Robust management and control of smart multi-carrier energy systems

ESR 2.3

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About me

- Born in Buenos Aires, Argentina
- Moved to Pavia, Italy, in 2004
- Studied Electronic Engineering at my Bachelor's degree and Automation Engineering at my Master's degree, both at the University of Pavia
- Master thesis on vehicular traffic modeling at INRIA - Rhône-Alpes, France

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Outline

- Introduction
- Distributed Model Predictive Control
- Robust control applied to power networks
- Hybrid Model Predictive Control

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Introduction (I)

- Changes in the recent years in power grids
- Increase in the share of renewable energy sources
- Technological improvements

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Introduction (II)

- One specific problem: intermittence of the power generated by renewable sources
- A possible solution is to introduce some energy storage systems into the grid, which imply some benefits:
  - Increase flexibility
  - Compensate the highly variable power
  - Maintain the power balance

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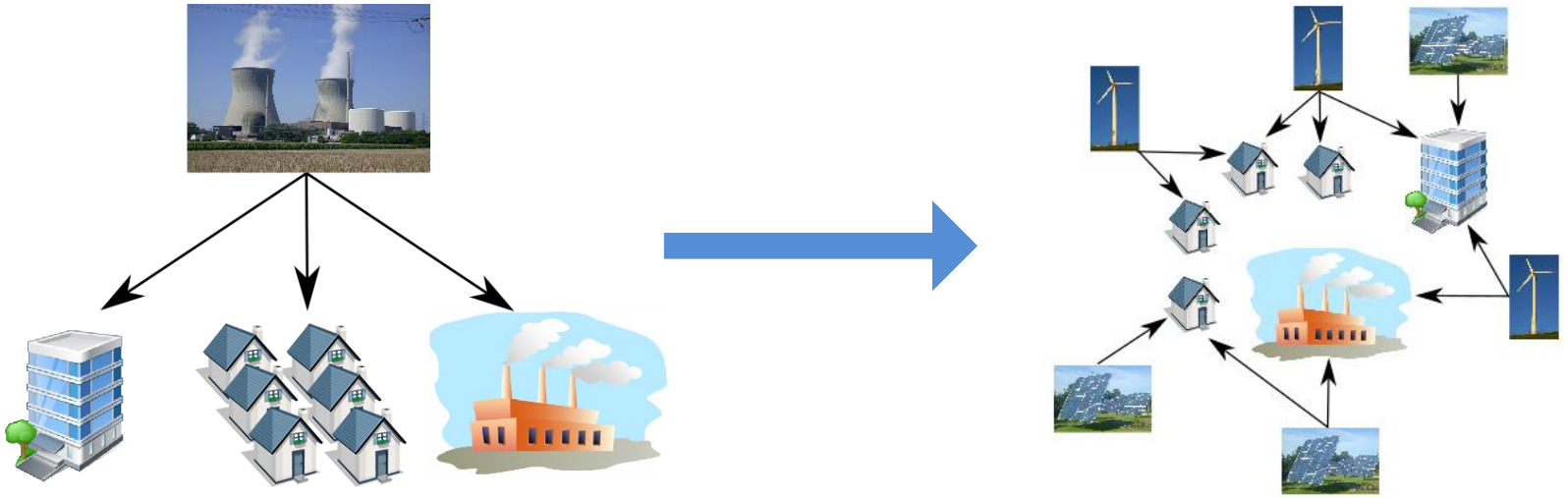
Introduction (III)

- Furthermore, there has been a shift from centralized generation to distributed generation
- Energy storage systems and distributed generation require new control paradigms



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Introduction (IV)

- Among the small-scale electricity generation systems, we will consider micro-Combined Heat and Power (µCHP) plants
- This technology is able to produce both heat and electrical energy by combining electricity and gas networks

