Representation of Energy Conversion Components and Strategies to select Adequate Storage Systems

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AAE – E3070 – Electrical Energy Storage Systems

Spring 2023

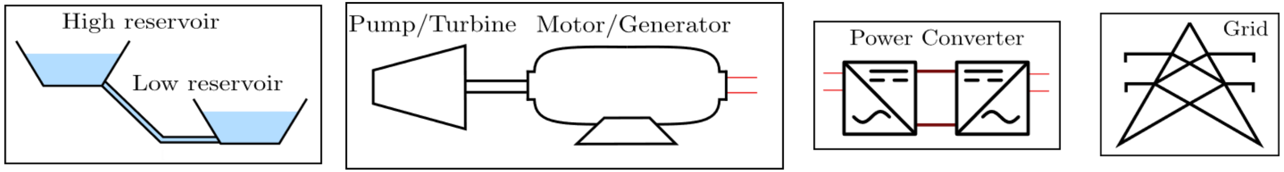
Expected Learning Outcomes

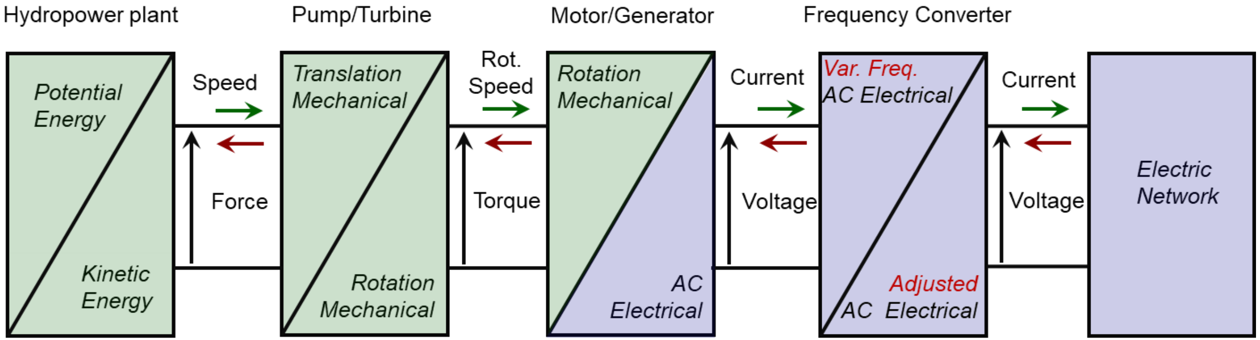
1. Understand the main quantities in energy conversion and transmission devices using effort/flow representation.

2. Representation of multiport AC electrical devices using two-port equivalent AC electrical systems.

3. Identify requirement specifications for a given application and select an adequate electrical storage technology accordingly.

Hydropower Storage System





Chain efficiency is the product of the efficiencies corresponding to each component

