Time-Adaptive Unit Commitment

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Unit commitment problem

- For given:
  - Set of generating units $g = 1, \ldots, N_G$
  - Set of time periods $t = 1, \ldots, N_T$
  - Known electricity demand d_t

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\min_{u_{gt}, p_{gt}} \quad & f(u_{gt}, p_{gt}) \\
\text{s.t.} \quad & g_j(u_{gt}, p_{gt}, d_t) \leqslant 0, \quad \forall j \\
& u_{gt} \in \{0, 1\}
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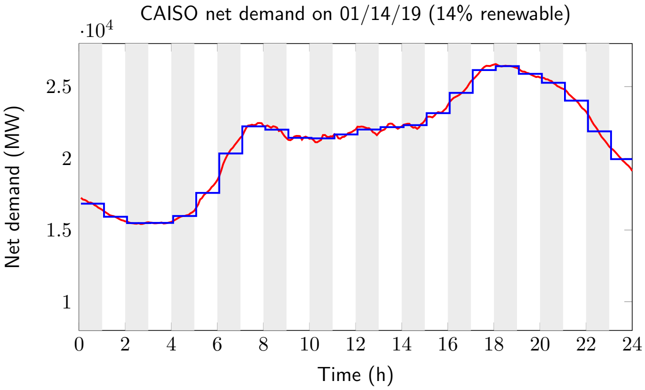
- UC problem is computationally expensive
- Increasing N_G or N_T may turn UC intractable

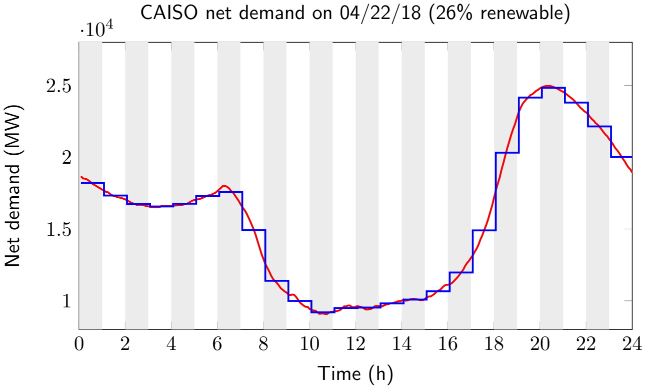
Motivation

- Traditionally: 24 hourly time periods
- Conventional hourly unit-commitment (CH-UC)



Motivation

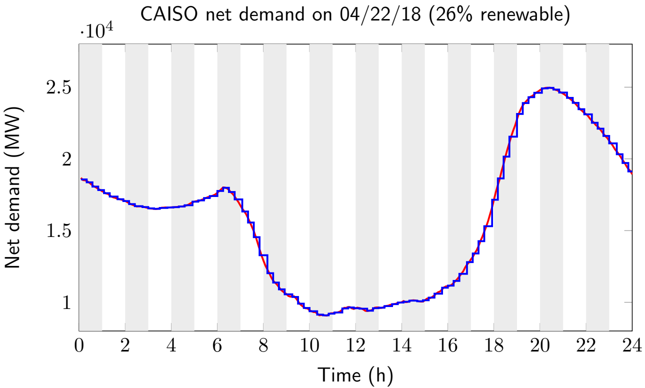
- What happens if renewable penetration increases?



- **FERC Order 764**: "hourly transmission scheduling protocols (...) are insufficient to provide system operators with the flexibility to manage their system effectively and efficiently"

Motivation

- What about increasing time resolution to 15 minutes?

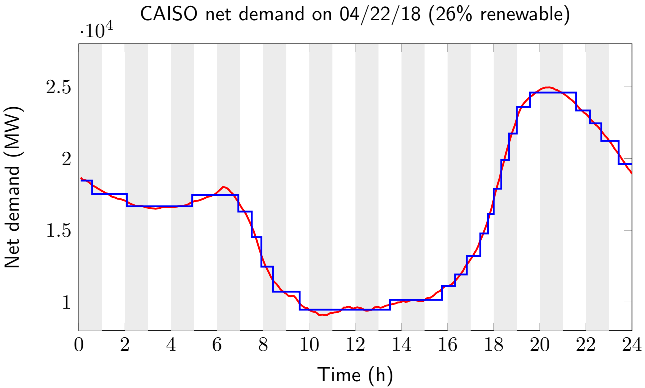


Motivation

- Existing approaches with finer time resolutions
    - Pandžić et al. 2014 (15 min)
    - Deane, Drayton, and Ó Gallachóir 2014 (5, 15, 30, 60 min)
    - Kazemi et al. 2016 (5, 10, 15, 30, 60 min)
    - Bakirtzis et al. 2014; Bakirtzis and Biskas 2017 (5-60 min)
- Operating cost savings
- Increase of computational time

