Power-Capacity and Ramp-Capability Reserves for Wind Integration in Power-based Unit Commitment[1]

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FERC: Increasing Market and Planning Efficiency through Improved Software

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[1] G. Morales-España, R. Baldick, J. García-González, and A. Ramos, "Power-Capacity and Ramp-Capability Reserves for Wind Integration in Power-Based UC," , *IEEE Transactions on Sustainable Energy*, vol. 7, no. 2, pp. 614–624, Apr. 2016

Outline

Reserves in UC

- Wind & Solar introduce uncertainty $\Rightarrow$ more difficult planning

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- **Stochastic UCs**
  - Implicit reserves
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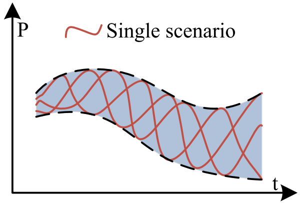
- Optimal quantity of reserves must be scheduled
  - $\Rightarrow$ providing flexibility to face real-time operation
- **Stochastic UCs**
  - Implicit reserves
  - $\uparrow$ computational burden
- **Reserve-based Deterministic UC**
  - Explicit reserves
  - $\downarrow$ computational burden

Outline

Why Ramp-Capability Reserves?

Stochastic



Implicitly guarantees availability of resources for a capacity and ramp range

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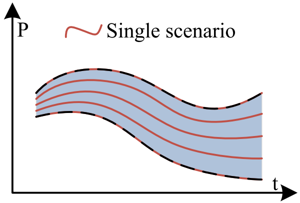

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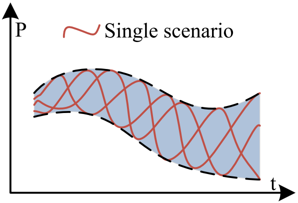

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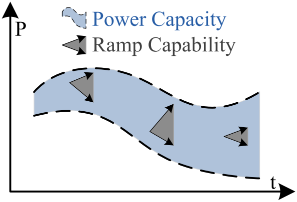
Capacity & Ramp Reserves



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Need for a clear difference between
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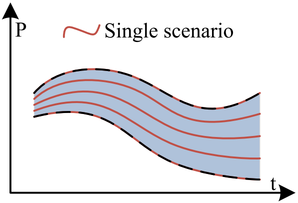

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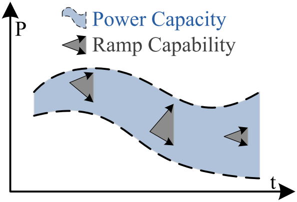

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- Feasible dispatch of the upper envelope of wind
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Single-level MIP for the Robust UC

- By considering dispatchable wind, the Robust UC becomes[2]

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\min \quad & \mathbf{b}^\top \boldsymbol{x} + \max \min \mathbf{c}^\top \boldsymbol{p} \\
\text{s.t.} \quad & \mathbf{F}\boldsymbol{x} \leq \mathbf{f},\ \boldsymbol{x} \text{ is binary} \\
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where uncertainty set Ξ is defined by $\xi_{bt} \in [\underline{\mathrm{w}}_{bt}, \overline{\mathrm{w}}_{bt}]\ \forall t \in \mathcal{T},\ b \in \mathcal{B}^{\mathrm{w}}$

- Which is a considerably simpler problem, we avoid
  - The local optimum of the bilinear program
  - Further complexity when trying to solve the two-level bilinear + MIP

[2] G. Morales-Espana, A. Lorca, L. Ramírez-Elizondo, and M. M. de Weerdt, "Robust Unit Commitment with Dispatchable Wind," Delft University of Technology, Technical Report, 2016

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- Which is a considerably simpler problem, we avoid
  - The local optimum of the bilinear program
  - Further complexity when trying to solve the two-level bilinear + MIP
- The worst-case wind scenario can be known a priori
  - this key worst-case scenario gives robustness to the UC solution

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- The procured ramp-capability $\leq$ power-capacity reserves
  - $\Rightarrow$ readjust ramp-capability reserves requirement

