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Addressing flexibility in clustered unit commitment formulations for generation expansion planning

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Outline

- Introduction and Motivation
- Classic Clustered UC Formulation
- Proposed Individual Unit's Constraints for CUC
- Numerical Experiments
- Conclusions

The flexibility problem…

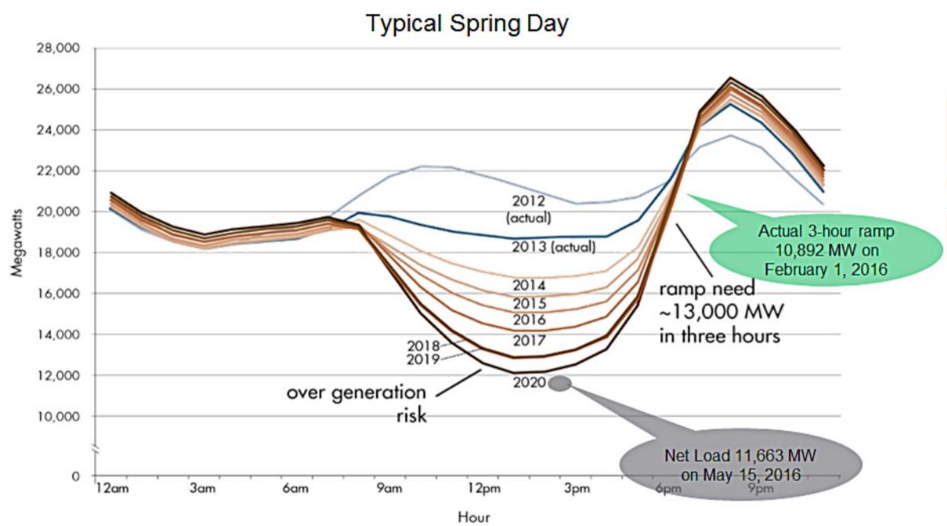
entsoe

1.2.6 Ensuring Flexibility in the region

The increases in renewable generation can result in significant load ramps being experienced within countries. These large ramps in load result from fast changes to variable generation output occurring at the same time as changes to the load profile. A present day example of this is the so called 'duck curve' load profile associated with the impact of solar generation. With the quantities of renewable generation described in the scenarios, TSOs will subsequently face challenges in maintaining system balance, as the size of the load ramps observed in section 3-3 could not solely be met with a country's installed thermal generation.

Source: https://tyndp.entsoe.eu/

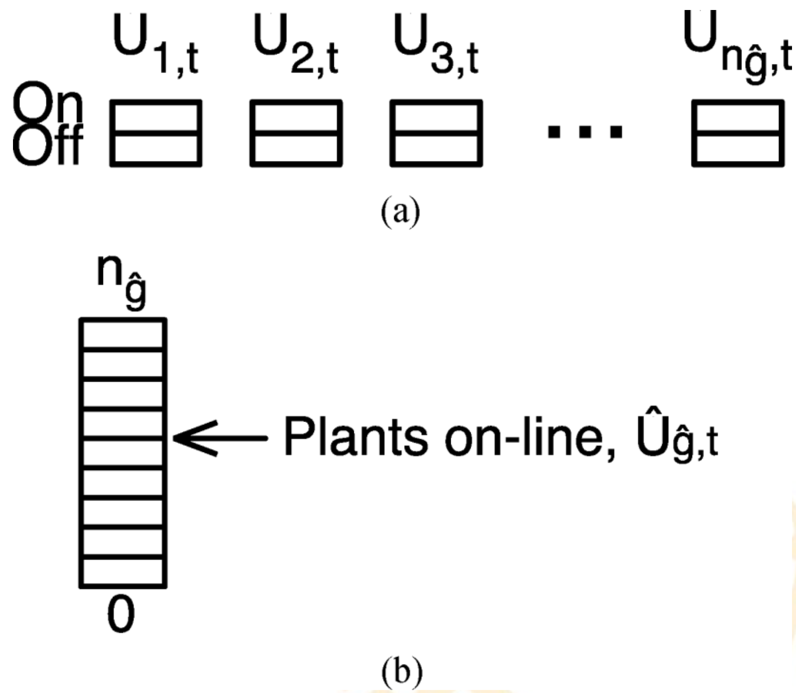
Figure 2: The duck curve shows steep ramping needs and overgeneration risk



