System, Day 1

- **Comparison of the proposed reserve model with:**
  - 1) Single-zone reserve model (myopic)
  - 2) Reserve model with varying reserve sharing (α) policies
  - 3) Extensive-form stochastic unit commitment
- **Four lines formulated with the post-contingency transmission constraint**

Market SCUC and OMC Costs

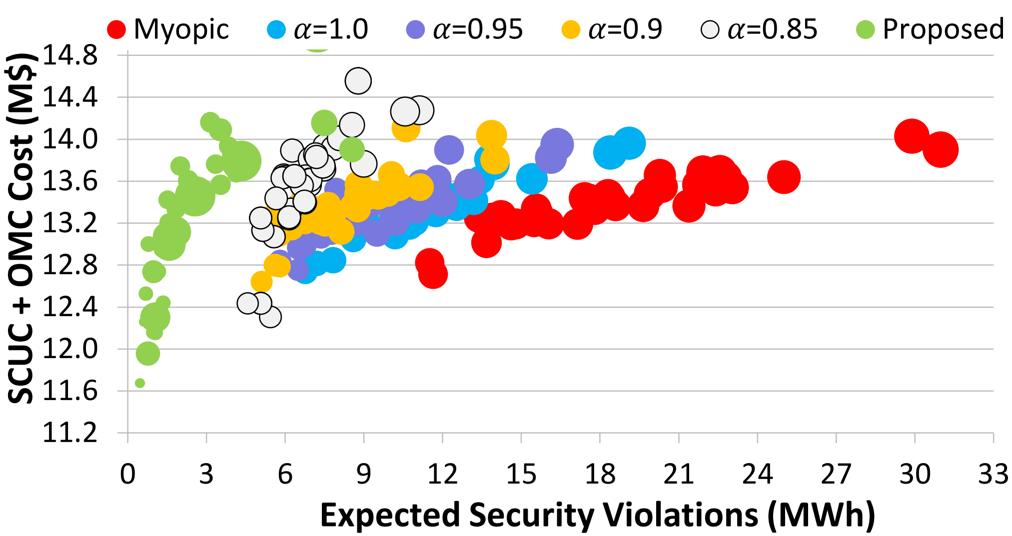


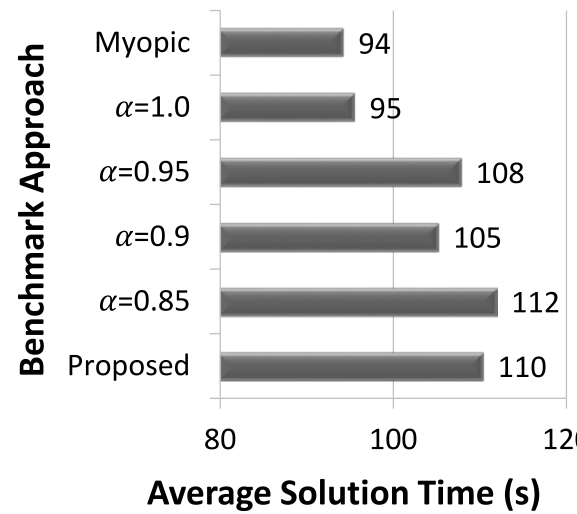
Percent Cost Savings



Results: 2383-Bus Polish System, Day 1

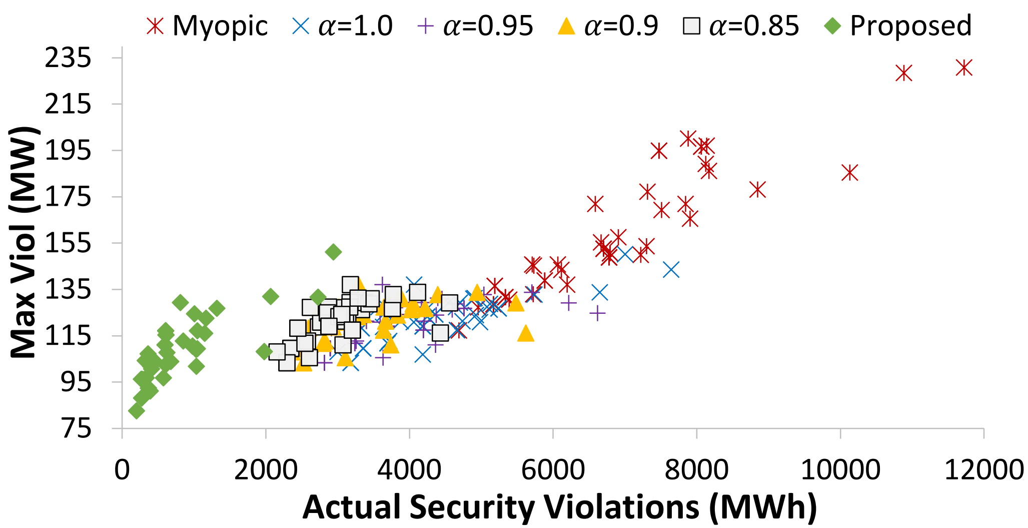
- **Bubble chart comparing the cost of the final *N*-1 reliable solution against the expected sum of security violations for the DA market SCUC solution for each scenario**
  - Size of the bubble represents the number of cases with violations for the corresponding scenario
- **Computational time comparison**

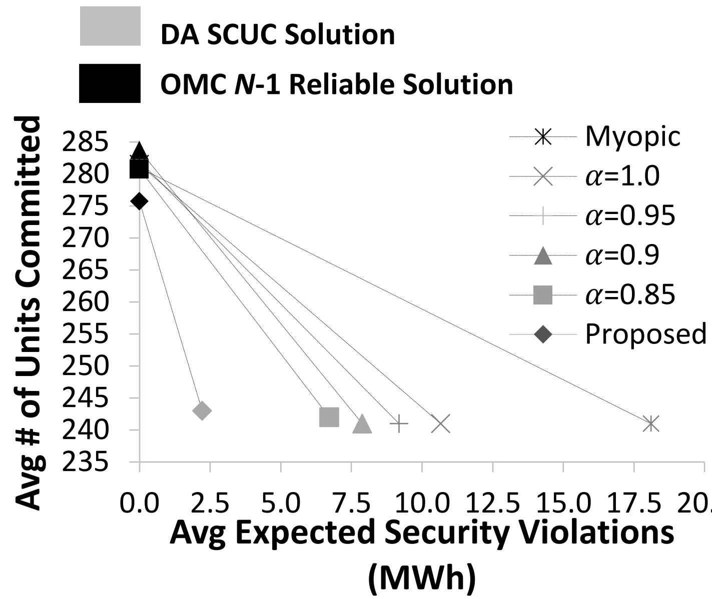




Results: 2383-Bus Polish System, Day 1

- **Comparison with respect to two additional reliability metrics**
  - Max viol: maximum reported (or worst-case) security violation
  - ∑viol: actual sum of security violations
- **Average number of additional units that are turned to obtain an *N*-1 reliable solution**





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Results: 2383-Bus Polish System, Day 2

- **Tested using net load scenarios from *different* test days**

Table 1. Average Results across Net Load Scenarios from Second Test Day

Approach	Myopic	α=1.0	α=0.95	α=0.90	α=0.85	Proposed	Extsv.
Final Cost (M$)	13.76	13.87	13.85	13.83	14.13	**13.62**	11.43
DA SCUC Solution							
SCUC Cost (M$)	**10.69**	10.83	10.93	11.07	11.66	11.91	11.43
Time (s)	**97**	111	103	106	115	112	911
Contingency Analysis							
E[viol] (MWh)	20.51	11.86	9.91	8.63	7.37	**1.84**	0
# viol	100	68	60	51	45	**43**	0
Out-of-Market Correction (*N*-1 Reliable Solution)							
OMC Cost (M$)	3.07	3.04	2.92	2.76	2.47	**1.71**	-

E[viol] – Expected sum of security violations (MWh)
 # viol – Number of cases with security violations

