Hidden Power System Inflexibilities Imposed by Traditional Unit Commitment Formulations

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FERC: Increasing Market and Planning Efficiency through Improved Software

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Outline

1 Introduction

2 Assumptions: Dealing with "Certainty"
- Infeasible Energy Delivery
- Startup and Shutdown Power Trajectories
- Power Scheduling: The Power-based UC

3 Case Studies: "Ideal" Stochastic UC

4 Conclusions

Short-term Generation Planning

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Underlying assumption:

UC generation schedule can always deliver what it promises

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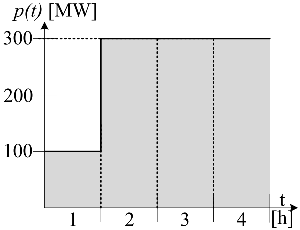
Energy Scheduling

Generation levels are usually considered as energy blocks.

Example: $\overline{P} = 300$MW; $\underline{P} = 100$MW; Up/Down ramp rate: 200 MW/h

Traditional UC



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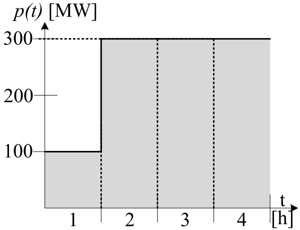

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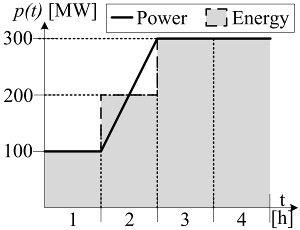

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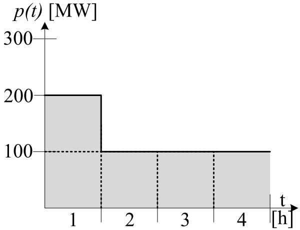

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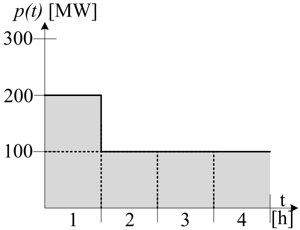

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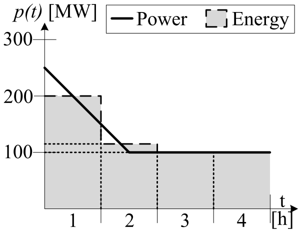

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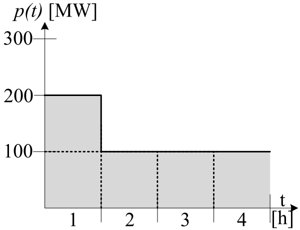

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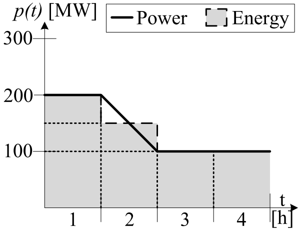

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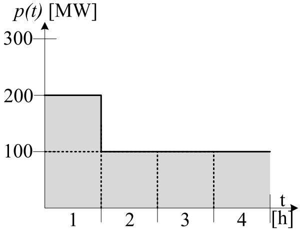

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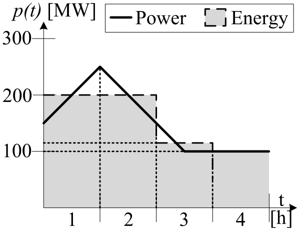

Infeasible energy delivery[1]

Overestimated ramp availability

⇓

A clear difference between power and energy is required in UCs

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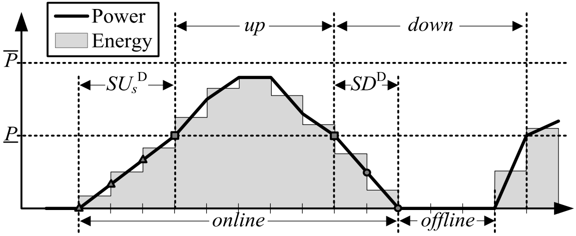
Startup (SU) and Shutdown (SD) power trajectories are neglected in UC scheduling stage: Why?