Chain efficiency is lower than the efficiency of the less efficient component

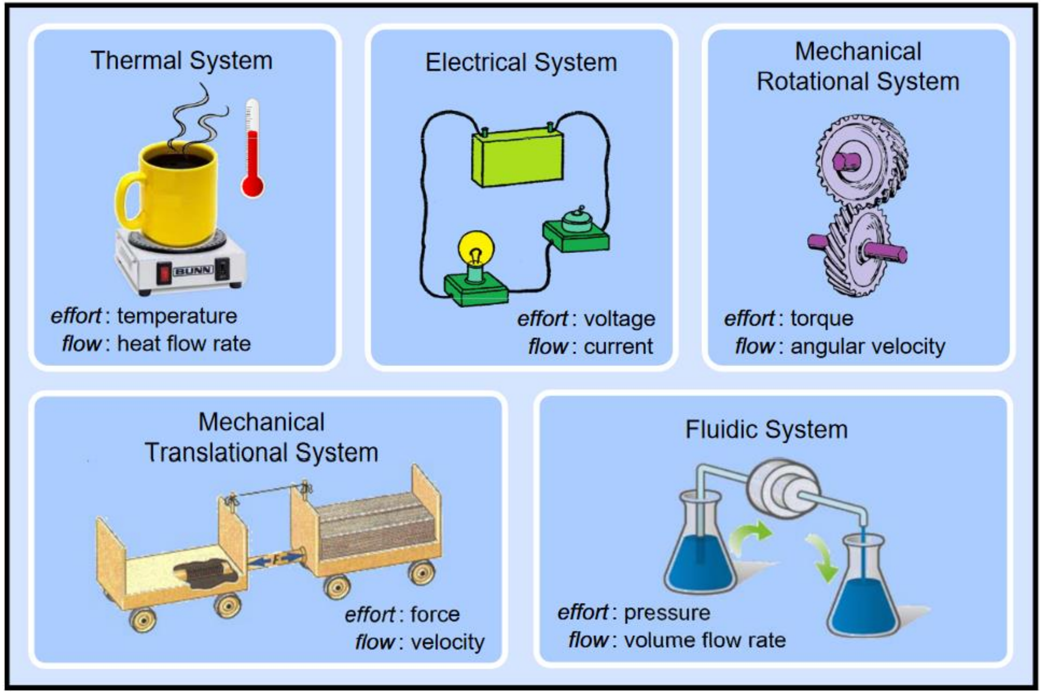
Avoid unnecessary energy conversion components to increase the round-trip efficiency

Representation of Energy Conversion Components

General Representation of Energetic Quantities

Energy-based physical modelling:

- Defining the physical systems based on energy conservation law;
- We define such system with *flow* and *effort* variables:
  - "The flow variable is associated with the act of delivering energy";
  - "The effort variable is associated with the act of measuring the flow of energy";



Examples of effort-flow variables of physical systems.

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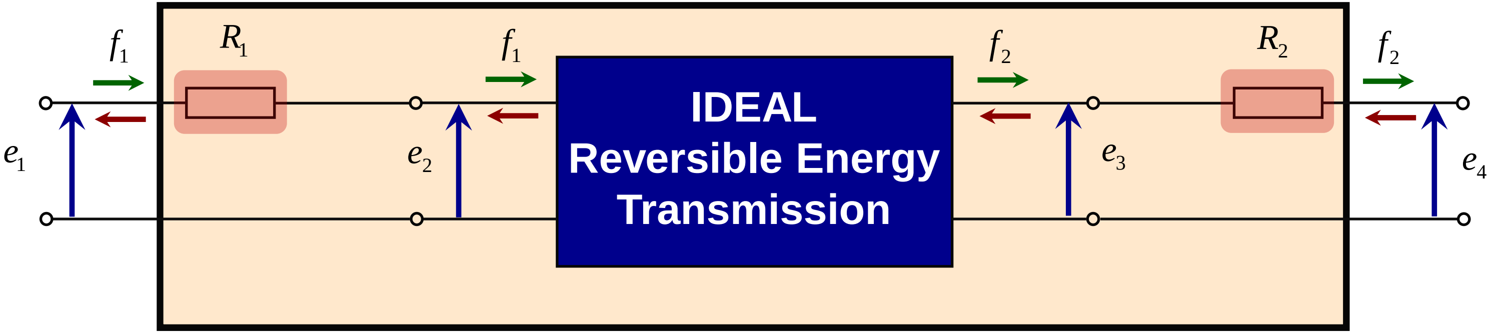
Source: M. Fadlisyah, *A Rewriting-Logic-Based Approach for the Formal Modeling and Analysis of Interacting Hybrid Systems*, PhD Dissertation, University of Oslo, Sept. 2014.

Focus on the Energy Transmission and Conversion

Realistic Reversible Energy Transmission Components



Realistic device

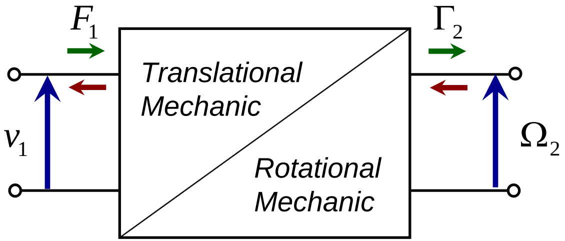
$$p_1 = e_1 f_1 \qquad p_{\text{loss1}} = R_1 f_1^2$$