Motivation

- What about using 24 time periods of different duration?
- Time-adaptive unit-commitment (TA-UC)



Research question

Can we determine the duration of 24 time periods to make

a more efficient use of the system flexibility

without increasing the computational burden of the UC?

Outline

- Proposed time-period aggregation
- Modifications of UC constraints
- Comparison: CH-UC vs. TA-UC
- Illustrative example
- Case study
- Conclusions

Proposed time-period aggregation

1. Original data (5-min resolution)

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2. Compute distance between each pair of adjacent clusters

9 7 4 2 5 8 3 2 4 5 4 6 7 7 1 9 6 2 5 2 9 3 2 6 2 9 4 4 3 2 8 3 7 5 9

Proposed time-period aggregation

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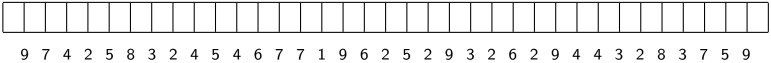
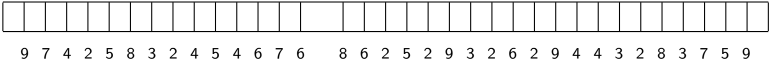


3. Merge the two closest adjacent clusters and update distances



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   9 7 4 2 5 8 3 2 4 5 4 6 7 6 8 6 2 5 2 9 3 2 6 2 9 4 4 3 2 8 3 7 5 9

4. Repeat 2 and 3 until the final number of clusters is obtained

Modifications of UC constraints

- Generating unit constraints
  - Minimum output
  - Ramping limits
  - Minimum up/down times

Type	Pmin	Ramp	Min time
Base (nuclear)	$\Uparrow\Uparrow$	$\Downarrow$	$\Uparrow\Uparrow$
Medium (coal)	$\Uparrow$	$\Uparrow$	$\Uparrow$
Peak (gas)	$\Downarrow$	$\Uparrow\Uparrow$	$\Downarrow$

Modifications of UC constraints

- Ramping limits (100MW/h)

p_1	p_2	p_3
1h	1h	1h

p_1	p_2	p_3
2h	0.5h	0.5h

$$|p_1 - p_2| \leqslant 100$$
$$|p_2 - p_3| \leqslant 100$$

$$|p_1 - p_2| \leqslant 125 = 100 \cdot 0.5 \cdot (2 + 0.5)$$
$$|p_2 - p_3| \leqslant 50 = 100 \cdot 0.5 \cdot (0.5 + 0.5)$$

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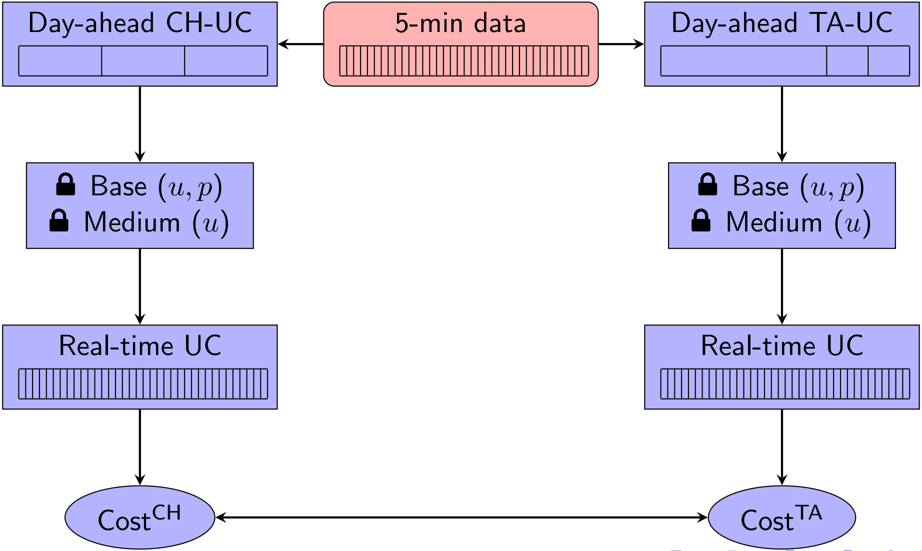
- Minimum up time (2h)