Outline

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  - 54 thermal units, 3 wind farms, 186 transmission lines
  - 24 hours time span

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- 3 Power-based UC formulations implemented:
  - DetRes[3]: UC with traditional power-capacity reserves
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[3] G. Morales-Espana, A. Ramos, and J. Garcia-Gonzalez, "An MIP Formulation for Joint Market-Clearing of Energy and Reserves Based on Ramp Scheduling," *IEEE Transactions on Power Systems*, vol. 29, no. 1, pp. 476–488, 2014

[4] G. Morales-España, R. Baldick, J. García-González, and A. Ramos, "Power-Capacity and Ramp-Capability Reserves for Wind Integration in Power-Based UC," , *IEEE Transactions on Sustainable Energy*, vol. 7, no. 2, pp. 614–624, Apr. 2016

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- 3 Power-based UC formulations implemented:
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- All problems solved with Cplex 12.6.0, stop criteria:
  - 0.05% opt. tolerance or 2h time limit

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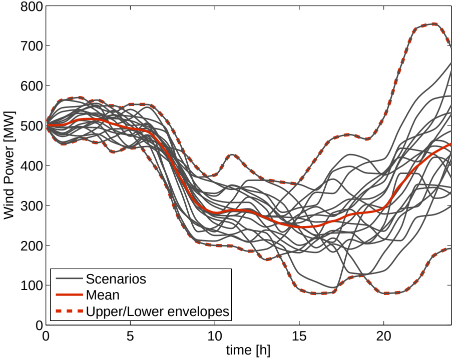
Scheduling & Evaluation Stages

- **Scheduling Stage**: **20 in-sample scenarios**
  - Obtains **hourly** commitment decisions for all units
  - by solving **hourly** network-constrained UCs
  - Reserves **obtained from** the in-sample scenarios:



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- **Evaluation Stage**: **200 out-of-sample scenarios**
  - **5 min** dispatch decisions for all units
  - by solving **5-min** network-constrained optimal dispatch
  - Penalizations:
    - Demand-balance violation costs: 10000 \$/MWh
    - Network violation costs: 5000 \$/MWh

Scheduling Performance

	Scheduling (hourly)	
	UC Costs† [k$]	# SU
DetRes	55.49	16
Stch	54.77	12
ResRPC		

† Commitment cost

- Stch optimized the level of reserves by dispatching wind
  - Scheduled less units
  - Lower UC costs than DetRes

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  - Scheduled less units
  - Lower UC costs than DetRes
- ResRPC also optimized the level of reserves

Evaluation: 200 out-of-sample scenarios

	Scheduling (hourly)		Real-time dispatch (5-min)	
	UC Costs† [k$]	# SU	Costs* [k$]	# Tot. Viol.
DetRes	55.49	16	857.20	**611**
Stch	54.77	12	808.97	**259**
ResRPC	51.98	14		

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*average dispatch + penalty costs of the 200 scenarios

- Compared with Stch, DetRes presented
  - **6%** higher average dispatch costs
  - **2.4x** more violations

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- Compared with Stch, DetRes presented
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  - **5%** lower average dispatch costs
  - **99%** less violations

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- Compared with Stch, ResRPC presented
  - **5%** lower average dispatch costs
  - **99%** less violations
  - mainly due to the robustness of ResRPC

Evaluation: 20 in-sample scenarios

	Scheduling (hourly)		Real-time dispatch (5-min)	
	UC Costs† [k$]	# SU	Costs* [k$]	# Tot. Viol.
DetRes	55.49	16	803.46	**611**
Stch	54.77	12	**768.79**	**12**
ResRPC	51.98	14	770.86	**1**

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- Compared with ResRPC, Stch presented
  - **0.3%** lower average dispatch costs
  - even with **12x** more violations

Power- vs. Energy-based UC: o-of-s evaluation

	Scheduling (hourly)		Real-time dispatch (5-min)	
	UC Costs† [k$]	# SU	Costs* [k$]	# Tot. Viol.
DetRes	55.49	16	857.2	**611**
Stch	54.77	12	808.97	**259**
ResRPC	51.98	14	**770.82**	**2**
E-Stch	**33.73**	10	**1166.67**	**1382**