$$p_4 = e_4 f_2 \qquad p_{\text{loss2}} = R_2 f_2^2$$

$$p_4 = \eta\, p_1 = p_1 - p_{\text{loss1}} - p_{\text{loss2}}$$

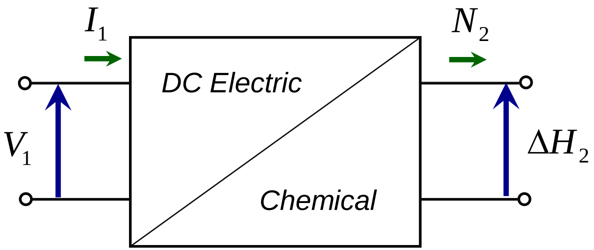
Ideal device $\quad p_2 = e_2 f_1 \quad p_3 = e_3 f_2 \quad p_3 = p_2$

General Representation of Energy Conversion Devices



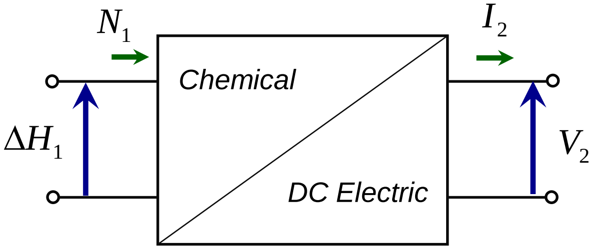
$$R\Omega_2 = \lambda v_1$$

Fan converts translational into rotational mechanic energy



$$\Delta H_2 = k_T V_1$$

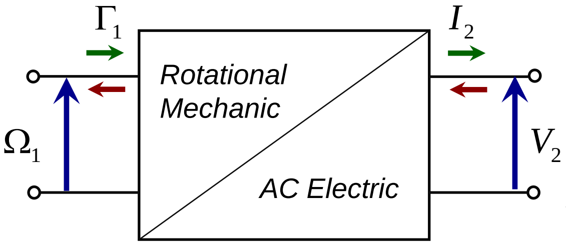
Electrolyser converts electrical energy into H_2 and O_2



$$V_2 = k_T \Delta H_1$$

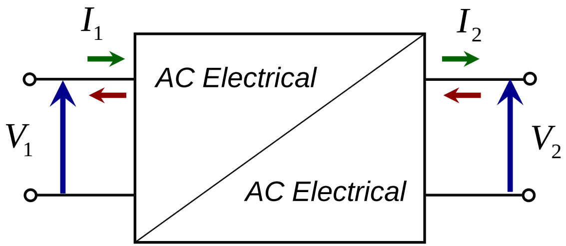
Fuel cell converts H_2 and O_2 into electrical energy

General Representation of Energy Conversion Devices



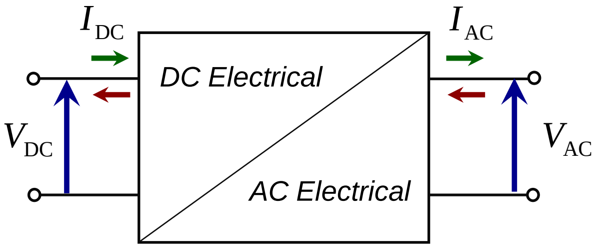
$$V_2 = k_\Omega \Omega_1 \qquad \Gamma_1 = k_\phi I_2$$

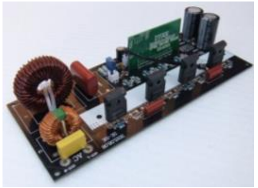
Motor/Generator conversion between mechanical and electrical energy



