Microgrids

Planning the operations of a microgrid

ELEN0445-1

LIÈGE université
Sciences Appliquées

Bertrand Cornélusse

Previous lecture

Content of this lecture

We take the role of the operator of the microgrid, who wants to optimize the way the energy is produced and used within the microgrid, and to optimize the interaction with the public grid (simple interaction for now).

We make the assumptions that the microgrid is **single-user**, and we also avoid the question of the “fast dynamics” of the components of the microgrid.

We stay at an abstract level. Components models will appear along the courses. Solution methods as well.

LIÈGE université
Sciences Appliquées

Introduction

Reminder: control levels

Level	Function	Examples
1	Device level control	BSS control, reactive control
2	Local area control	Frequency regulation, fast load shedding
3	Supervisory control	Forecasting, operational planning
4	Public Grid interaction	Ancillary services, energy markets

We will be mainly focused on levels 3 and 4, and a bit about level 2

LIÈGE université
Sciences Appliquées

Level 1: device level control

- Generator control
- PV panel + MPPT + inverter
- A great variety of interfaces for loads.
- Battery storage: battery management system (BMS)
- Battery inverter/charger
- Islanding detection: Automatic transfer switch

Level 2: local area control

- Fast automatic load/generation control to ensure constant balance and achieve stable operating points:
    - regulate active and reactive power in AC microgrids
    - achieving stable operation may be a challenging problem because of:
        - dynamic response mismatches between loads and sources,
        - generated power capacity close to nominal load,
        - reduced added energy storage in generator rotors (if any).
- (Unplanned) disconnection management
- Resynchronization

LIÈGE université
Sciences Appliquées

Level 3: supervisory control

- Generation and load dispatch
- Economic optimization
- Spinning reserve
- Forecasting
- Data visualization and data management

Level 4: public grid interaction

- Distribution Management System interaction
- Electricity markets
- Ancillary services markets

LIÈGE université
Sciences Appliquées

Note: centralized vs decentralized control

- Centralized controller: controls power flow from each source and monitors overall system condition
- Fully decentralized – also called autonomous – control strategy :
  - prevent potential system outages, as may happen if the controller fails in a centralized scheme.
  - make decisions without communicating with other system components by estimating system conditions from locally measured variables
  - More complex to implement than centralized => more risk of "bug"
- Some decentralized control schemes require a communication link among their distributed controllers in order to coordinate their actions.
  - reduces control complexity, but decreases reliability

In this lecture: level 3 & centralized control

The operation problem

Definition of “operation”

In our context, operation encompasses all the decisions that are taken to configure the microgrid components along their lifetime.

We consider only active power exchanges.

Example: the sun is shining, which amount of power should I send to the battery? Is it better to send it back to the grid? Should I rather start a consumption process? Or maybe switch off my PV panels?

LIÈGE université
Sciences Appliquées

Decision criteria

- Balance demand and consumption
- Maximize self-consumption
- Minimize cost
- Do not “overload” components
- etc.

When are operation decisions taken?

- It can be in real time: **corrective** decisions
- Or in anticipation: **preventive** decisions
- Why should we anticipate? because of time coupling constraints:
  - The typical periodicity of renewable generation devices and consumption is a day
  - Human activity has weekly and seasonal periodicity

In this course, we focus on preventive decisions, and the problem of determining preventive decisions is called **operational planning**

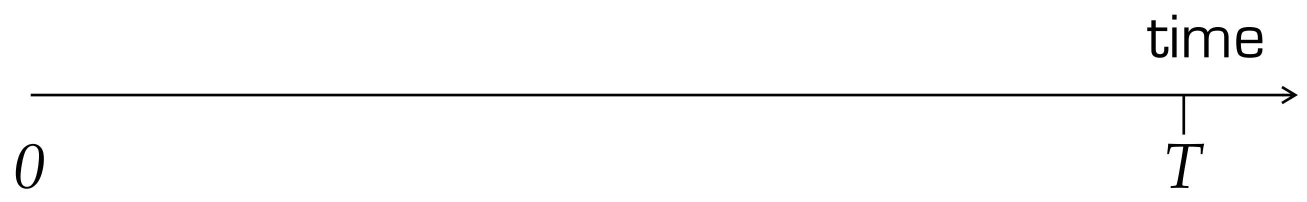
LIÈGE université
Sciences Appliquées

Operational planning decision horizon T

We cannot take preventive operation decisions too much in advance:

- too high uncertainty on the evolution of the state of the microgrid and its environment
- anticipating a bit on the sequel, the problem we will have to solve may be intractable

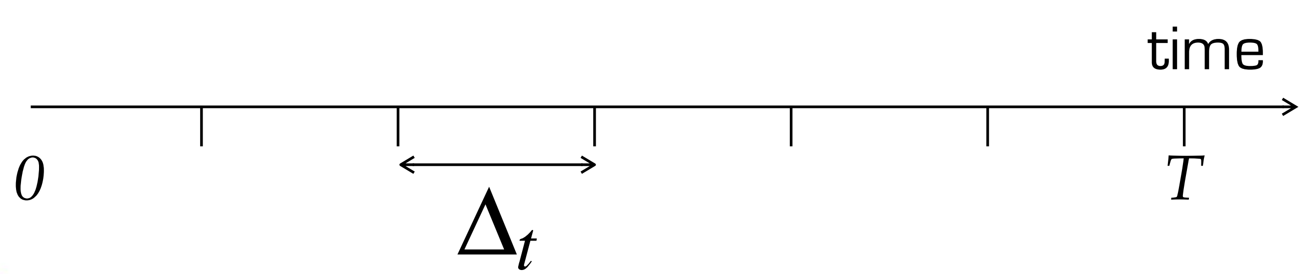
We thus consider operating the system over one day to approx. one week. This can be more or less, depending on the particular situation of the microgrid (type of storage, type of business activity, etc.)



LIÈGE université
Sciences Appliquées

Operational planning decision duration Δ_t

- For computational reasons, we discretize the decisions in time
- Depending on the decision horizon, we may consider periods of 1 to 15 minutes where decisions are assumed constant
    - Example: constant charge power for a battery
    - Determining good decisions may become intractable if we have too many decisions in the decision horizon
    - Forecasts may anyway not be meaningful with a too high temporal resolution
    - This is coherent with market period duration



