Power sharing in DC microgids

DC microgrid modeling

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Goal of this module

- Optimal power sharing in DC microgrids
  - Power sharing usually implemented through **decentralized** droop control
  - Optimal => add an communication and optimization layer
    - Either fully **centralized**
    - Or **distributed**

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Module organization

1. DC microgrid modelling: concepts and tools
   - Theory and practice
2. Optimization tools, OPF problem example
   - Theory and practice
3. Presentation of related articles
   - You teach us, we discuss
4. Little demo of a working system

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This lecture is not comprehensive, this is to give you hints to understand the scientific articles

What will we learn in this lecture

- We will learn to model a DC microgrid
- We will see how power sharing is achieved through primary control
- In the next lectures, we will learn how optimization techniques can be used to improve primary control by adding a supervisory control layer

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Introduction

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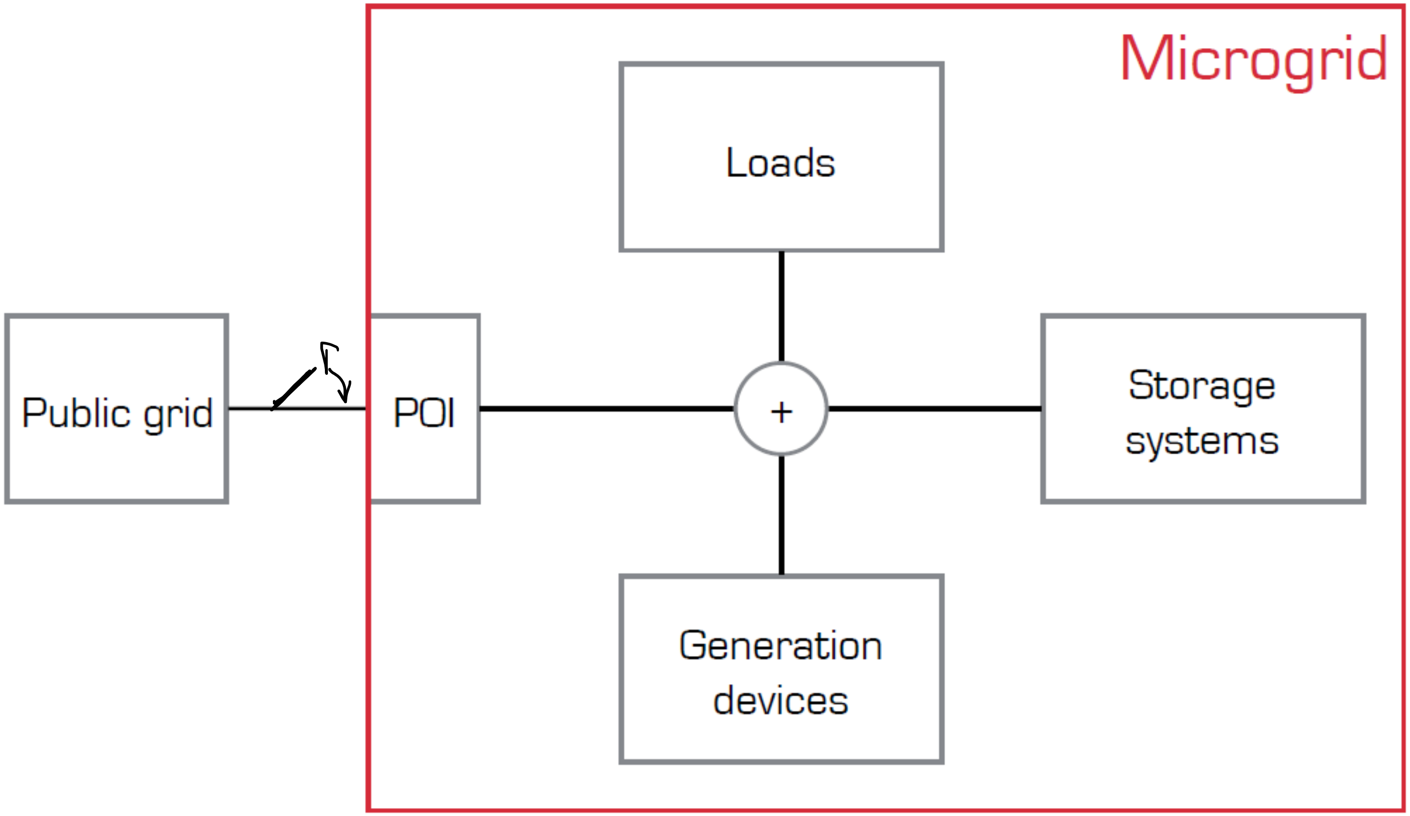
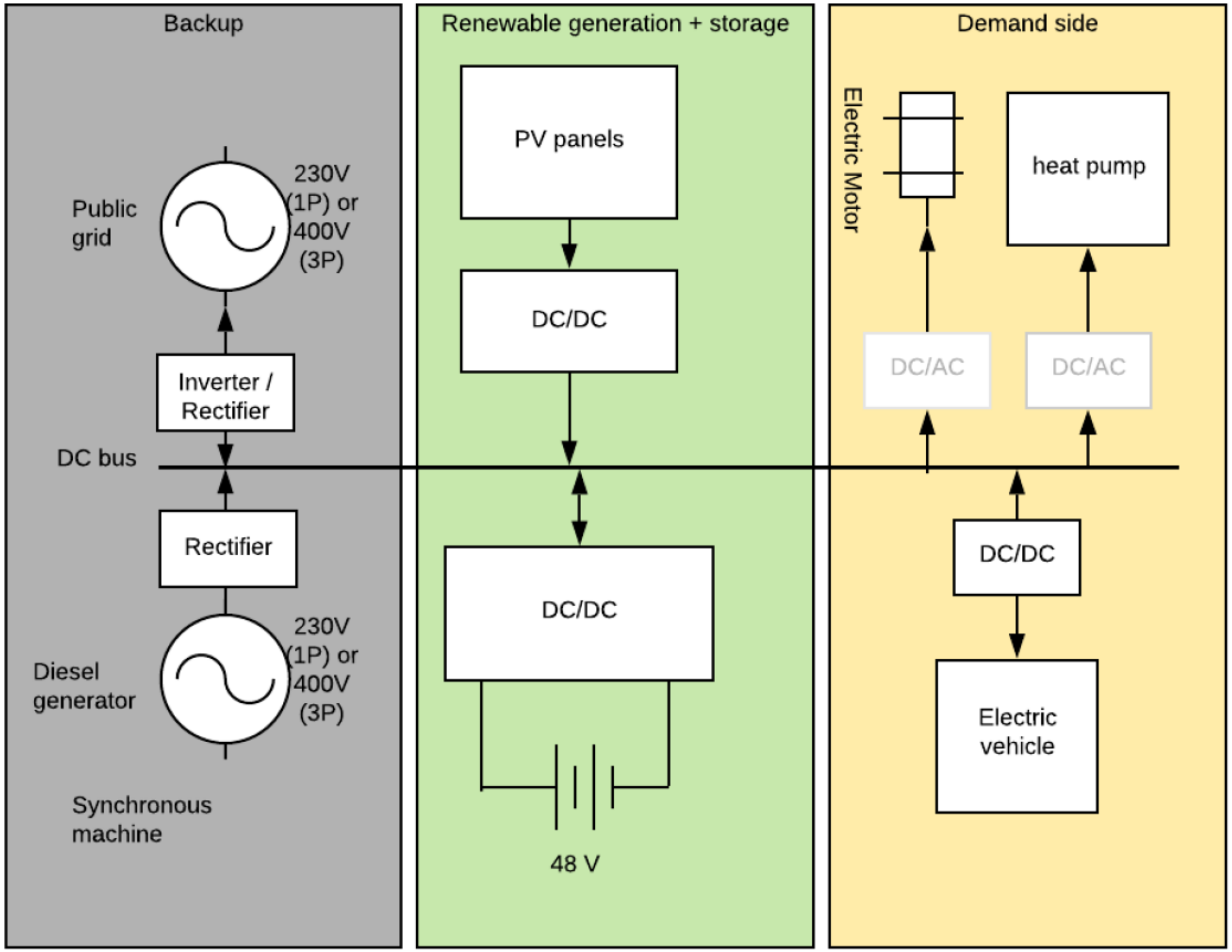
What is a microgrid



What is a DC microgrid



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Why DC microgrids?

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- DC systems enable a simpler integration of distributed energy resources (DERs*), since many of them are either DC by nature or require a DC interface anyway
- Fewer conversion losses
- Parallel distributed architectures are simpler to realize in DC:
  - unnecessary frequency control and phase synchronization
- Frequency control is not necessary in DC systems
  - unwanted harmonic content may by easier to filter too

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- Autonomous distributed control harder in DC than in AC because no information carried through the signal (frequency, phase)
- There may be stability issues due to DC-DC conversion stages
- It is more difficult to clear fault currents: the signal "does not go through zero". Hence protections are more costly and harder to set up.

