Iowa State University

Industrial & Manufacturing Systems Engineering

Scenario Reduction for Scalable Stochastic Unit Commitment

Sarah M. Ryan, Yonghan Feng

Cesar Silva-Monroy, Jean-Paul Watson

Sandia National Laboratories

David L. Woodruff

UC Davis University of California

FERC Technical Conference, June, 2014

Outline

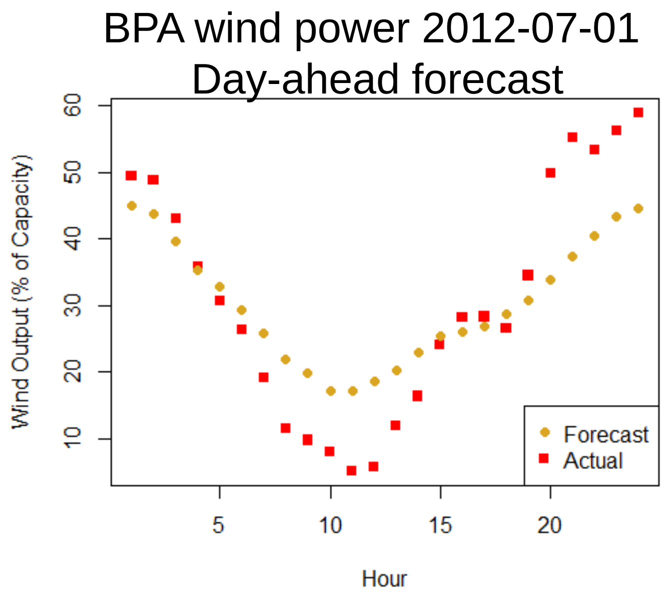
- Motivation
- Stochastic unit commitment context
- Scenario reduction approach
- Results on an ISO-NE test case
  - Nondispatchable wind: Net load scenarios
  - Dispatchable wind: Load and wind power scenarios
- Conclusion

Motivation

- Hard to accurately and precisely predict hourly load in advance
- Increasing share of variable generation
- Deterministic unit commitment is a large mixed-integer program
- Large set of scenarios multiplies the difficulty of solving the stochastic version

GEFCom2012

- Winning entry had ~3% RMSE for backcasting
- Weather uncertainty?



Problem Statement

- Why do we need scenario reduction?
  - Extensive form overwhelms memory capacity
  - Each iteration of decomposition method takes longer with more scenarios (even when parallelized)
  - Few, carefully constructed scenarios for individual parameters combine into many multidimensional scenarios
- How to select a subset of scenarios that approximates well?
  - Distances among scenarios: classical probability metrics
  - Influences of scenarios on decisions
- How to evaluate selected scenarios?
  - Apply the UC schedule found with reduced set to the whole set of scenarios

Two-Stage Stochastic Program

Stochastic reliability unit commitment (SRUC)

Commitment cost

Expected generation cost and penalties

$$f(S)\ \ \min c^T x + E_S[Q(x,s)]$$

$$Ax = b$$

Min up/down time constraints

$$x\ \ binary$$

States of units

$$Q(x,s) = \min_{y_s}\{q^T y_s \mid W y_s = h_s - Tx\}$$

Operational constraints, various rhs

Nondispatchable Wind

Startup & no-load cost given unit commitment status v_{gt}

$$\min \sum_t \sum_g c^u_{gt}\left(v_{gt}\right) + \sum_s \pi_s \xi_s$$

Generation cost

Penalties on load imbalance

$$\xi_s = \sum_t \sum_g c^p_{gt}\left(p_{gts}\right) + \sum_t \left(\Gamma^+ \alpha^+_{ts} + \Gamma^- \alpha^-_{ts}\right)$$

Constraints for each net load scenario

Relatively complete recourse

s.t. $$\sum_g p_{gts} + \alpha^+_{ts} - \alpha^-_{ts} = d_{ts}$$

Energy generation + shortage – excess = net load

$$v_{gt} P^{\min}_g \le p_{gts} \le \overline{p}_{gts} \le v_{gt} P^{\max}_g$$

Power output less than maximum available power output and installed capacity

Operational constraints on ramping, contingency reserve reqmts, etc.

$$v_{gt}\ binary,\ p_{gts}, \overline{p}_{gts}, \alpha^+_{ts}, \alpha^-_{ts} \ge 0$$

Dispatchable Wind

Startup & no-load cost given unit commitment status v_{gt}

$$\min \sum_t \sum_g c_{gt}^u \left(v_{gt}\right) + \sum_s \pi_s \xi_s$$

Generation cost | Penalties on load imbalance

$$\xi_s = \sum_t \sum_g c_{gt}^p \left(p_{gts}\right) + \sum_t \left(\Gamma^+ \alpha_{ts}^+ + \Gamma^- \alpha_{ts}^-\right)$$

Constraints for each net load scenario | Relatively complete recourse

$$\text{s.t.} \quad \sum_g p_{gts} + \alpha_{ts}^+ - \alpha_{ts}^- = d_{ts}$$

Energy generation incl. wind + shortage – excess = loac

Thermal: $v_{gt} P_g^{\min} \le p_{gts} \le \overline{p}_{gts} \le v_{gt} P_g^{\max}$ Wind: $0 \le p_{wts} \le \overline{p}_{wts} \le P_{wts}^{\max}$

Operational constraints on ramping, contingency reserve reqmts, etc.

$$v_{gt} \text{ binary}, \; p_{gts}, \overline{p}_{gts}, \alpha_{ts}^+, \alpha_{ts}^- \ge 0$$

Scenario Generation

- Load scenarios from epi-spline approximations of expected values and error distributions (this conference, last year)
- Wind energy scenarios from 3TIER, Inc., using analogue approach
- Nondispatchable wind: Net load = load – available wind energy
    - If net load < minimum power from committed thermal generators then wind power is curtailed
- Dispatchable wind: Scenario includes (load, available wind energy)
- Ideally, would estimate joint distribution of load and wind energy from common underlying weather forecast, but
- 3TIER weather analogues not strongly related to ISO-NE weather forecasts

Load scenarios $i = 1,\ldots, n$; Probabilities p_i X Wind power analogues $j = 1,\ldots, m$; Weights q_j → Net load or pairs of scenarios $k = 1,\ldots, nm$; Probabilities $p_i q_j$

