

Battery Energy Storage Systems

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EPFL EE-466
Week 4

Slides compiled on: October 3, 2024

Program of the afternoon

- Discussion on last week exercises – 15 mins
- Battery energy storage systems (BESSs) – 30 mins
- Pause – 10 mins
- BESSs (continuation) – 45 mins
- Visit to the BESS of EPFL
- Class is over $\approx$ 15h45

Largest BESS in the world (2022)



Edwards & Sanborn solar-plus-storage (California, US) 875 MW/3'287 MWh.

Largest BESS in the world (2022) vs Nant De Drance im Wallis

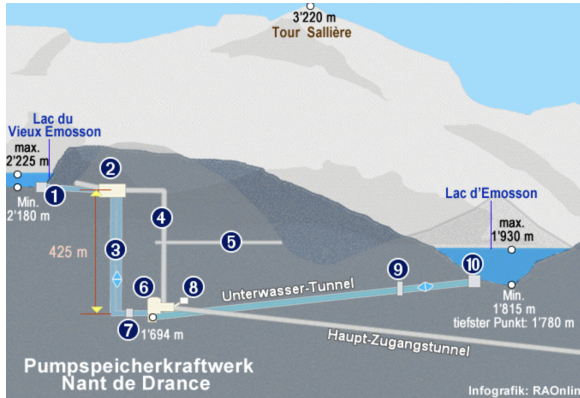
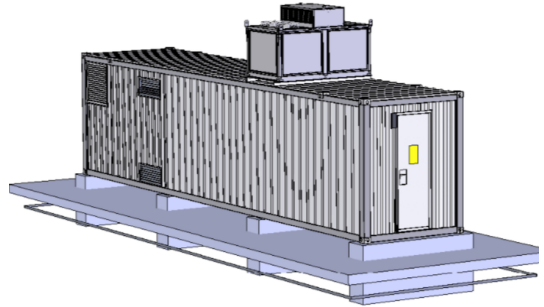


Figure: The pumped storage hydropower (PSH, in French, "station de transfert d'énergie par pompage", STEP) station of **Nant de Drance**, 900 MW (delivered by 6 Francis turbines)/20 GWh. Nominal flow rate: 240 cubic meter per second (twice the Aare river in Bern).

Working example: the BESS of EPFL

(You will visit this later)

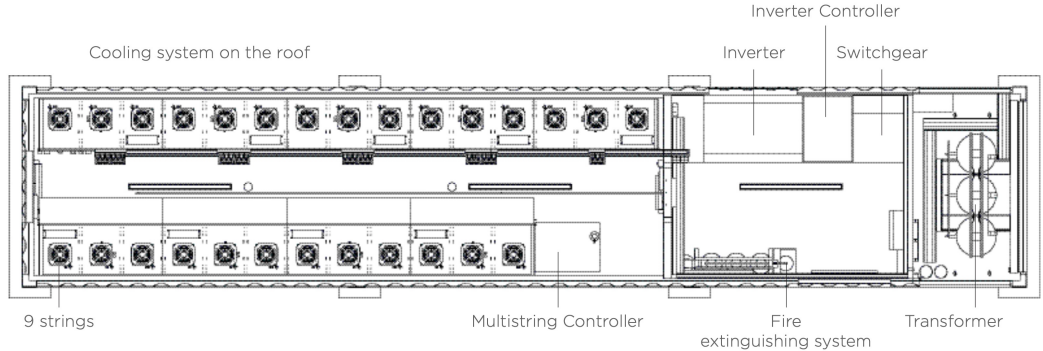


Power rating and energy capacity: 0.72 MVA, 0.56 MWh.

Technology: Lithium-titanate.

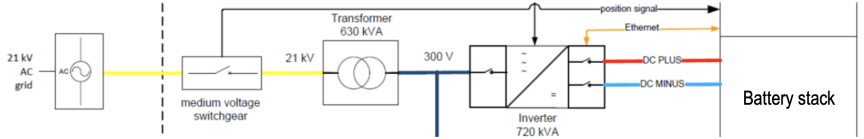
Container size: 12 x 3 x 2 m, $\approx$ 20 tonnes.

Inside the container



Three main systems: battery and battery management system, grid-interfacing components, and auxiliaries (fire-extinguishing system, air cooling, lightning)

Electrical stack



From right to left: battery stack , DC (direct current) bus, Power converter, Step-up transformer, Circuit breaker, grid connection.