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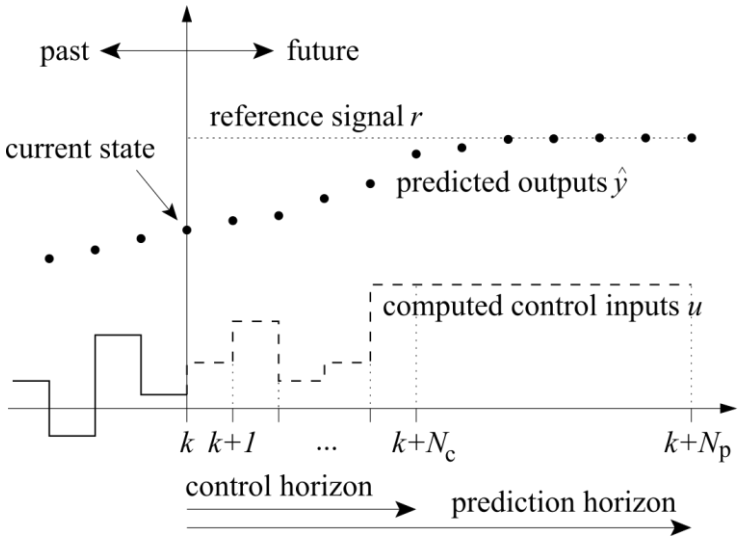
Model Predictive Control (I)

- MPC transforms a control problem into an optimization one
- Explicitly allows to integrate constraints
- At each sampling instant, a constrained, discrete-time optimal control problem is solved, producing an optimal open-loop control sequence
- The first input is applied and at the next sampling instant the procedure is repeated



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Distributed Model Predictive Control (I)

- The topology of power networks is shifting from a centralized to a distributed fashion
- The overall network is geographically dispersed
- Main problems:
  - Access to different entities' data
  - Different legislations
  - Computational burden
  - Physical distances imply delays

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Distributed Model Predictive Control (II)

- For these reasons, a centralized approach is infeasible! A distributed control strategy is needed
- Distributed Model Predictive Control (DMPC) will be studied and applied to this project
- Many strategies are possible:
  - Cooperative/Non-cooperative algorithms
  - Iterative/Non-iterative algorithms

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Distributed Model Predictive Control (III)

- The applied control strategies will also be multi-scale
- Examples of multi-scale modeling:
  - Different models in dynamics (quantum, molecular, continuum mechanics)
  - Power networks
- Improvements:
  - Computational tractability
  - Control applied to a bigger area

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Robust control applied to power networks (I)

- Power networks are subject to various kinds of disturbances
- Convergence of the local control agents to consistent control actions is required
- Some magnitudes have to stay within specific sets, e.g. the voltage

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Robust control applied to power networks (II)

- The adopted control strategy is Robust Model Predictive Control (RMPC)
- Approaches like tube-based MPC, scenario-based MPC or stochastic MPC will be further studied, extended and applied to power networks

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Robust control applied to power networks (III)

- Different approaches:
  - Tube-based MPC: the closed-loop trajectories lie in a “tube” that satisfy the constraints
  - Stochastic MPC: "chance constraints” are considered and the expected value of an objective function is considered
  - Scenario-based MPC: the optimization problem is considered only for a finite number of scenarios; both hard constraints or chance constraints are possible

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Hybrid systems in power networks (I)

- In power systems, the model description may include continuous and discrete variables:
  - Continuous variables include components that obey physical laws linked to differential and algebraic equations, e.g. generators, loads
  - Discrete variables are linked to discrete events/inputs, e.g. connecting/disconnecting transmission lines or loads, on/off switches, saturation effects

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Hybrid systems in power networks (II)

- A hybrid system description is needed
- Many hybrid models have been proposed
- We will focus on Piecewise Affine (PWA) or Mixed Logical Dynamical (MLD) models
- They are equivalent under mild assumptions
- More theoretical results for PWA models

PWA models:

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

MLD models:

$$\begin{aligned} x(k+1) &= Ax(k) + B_1 u(k) + B_2 \delta(k) + B_3 z(k) \\ y(k) &= Cx(k) + D_1 u(k) + D_2 \delta(k) + D_3 z(k) \\ E_1 x(k) &+ E_2 u(k) + E_3 \delta(k) + E_4 z(k) \leq g_5 \end{aligned}$$

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Hybrid systems in power networks (III)

- Hybrid MPC still has many open challenges, especially for what concerns stability and computational issues
- Indeed, when applying MPC on MLD or PWA models, the resulting optimization problem is a mixed integer linear/quadratic one
- New hybrid robust MPC strategies will be developed during this project