Scenario Reduction Approach

Goals:

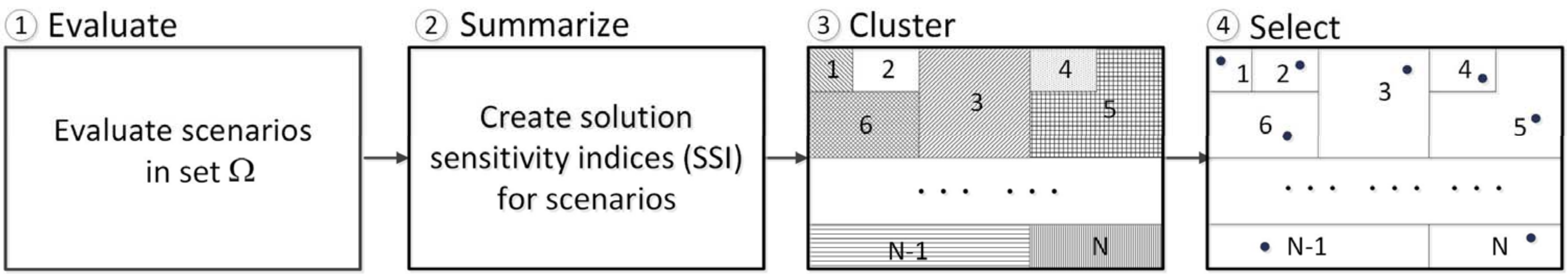
- Select modest number of scenarios that well approximates the whole set
- Follow decision maker's concerns: cost & reliability

Method: Forward selection in recourse clusters (FSRC)

Based on probability metric *Impacts on solution, cost and reliability*

FSRC and Its Customization

Select *N* scenarios



Solve each scenario recourse problem

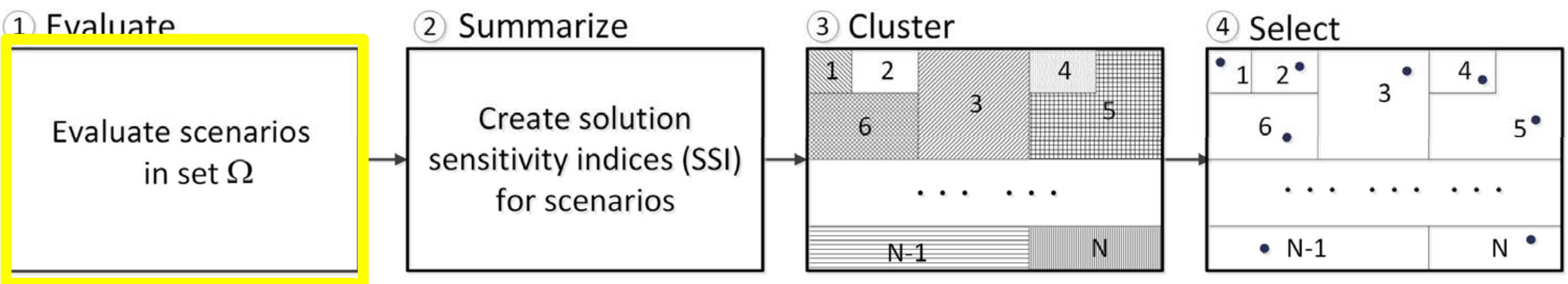
Associate scenarios to their SSIs

Put scenarios with similar SSI into the same cluster

1 "representative" scenario from each cluster .

FSRC and Its Customization

FSRC:



Expected value problem

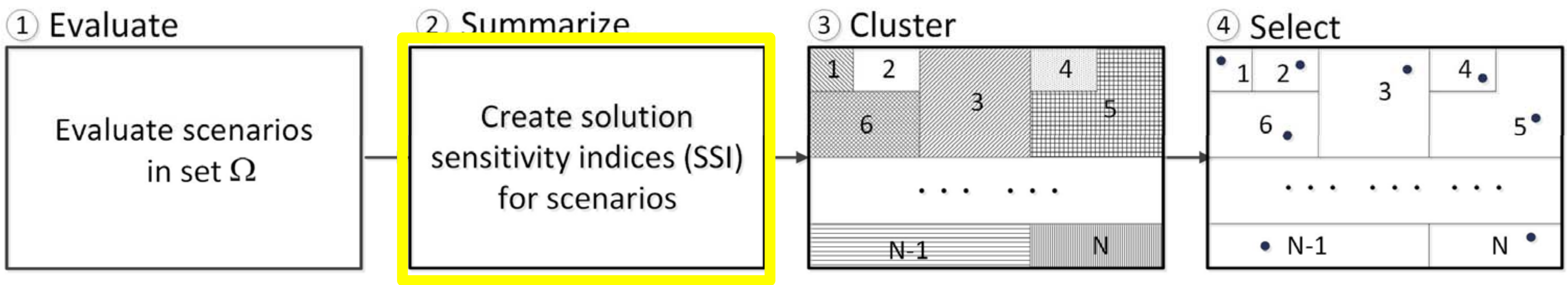
$$\begin{aligned} &\min c^T x + q^T y \\ &\text{s.t.} \quad Ax = b \\ &\qquad Tx + Wy = \bar{h} \\ &\qquad x \;\; binary \end{aligned}$$

$\bar{x}^*$ →

Recourse problem for scenario s

$$\begin{aligned} &\min q^T y_s \\ &\text{s.t.} \quad W y_s = h_s - T\bar{x}^* \end{aligned}$$