Source: https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

Clustered Unit Commitment

- **Goal**: reduce size and combinatorial complexity of unit commitment constraints
- **How**: clustering different units by technology (e.g., nuclear, coal, CCGT)
- **Uses**: long-term planning such as generation and transmission expansion planning
- **Advantage**: good quality solutions in lower time
- **Drawback**: it overestimates some technical characteristics of the individual units within the cluster



B. S. Palmintier and M. D. Webster, "Heterogeneous unit clustering for efficient operational flexibility modeling," IEEE Trans. Power Syst., vol. 29, no. 3, pp. 1089–1098, May 2014.

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Clustered Unit Commitment Formulation

There are some drawbacks in these types of formulations that have been pointed out in the literature (**even if all units are identical**):

- Overestimation of startup/shutdown (SU/SD) capabilities:

$$p_t + r_t^+ \leq (\overline{P} - \underline{P})\, u_t - (\overline{P} - SU)\, y_t - (\overline{P} - SD)\, z_{t+1} \quad \forall t$$

Integer variables yield an overestimation depending on the individual ramping limits

- Overestimation of Minimum and up/down time limits:

$$u_t - u_{t-1} = y_t - z_t \quad \forall t$$

$$\sum_{i=t-TU+1}^{t} y_i \leq u_t \quad \forall t \in [TU, T]$$

$$\sum_{i=t-TD+1}^{t} z_i \leq G - u_t \quad \forall t \in [TD, T].$$

This constraint is for the whole group, individual units could stay up less than their min TU

J. Meus, K. Poncelet, and E. Delarue, “Applicability of a Clustered Unit Commitment Model in Power System Modeling,” IEEE Trans. Power Syst., vol. 33, no. 2, pp. 2195–2204, Mar. 2018.

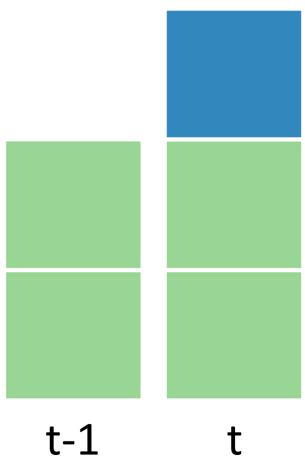
Clustered Unit Commitment (CUC) Formulation

There is one extra *overestimation* that has not been analyzed in the literature:

- Overestimation of ramping limits:

$$(p_t + r_t^+) - p_{t-1} \leq RU \cdot u_t \quad \forall t$$
$$-(p_t - r_t^-) + p_{t-1} \leq RD \cdot u_{t-1} \quad \forall t.$$

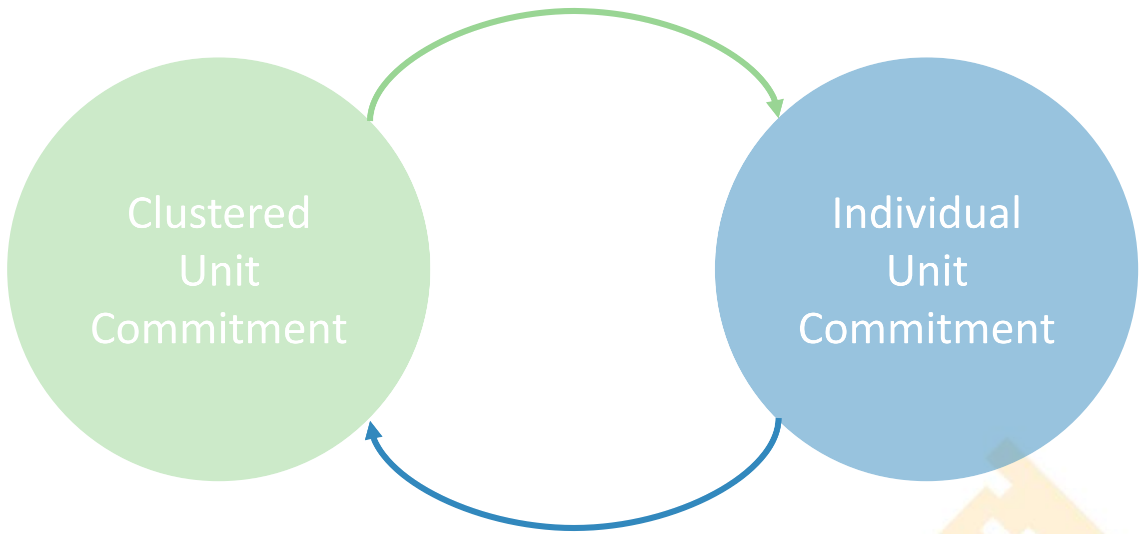
Integer variables yield an overestimation of ramping capabilities, and therefore, flexibility