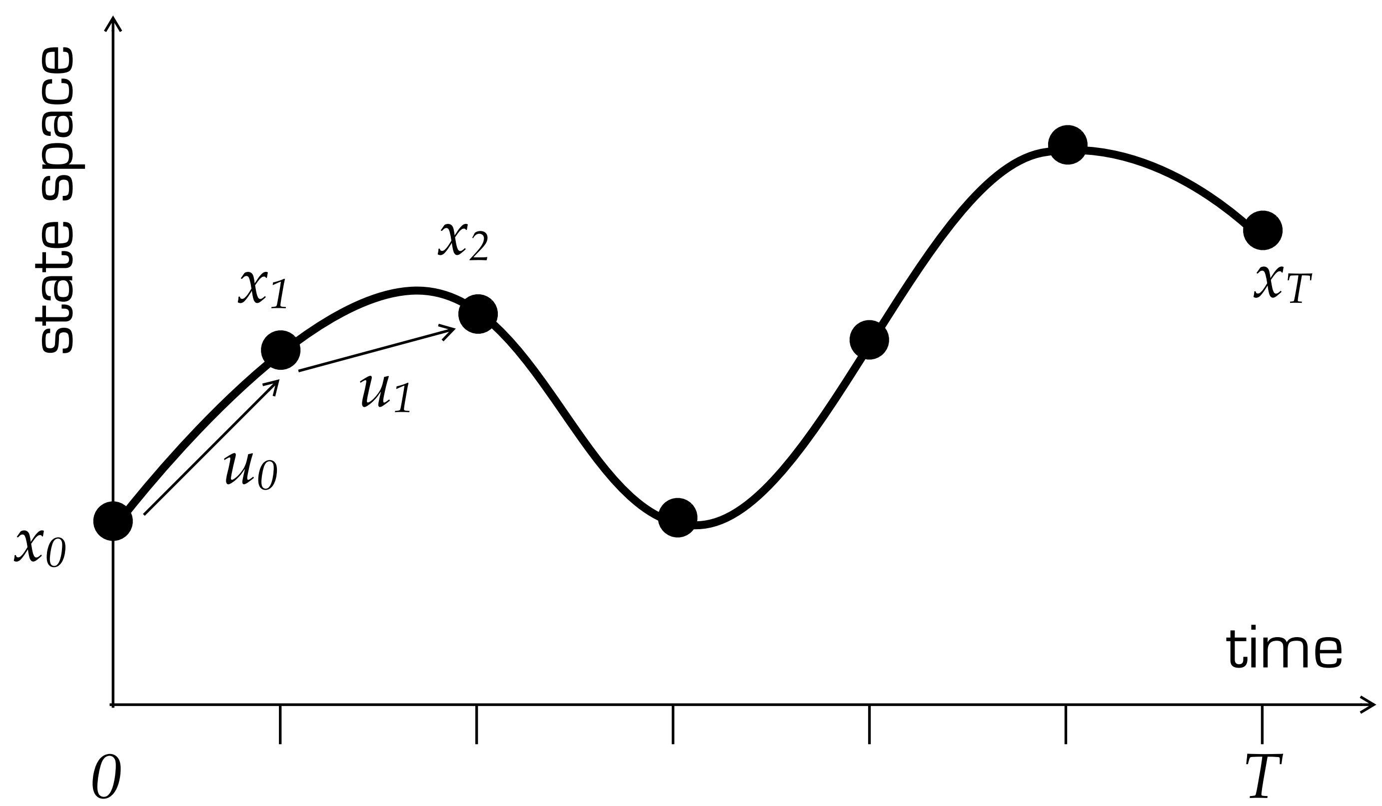
LIÈGE université
Sciences Appliquées

Operation as a sequential decision-making problem

We have a discrete time system represented by a **state** x_t

$x = (x_0, x_1, \ldots, x_T)$ represents the **state evolution** of the system

$u = (u_1, \ldots, u_T)$ is a **sequence of control actions** (decisions)



Given a criterion, we can compute an open-loop sequence of actions u^* to drive the system

We estimate demand, generation, availability of system components, etc. and then solve

minimize cost of u

subject to 1. balance generation and demand

2. dynamics: $x_t, u_t \rightarrow x_{t+1}$

3. action sequence and state evolution restrictions

4. initial state x_0

LIÈGE université
Sciences Appliquées

Uncertainty

- Microgrid operation is impacted by factors that are not easily predictable
  - the weather, which impacts renewable generation and consumption
  - outages of steerable generation or storage
- Some events may thus turn the open-loop sequence u^* suboptimal or infeasible
- This can be mitigated by the a receding horizon approach

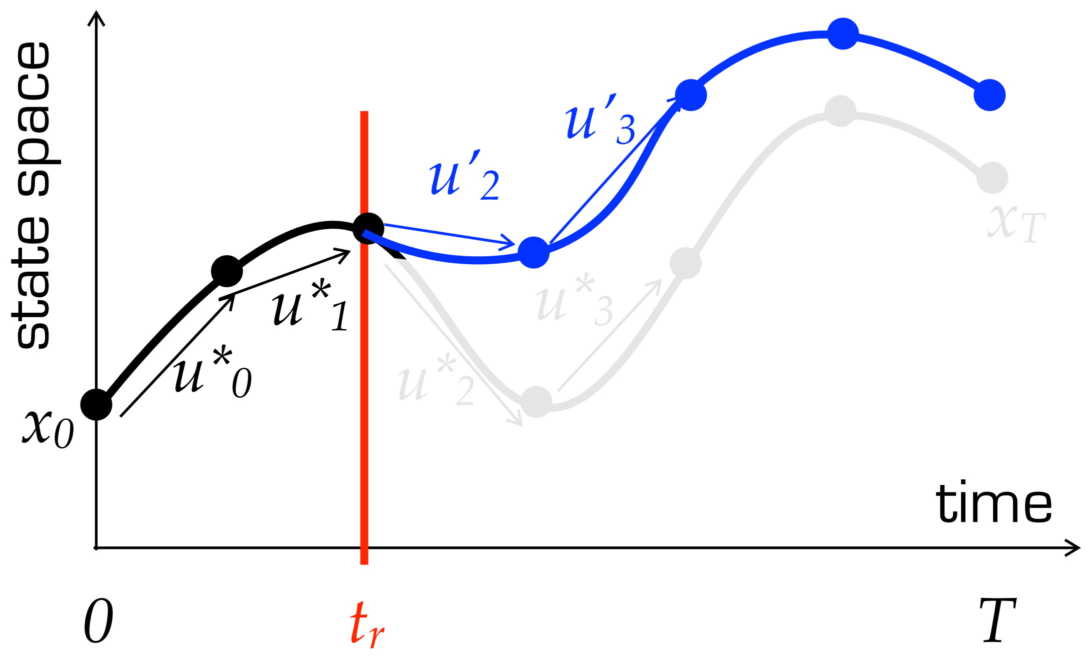
LIÈGE université Sciences Appliquées

Receding horizon approach

Example: demand variation or restriction on x or u are observed at time t_r

Receding horizon approach: update the sequence of control actions

1. Re-estimate the parameters (demand, availabilities)
2. Re-solve the open-loop formulation



So, finally, when are decisions applied?