FSRC and Its Customization



$$\min q^T y$$

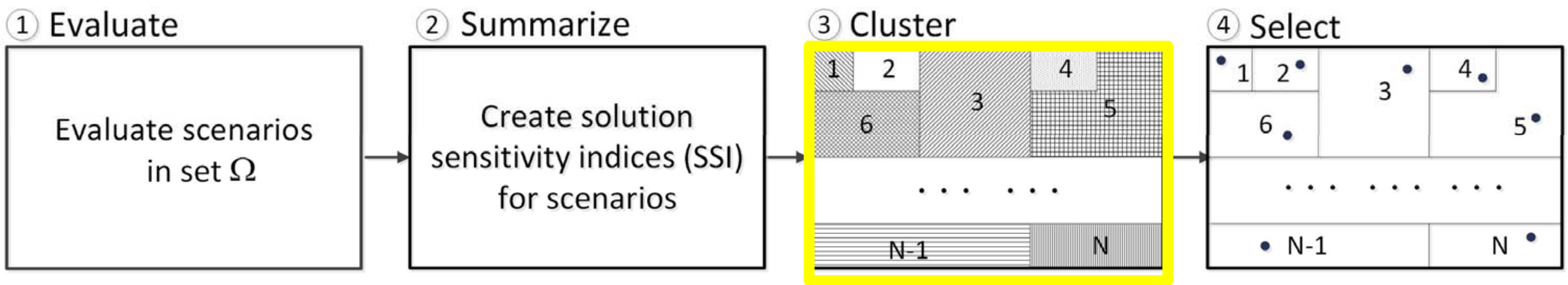
$$\text{s.t.} \quad Wy_s = h_s - T\overline{x}^*$$

Record y_s for each scenario s

Total cumulation (TC) →

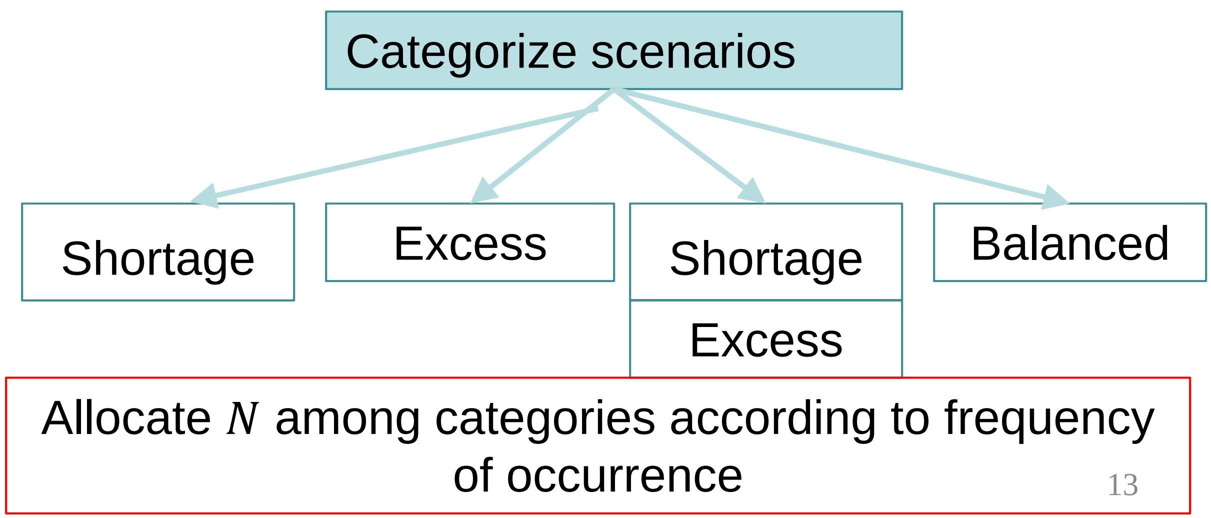
SSI
Total generation cost
Total shortage
Total excess

FSRC and Its Customization

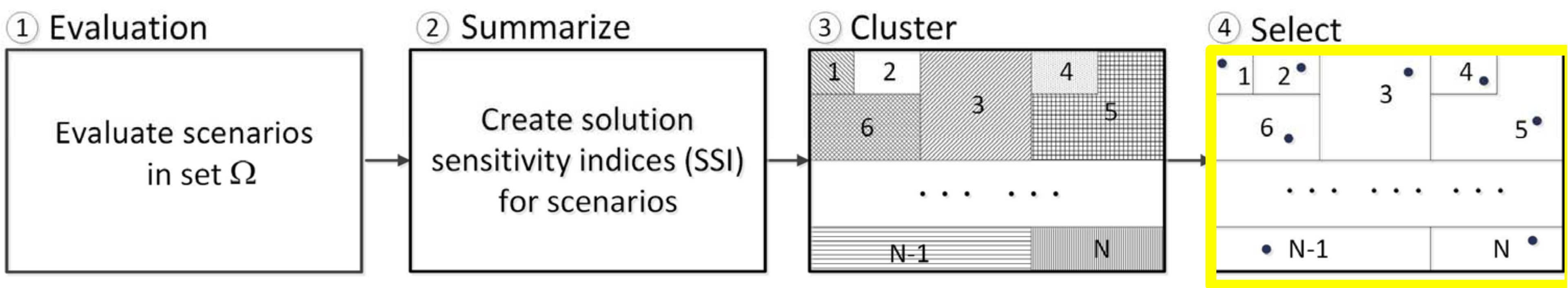


TC: cluster scenarios by *k*-means directly.

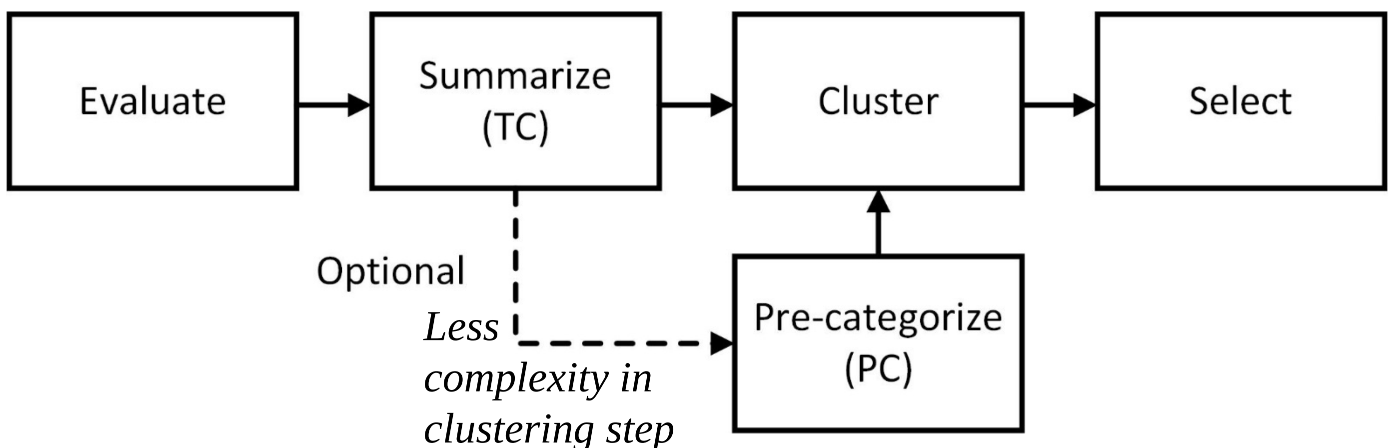
TC+PC: pre-categorize scenarios, then cluster



