EPFL

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Conception et défis opérationnels des systèmes électriques à haute pénétration de PV

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DESL

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Main challenges for power grids hosting large shares of PV

- Grid-reinforcement to increase the PV hosting capacity of power distribution networks
  - Lines, transformers reinforcement and grid extension (planning)
  - Use of local energy storage systems and demand response along with adequate control layers (operational)
- Availability and control of the primary, secondary and tertiary reserve
  - Quantification of time-space PV stochasticity (forecasting)
  - Use of energy storage systems vs conventional power plants
  - Development of new reserves scheduling and control schemes
- Inter-seasons energy storage
  - Oversizing of PV plants + curtailment
  - PV fuels (hydrogen, syngas + CO_2 capture)
  - Different use of hydro accumulation due to climate changes

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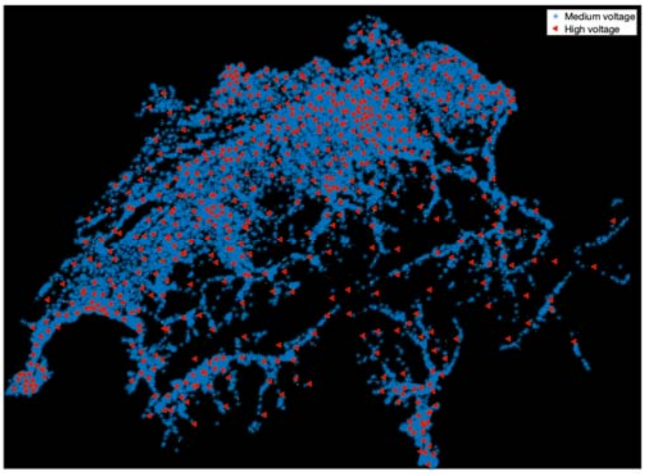
Planning of the power distribution grid

Identification of the most likely power distribution grid model for the whole Switzerland (activity carried out within the context of the SCCER JASM).



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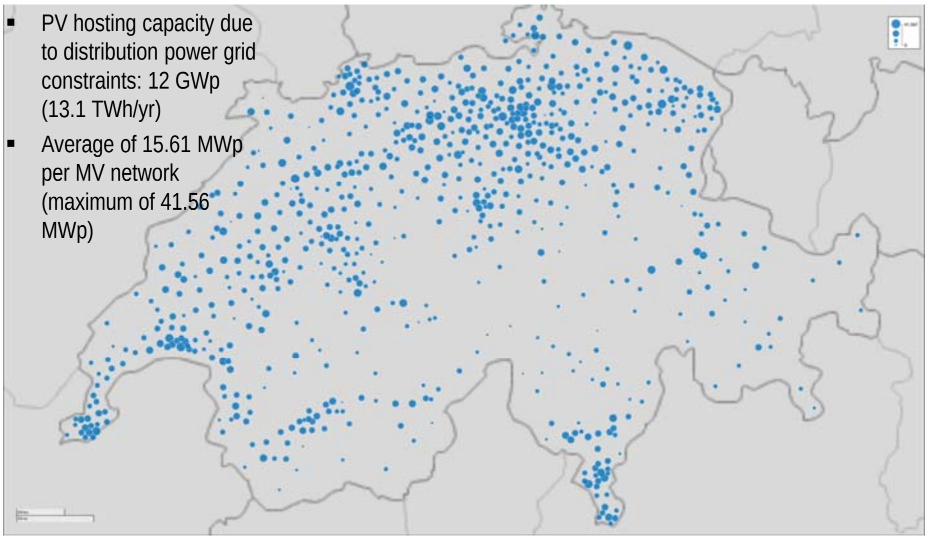
Planning of the power distribution grid

Quantification of the PV hosting capacity due to power distribution grids constraints

- PV hosting capacity due to distribution power grid constraints: 12 GWp (13.1 TWh/yr)
- Average of 15.61 MWp per MV network (maximum of 41.56 MWp)