Let's consider a cluster of N units
If N-1 units are at their maximum capacity, then the real ramp capacity of the cluster is limited by the ramping limit of one unit; however, these constraints state that the ramping limit is proportional the number of committed units

How to solve this situation?

Hybrid Method iterating between CUC and IUC models (Meus et al., 2018):



Can we improve the current CUC formulation to avoid/reduce iterations?

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Proposed Individual Unit's Constraints for CUC

u_t	Integer variable indicating the number of units producing above minimum output
y_t	Integer variable indicating how many units start up
z_t	Integer variable indicating how many units shut down

We add individual additional constraints in order to overcome the overestimation problem in the CUC

$\tilde{u}_{gt}$	Binary variable which is equal to 1 if the unit g is producing above minimum outputand 0 otherwise

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Proposed Individual Unit's Constraints for CUC

- Order the commitment of the units:

$$\tilde{u}_{g+1,t} \leq \tilde{u}_{gt} \quad \forall g \in [1, G), t$$
$$\tilde{u}_{1t} \leq 1, \quad \tilde{u}_{Gt} \geq 0 \quad \forall t.$$

- Relationship between the units and the cluster:

$$u_t = \sum_{g \in \mathcal{G}} \tilde{u}_{gt}, \quad p_t = \sum_{g \in \mathcal{G}} \tilde{p}_{gt} \quad \forall t$$
$$r_t^+ = \sum_{g \in \mathcal{G}} \tilde{r}_{gt}^+, \quad r_t^- = \sum_{g \in \mathcal{G}} \tilde{r}_{gt}^- \quad \forall t.$$

Proposed Individual Unit's Constraints for CUC

- Basic capacity limits:

$$\tilde{p}_{gt} - \tilde{r}^{-}_{gt} \geq 0, \quad \tilde{p}_{gt} + \tilde{r}^{+}_{gt} \leq \left(\overline{P} - \underline{P}\right) \tilde{u}_{gt} \quad \forall g, t.$$

- Enhanced capacity limits to overcome the SU/SD capacity problem

TU>1

$$\tilde{p}_{gt} + \tilde{r}^{+}_{gt} \leq (SU - \underline{P})\, \tilde{u}_{gt} + \left(\overline{P} - SU\right) \tilde{u}_{g,t-1} \quad \forall g, t$$

$$\tilde{p}_{gt} + \tilde{r}^{+}_{gt} \leq (SD - \underline{P})\, \tilde{u}_{gt} + \left(\overline{P} - SD\right) \tilde{u}_{g,t+1} \quad \forall g, t \in [1, T)$$

TU=1

$$\tilde{p}_{gt} + \tilde{r}^{+}_{gt} \leq (SU - \overline{P} + SD - \underline{P})\, \tilde{u}_{gt} + \left(\overline{P} - SU\right) \tilde{u}_{g,t-1} + \left(\overline{P} - SD\right) \tilde{u}_{g,t+1} \quad \forall g, t \in [1, T) \qquad (17)$$

Proposed Individual Unit's Constraints for CUC

- Ramping limit for individual units:

$$(\tilde{p}_{gt} + \tilde{r}^{+}_{gt}) - \tilde{p}_{g,t-1} \leq RU \cdot \tilde{u}_{gt} \quad \forall g, t$$

$$-(\tilde{p}_{gt} - \tilde{r}^{-}_{gt}) + \tilde{p}_{g,t-1} \leq RD \cdot \tilde{u}_{g,t-1} \quad \forall g, t.$$

These constraints guarantee that individual limits are satisfied

The proposed individual constraints avoid the overestimation of ramping limits and SU/SD capabilities without using an iterative approach

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Case Studies

Well-known case studies for individual unit commitment problems:

- IEEE 39-bus test system
- IEEE 118-bus test system

https://github.com/datejada/CUC-data

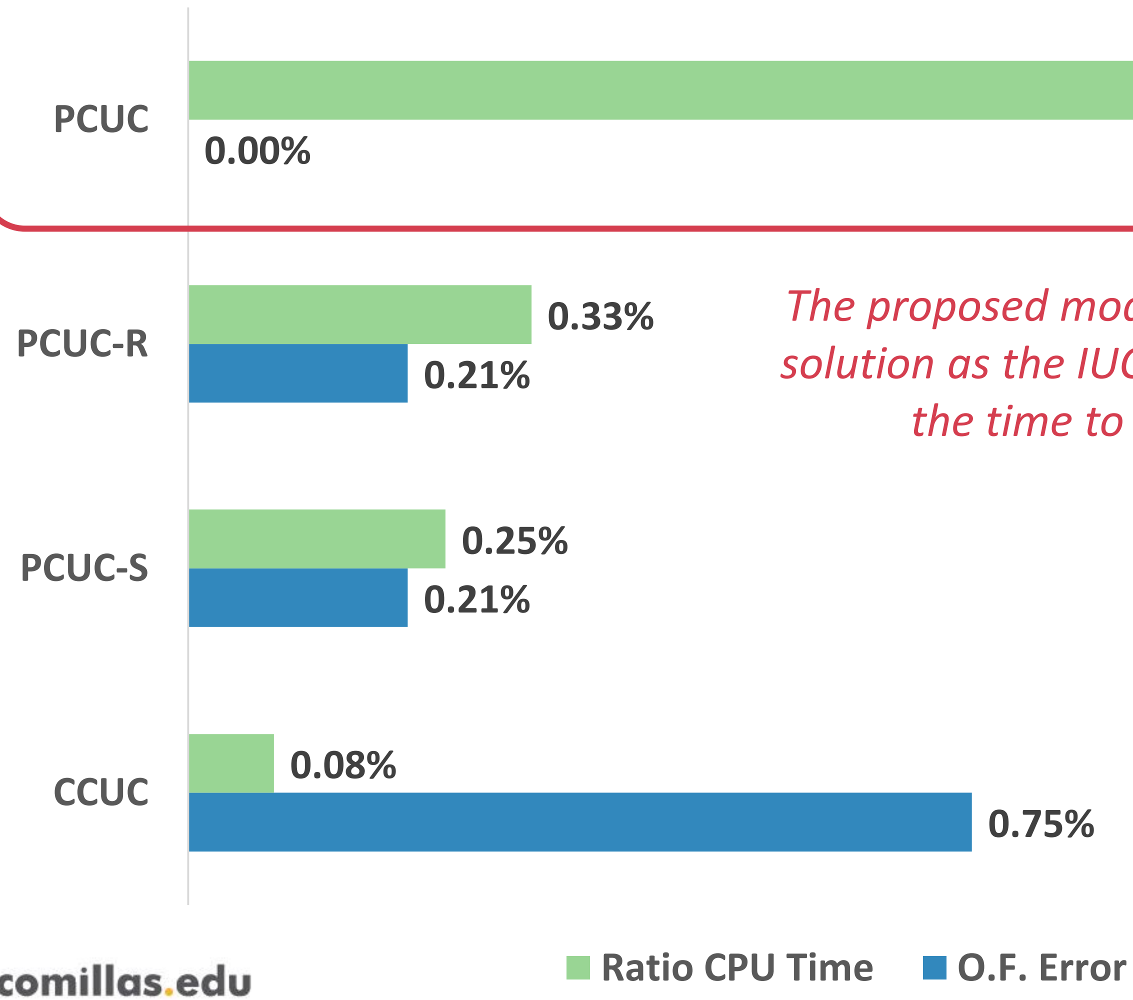
Both are scaled by 10, i.e., 10 times the demand, the transmission capacity and the number of generators.

IEEE 39-bus -> 90 units, 9 clusters of 10 units.
IEEE 118-bus -> 540 units, 54 clusters of 10 units.