Control levels

- A microgrid controller is some software sensing the microgrid (currents, voltages, frequency, etc.) and taking control actions so as to operate safely, reliably and optimally the microgrid.
- In practice, a microgrid is run by multiple controllers, because there are several levels of control, which differ by their spatial and temporal scopes.
- Next to technological advances in production, consumption and storage, controllers are key elements for advanced microgrids.

Level	Function	Examples
1	Device level control	BSS control, reactive control, MPPT
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 focus mainly on levels 1 and 2

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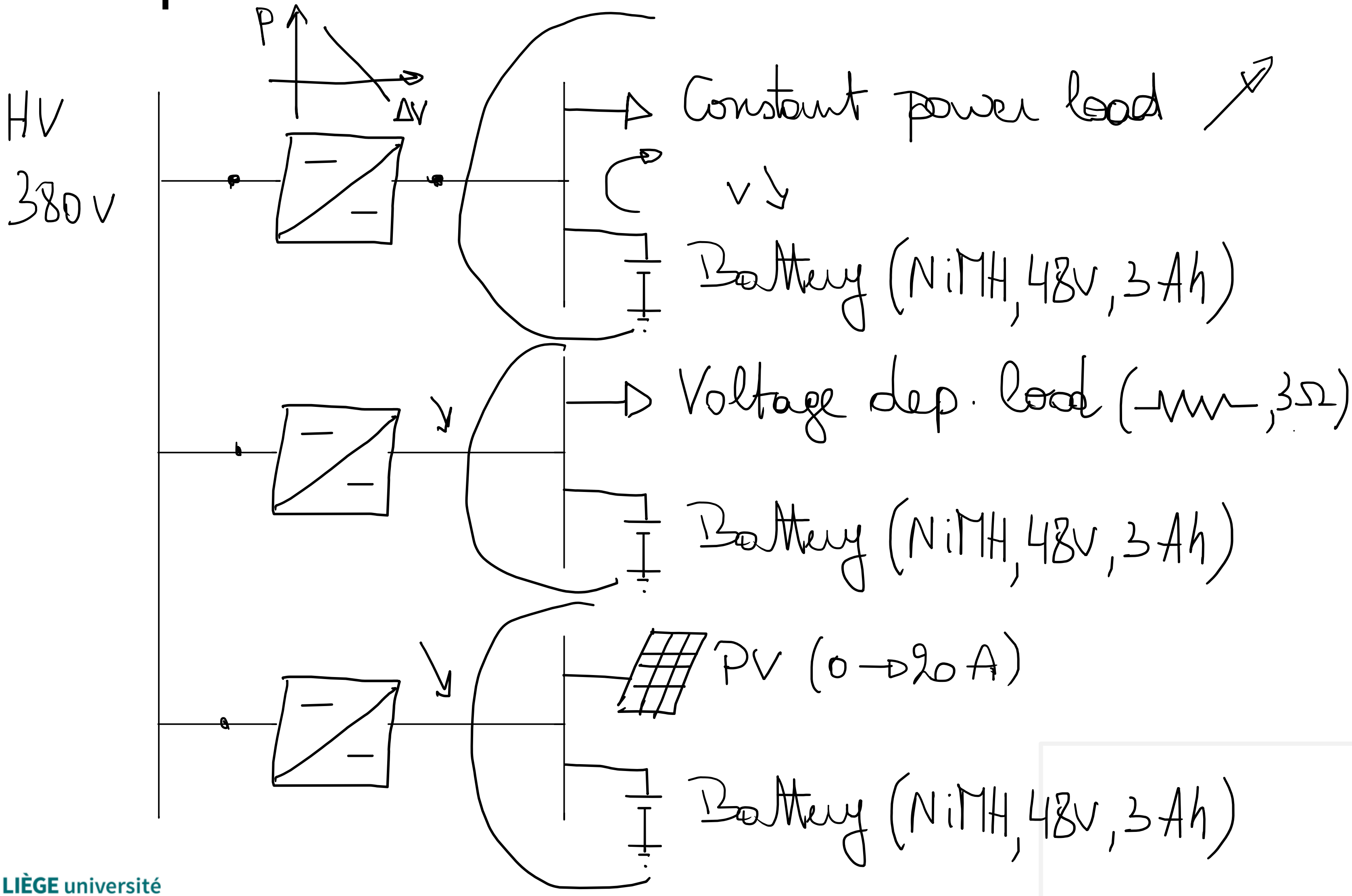
Example DC network



Static model

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Static model

- This is similar to a power flow model in an AC grid
- The DC grid is modelled as a graph (N, E) where
  - $N = \{0, \ldots, n\}$ is the set of nodes,
  - E is the set of edges.
- Let's denote $\{k, l\} \in E$ as $k \sim l$