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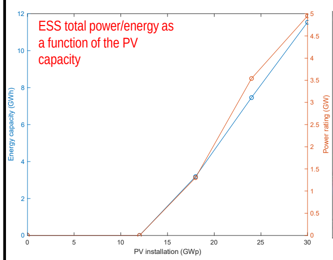
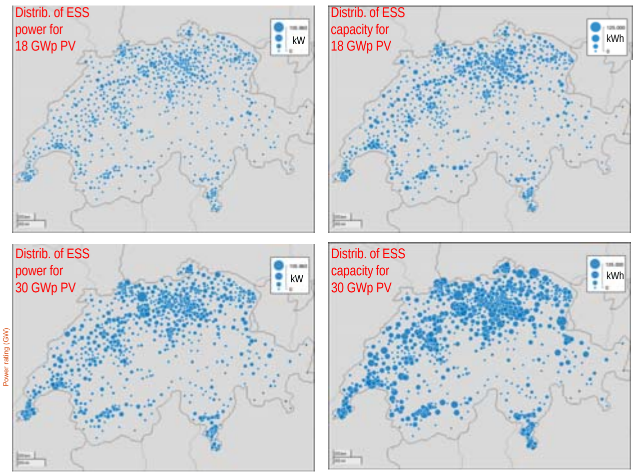
Planning of the power distribution grid

Quantification of the (local) energy storage power/energy to increase the PV hosting capacity of the Swiss power distribution grids

PV scenario (GWp)	ESS power (GW)	ESS cap. (GWh)
12 (base case)	0	0
18 (150% of base case)	1.30	3.18
24 (200% of base case)	3.54	7.46
30 (250% of base case)	4.95	11.54





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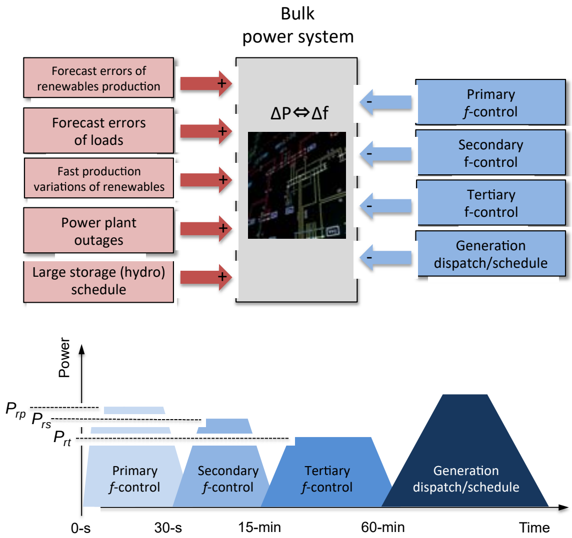
The issue of the reserve scheduling



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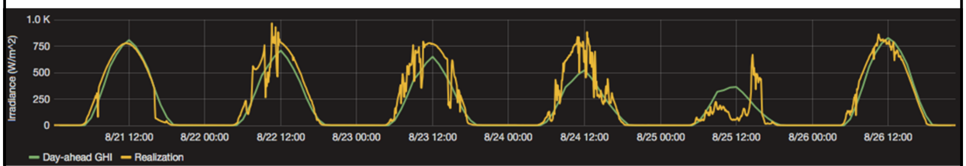
Importance of PV uncertainties



Example of deviation from predicted (24h-ahead) and actual Global Horizontal Irradiance (GHI) @ EPFL, August 21-26, 2018.

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The issue of the reserve scheduling

Fundamental observation

The increasing connection of stochastic renewables and the upcoming penetration of distributed storage and demand-response mechanisms, are expected to affect significantly this control philosophy.

This will require, in general, an increase of the primary/secondary reserves in order to keep safe margins and maintain the grid vulnerability at acceptable levels.

Dispatching of power distribution systems: why ?

- Achieving **dispatched-by-design operation** of traditionally stochastic prosumption allows **reducing grid reserve requirements**.
- The **dispatch plan** is built to satisfy a **local objective**, such as **peak shaving**, **load levelling** or **minimization of the cost of imported electricity**.