u_1	u_2	u_3
1h	1h	1h
0	0	0
1	1	0
0	1	1
1	1	1

u_1	u_2	u_3
2h	0.5h	0.5h
0	0	0
1	0	0
-	-	-
1	1	1

Comparison: CH-UC vs. TA-UC



Illustrative example

Technology	$\underline{P}_g^G$ (MW)	$\overline{P}_g^G$ (MW)	C_{gt}^M (€/MWh)	# units
Base	150	200	10	4
Medium	50	100	30	1
Peak	0	50	50	1

Time period	$t1$	$t2$	$t3$	$t4$	$t5$	$t6$
Duration (h)	0.5	0.5	0.5	0.5	0.5	0.5
Demand (MW)	500	500	500	500	650	850
Solar (MW)	300	300	300	300	200	0
Net demand (MW)	200	200	200	200	450	850

- Limited flexible generation (minimum output)
- Demand increases when solar decreases

Illustrative example

Table: Conventional Hourly Unit Commitment (CH-UC) – Example

Day-ahead dispatch			
Time periods	$t1 + t2$	$t3 + t4$	$t5 + t6$
Net demand	200	200	650
Base	200	200	600
Medium	0	0	50
Peak	0	0	0

Real-time operation						
Time periods	$t1$	$t2$	$t3$	$t4$	$t5$	$t6$
Net demand	200	200	200	200	450	850
Base	200	200	200	200	600	600
Medium	0	0	0	0	50	100
Peak	0	0	0	0	0	50
Load shed	0	0	0	0	0	100
Solar spillage	0	0	0	0	200	0

Illustrative example

Table: TIME-ADAPTIVE UNIT COMMITMENT (TA-UC) – EXAMPLE

Day-ahead dispatch			
Time periods	$t1 + t2 + t3 + t4$	$t5$	$t6$
Net demand	200	450	850
Base	200	400	800
Medium	0	50	50
Peak	0	0	0

Real-time operation						
Time periods	$t1$	$t2$	$t3$	$t4$	$t5$	$t6$
Net demand	200	200	200	200	450	850
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Medium	0	0	0	0	50	50
Peak	0	0	0	0	0	0
Load shed	0	0	0	0	0	0
Solar spillage	0	0	0	0	0	0

Case study

- Demand is 10% of that in Spain in 2017 (3800 MW peak demand)
- Wind and solar capacity factors in Spain in 2017
- Renewable penetrations from 20% to 60%
- Start-up costs, ramp limits and minimum times of thermal units
- Three generation portfolios:

	Base (MW)	Medium (MW)	Peak (MW)
Base case	1200	1200	1500
High-flex case	-	2400	1500
Low-flex case	2400	-	1500

Case study

Table: Relative Cost Savings (%)

Wind (%)	Solar (%)	*Base* case	*High-flex* case	*Low-flex* case
10	10	0.01	0.00	0.27
20	0	0.01	0.01	0.30
0	20	0.12	0.07	0.53
30	30	2.35	1.04	3.49
60	0	0.56	0.08	1.02
0	60	2.56	1.43	4.76

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- More renewables ➔ Higher savings
- More solar ➔ Higher savings
- Low flexibility ➔ Higher savings

Summary

- The conventional-hourly UC is proven inadequate for high penetration of renewables (Duck curve)
- Finer time discretizations reduce operating costs while increasing computational time
- The proposed time-adaptive UC reduces operating costs without increasing computational time
- The cost savings increase with renewable (solar) penetration and decrease with generation flexibility

Thanks!! Questions??

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S. Pineda, R. Fernández-Blanco and J.M. Morales, "*Time-Adaptive Unit Commitment*", in **IEEE Transactions on Power Systems**, 34(5), 3869-3878, 2019.

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