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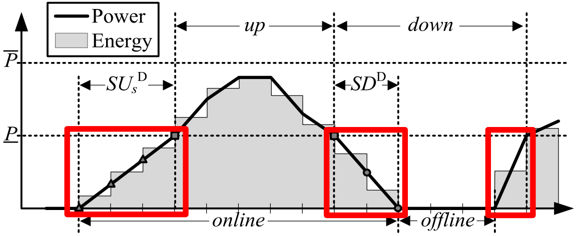

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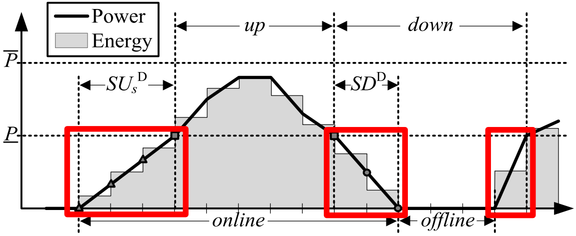

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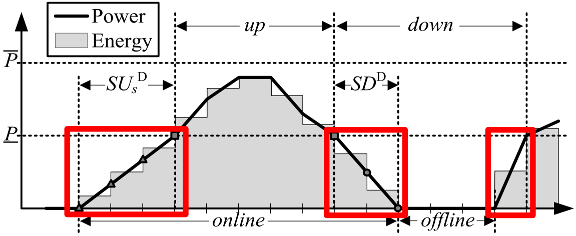

- Insignificant impact is assumed? To avoid complex models?
- Ignoring them changes commitment decisions ⇒ ↑ costs[2]

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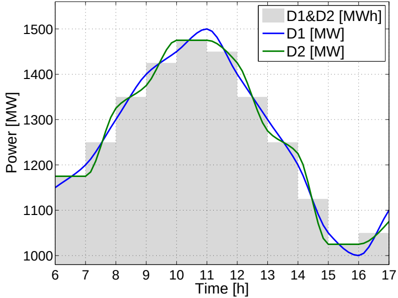
Energy vs. Power Profiles

Demand Example



Demand requirements

	Hour	D1	D2
Ramp [MW/h]	9-10	50	100
Ramp [MW/h]	10-11	50	0

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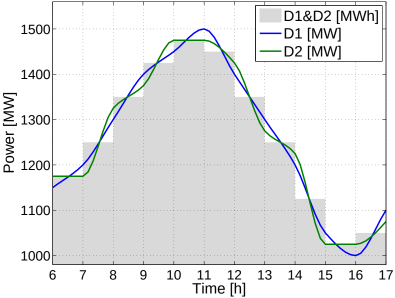

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Max P [MW]	10-11	1500	1475
Min P [MW]	15-16	1000	1025

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Planning 1 **Energy** Profile ⇒ cannot guarantee the final **power** profile[3]

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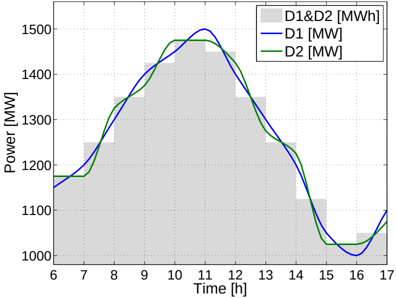

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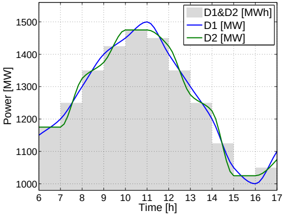
Power Scheduling: Power-Based UC

UC was reformulated for better scheduling (↓ costs)[4,5]

- New features:
  - Clear distinction: **energy** vs. **power**



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- New features:
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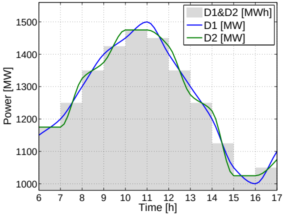
  - Linear piecewise power scheduling
    - Power demand balance
  - SU & SD power trajectories[6]