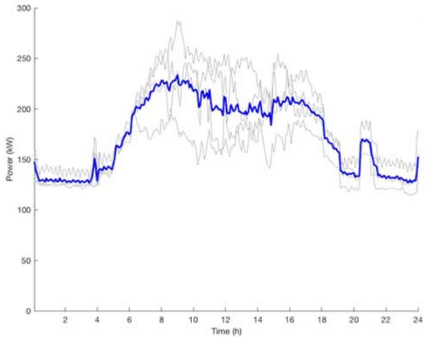
Day-ahead objective and problem

1. **Objective**: control an energy storage asset (for instance, a battery energy storage system - BESS) in order to dispatch the operation of a MV network hosting <u>non-controllable stochastic generation and demand</u>.

2. **Stochastic aspects**: determine a set of possible consumption/generation scenarios for the stochastic resources (prosumption).

3. **Problem**: maximize the exploitation of the BESS capacity subject to energy and power constraints and to the uncertainty due to the stochastic nature of the resources (PV generation, loads).

Feeder forecasted prosumption
Prosumption scenarios



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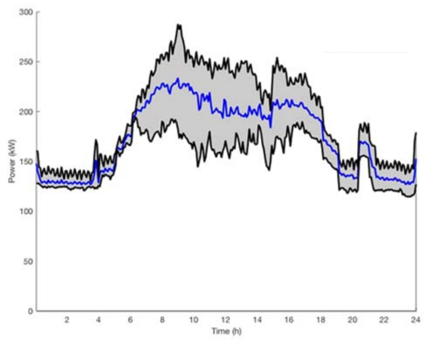
Feeder forecasted presumption
$L^{\uparrow}$ and $L^{\downarrow}$min-max scenarios



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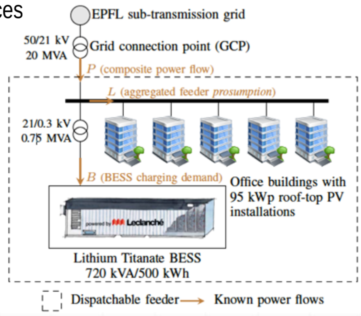
Experimental evidences

Dispatch of heterogeneous EPFL campus aggregated resources



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Provision of multiple ancillary services

Single service applications lead to poor exploitation of battery's power and energy ratings.

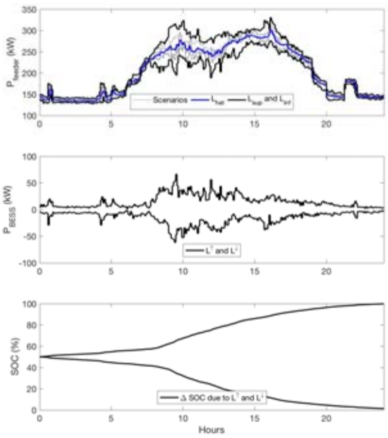

Fig.: Dispatch planning with **higher** uncertainty.

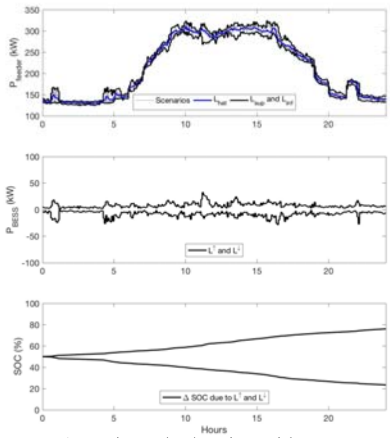

Fig.: Dispatch planning with **lower** uncertainty.

Residual power/energy capacity can be used to provide multiple ancillary services simultaneously.

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Provision of multiple ancillary services

Dispatch + primary frequency regulation (PFR)

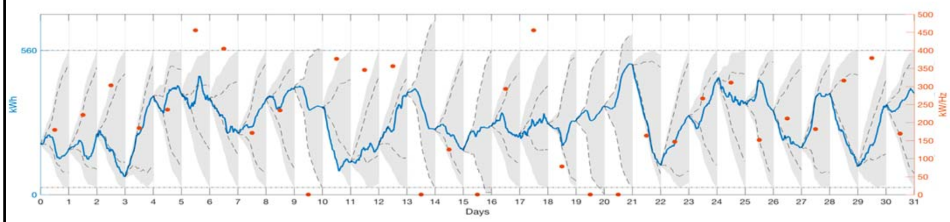

Fig.: Battery's state of energy (SOE): realization (**thick** blue line), worse cases for dispatch (dashed black line), worse cases for dispatch + PFR (shaded grey), and allocated drop coefficient (orange dots).