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- Compared with a traditional Energy-based stochastic UC E-Stch, DetRes
  - presented **27%** lower average dispatch costs
  - presented **56%** less violations

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- Compared with a traditional Energy-based stochastic UC E-Stch, DetRes
  - presented **27%** lower average dispatch costs
  - presented **56%** less violations
  - and solved **23.6x** faster

Computational Burden

- The power-based formulations DetRes[5], Stch, ResRPC[6]
  - include startup and shutdown power trajectories[7]
  - are built upon a convex-hull[8]

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[5] G. Morales-Espana, A. Ramos, and J. Garcia-Gonzalez, "An MIP Formulation for Joint Market-Clearing of Energy and Reserves Based on Ramp Scheduling," *IEEE Transactions on Power Systems*, vol. 29, no. 1, pp. 476–488, 2014

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[7] G. Morales-Espana, J. M. Latorre, and A. Ramos, "Tight and Compact MILP Formulation of Start-Up and Shut-Down Ramping in Unit Commitment," *IEEE Transactions on Power Systems*, vol. 28, no. 2, pp. 1288–1296, 2013

[8] G. Morales-España, C. Gentile, and A. Ramos, "Tight MIP formulations of the power-based unit commitment problem," en, *OR Spectrum*, vol. 37, no. 4, pp. 929–950, May 2015

Computational Burden

- The power-based formulations DetRes[5], Stch, ResRPC[6]
  - include startup and shutdown power trajectories[7]
  - are built upon a convex-hull[8]
- Two energy-based UC formulations:
  - E-Stch[9], also based on a convex-hull[10]
  - TE-Stch[11], Traditional formulation, var. startup costs[12]

[5] G. Morales-Espana, A. Ramos, and J. Garcia-Gonzalez, "An MIP Formulation for Joint Market-Clearing of Energy and Reserves Based on Ramp Scheduling," *IEEE Transactions on Power Systems*, vol. 29, no. 1, pp. 476–488, 2014

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[10] C. Gentile, G. Morales-España, and A. Ramos, "A tight MIP formulation of the unit commitment problem with start-up and shut-down constraints," en, *EURO Journal on Computational Optimization*, pp. 1–25, Apr. 2016

[11] FERC, "RTO Unit Commitment Test System," Federal Energy and Regulatory Commission, Washington DC, USA, Tech. Rep., Jul. 2012, p. 55

[12] M. Carrion and J. Arroyo, "A computationally efficient mixed-integer linear formulation for the thermal unit commitment problem," *IEEE Transactions on Power Systems*, vol. 21, no. 3, pp. 1371–1378, 2006

Computational Burden

	MIP Time [s]	LP relaxation [s]
DetRes	8.8	0.34
Stch	867.8	38.1
ResRPC	**90.4**	**16.8**
E-Stch	206.5	22.1
TE-Stch		

- ResRPC solved
  - **10.3x** slower than DetRes
  - but **9.6x** faster than Stch
  - and **2.3x** faster than E-Stch

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- E-Stch could not reach 0.05% within the 2h time limit
- ResRPC, Stch and DetRes TE-Stch solved the MIP before E-Stch solved the LP

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  - outperforms a power-based UC with traditional reserves
  - can beat a stochastic power-based UC
  - is deterministic $\Rightarrow \downarrow$ computational burden
- Compared with traditional energy-based UC, the deterministic power-based UCs
  - presented lower average costs and fewer violations in the out-of-sample 5/min dispatch evaluation
  - while solving MIP problems faster

Questions

Thank you for your attention

Contact Information:
g.a.moralesespama@tudelft.nl

For Further Reading

- M. Carrion and J. Arroyo, “A computationally efficient mixed-integer linear formulation for the thermal unit commitment problem,” *IEEE Transactions on Power Systems*, vol. 21, no. 3, pp. 1371–1378, 2006.
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