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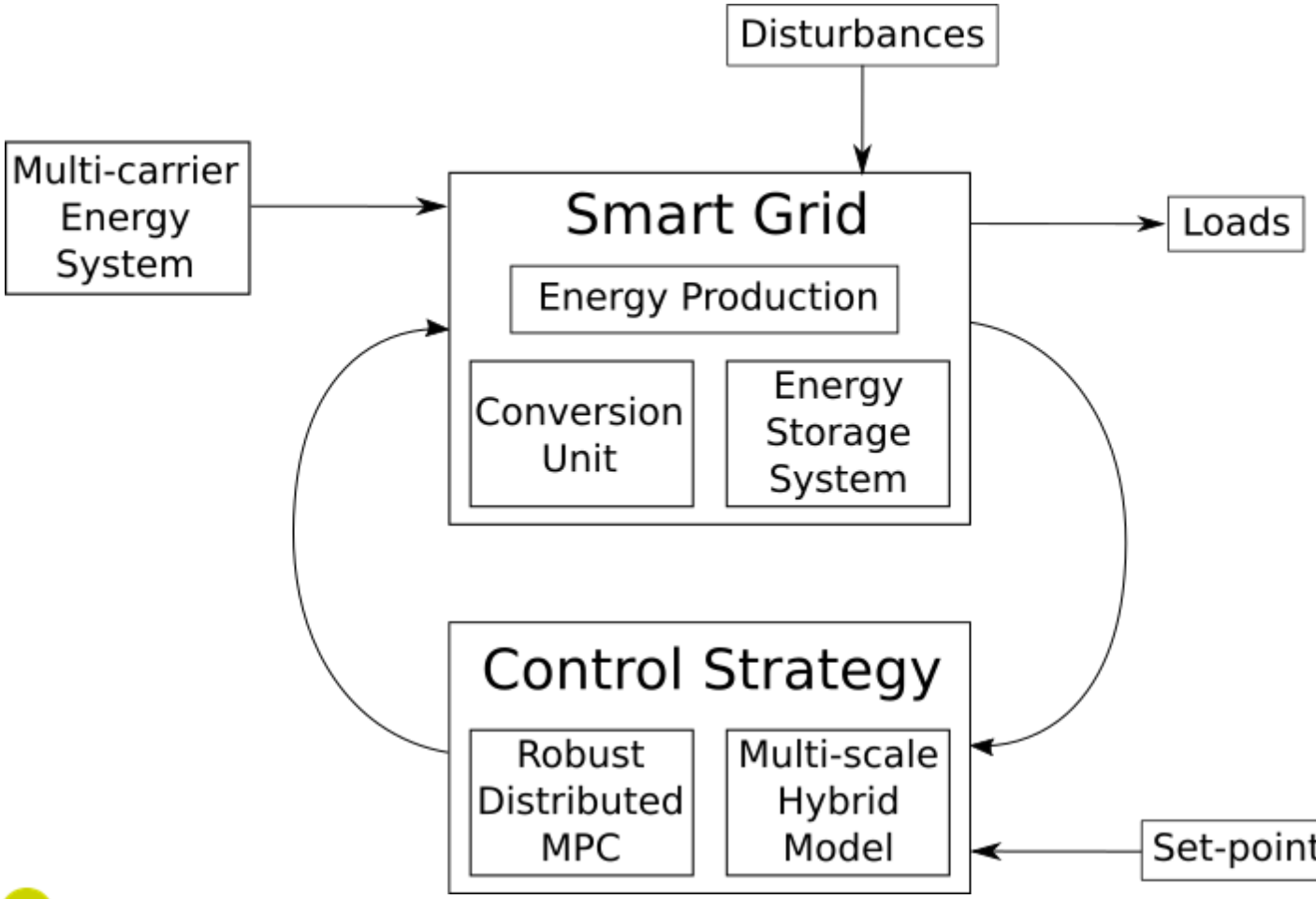
Overall control scheme



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Summary

- Energy storage systems can be included into electrical grids to reduce the intermittence of power provided by renewable sources
- Power networks are subject to disturbances and are geographically widespread, so a robust and distributed control strategy is required
- A hybrid model description will be used since power networks include both discrete and continuous variables

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Future work and plan

- Continue the literature survey and reading related to the previously mentioned topics
- Further analyze which are the already implemented solutions that can be applied to or extended in this project

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