FSRC and Its Customization

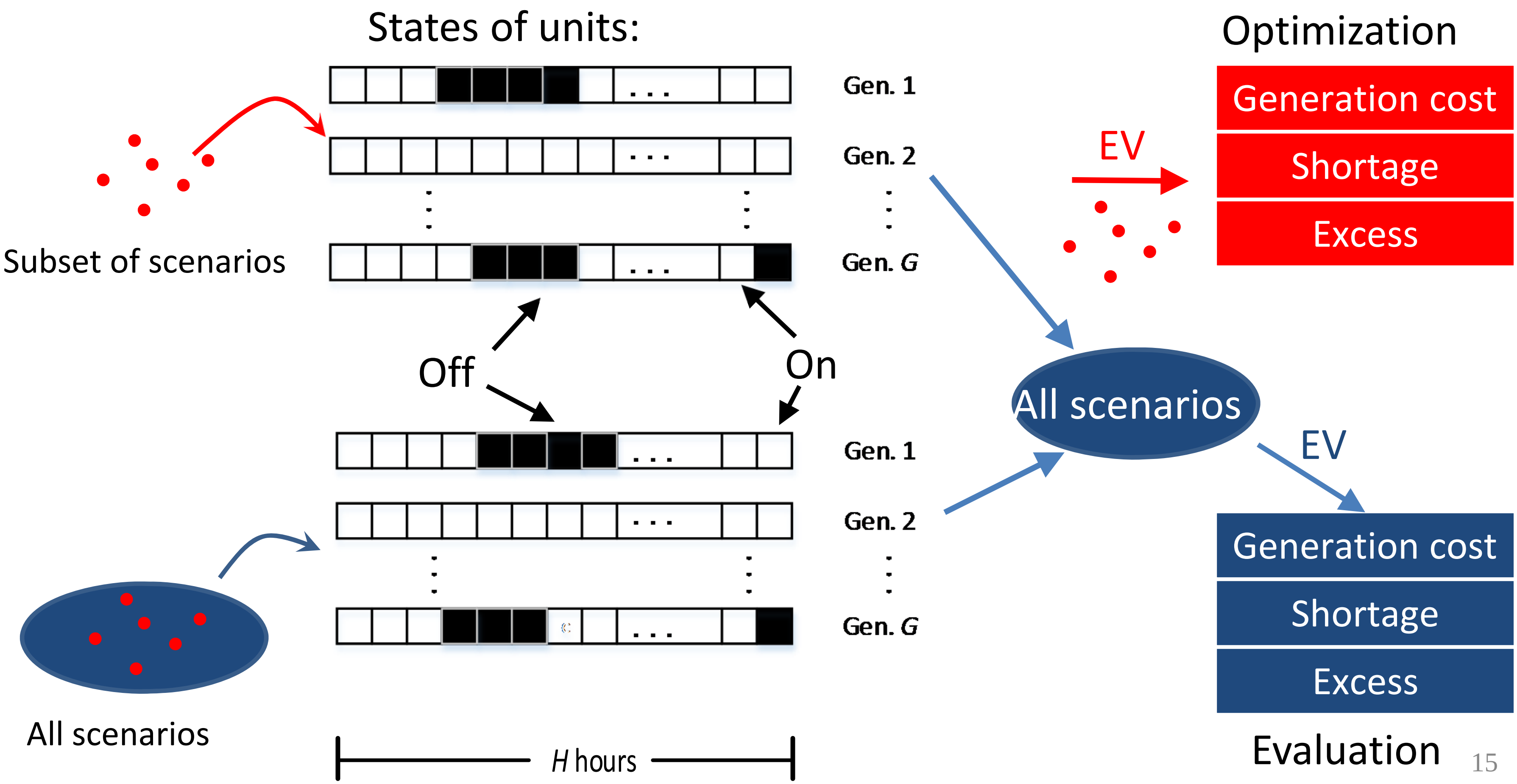


Fast forward selection (FFS): minimize probability transportation between distributions



Evaluation of Selected Scenarios

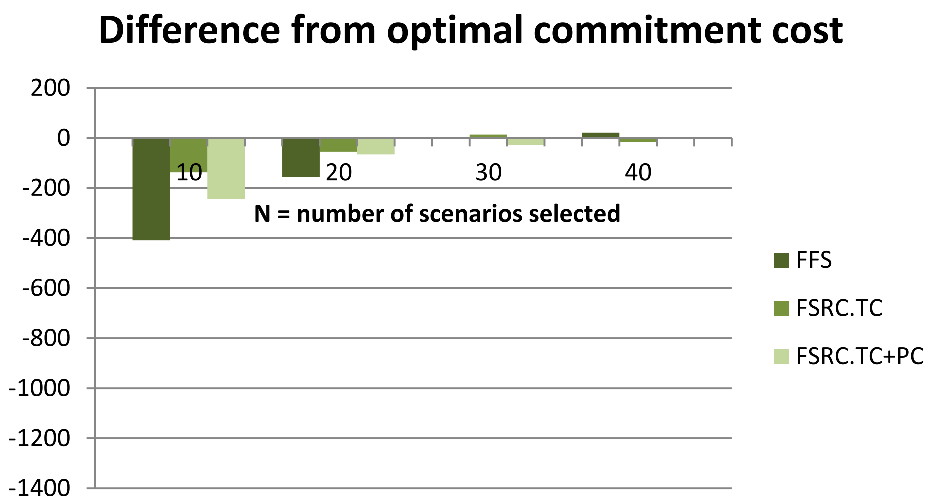
How well does the selected subset of scenarios approximate the whole set?