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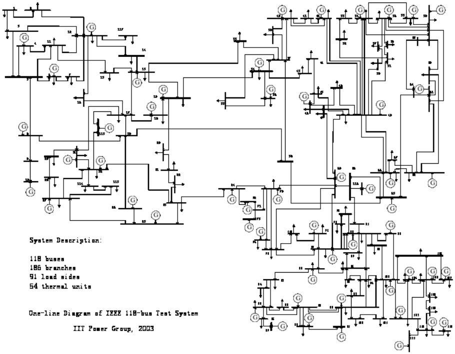
IEEE-118 Bus System



- 54 thermal units; 118 buses; 186 transmission lines; 91 loads
  - + 10 Quick-start units (∼10x more expensive)
  - 24 hours time span
  - 3 wind farms, 20 wind power scenarios

Case Study

- 3 Stochastic UC formulations implemented:
  - **E-UC**: Traditional Energy-based UC
  - **Es-UC**: Energy-based UC + SU/SD trajectories

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- All problems solved with Cplex 12.6.0, stop criteria:
  - 0.05% opt. tolerance or 24h time limit

Evaluating “**Ideal**” Stochastic UCs

- **Scheduling Stage**:
  - Obtains **hourly** commitment decisions for **slow-start** units
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  - Penalizations:
    - Demand-balance violation costs: 10000 $/MWh
    - Network violation costs: 5000 $/MWh
    - Negative wind bids: -50 $/MWh

Energy-Based vs. Power-based UC: Scheduling

	Scheduling (hourly)	
	Costs† [k$]	Curt [%]
E-UC	**747.3**	**1.3**
Es-UC	739.7	2.5
Ps-UC		

† Commitment + dispatch + penalty costs

- Including SU/SD trajectories
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- Power-based UC seems to be less flexible (↑ wind curtailment)

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- Ps-UCs turned out to be more flexible (↓ Curt) than E-UC

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  - $\Rightarrow$ **using the reserves to deal with known conditions** in real-time
- To achieve an optimal economic operation
  - All predictable events must be scheduled in advance
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- Energy-Based UCs cannot deal efficiently with known conditions
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  - ⇒ **using the reserves to deal with known conditions** in real-time
- To achieve an optimal economic operation
  - All predictable events must be scheduled in advance
  - **only** unforeseen events must be addressed using reserves
- Power-Based UC[7,8]
  - More accurate system representation
  - ⇒ better exploitation of unit's flexibility in real-time
  - especially when more flexibility is demanded by the system

[7] 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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Questions

Thank you for your attention

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For Further Reading

FERC, "RTO unit commitment test system," Federal Energy and Regulatory Commission, Washington DC, USA, Tech. Rep., Jul. 2012, p. 55.

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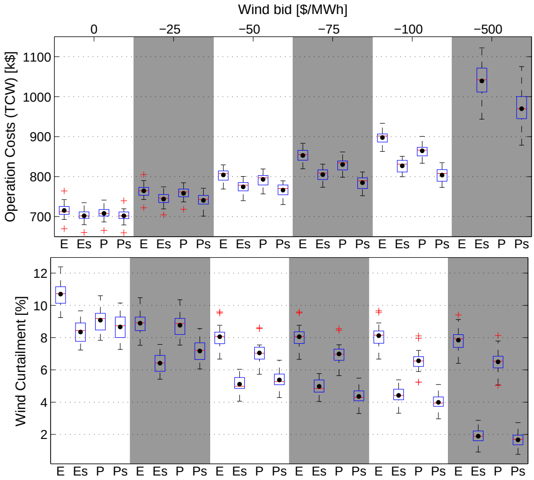
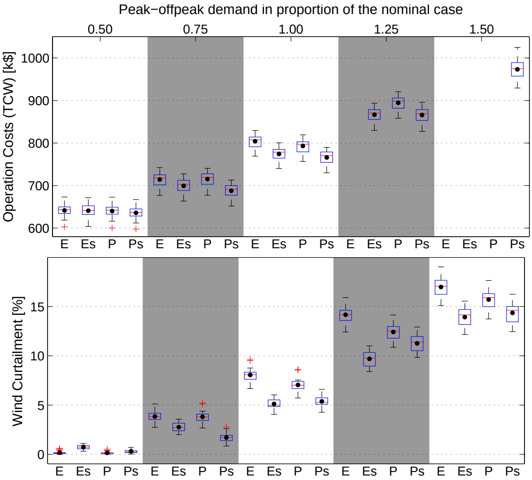
Impact of $\neq$ Negative Wind Bids



