Robust management and control of smart multi-carrier energy systems

Tomás Pippia
ESR 2.3

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Marie Sklodowska-Curie grant agreement No 675318

Previously on ESR 2.3…

- PhD student at TU Delft
- Currently carrying out the first secondment at UPC until mid July
- Working on:
  - Extension of tube-based MPC to hybrid systems
  - Stability analysis for time-varying partitioned systems (joint work with ESR 1.1, Wicak Ananduta)

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Outline

- Extension of tube-based MPC to hybrid systems
- Stability analysis for time-varying partitioned systems

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µCHPs and Hybrid Systems

- "Developing robust control methods [...] for mixed electricity/gas networks"
- µ-Combined Heat and Power (µCHP) plants, described using hybrid models
- Hybrid models include both continuous and discrete variables
- Focus on Piecewise Affine (PWA) models

$$\begin{aligned} x\left(k+1\right) &= A_i x(k) + B_i u(k) + f_i \\ y(k) &= C_i x(k) + D_i u(k) + g_i \end{aligned} \quad \text{for} \quad \begin{bmatrix} x(k) \\ u(k) \end{bmatrix} \in \Omega_i$$

incite

TU Delft

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Model Predictive Control

- The adopted control strategy is Model Predictive Control (MPC)
- In MPC, a model is used to predict the future states of the system
- An optimal input is computed and at the next time instant the problem is solved again
- Robust MPC copes with disturbances in the model

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Tube-based MPC (I)

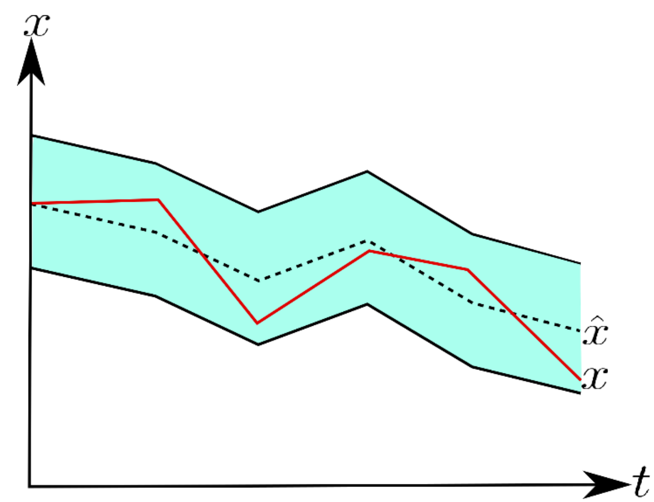
- In tube-based MPC, the state is split into nominal and disturbed
- The nominal state is subject to tighter constraints with respect to the disturbed one
- The disturbed state trajectory will lie in a "tube" that satisfies the constraints

Disturbed state:

$$x(k+1) = Ax(k) + Bu(k) + w(k)$$

Nominal state:

$$\hat{x}(k+1) = A\hat{x}(k) + B\hat{u}(k)$$



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Tube-based MPC (II)

- Tube-based MPC developed mainly for linear systems
- Extension of tube-based MPC for hybrid systems
- Challenges:
  - The nominal state and real state might be in different modes of operation
  - Find a robust positively invariant set independently of the mode of operation

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Time-varying partition (I)

- Large-scale systems are usually split into smaller subnetworks
- The partitioning process is usually done offline
- Power network are subject to disturbances and changes in generation/load profiles

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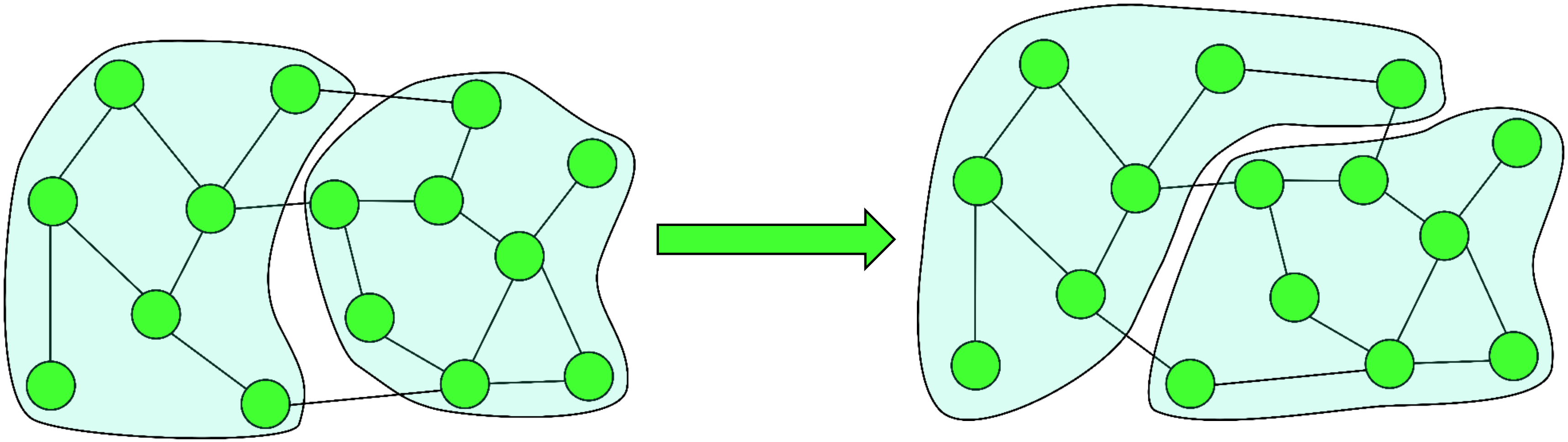
Time-varying partition (II)

- (Re)Partition the system periodically



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Time-varying partition (III)

- Challenge: guarantee stability of the system even during the partition change
- Idea: use results from switching systems theory!

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Switching systems (I)

- Dynamics are given by
$$x(k+1) = A_{\sigma(k)}x(k)$$
- We suppose $A_{\sigma(k)}$ matrices are Schur stable
- The switched system is asymptotically stable if some conditions on $\sigma(k)$ are met
- Average dwell time

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Switching systems (II)

- We consider dynamics of the centralized system
- Each subsystem's dynamics is Schur stable

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Switching systems (III)

- Define the activation time as $k_i - k_{i-1}$
- During activation time, system follows dynamics $x(k+1) = A_i x(k)$
- State can be written as $x(k) = A_{i+1}^{k-k_i} \ldots A_1^{k_1} x(0)$
- Through some properties, we reach inequality

$$\|x(k)\| \leq \left\| A_i^{k-k_i} \right\| \ldots \left\| A_1^{k_1} \right\| \|x(0)\| \leq c\lambda^k \|x(0)\| \, , \;\; \lambda \in (0,1)$$

- Key point: “slow” switching!

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Conclusions and future work

- Hybrid systems like µCHPs require a robust control action
- Tube-based MPC can be used to guarantee satisfaction of constraints at all times
- Time-varying partitioning can be used to better adapt to the intermittent nature of renewable energy sources
- Stability can be achieved using results from switching systems

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