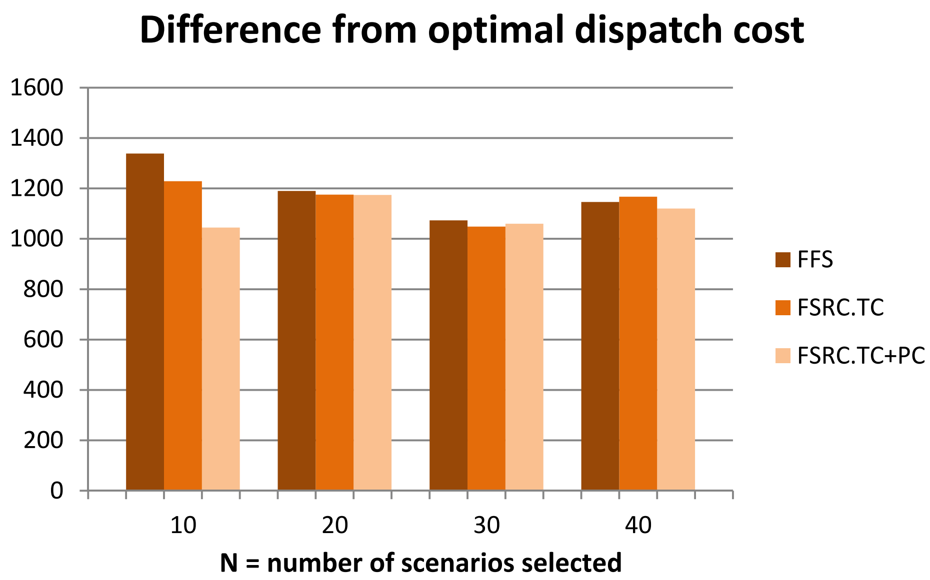


Nondispatchable Wind

Results: Single Summer Days

- Single-day SRUC from 2011-07-10 to 2011-07-16
- 50 generators downsampled from ISO-NE
- 80 net load scenarios (8 load scenarios X 10 wind energy scenarios)
- Comparison to **optimal** solution from **all** scenarios

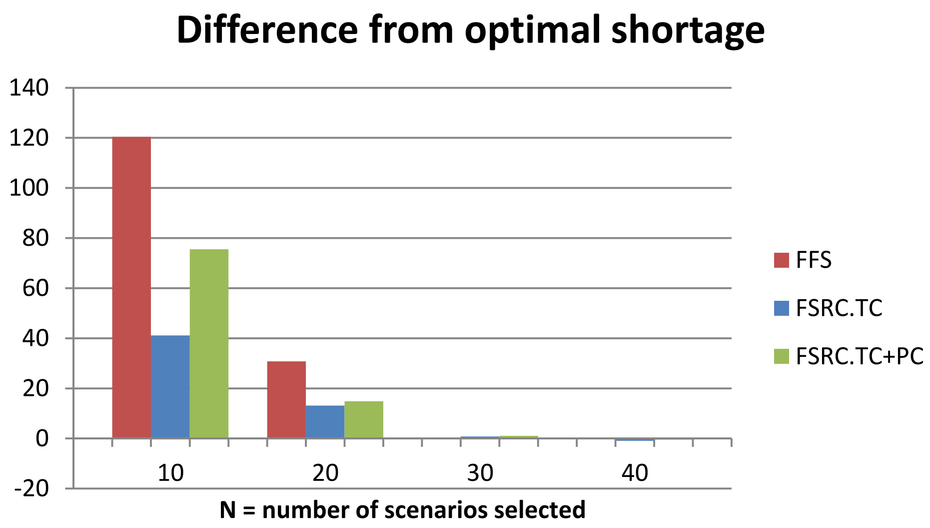


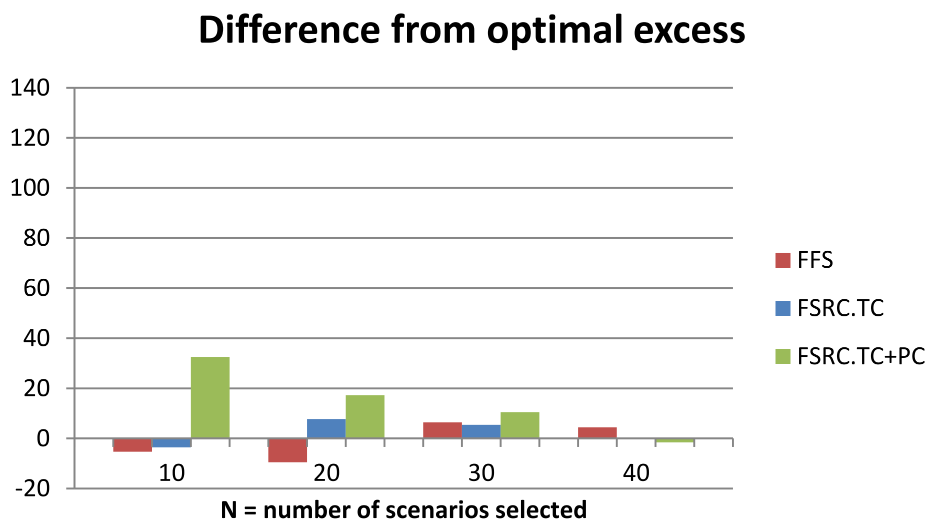


Nondispatchable Wind

Results: Single Summer Days

- Single-day SRUC from 2011-07-10 to 2011-07-16
- 50 generators
- 80 net load scenarios (8 load scenarios X 10 wind energy scenarios)
- Comparison to **optimal** solution from whole set of scenarios