More significant differences between Ps-UC and E-UC when requiring ↓ curtailment

Impact of $\neq$ Demand Variability



More significant differences between Ps-UC and E-UC when demanding ↑ system flexibility

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- Stochastic UCs: IEEE-118 Bus System

UC performance comparisons (I)

	Traditional Energy-Block Scheduling	
	3binTUTD[9]	*TC*
o.f. [k$]	829.04	829.02
opt.tol [%]	0.224	0.023
IntGap [%]	1.27	0.58

- Compared with *3binTUTD*, *TC*:
  - lowered IntGap by 53.3%

[9] FERC, "RTO unit commitment test system," Federal Energy and Regulatory Commission, Washington DC, USA, Tech. Rep., Jul. 2012, p. 55

UC performance comparisons (I)

	Traditional Energy-Block Scheduling	
	3binTUTD[9]	*TC*
o.f. [k$]	829.04	829.02
opt.tol [%]	0.224	0.023
IntGap [%]	1.27	0.58
MIP runtime [s]	**86400**	**206.5**

- Compared with *3binTUTD*, *TC*:
  - lowered IntGap by 53.3%
  - is more than 420x faster

[9] FERC, "RTO unit commitment test system," Federal Energy and Regulatory Commission, Washington DC, USA, Tech. Rep., Jul. 2012, p. 55

UC performance comparisons (II)

	Traditional Energy-Block Scheduling	
	3binTUTD[10]	*TC*
o.f. [k$]	829.04	829.02
opt.tol [%]	0.224	0.023
IntGap [%]	1.27	0.58
MIP runtime [s]	86400	**206.5**
LP runtime [s]	**246.76**	22.03

- *TC* solved the MIP before *3binTUTD* solved the LP
  - within the required opt. tolerance (0.05%)

[10] FERC, "RTO unit commitment test system," Federal Energy and Regulatory Commission, Washington DC, USA, Tech. Rep., Jul. 2012, p. 55

UC performance comparisons (III)

	Traditional Energy-based UC		Power-Based UC
	3binTUTD	*TC*	*P-TC*
o.f. [k$]	829.04	829.02	**818.13**
opt.tol [%]	0.224	0.023	0.049
IntGap [%]	1.27	0.58	
MIP runtime [s]	**86400**	206.5	
LP runtime [s]	246.76	22.03	

- *P-TC*[11] has a more detailed and accurate UC representation

[11] 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

UC performance comparisons (III)

	Traditional Energy-based UC		Power-Based UC
	3binTUTD	*TC*	*P-TC*
o.f. [k$]	829.04	829.02	**818.13**
opt.tol [%]	0.224	0.023	0.049
IntGap [%]	1.27	0.58	0.74
MIP runtime [s]	**86400**	206.5	**867.9**
LP runtime [s]	246.76	22.03	38.1

- *P-TC*[11] has a more detailed and accurate UC representation
  - it solved 100x faster than *3binTUTD*
  - its UC core is also a convex hull[12]

[11] 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

[12] G. Morales-España, C. Gentile, and A. Ramos, "Tight MIP formulations of the power-based unit commitment problem," en, *OR Spectrum*, pp. 1–22, May 2015