$$V_2 = mV_1$$

Transformer amplifies or drops the output voltage



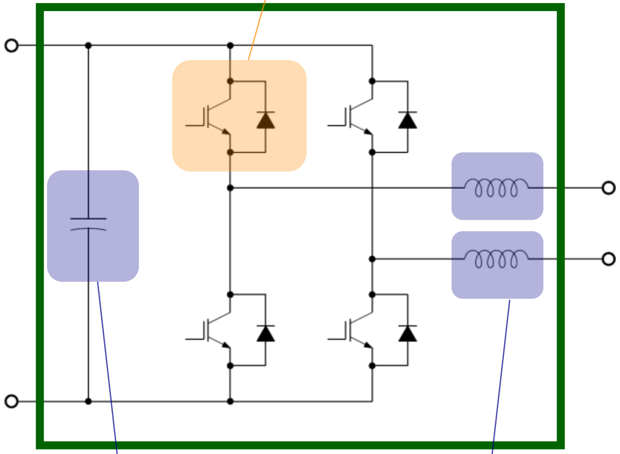


$$V_{AC} = kV_{DC}$$

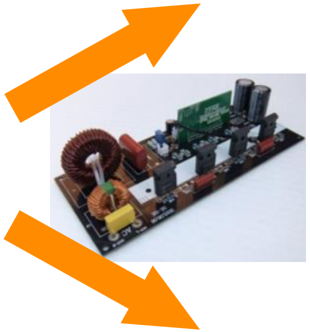
Inverter/Rectifier electrical energy conversion between AC and DC

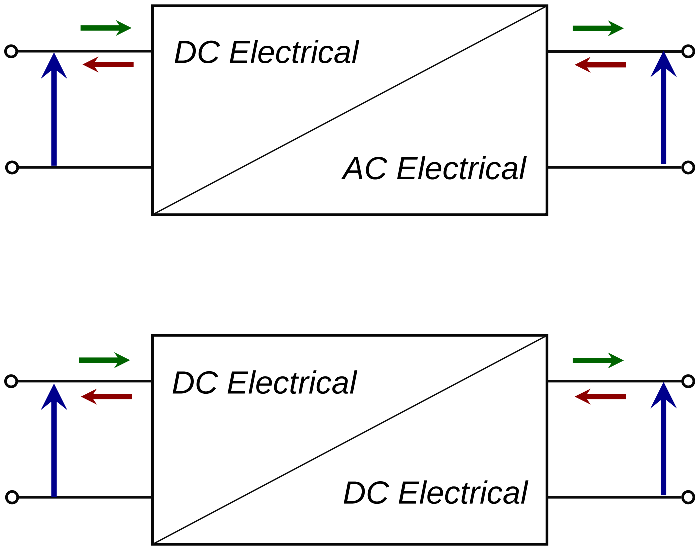
Reversible Electric Conversion Components

Semiconductor Switches
Enable reversible electrical energy conversion



Passive Elements
Capacitor smooths the DC voltage
Inductor smooths the current



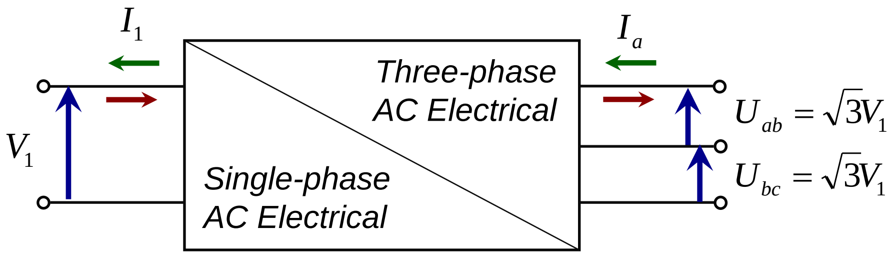


Electrical Flow
Current [A]

Electrical Effort
Voltage [V]

Multiports Electric Conversion Components

High power AC electrical components transfer energy with three phases.



$$p_1 = V_1 I_1 \cos(\varphi)$$

$$p_2 = 3V_1 I_1 \cos(\varphi) = \sqrt{3} U_{ab} I_a \cos(\varphi)$$

φ is the phase shift beetween the voltage and the current

For transfering the same power ($p_1 = p_2$), we need 3 times less current.

With the same current ($I_1 = I_a$), we transfer 3 times more power.

Strategies to Select Suitable Storage System

Strategies to Select Suitable Storage System

What should we consider to select an adequate Electrical Storage System ?