Models in the Case Study

- Individual Unit Commitment (**IUC**) -> **benchmark**
- Classic Clustered Unit Commitment (**CCUC**)
- Proposed Clustered Unit Commitment with enhanced individual SU/SD constraints (**PCUC-S**)
- Proposed Clustered Unit Commitment with individual ramping constraints (**PCUC-R**)
- Proposed Clustered Unit Commitment with both individual constraints (**PCUC**)

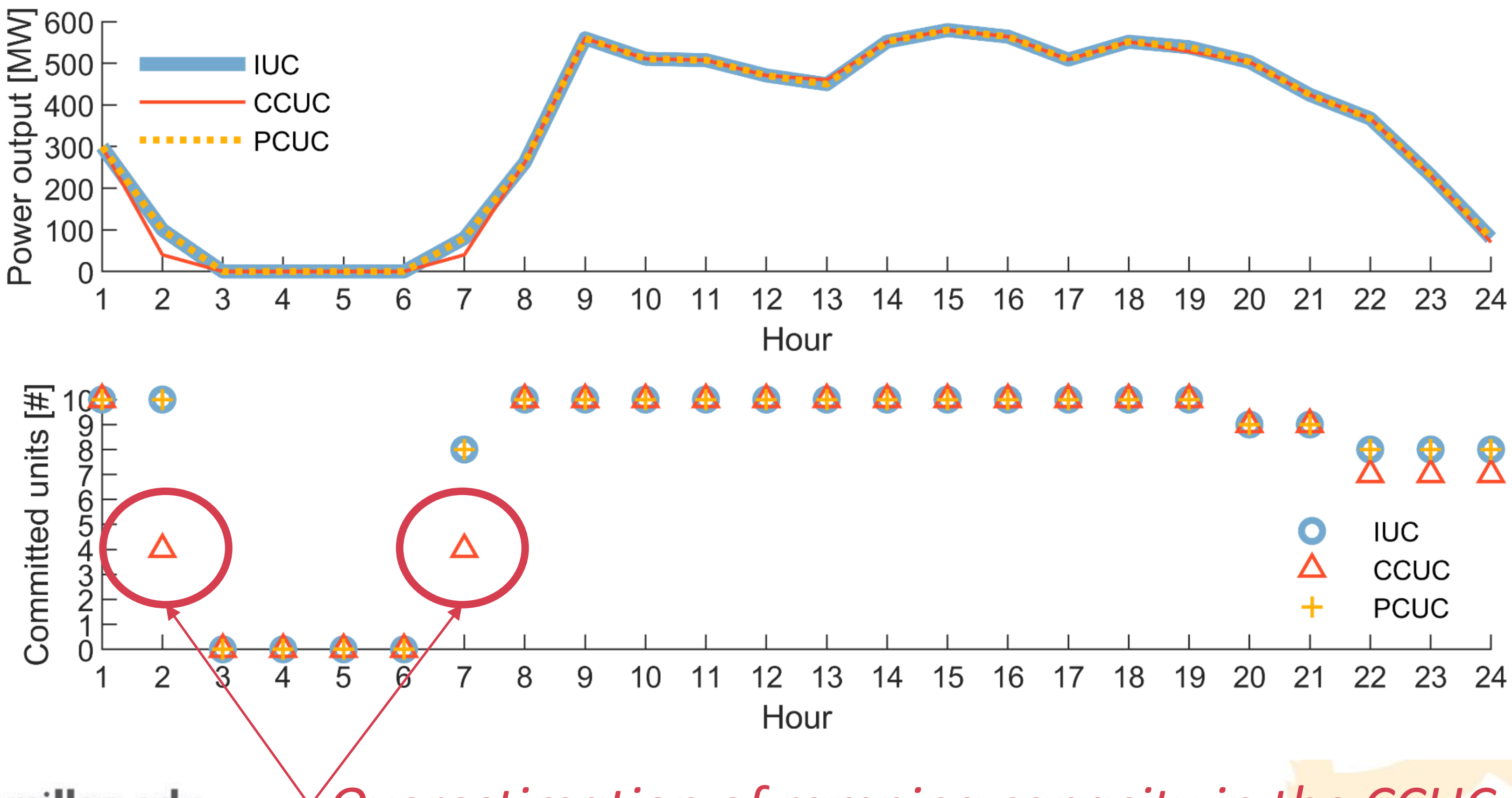
Results: IEEE 39-bus System



The proposed model obtains the same solution as the IUC in less than 1.2% of the time to solve the IUC.