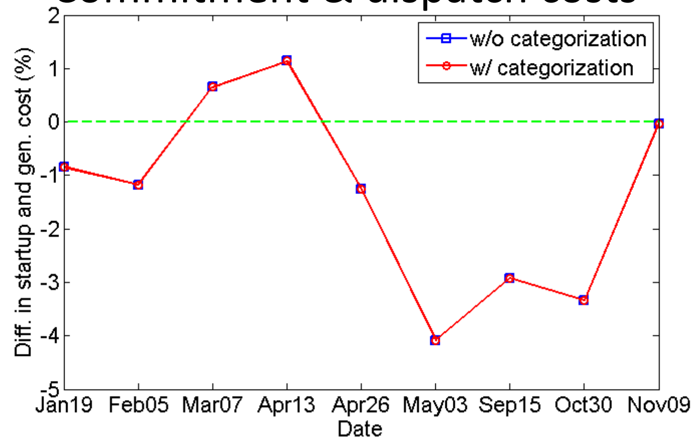
Nondispatchable Wind

Results: Single Days in Different Seasons

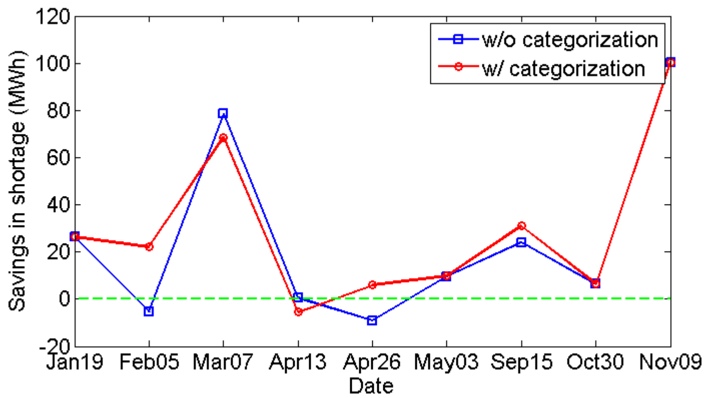
- 50 generators
- 80 net load scenarios
- Comparison to solution from FFS

$$\text{rel. diff.} = \frac{(\text{value}_{FFS} - \text{value}_{FSRC})}{\text{value}_{FFS}} \times 100\%$$

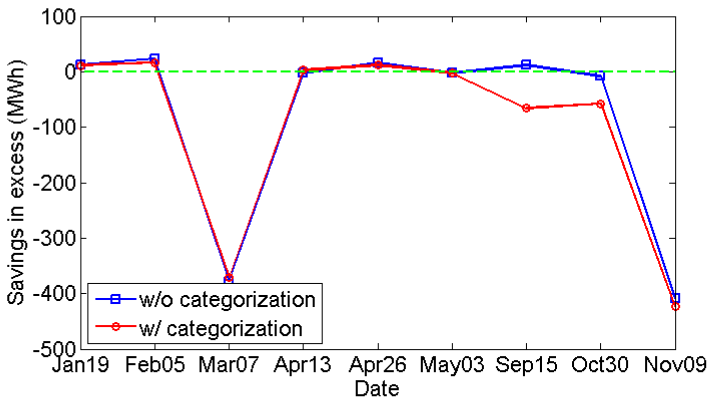
Commitment & dispatch costs



FSRC lowers expected shortage



FSRC raises expected excess



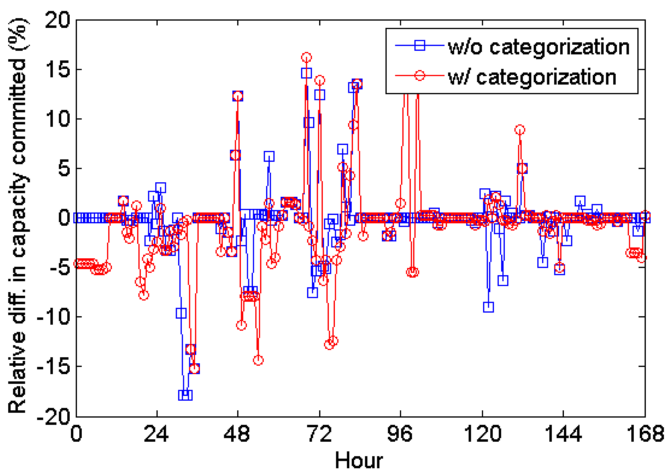
Nondispatchable Wind

Results: Rolling Through a Summer Week

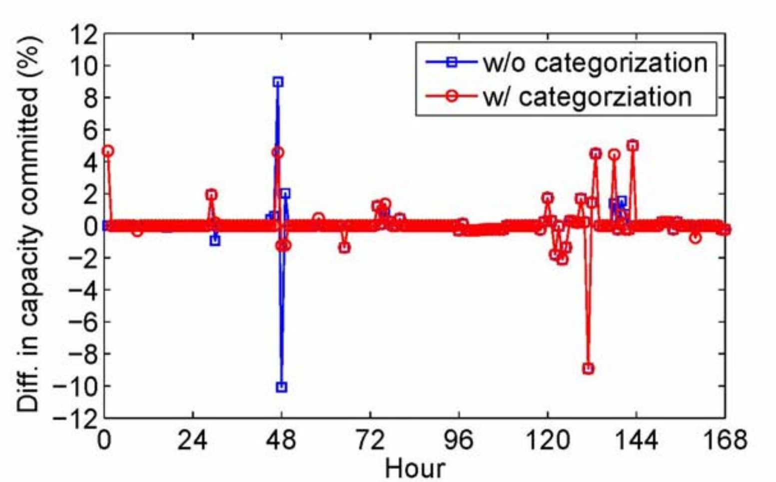
- Rolling horizon stochastic unit commitment from 2011-07-10 to 2011-07-16
- 20 generators
- 80 net load scenarios (8 load scenarios X 10 wind energy scenarios)
- 10% - 50% of scenarios selected, comparison to **optimal** solution

$$\text{rel. diff.} = \frac{(\text{value}_{subset} - \text{value}_{whole})}{\text{value}_{whole}} \times 100\%$$

Hourly capacity committed
N = 8 (10% of scenarios)



Hourly capacity committed
N = 40 (50% of scenarios)



