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Continuous-Trajectory Robust Unit Commitment Considering Beyond-the-Resolution Uncertainty

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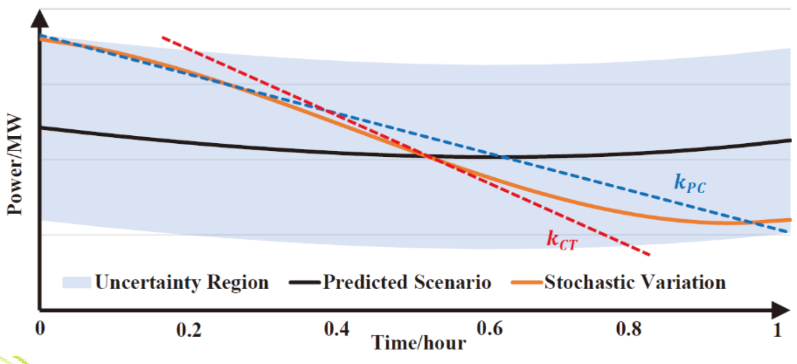
Background

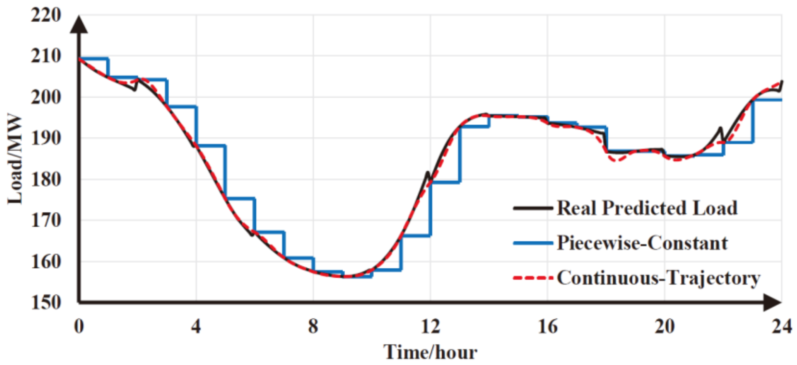
- Beyond-the-resolution (BtR) uncertainty
  - Renewable generation developes rapidly, yet its uncertainty challenges the power system operating security.
  - Existing piecewise-constant (PC) scheduling can not access the power variation inside scheduling periods, which is unreasonable when renewable penetration gets higher.



- Continuous-Trajectory (CT) Method
  - Derive an analytical continuous trajectory with more information to approximate the load curve for more accurate and secure scheduling.
  - Break scheduling horizon into some periods and use Bernstein splines to approximate BtR variation of each period.

$$B_{3,k}(t) = C_3^k t^k (1-t)^{3-k},\ k = 0,1,2,3$$

$$P(t) = \sum_{k=0}^{3} P^{Bk} B_{3,k}(t) = (\boldsymbol{P^B})^T \boldsymbol{B_3}(t),\ t \in [0,1]$$



Proposed method

- Basic BtR Variations
  - Any BtR variation can be linearly combined by Basic BtR Variations.

$$\begin{cases}(1-\gamma)P_{u0}(t)\le P_u(t)\le(1+\gamma)P_{u0}(t)\\ P_u(t)=(\boldsymbol{P}_u^B)^T\boldsymbol{B}_3(t),\ P_{u0}(t)=(\boldsymbol{P}_{u0}^B)^T\boldsymbol{B}_3(t)\end{cases}$$

$$\Downarrow$$

$$\begin{cases}[(1-\gamma)\boldsymbol{P}_{u0}^B-\boldsymbol{P}_u^B]^T\boldsymbol{B}_3(t)\le 0\\ [\boldsymbol{P}_u^B-(1+\gamma)\boldsymbol{P}_{u0}^B]^T\boldsymbol{B}_3(t)\le 0\end{cases}$$

$$\Downarrow$$

$$\begin{cases}\max\{(1-\gamma)\boldsymbol{P}_{u0}^B-\boldsymbol{P}_u^B\}\le 0\\ \max\{\boldsymbol{P}_u^B-(1+\gamma)\boldsymbol{P}_{u0}^B\}\le 0\end{cases}$$

$$\Downarrow$$

$$(1-\gamma)\boldsymbol{P}_{u0}^B\le\boldsymbol{P}_u^B\le(1+\gamma)\boldsymbol{P}_{u0}^B$$