Link to results

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Impact on the bulk power system reserve

Working HP: BESSs are deployed to achieve dispatch-by-design operation of distribution systems.

Key Questions

- What is the impact on total power system reserve requirements ?
- Is this integration approach economically viable compared to the centralized procurement of reserve from traditional sources ?

Approach

- Case study: we consider the case of the **Danish transmission grid** and the associated fleet of conventional power plants and compare it against local dispatched distribution grids.
- We perform **stochastic simulations** to quantify and validate the reserve requirement necessary to operate this power systems with a desired reliability level.
- We establish a **numerical equivalence between saved conventional reserve capacity and amount of BESS storage** deployed in distribution networks.
- Finally, we quantify the **economic pay-back times of BESSs** capital expenditure (CAPEX).

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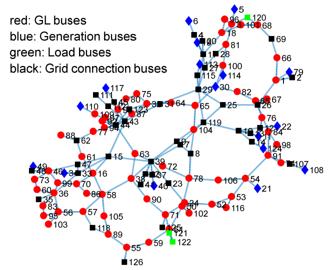
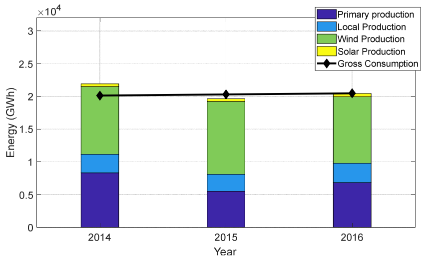
Case study – West Denmark power system

- 126 buses at 400 kV and 165 kV connected by 147 transmission lines and 41 high voltage transformer.
- 227 power generation units with overall capacity of 7323,1 MW. Stochastic generation (wind) penetration is 50%.
- Total load (electric energy demand), during one hour, is 2071,9 MWh.





Generation mix in terms of annual energy production

Note

- Technical details of system components are considered based on realistic data sets provided by ENTSO-E and Energinet.dk.
- Interconnections with neighbouring countries is not considered as the system is balanced in terms of overall generation and consumption.

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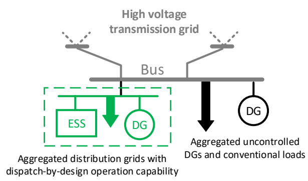
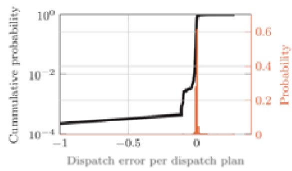
Dispatched-by-design distribution networks

Composition of an HV bus: a dispatched-by-design distribution system (left) and a conventional distribution system (right) are connected to the bus

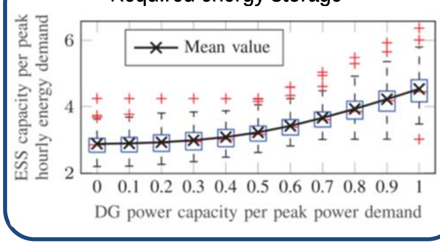


Dispatch following error



Operation for three weeks at 5 minute resolution using the EPFL experimental setup

Required energy storage



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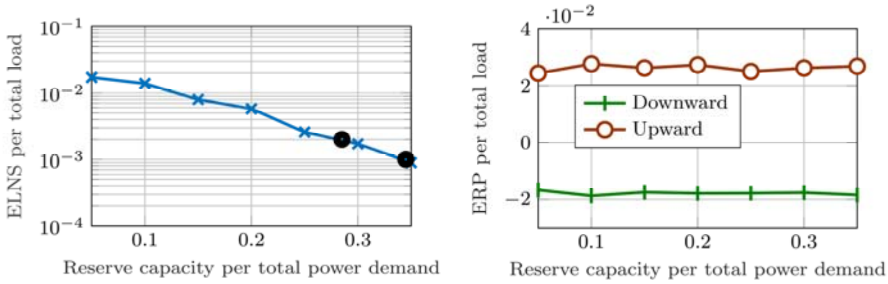
(Base) Case I – Reliability assessment

The power reserve capacity is entirely provided by conventional power plants



- The TSO requires to provide reserve capacities up to 28.5% and 34.5% of the total in order to satisfy the 0.001 and 0.002 ELNS target values, respectively.
- Increasing reserve capacity does not change the amount of Expected Regulating Power (ERP).