- **Installed power ?**
  - Low/high power application;
  - Rack of units if needed,
- **Response time ?**
  - How fast the system responds;
  - Depends on technology;
- **Required stored energy ?**
  - Time scale of service;
  - Is linked to discharge time;
- **Storage time ?**
  - How long should we store energy;
  - Are there some losses in the ESS;
- **Number of cycles ?**
  - How often do I need to charge it;
  - How many cycles before failure;
- Technology maturity ?

Discharge Time versus Installed Power

How is the power sizing and discharge time impacting the selection of ESS ?

- There are energy and power applications and the selection of the ESS;
- Large range of applications;

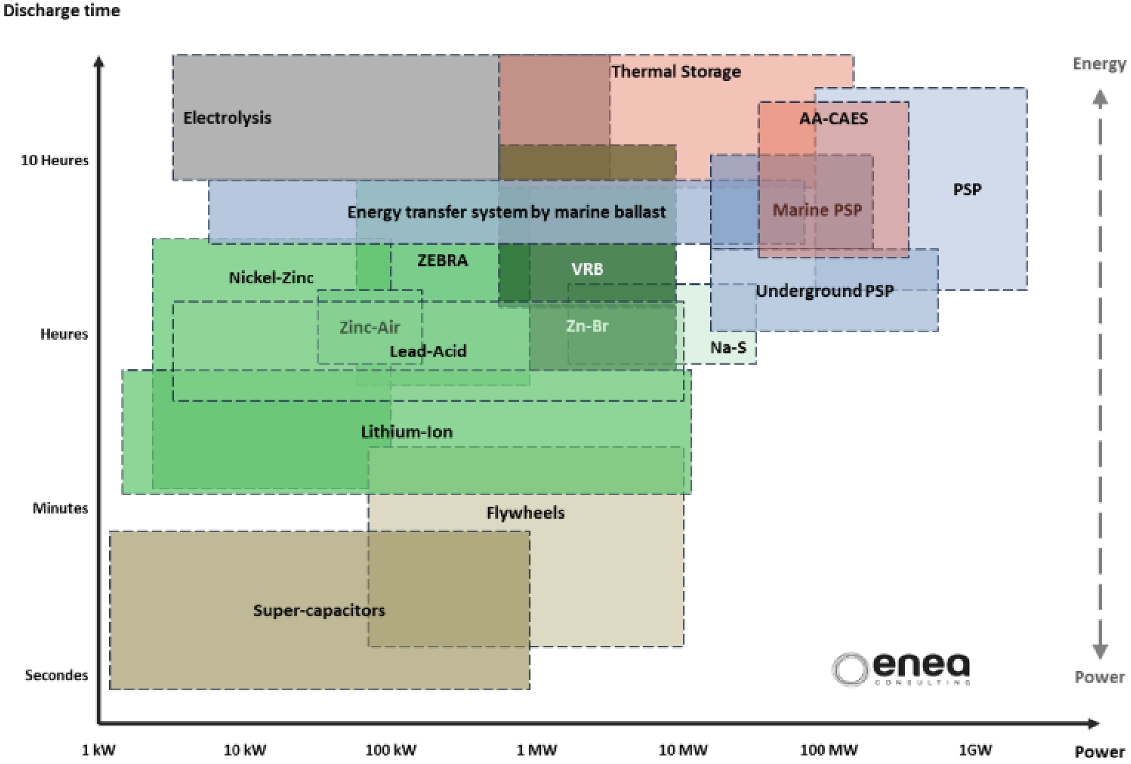


Fig. Source: METIS Studies, Study S07, *The role and need of flexibility in 2030: focus on energy storage*, retrieved from https://ec.europa.eu/energy/sites/ener/files/documents, 2015-2016

Example: Support of Frequency in the Nordic Grid

Grid frequency (ω) is a metric corresponding to the balance between production and consumption