- Every time we solve the optimization problem above, we “freeze” some decisions:
  - not only the decisions for the decisions occurring before the next re-optimization
  - but also decisions that have a high impact on the interactions within the microgrid or with the public grid, and that span the whole decision horizon
- Hence, depending on the moment of the day, some decisions may or may not be re-optimized

LIÈGE université
Sciences Appliquées

Real-time dispatch

Operational planning decisions thus have a relatively long duration with respect to time constants of generation and consumption devices, and the instantaneous state of the microgrid can thus differ significantly from the average state over a control period.

Corrective control, closer to real-time, should thus compensate for the errors inherent to this time discretization (among other goals)

See our paper submitted to PSCC: Coordination of operational planning and real-time optimization in microgrids, Jonathan Dumas, Selmane Dakir, Bertrand Cornélusse, ULiège.

Decisions, in practice

- Storage devices: Set point for charging / discharging
- Steerable generation
- Non-steerable renewable generation: curtailment
- Load shedding
- Load flexibility
- Power electronics

LIÈGE université
Sciences Appliquées

Remark: decisions we do **not** consider

We do not consider **investment decisions**

- This is the topic of another lecture on sizing

We do not consider **maintenance decisions**

- Maintenance cost can be accounted for in sizing
- In operation, scheduled maintenance are just extra constraints or data updates (e.g. PV is out)
- If necessary, maintenance scheduling could be stated as an extension of operational planning

LIÈGE université
Sciences Appliquées

Constraints, in practice

- Capacity of devices
- Inverters constraints
- Demand-side management
- Generation management
- Regularization:
  - avoid changing decisions if unnecessary/undesirable

Optimization objectives

The invoice

- (In Belgium), the invoice of a user connected to a distribution network is composed of:
  - A part proportional to the energy consumed
  - A part proportional to the capacity of the connection, i.e. the amount of power the user can withdraw from the distribution grid
  - A part proportional to the cos phi
  - Taxes and other contributions
- This varies a lot as a function of the type of connection (i.e. of the voltage level and overall consumption)

Minimize the energy purchase cost

- The microgrid is subject to a dynamic price signal. At every time t, it can buy electricity at a price p_t
- Then, it will try to
  - consume & charge the storage devices during low price periods
  - produce & discharge the storage devices during high price periods
- Note: for now, we consider that
  - the microgrid cannot influence the price
  - there is no imbalance penalty
  - on the other hand, we will not always assume the price is known in advance.

LIÈGE université
Sciences Appliquées

Maximize the electricity sale price

- In a similar way, the price at which a retailer will buy back the energy can be described as a vector of prices, one per each hour of the day.
- The sale price is obviously always lower than the purchase price:
  - because the retailer takes a margin
  - because the purchase price includes the grid fees, taxes, etc.
- There may be an injection fee depending on the DSO

Minimize the peak

- A grid user pays a monthly fee function of his peak quarter-hourly consumption over the last 12 months.