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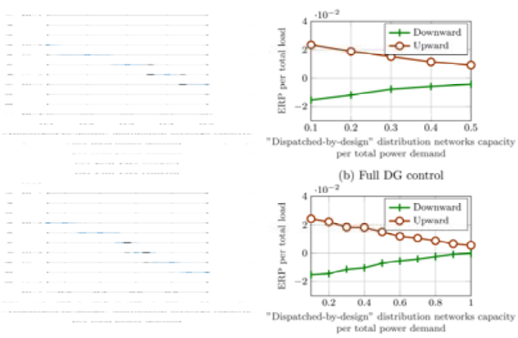
Case II – Reliability assessment

Case II Full control: All stochastic DG connected to the distribution network is under the dispatched-by-design regime.
Case II Half control: 50% of the stochastic DG, in terms of power capacity, connected to the distribution network is under the dispatched-by-design regime.

An energy storage capacity of 4.49 (3.21) times the hourly peak load (in MWh) is required to ensure the full (half) DG control scheme.

To satisfy 0.001 and 0.002 ELNS target value:
In Case II Full control: 44% and 36% dispatched-by-design penetration levels correspond to the installation of 4093 MWh and 3348 MWh BESSs within the distribution networks are required.

The Expected Regulating Power (ERP) is considerably decreasing by increasing the penetration level of dispatched.by-design distribution networks.



(b) Full DG control
(c) Half DG control
(d) Half DG control

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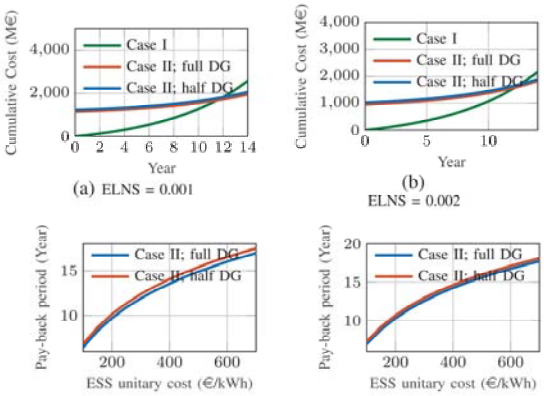
Comparison of Case I and II: economic evaluation

The yearly cumulative costs for two desired reliability levels (Fig. a,b). The year 0 corresponds to 2016 and BESS unitary cost is 280 Euro/kWh.

- Cumulative cost of Case II becomes lower than of Case I after 11 (12) years when the target ELNS per total load is 0.001 (0.002).
- Sensitivity analysis is provided to quantify the pay-back time (i.e., break-even points) of investment costs associated with Case II, as a function of the unitary cost of BESS (Fig. c,d).



(a) ELNS = 0.001 (b) ELNS = 0.002 (c) ELNS = 0.001 (d) ELNS = 0.002

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Take home messages

- Stochastic electricity production from photovoltaics have a large impact on the planning and operation of the power grid.
- Thanks to the use of local energy storage systems, it is possible to significantly augment the PV hosting capacity of power distribution grids and enable the concept of dispatched-by-design distribution systems.
- This concept, although working on a medium-voltage scale, has an impact on the bulk grid reserve that has been scarcely studied. In order to address this point, the Danish transmission grid, and the associated fleet of conventional power plants, has been modelled in detail.
- A technical/economic assessment has been performed with respect to the Danish power transmission system with the following outcomes: 1) large scale deployment of dispatch-by-design distribution network is a viable technical solution to address flexibility requirements of power systems and 2) this solution is economically viable with a pay-back time in the range of 10 years compared to providing flexibilities from conventional power plants.

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