Swing equation:

$$\frac{2H}{\omega_s} \cdot \frac{d\omega}{dt} = P_{prod} - P_{load}$$

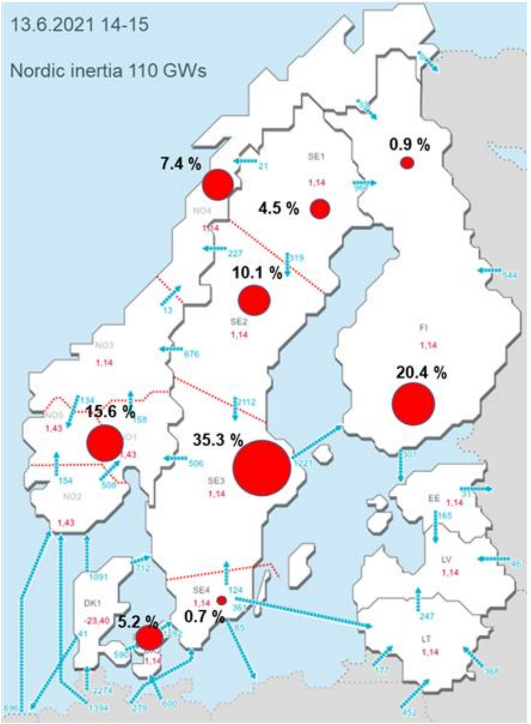
produced power (P_{prod})

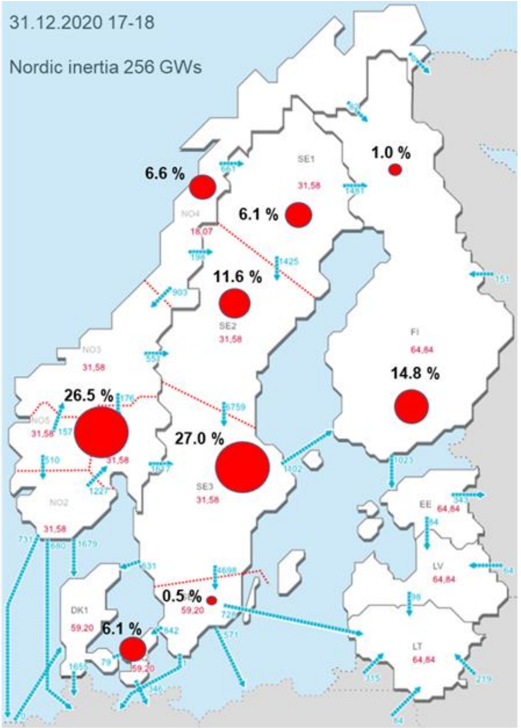
base frequency (ω_s)

consumed power (P_{load})

But the inertia constant (H) depends on the types of generators and loads we are connecting to the grid.

Source: F. Milano et al., *Foundations and Challenges of Low-Inertia Systems,* 2018 Power Systems Computation Conference (PSCC), 2018.



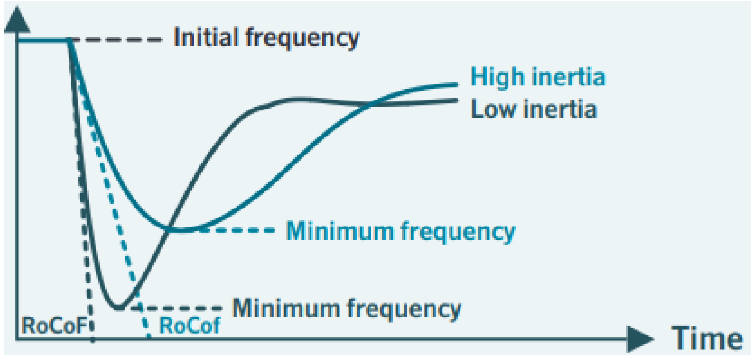


Figs. Source: FINGRID, *Inertia of the Nordic power system*, retrieved from https://www.fingrid.fi/en/electricity-market-information/InertiaofNordicpowersystem/, 2022.