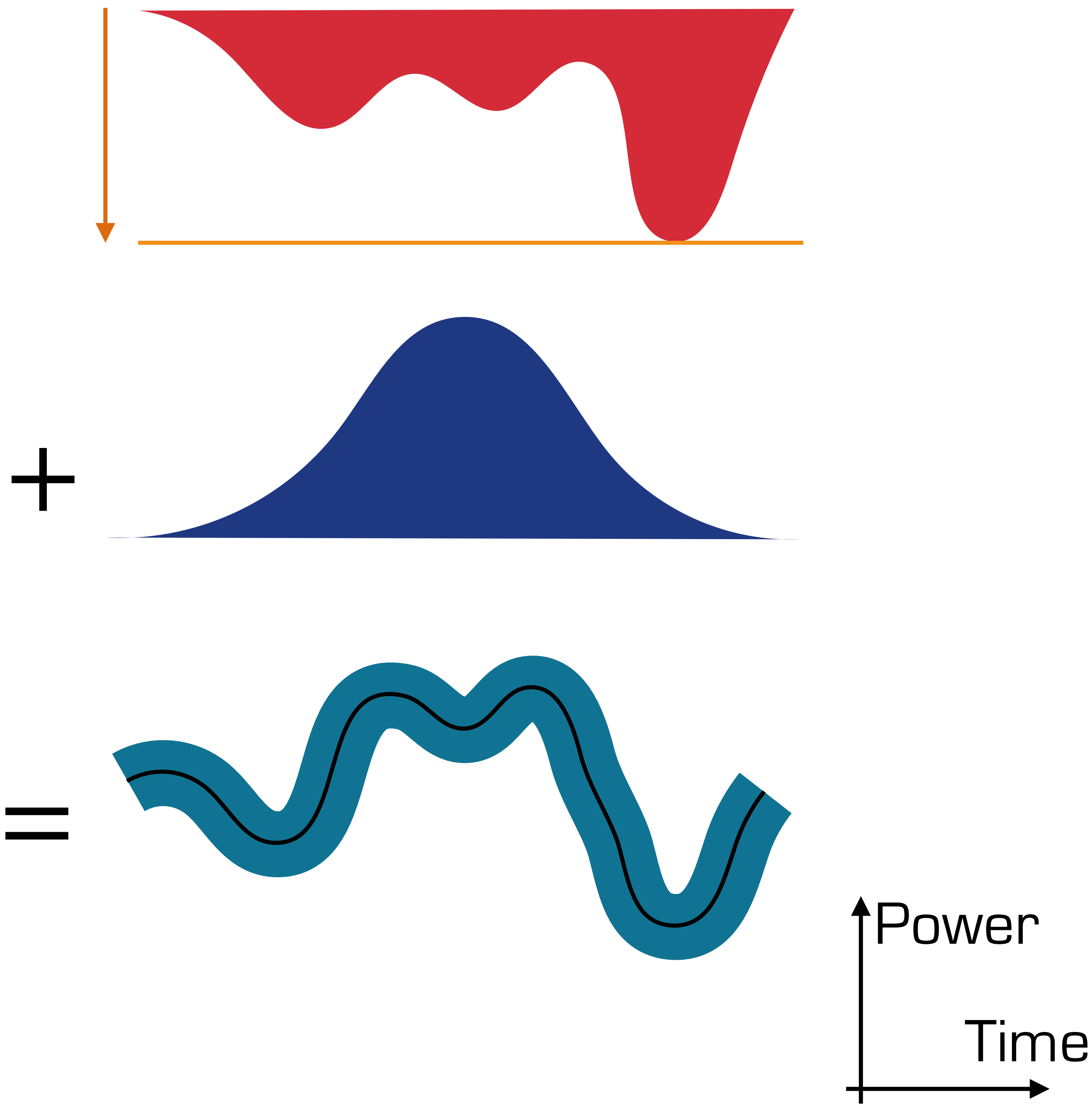
- Remark: this introduces a huge time coupling in the operation problem.

Maximize the reserve

- Keeping some reserve, i.e. some flexibility to quickly change the net position (total generation - total consumption) of the microgrid is important for two reasons:
  - It can be used to sell ancillary services to the grid
  - It can be used to stabilize the microgrid, in islanded mode.

In summary

- Costs
  - Energy consumption
  - Peak penalty
- Revenues
  - Energy production
  - Ancillary services



LIÈGE université
Sciences Appliquées

Minimize components' degradation

- Generation devices, such as internal combustion machines, have a lifetime which varies significantly with the way they are used.
- Batteries suffer of the same problem. However, this depends a lot with the type of battery technology.

(Islanded mode) Ensure security of supply

In case of public grid service interruption, the objective of the microgrid may suddenly switch to simply keeping the critical loads powered as long as possible.

All these objectives are (most of the time) conflictual

- For instance:
  - Minimizing the peak can lead to opportunity losses with respect to low energy purchase prices
  - Maintaining a level of reserve can lead to peak increases and also to some opportunity losses with respect to energy purchase/sale price
  - Minimizing component degradation should be put in perspective with the opportunity losses it generates
- Hence we must **reach a tradeoff between these objectives**

Hedging uncertainty

Improving robustness

In addition to the receding approach mentioned above, explicitly integrating uncertainty in the optimization problems can improve the robustness of the controller