Max viol – Worst case security violation (MW)
∑viol – Actual sum of security violations (MWh)

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Concluding Remarks, Looking Forward

- **Traditional modeling of reserve and ramp products:**
  - Inadequate account of pre- and post-contingency congestion aptly
  - Consequence:
    - Over-procurement of ancillary services (market inefficiency, market distortion)
    - Or required out-of-market corrections / discretionary operator modifications (expensive, market transparency issues, market distortion)
  - Consequences grow with increased reliance on stochastic resources
- **Proposed approach:**
  - Designed to avoid practical (market, scalability) barriers while still capturing most of the potential cost savings
  - Most applicable to existing practices, least disruptive
  - Successful in finding solutions that capture congestion reasonably
  - Requires fewer OMCs; improves market transparency and pricing

Concluding Remarks, Looking Forward

- **Via communication with Jim Price on CAISO's recently proposed generator contingency modeling changes:**
  - Enhanced reserve modeling and ramp products… capture majority of the savings… compared to a market design overhaul that implements two-stage stochastic programs
- **Path forward for industry: dynamic reserve (and ramp) products/policies**
  - CAISO's recent proposed changes, MISO's reserve deliverability constraints
- **Continue pursuit through ARPA-E NODES project and partnerships with industry (PJM, looking for others), software developers (Nexant Inc.), and DOE (Sandia National Laboratories)**

Questions

Thank you.

Comparison: Base Case Reserve Model

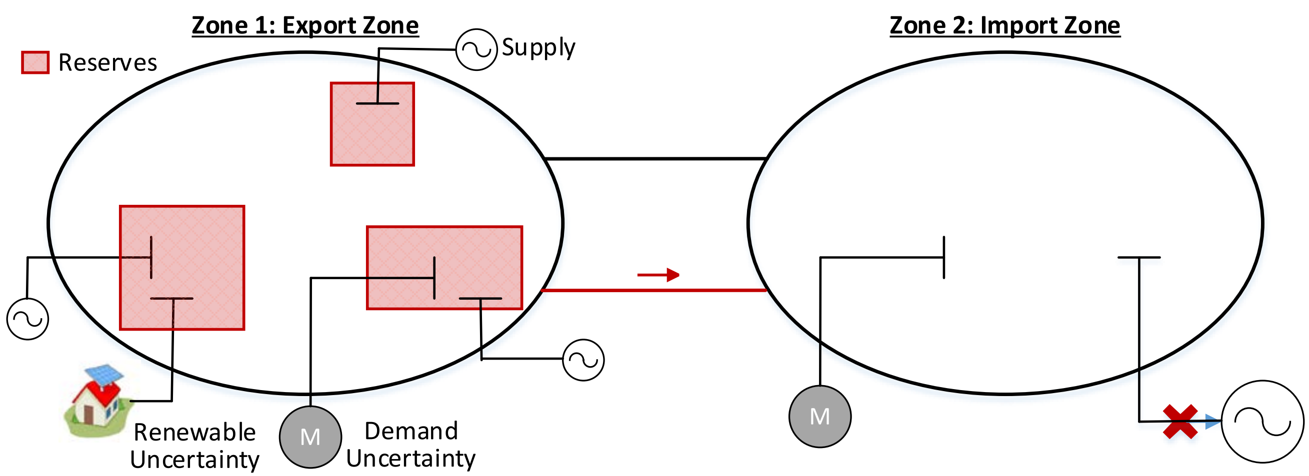
- $\sum_{k \in Z} \tilde{r}_{kt}^{c} \geq P_{ct} + r_{ct}, \quad \forall c \in G, t \in T$
- $\tilde{r}_{kt}^{c} \leq \sum_{g \in G(k)} r_{gt}, \quad \forall c \in G, k \in Z, t \in T$
- Reserve sharing between zones: also limited by,

$$\boldsymbol{S_{kt}^{z(c)} = \bar{\alpha}\left(\bar{F}_{l_{k-z(c)}}^{RateC}\right) \pm F_{l_{k-z(c)}t}, \qquad \forall c \in G, k \in Z, t \in T}$$