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Electrical quantities

- We are interested in knowing
  - currents and powers in all the branches: i_{kl} and p_{kl}
  - currents and powers absorbed at buses: i_k and p_k
  - voltages at all the nodes: v_k
- Measurements or variables? some of these quantities are measured, some are not. This is really case dependent.
  - In DC grids, it is easy to measure currents and voltages, or to determine currents from power and voltage measurements

Fundamental laws relate these quantities

- Ohm (Y_{kl} is the conductance of the branch):

$$i_{kl} = Y_{kl}(v_k - v_l) \text{ for } \{k, l\} \in E$$

- Kirchhoff Current Law:

$$i_k = \sum_{l:k\sim l} i_{kl} \text{ for } k \in N$$

- Power withdrawn at buses:

$$p_k = v_k i_k \text{ for } k \in N$$

DC-DC converter model

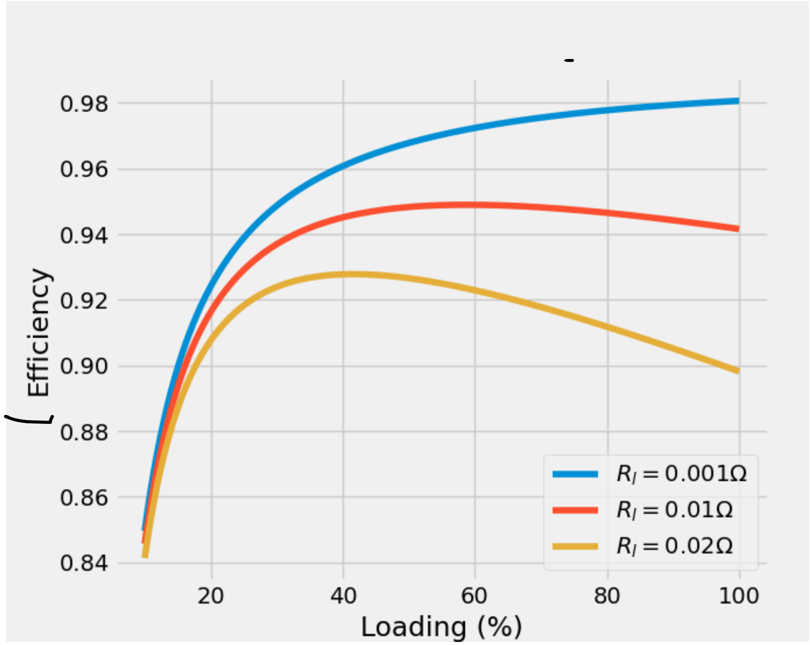
Let's simply use power conservation

$$p_{in} = p_{out} -$$

Losses in a series resistance R_l

« Standby losses » can be added but requires

1. Binary variable
2. Determining the direction of the flow (in case the converter is biderectional)



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Solving this set of equations gives you the electrical state of the system

Depending on the type of information available and the behavior of components, the system is linear or not :

- Only power and some voltage measurements:
  - $p_k = v_k \sum_{l:k\sim l} Y_{kl}(v_k - v_l)$ for $k \in N$
  - Non-linear problem
- A sufficient number of current and voltage measurements: linear problem

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Dynamic model

Which type of dynamic model?

- A full dynamical model requires modeling the state evolution as a set of non-linear differential equations, taking into account converters switching etc. -> Typhoon HIL type model

- In our context of optimal power sharing, the goal is to devise a discrete time model to predict what's gonna be the **state** of the system in $\Delta t \in [0.1, 10]$ seconds given its current state and some control actions that we can take

  - assuming average models for converters

  - assuming transients are much faster than Δt

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At this time scale, batteries state of charges are the main state variables

Real battery model:

- voltage source function of the state of charge (and temperature, current, etc. *)
- Internal resistance

Battery State of Charge evolves with the number of *Ah* that come in or out:

$$s_{t+\Delta t} = S_t + i_t \Delta t \text{ [Ah]}$$

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* See for instance https://nl.mathworks.com/help/physmod/sps/powersys/ref/battery.html

Droop control

- Keep the system running when there are variations of load or generation
- Share the power (or the current) between the sources
- Principle of power sharing similar to primary frequency control in AC grids (see https://bcornelusse.github.io/ELEC0447-analysis-power-systems/?p=lecture9.md#7)
- But here we have only voltages and power / current

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Pros and cons of primary control

- Primary control
  - is decentralized, hence robust
  - is fast, just requires local measurement and a proportional controller
- But
  - It is suboptimal w.r.t. some criteria
  - Parameters must be adapted depending on the topology of the grid

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