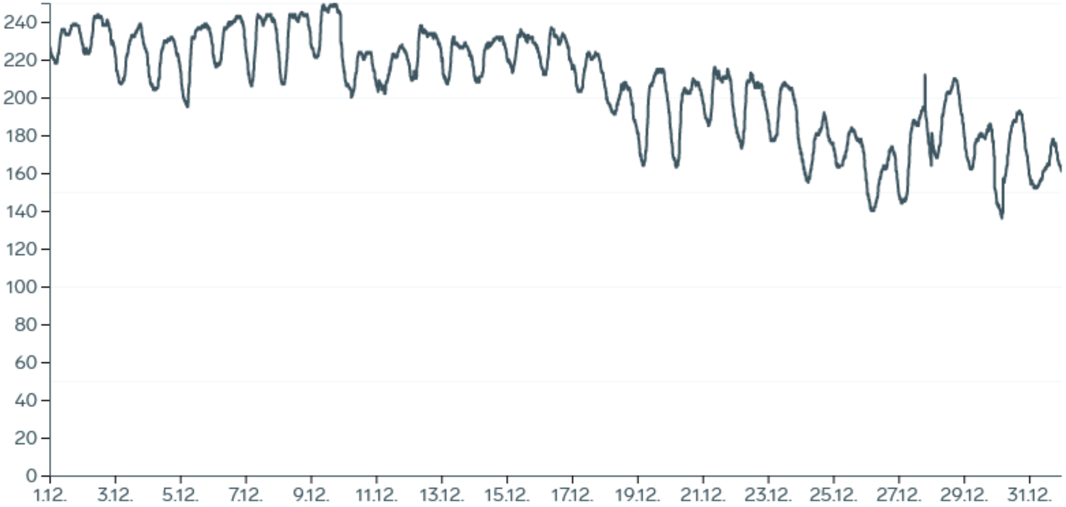
Example: Inertial Support to Power System Stability

Grid frequency may vary depending on power unbalances:

- If the changes are too abrupt, it may lead to unstable system and then to a blackout;
- It makes inertia is a crucial feature.



Inertia variations in Dec 2022 in the Nordic power system (in GWs) versus time (in days).



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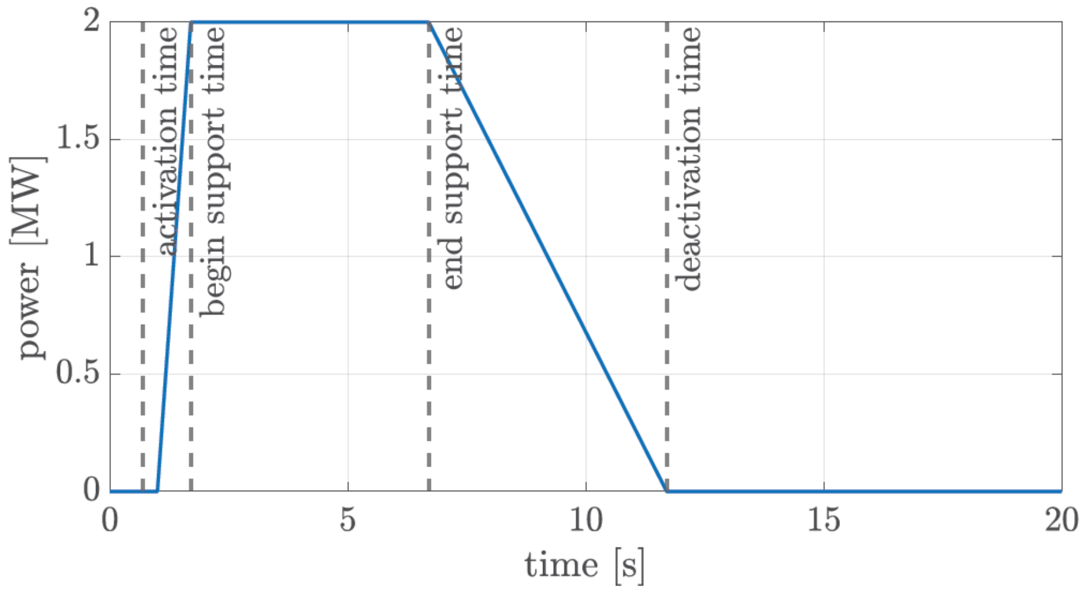
Figs. Source: FINGRID, *Inertia of the Nordic power system*, retrieved from https://www.fingrid.fi/en/electricity-market-information/InertiaofNordicpowersystem/, 2022.