Cell stack

Composition: cell $\longrightarrow$ module $\longrightarrow$ rack $\longrightarrow$ stack.

Cell information:

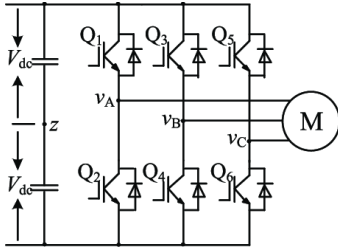
- Nominal voltage: 2.3 V
- Min/max voltage: 1.7 V, 2.7 V
- Current capacity: 30 Ah
- Similar [cell datasheet](#)
- Module: 20s3p (20 cells in series, 3 in parallel)
- Modules in a rack: 15s
- Stack: 9 modules in parallel
- Total cells: $20 \times 3 \times 15 \times 9 = 8'100$
- System voltage: $600 \div 800$ V (DC bus)

Series composition of cells increases the voltage; parallel composition increases the current capacity (Ah).

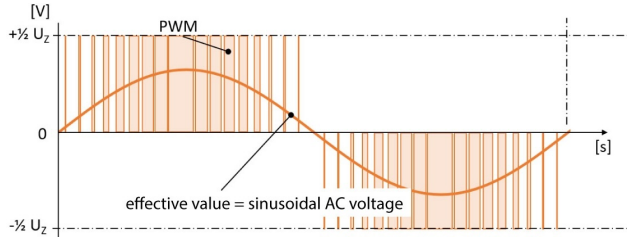
Because the energy capacity (kWh) is voltage times the current capacity, it scales with the number of cells regardless of composition (series | parallel).

Power converter

The power converter adapts voltage levels from DC to AC.



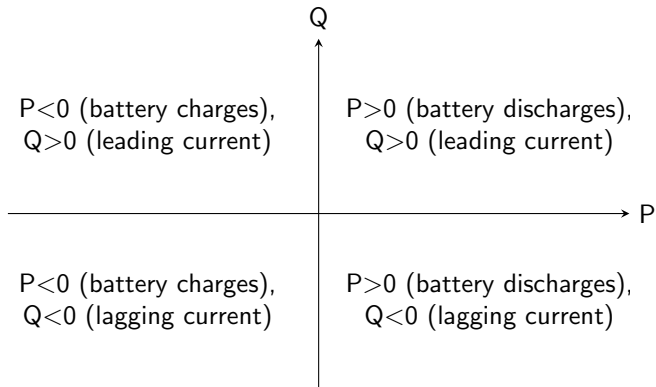
Topology of a two-level power converter. The three-phase grid connection is at "M".



Modulation in a single-phase power converter: from DC to AC.

Four-quadrant power converter

BESSs are normally equipped with four-quadrant power converters, meaning they are capable to operate in all four quadrants of the P (active power)-Q(reactive power) plane.



Positive values refer to generation and vice-versa.

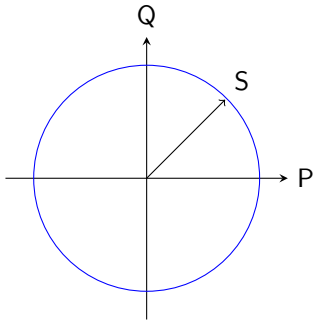
Power converter: reactive power

- The capability of providing reactive power comes for free with 4-quadrant power converter
- It is of interest for voltage regulation in transmission lines and power factor correction
- It generally does not impact on the BESS state-of-charge level

Power converter: ideal capability curve

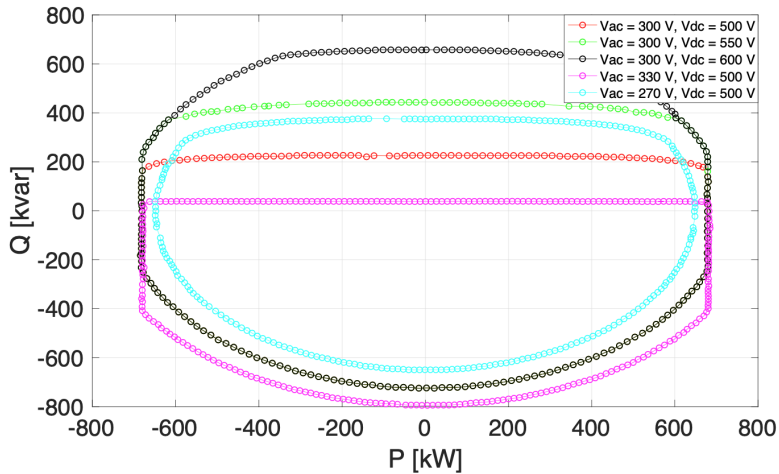
Say S is the kVA (apparent power) rating of the converter, the (ideal) capability curve is given by the set:

$$P^2 + Q^2 \leq S^2$$

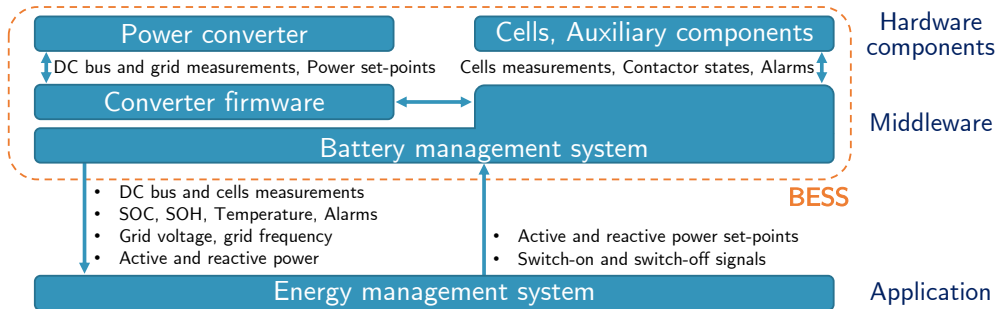


In blue, $P^2 + Q^2 = S^2$. The inner part of the set is the converter's feasible operating region. What's the relation with the power constraint studied in Week 3's scheduling problem?

Power converter capability

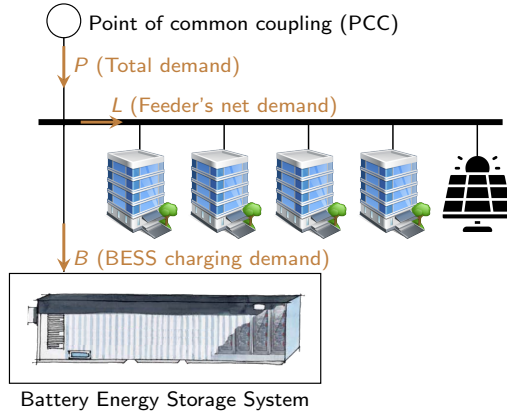


Software layers in a BESS

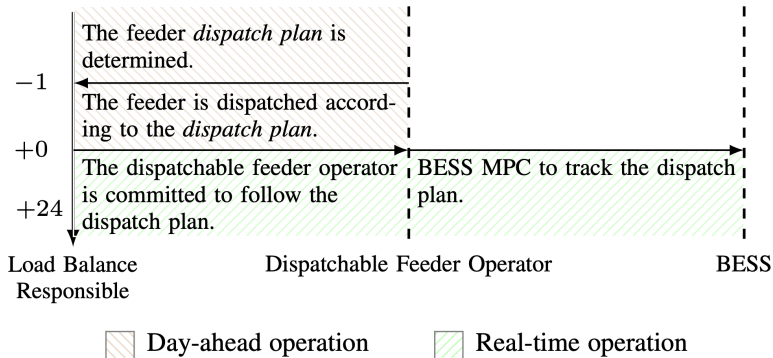


BESS of EPFL: Application examples

Configuration and operations



Timeline of operations



Applications: dispatch, peak shaving, load levelling

Links to externally-stored data bins and dashboards:

- [Dispatch on Jan 14, 2016](#)
- [Dispatch on Jan 13, 2016](#)
- [Dispatch with peak-shaving on Jun 22, 2016](#)
- [Dispatch with load levelling on Mar 14, 2016](#)
- [Continuous dispatch over three days](#)

For the formulation of the scheduling (and control) problem, see research paper *Achieving the Dispatchability of Distribution Feeders through Prosumers Data Driven Forecasting and Model Predictive Control of Electrochemical Storage*. [Link here](#).

Walk to the EPFL's BESS



[Link to plan.epfl.ch](http://plan.epfl.ch), [Link to maps.google.com](https://maps.google.com)