k: index for zones; $z(c)$: index for contingency zone c

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

Proposed Reserve Model

- **Proposed reserve model**

$$\sum_g r_{gt} \geq P_{gt} + r_{gt} \qquad \forall g \in G, t \in T$$

$$\sum_g r_{gt} \geq \eta\% \sum_n D_{nt} \qquad \forall t \in T$$

$$\sum_{k \in Z} \tilde{r}_{kt}^c \geq P_{ct} + r_{ct} \qquad \forall c \in G, t \in T$$

$$\tilde{r}_{kt}^c \leq \sum_{g \in G^k} r_{gt} \qquad \forall c \in G, k \in Z, t \in T$$

$$\tilde{r}_{kt}^c \leq F_{l_{k-z(c)}}^{RateC} \pm F_{lt_{k-z(c)}} \qquad \forall c \in G^{NC}, k \in Z, t \in T$$

$$-F_l^{RateC} \leq F_{lt} - P_{ct} PTDF_{n(c),l} + \sum_{g:g \neq c} r_{gt} \beta_{g,l,t}^c \leq F_l^{RateC}$$

$$\forall c \in G^C, l \in L^C, t \in T.$$

k: index for zones; $z(c)$: index for contingency zone c

Results: 2383-Bus Polish System, Day 2

- **Tested using net load scenarios from *different* test days**

Table 1. Average Results across Net Load Scenarios from Second Test Day

Approach	Myopic	α=1.0	α=0.95	α=0.90	α=0.85	Proposed	Extsv.
Final Cost (M$)	13.76	13.87	13.85	13.83	14.13	**13.62**	11.43
DA SCUC Solution							
SCUC Cost (M$)	**10.69**	10.83	10.93	11.07	11.66	11.91	11.43
Time (s)	**97**	111	103	106	115	112	911
# Online Units	244	243	244	244	250	247	253
Contingency Analysis							
E[viol] (MWh)	20.51	11.86	9.91	8.63	7.37	**1.84**	0
# viol	100	68	60	51	45	**43**	0
Max viol (MW)	175	132	131	133	129	**66**	0
∑viol (MWh)	7,450	4,578	3,901	3,386	2,967	**644**	0
Out-of-Market Correction (*N*-1 Reliable Solution)							
OMC Cost (M$)	3.07	3.04	2.92	2.76	2.47	**1.71**	-
# Online Units	289	288	288	288	286	**282**	-

E[viol] – Expected sum of security violations (MWh)
 # viol – Number of cases with security violations
Max viol – Worst case security violation (MW)
∑viol – Actual sum of security violations (MWh)

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Results: 2383-Bus Polish System, Day 3

- Tested using net load scenarios from ***different*** test days

Table 2. Average Results across Net Load Scenarios from Third Test Day

Approach	Myopic	α=1.0	α=0.95	α=0.90	α=0.85	Proposed	Extsv.
Final Cost (M$)	13.67	13.91	13.92	13.90	14.08	13.56	11.83
DA SCUC Solution							
SCUC Cost (M$)	10.63	10.85	11.04	11.29	12.15	11.96	11.83
Time (s)	96	113	109	108	112	121	815
# Online Units	244	244	245	249	268	249	263
Contingency Analysis							
E[viol] (MWh)	18	10.31	9.32	9.34	7.05	2.27	0
# viol	96	60	49	48	41	36	0
Max viol (MW)	163	138	135	153	127	105	0
∑viol (MWh)	6,575	4,022	3,554	3,377	2824	903	0
Out-of-Market Correction (*N*-1 Reliable Solution)							
OMC Cost (M$)	3.04	3.06	2.88	2.61	1.93	1.60	-
# Online Units	292	292	290	288	290	285	-

E[viol] – Expected sum of security violations (MWh)
 # viol – Number of cases with security violations
Max viol – Worst case security violation (MW)
∑viol – Actual sum of security violations (MWh)

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