(Two-stage) stochastic Programming to account explicitly for uncertainty

Evaluate the probability distribution of exogenous variables, p

Determine a **first stage** sequence u^* and a **recourse strategy** $\pi_{tr}{}^*(p)$ that

minimize **Expectation**$_p$ {cost of $(u + \pi_{tr}(p))$}

subject to 1. dynamics: $x_t, (u_t + \pi_{tr}) \rightarrow x_{t+1}$

2. action sequence and state evolution restrictions

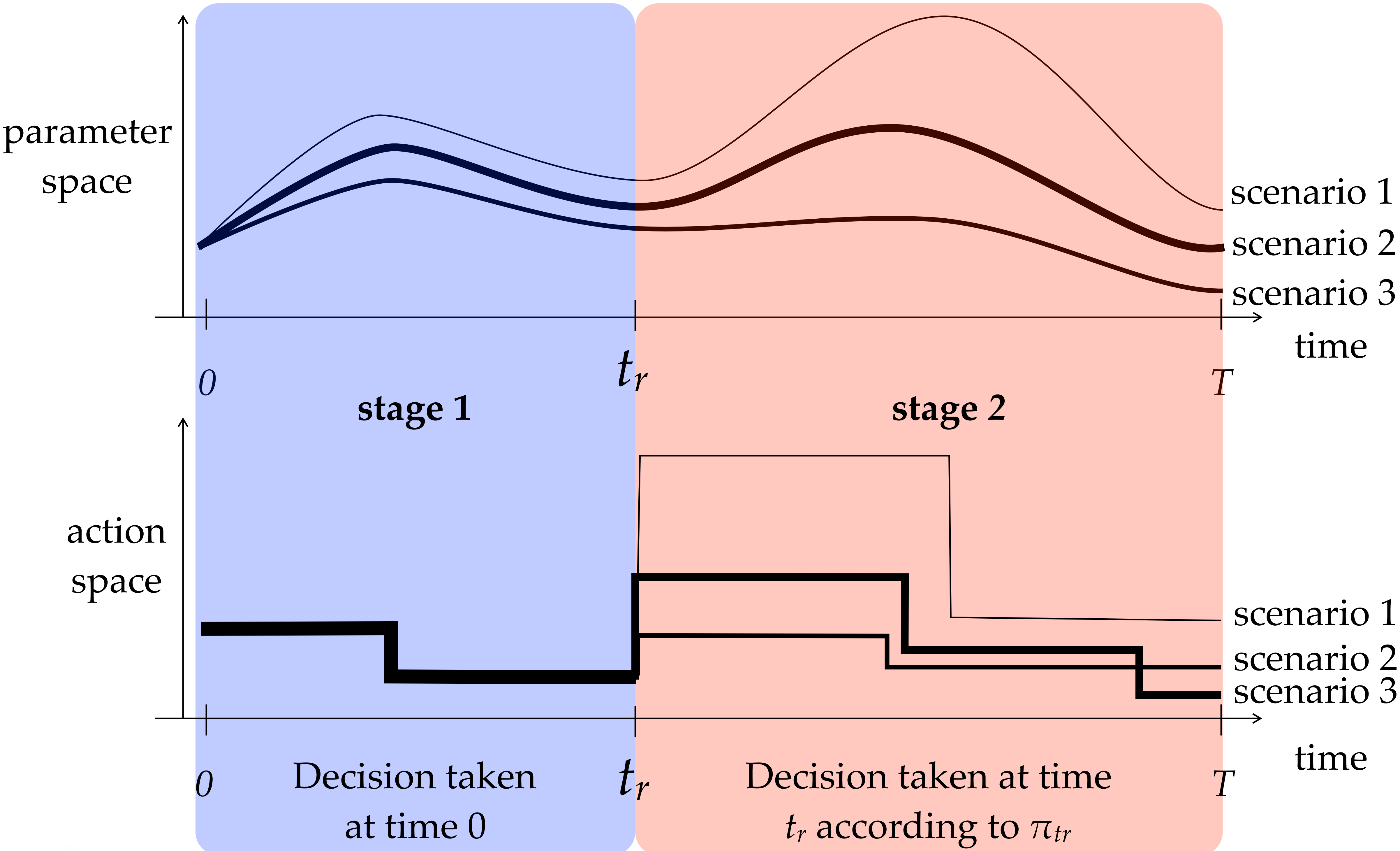
3. initial state x_0

4. Non-anticipativity (uniqueness of u)

This formulation can be extended to multistage

LIÈGE université
Sciences Appliquées

In practice: discretize the (uncertain) parameter space in scenarios and assign them weights reflecting their probabilities



LIÈGE université Sciences Appliquées

Two-stage scenario based stochastic programming

Large optimization problem:

- number of variables multiplied by number of scenarios
- non-anticipativity constraints create a coupling between scenarios

But **potentially better than deterministic** receding horizon control if scenarios are well chosen

LIÈGE université
Sciences Appliquées