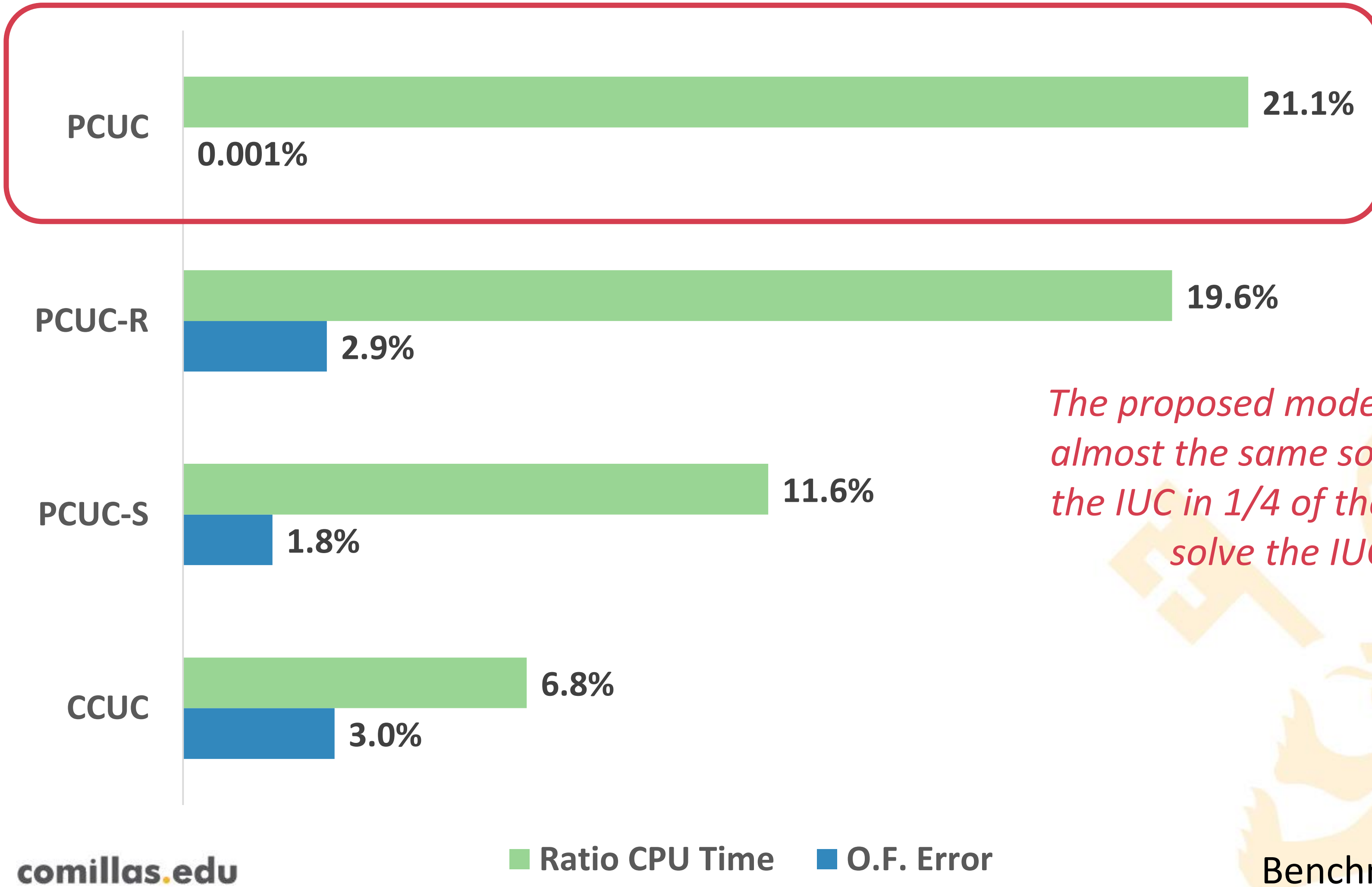
Benchmark: IUC

IEEE 39-bus system wit 5% reserve: Results for cluster 9.



Overestimation of ramping capacity in the CCUC

Results:
IEEE 118-bus System



The proposed model obtains almost the same solution as the IUC in 1/4 of the time to solve the IUC.

Benchmark: IUC

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Conclusions

- *Are you using a* ***CCUC*** *in your investment model?* **Be careful!** Maybe, you are overestimating the flexibility.