$$\xrightarrow{\text{convex hull property}}$$

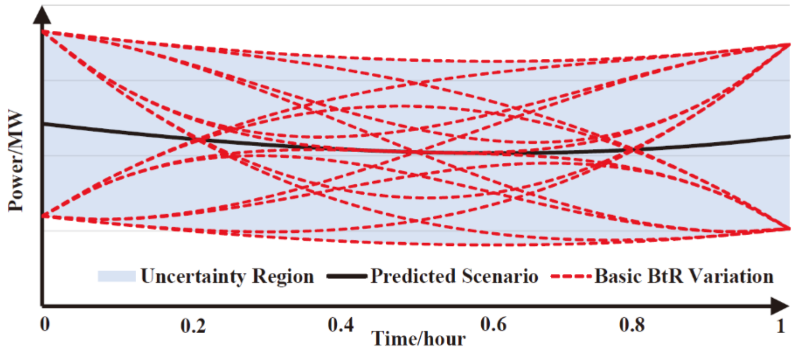
$$\begin{cases}\boldsymbol{P}_u^B=[\boldsymbol{P}_{u,e1}^B\ \boldsymbol{P}_{u,e2}^B\ \cdots\ \boldsymbol{P}_{u,eN}^B]\boldsymbol{\omega}\\ \boldsymbol{\omega}\ge 0,\ \mathbf{1}^{\mathrm{T}}\boldsymbol{\omega}\le 1\end{cases}$$

$$\Downarrow$$

$$\begin{cases}P_{u,en}^{Bk}=P_{u0}^{Bk}+\alpha_k\gamma P_{u0}^{Bk}-(1-\alpha_k)\gamma P_{u0}^{Bk},\ k=0,1,2,3\\ n=1+\alpha_0+2\alpha_1+4\alpha_2+8\alpha_3,\ \alpha_k\in\{0,1\}\end{cases}$$

$$\Downarrow$$

$$P_u(t)=(\boldsymbol{P}_u^B)^T\boldsymbol{B}_3(t)=([\boldsymbol{P}_{u,e1}^B\ \boldsymbol{P}_{u,e2}^B\ \cdots\ \boldsymbol{P}_{u,eN}^B]\boldsymbol{\omega})^T\boldsymbol{B}_3(t)$$
$$=\boldsymbol{\omega}^T[\boldsymbol{P}_{u,e1}^B\ \boldsymbol{P}_{u,e2}^B\ \cdots\ \boldsymbol{P}_{u,eN}^B]^T\boldsymbol{B}_3(t)=\sum_{n=1}^{N}\omega_n P_{u,en}(t)$$



- CT Robust UC (CT-RUC)
  - CT-RUC can be shifted from the time domain to the time-function space for tractable computation.

$$\begin{cases}G(t)=0\Rightarrow\boldsymbol{G}^B=0\\ G(t)\le 0\Rightarrow\boldsymbol{G}^B\le 0\\ \int_0^T G(t)dt=(G^{B0}+G^{B1}+G^{B2}+G^{B3})T/4\end{cases}$$

$$\mathbf{g}(\boldsymbol{x}(\tau),\boldsymbol{y}(\tau),\boldsymbol{u}(\tau))\le 0 \longrightarrow \mathbf{A}\boldsymbol{x}+\mathbf{B}\mathbf{y}+\mathbf{C}\boldsymbol{u}\le\mathbf{D}$$

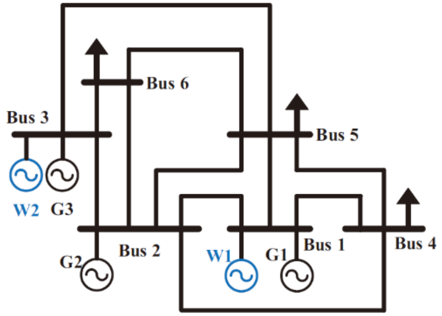
CT-RUC: $\min\ \sum_t\sum_i(C_{suit}+C_{sdit}+C_{fuel,it}^E)$

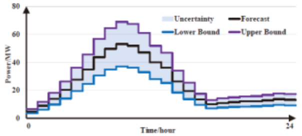
$$s.t.\ \mathbf{A}\boldsymbol{x}+\mathbf{B}\mathbf{y}^E+\mathbf{C}\boldsymbol{u}^E\le\mathbf{D}$$

$$\mathbb{F}=\left\{\boldsymbol{x}\left|\begin{array}{l}\mathbb{U}=\{\boldsymbol{u}|(1-\gamma)\boldsymbol{P}_{u0,it}^B\le\boldsymbol{P}_{uit}^B\le(1+\gamma)\boldsymbol{P}_{u0,it}^B\}\\ \forall\boldsymbol{u}\in\mathbb{U},\ \exists\mathbf{y},\text{such that }\mathbf{A}\boldsymbol{x}+\mathbf{B}\mathbf{y}+\mathbf{C}\boldsymbol{u}\le\mathbf{D}\end{array}\right.\right\}$$