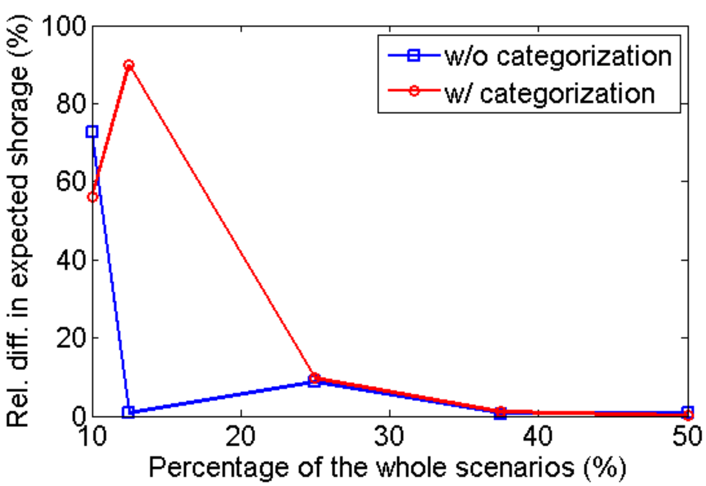
Nondispatchable Wind

Results: Rolling Through a Summer Week

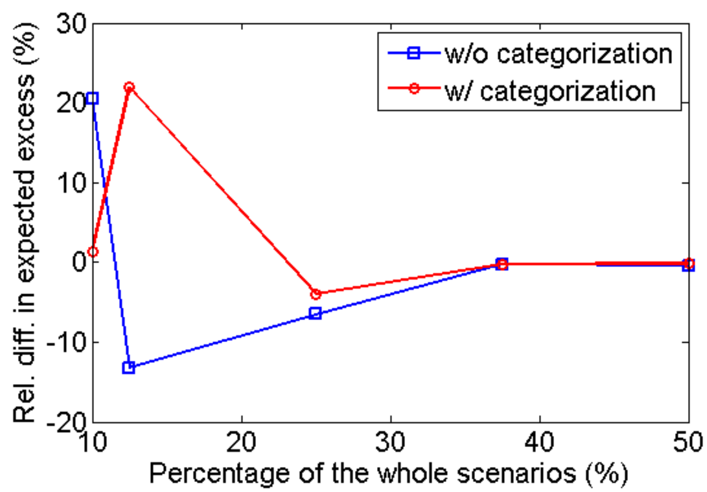
- Rolling horizon stochastic unit commitment from 2011-07-10 to 2011-07-16
- 20 generators
- 80 net load scenarios (8 load scenarios X 10 wind energy scenarios)
- 10% - 50% of scenarios selected, comparison to **optimal** solution

$$\text{rel.diff.} = \frac{(\text{value}_{subset} - \text{value}_{whole})}{\text{value}_{whole}} \times 100\%$$

Relative difference in shortage



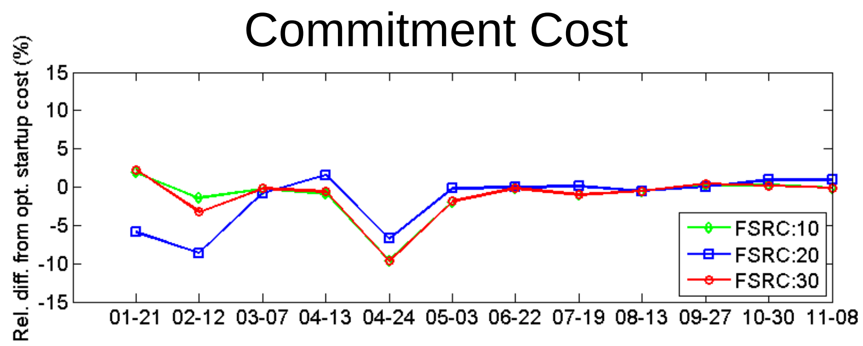
Relative difference in excess

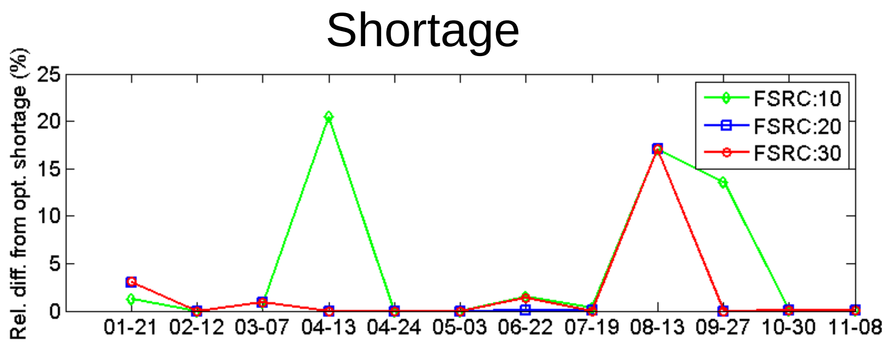


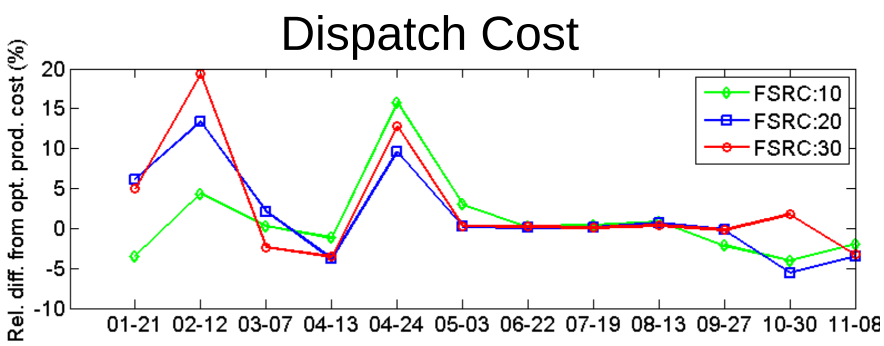
Dispatchable Wind

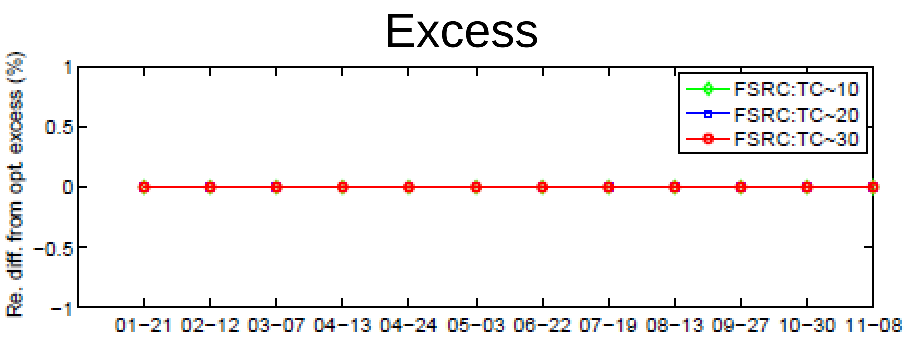
Results: Single Days in Different Seasons