Fast Frequency Response (FFR) for Grid Support in Finland

In power grids, providing FFR is a service that can be asked to support the power system in active power.

Feature	Data
Installed power	2 MW
Response time	0.7 s
Required energy	4.4 kW.h
Discharge time	~10 s



Profile based on Fingrid data for FFR requirements.

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In this case, the most adequate solution is supercapacitor !

Technology Maturity

Important to consider other technical criteria as well, depending on your application:

- Response time;
- Stored energy;
- Number of cycles;
- Volume / Weight;

Costs and sustainability should also be considered when proposing a solution !

→ See next flash talks

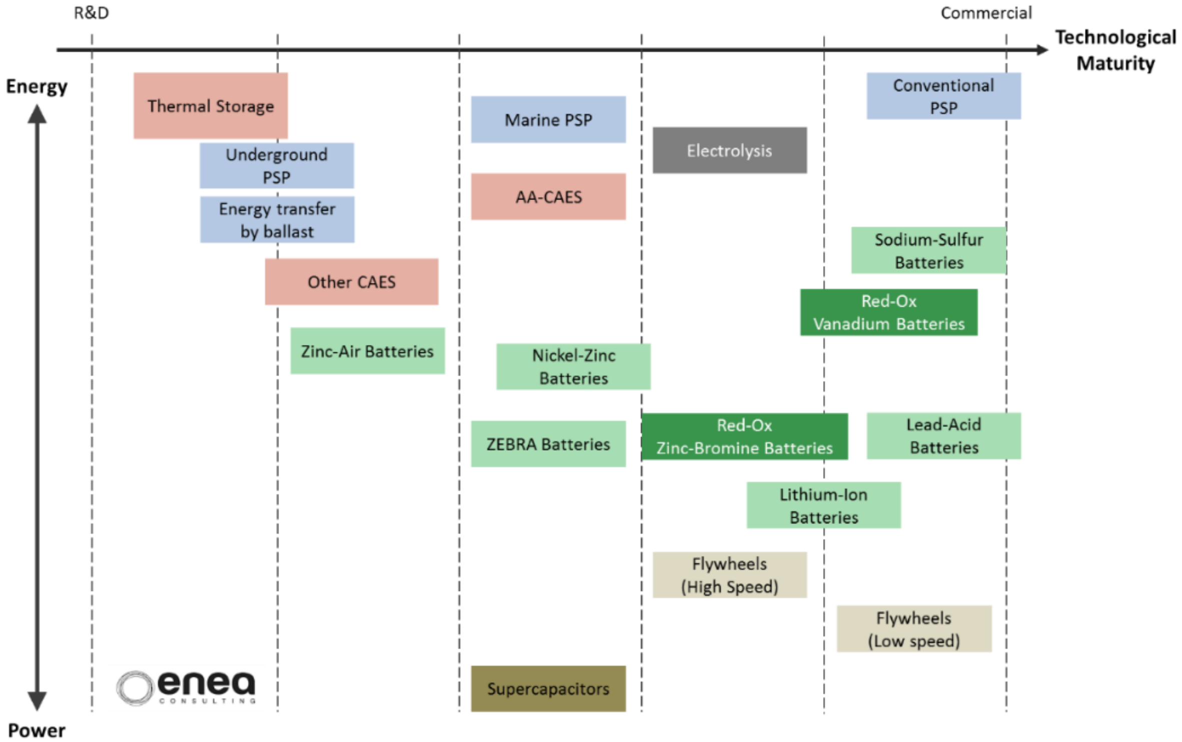

Fig. Source: METIS Studies, Study S07, *The role and need of flexibility in 2030: focus on energy storage*, retrieved from https://ec.europa.eu/energy/sites/ener/files/documents, 2015-2016

Take-home Messages

1. Effort/flow representation is useful for multi-physics conversion systems and thus to describe the energy chain.

2. EESS selection should be based on technical requirements of the specific application and pre-designed accordingly.

3. Technical requirements are not the only constraints. Technology maturity, resource availability, environmental aspects and costs must also be considered in the design.

End of Presentation

Please, feel free to ask all your questions

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