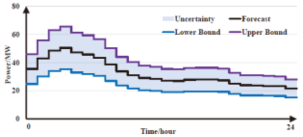
Case studies

- Case settings

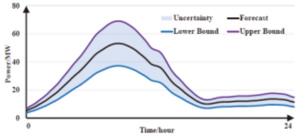




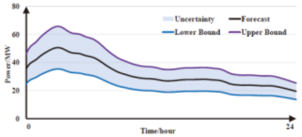
(a) Wind Farm1 in PC-RUC



(b) Wind Farm2 in PC-RUC

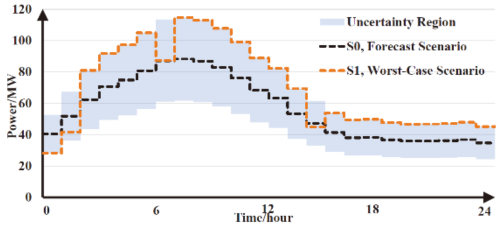


(c) Wind Farm1 in CT-RUC

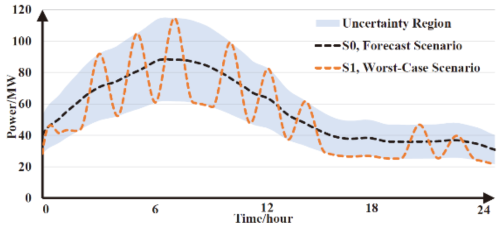


(d) Wind Farm2 in CT-RUC

- Simulation results



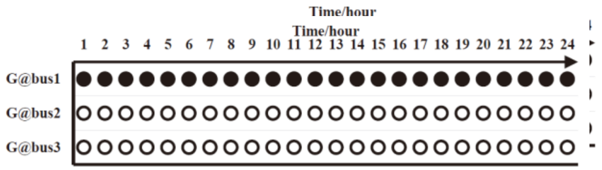
(a) PC-RUC



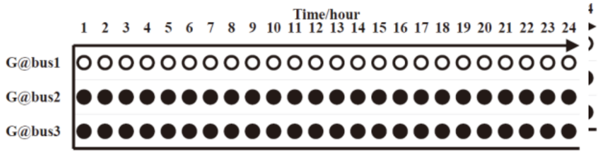
(b) CT-RUC

Scheduling scheme	PC	CT
Load demand/MWh	4427.33	4423.79
Wind energy/MWh	1368.50	1365.74
Unit generation/MWh	3058.83	3058.05
Iteration number of C&CG	2	2
Computation time/s	1.40	5.68
Startup/shutdown Number	0	0
Online-unit-time/hour	24	48
Total cost in forecast scenario/$	43054.34	44639.83
Startup/shutdown cost in forecast scenario/$	0	0
Fuel cost in forecast scenario/$	43054.34	44639.83
Robustness in 10000 test scenarios	31.82%	100%

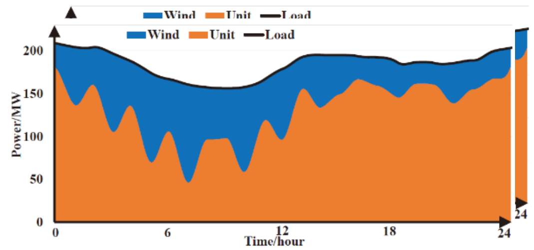
CT-RUC is much more robust!



(a) PC-RUC

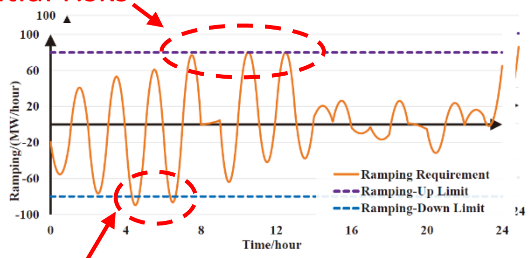


(b) CT-RUC



(a) Power Load and Generation

Potential risks



(b) Ramping Requirement

Ramping scarcity events

Conclusions

- This paper proposes the continuous-trajectory robust unit commitment considering the beyond-the-resolution uncertainty in the computationally tractable formulation. With the BtR uncertainty considered, the proposed CT-RUC can provide a more robust solution than traditional PC-RUC, especially in the high renewable energy penetrated power system. The numerical comparison between PC-RUC and CT-RUC demonstrates that,
  - in CT-RUC, the worse scenario with the BtR variation is considered, and sufficient ramping capacity is scheduled.
  - The robustness of the proposed CT-RUC is higher than that of traditional PC-RUC.
- Future works include more accurate modeling of CT-RUC and the coordination of the operational security and economy under BtR uncertainties.