- 50 generators
- 80 load and wind scenarios: 10, 20 or 30 selected, including extremes
- Comparison to **optimal** solution from all scenarios $\text{rel.diff.} = \frac{(\text{value}_{subset} - \text{value}_{whole})}{\text{value}_{whole}} \times 100\%$









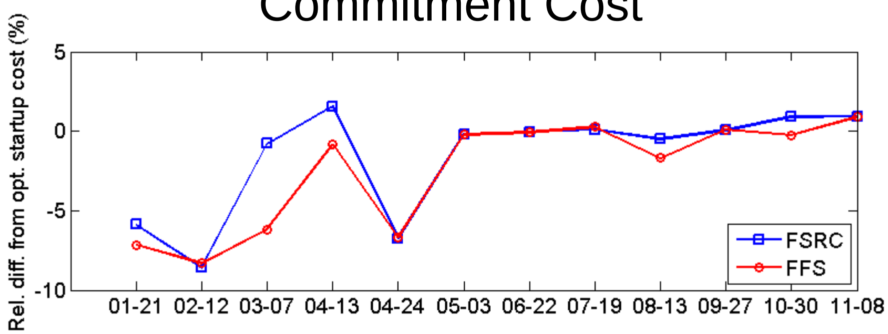
Dispatchable Wind

Results: Single Days in Different Seasons

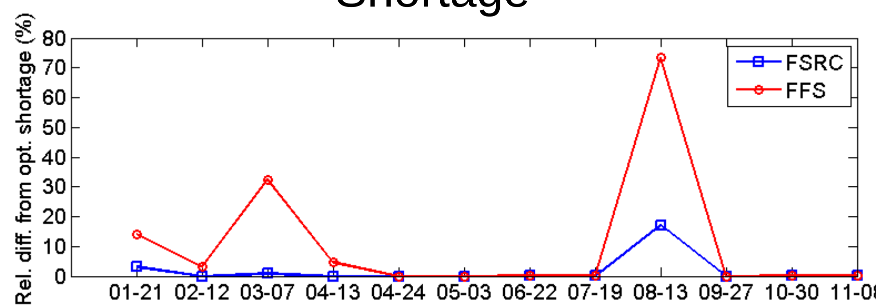
- 50 generators
- 80 load and wind scenarios: 20 selected incl. extremes
- FSRC, FFS compared to **optimal** from all scenarios

$$\text{rel.diff.} = \frac{(\text{value}_{subset} - \text{value}_{whole})}{\text{value}_{whole}} \times 100\%$$

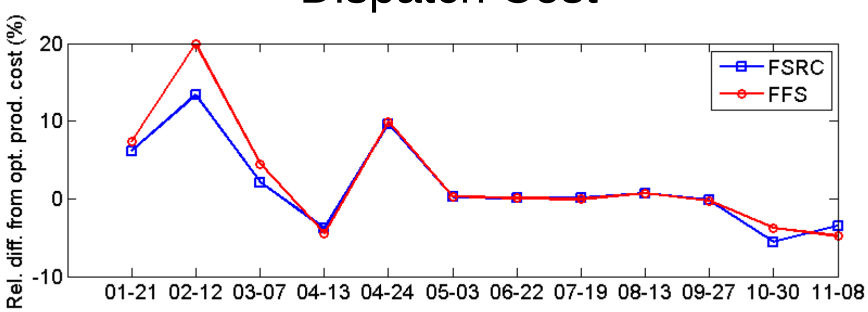
Commitment Cost



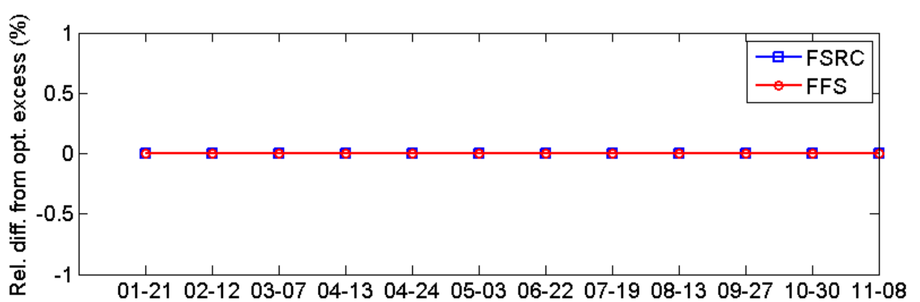
Shortage



Dispatch Cost



Excess



Conclusions

- FSRC maintains solution quality if at least 20% of scenarios selected
  - Precategorization can lower the scenario reduction computation time, little difference in results
- As the number of scenarios increases, solution from subset of scenarios converges to the optimal solution
- FSRC follows decision maker's concerns for cost and reliability
  - More conservative solutions than from FFS

References

- Feng, Y. and Sarah M. Ryan. "Scenario Reduction for Stochastic Unit Commitment with Wind Penetration," *Proceedings of IEEE Power & Energy Society General Meeting*, July, 2014.
- Feng, Y. and Sarah M. Ryan (2014). "Solution Sensitivity-Based Scenario Reduction for Stochastic Unit Commitment," *Computational Management Science*, under 2nd review.
- Watson, J.-P., Y. Feng, S. Ryan, D. Woodruff, R. Wets, I. Rios and K. Spurkel (2014). Toward Scalable Stochastic Unit Commitment - Part 1: Load Scenario Generation. http://www.optimization-online.org/DB_HTML/2014/05/4360.html
- Watson, J.-P., S. Ryan, K. Cheung, D. Gade, C. Silva-Monroy, D. Woodruff and R. Wets (2014). Toward Scalable Stochastic Unit Commitment - Part 2: Assessing Solver Performance. http://www.optimization-online.org/DB_HTML/2014/05/4361.html