- The **proposed formulation** improves the **CCUC** without significantly increasing the computational burden.

- In addition, it takes advantage of the clustering, while maintaining the key **individual constraints** to avoid the overestimation of flexibility.

Future work

- The proposed formulation tackles 2 out of 3 overestimation problems:
  - ✅ **Overestimation of SU/SD capacities**
  - ✅ **Overestimation of ramping limits**
  - ❌ **Overestimation of minimum up/down time**

- However, the proposed formulation is compatible with the **hybrid method** in order to solve the overestimation of the minimum up/down time. **We expect** that our proposal helps to speed up the convergence of the hybrid method.

Thank you!
Questions?

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Annex

Overestimation of startup/shutdown (SU/SD) capabilities

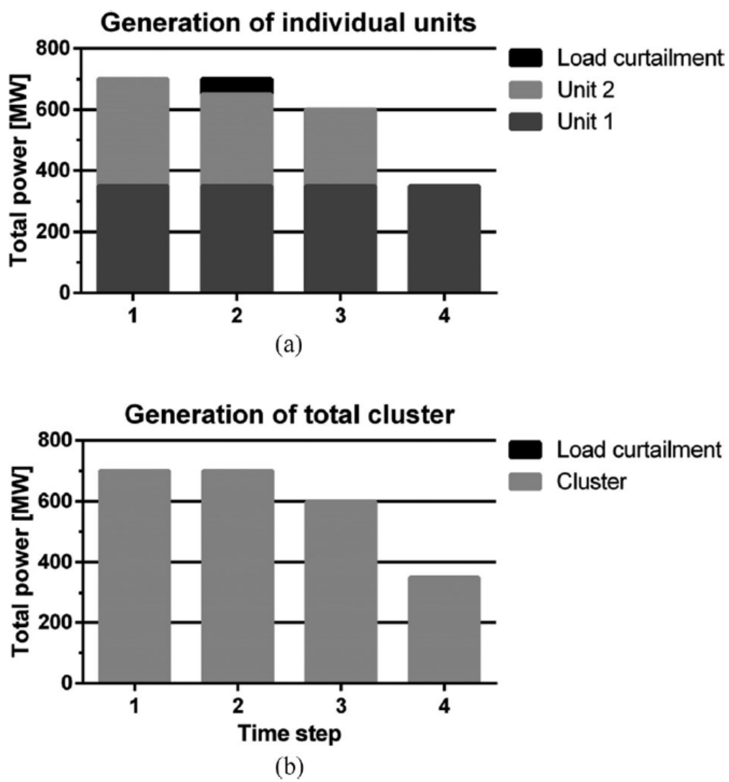

Fig. 3. (a) Generation plots of the BUC solution for the illustration 'overestimation of the shut-down capabilities (Tables I and II). (b) As for (a) but for the CUC solution.

TABLE I
PROPERTIES OF THE INDIVIDUAL POWER PLANTS IN THE ILLUSTRATION 'OVERESTIMATION OF THE SHUT-DOWN CAPABILITIES'

$\underline{P_i}$	$\overline{P_i}$	RU_i/RD_i	SU_i/SD_i	MUT_i/MDT_i
200 MW	350 MW	50 MW/period	250 MW	1 period

TABLE II
DEMAND REQUIREMENTS FOR THE CLUSTER IN THE ILLUSTRATION 'OVERESTIMATION OF THE SHUT-DOWN CAPABILITIES'

Time step	1	2	3	4
Demand	700 MW	700 MW	600 MW	350 MW

J. Meus, K. Poncelet, and E. Delarue, "Applicability of a Clustered Unit Commitment Model in Power System Modeling," IEEE Trans. Power Syst., vol. 33, no. 2, pp. 2195–2204, Mar. 2018.

Overestimation of Minimum and up/down time limits

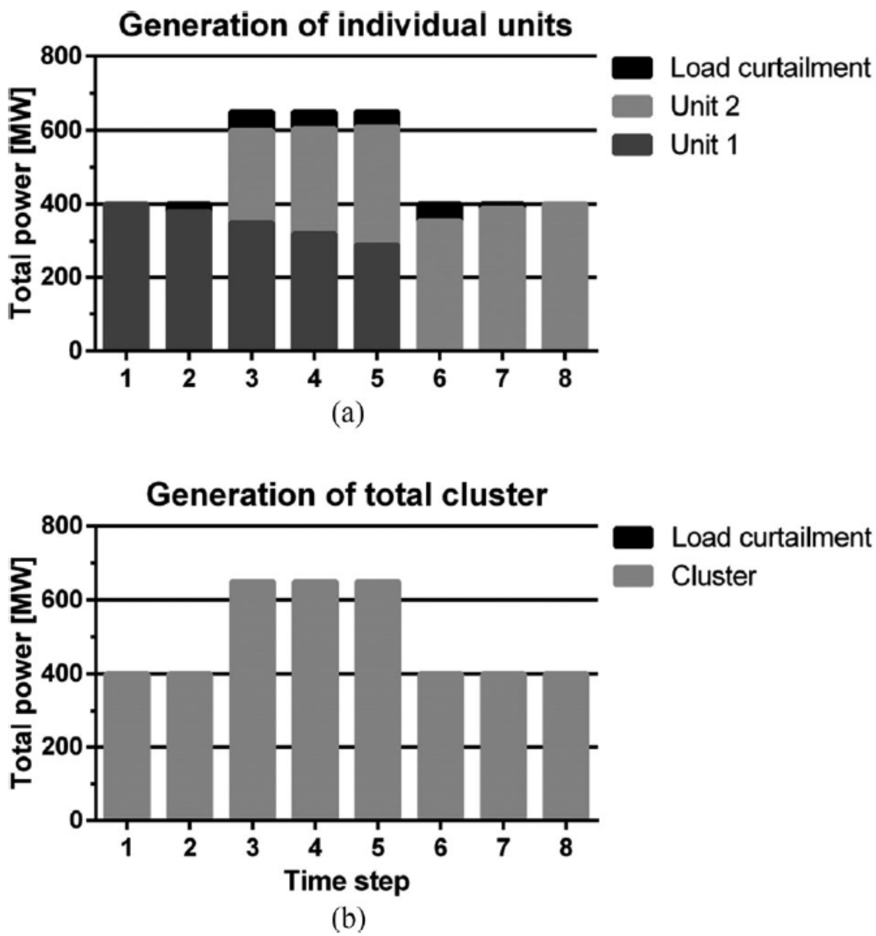

TABLE III
PROPERTIES OF THE INDIVIDUAL POWER PLANTS IN THE ILLUSTRATION 'VIOLATION OF THE MAXIMUM GENERATION LIMITS'

$\underline{P_i}$	$\overline{P_i}$	RU_i	RD_i
200 MW	400 MW	35 MW/period	30 MW/period
SU_i	SD_i	MUT_i	MDT_i
250 MW	290 MW	4 periods	4 periods

TABLE IV
DEMAND REQUIREMENTS OF THE CLUSTER IN THE ILLUSTRATION 'VIOLATION OF THE MAXIMUM GENERATION LIMITS'

Time step	1	2	3	4
Demand [MW]	400	400	650	650
Time step	5	6	7	8
Demand [MW]	650	400	400	400

J. Meus, K. Poncelet, and E. Delarue, "Applicability of a Clustered Unit Commitment Model in Power System Modeling," IEEE Trans. Power Syst., vol. 33, no. 2, pp. 2195–2204, Mar. 2018.

Results:

TABLE I
CASE STUDIES RESULTS

	Reserve	Result	IUC	CCUC	PCUC-S	PCUC-R	PCUC
39-bus system	10%	O.f. [M$]	1.0070	0.9998	1.0051	1.0051	1.0070
		O.f. Error	-	0.72%	0.20%	0.20%	0.00%
		Rtime [s]	4599	4	6	5	15
	5%	O.f. [M$]	0.9901	0.9826	0.9880	0.9880	0.9901
		O.f. Error	-	0.75%	0.21%	0.21%	0.00%
		Rtime [s]	1218	1	3	4	14
118-bus system	5%	O.f. [M$]	14.4787	14.0853	14.2463	14.1010	14.4789
		O.f. Error	-	2.72%	1.61%	2.61%	-0.001%
		Rtime [s]	12543	170	749	388	810
	2.5%	O.f. [M$]	13.9725	13.5540	13.7247	13.5747	13.9724
		O.f. Error	-	3.00%	1.77%	2.85%	0.001%
		Rtime [s]	1924	131	223	377	406