Operation and control of power systems with reduced synchronous inertia

Challenges and solutions

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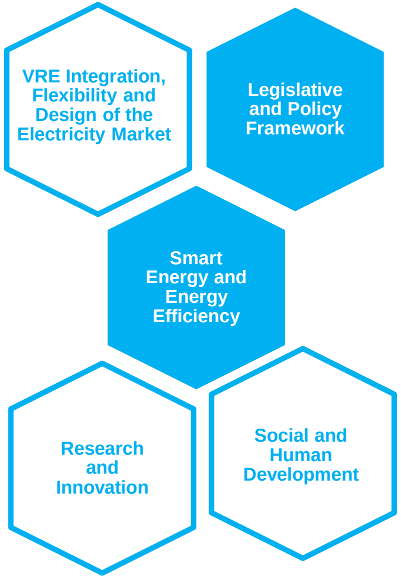
Context

asset

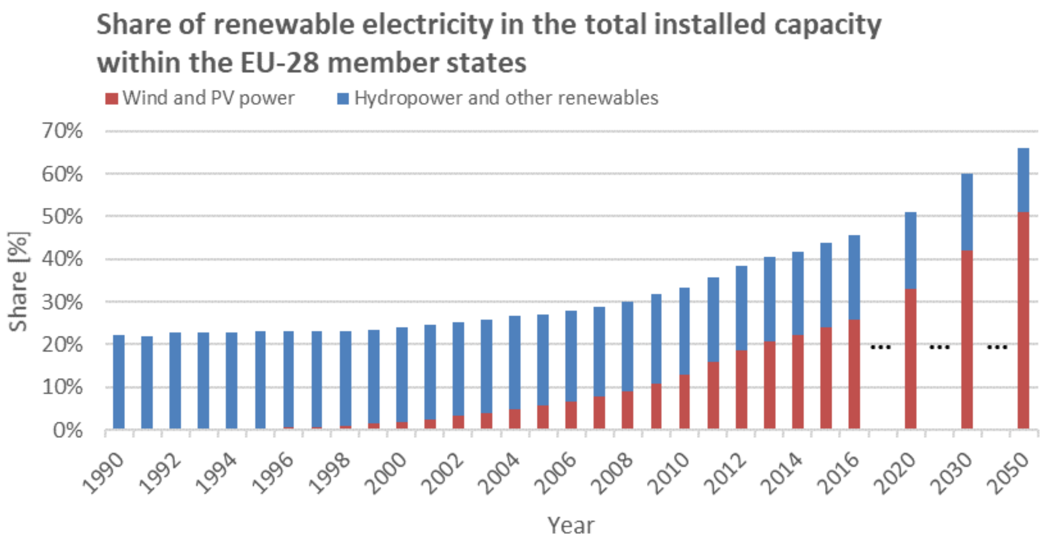
- **A**dvanced **S**ystem **S**tudies for **E**nergy **T**ransition
- Deliver studies in support to EU policy making in the field of energy
- 12 studies performed, 2 ongoing
- Consortium led by Tractebel together with Ecofys and E3MLab
- All information available on http://www.asset-ec.eu
- This study:

To what extend will the reduction in system inertia influence the operation and control of the power system of Continental Europe?

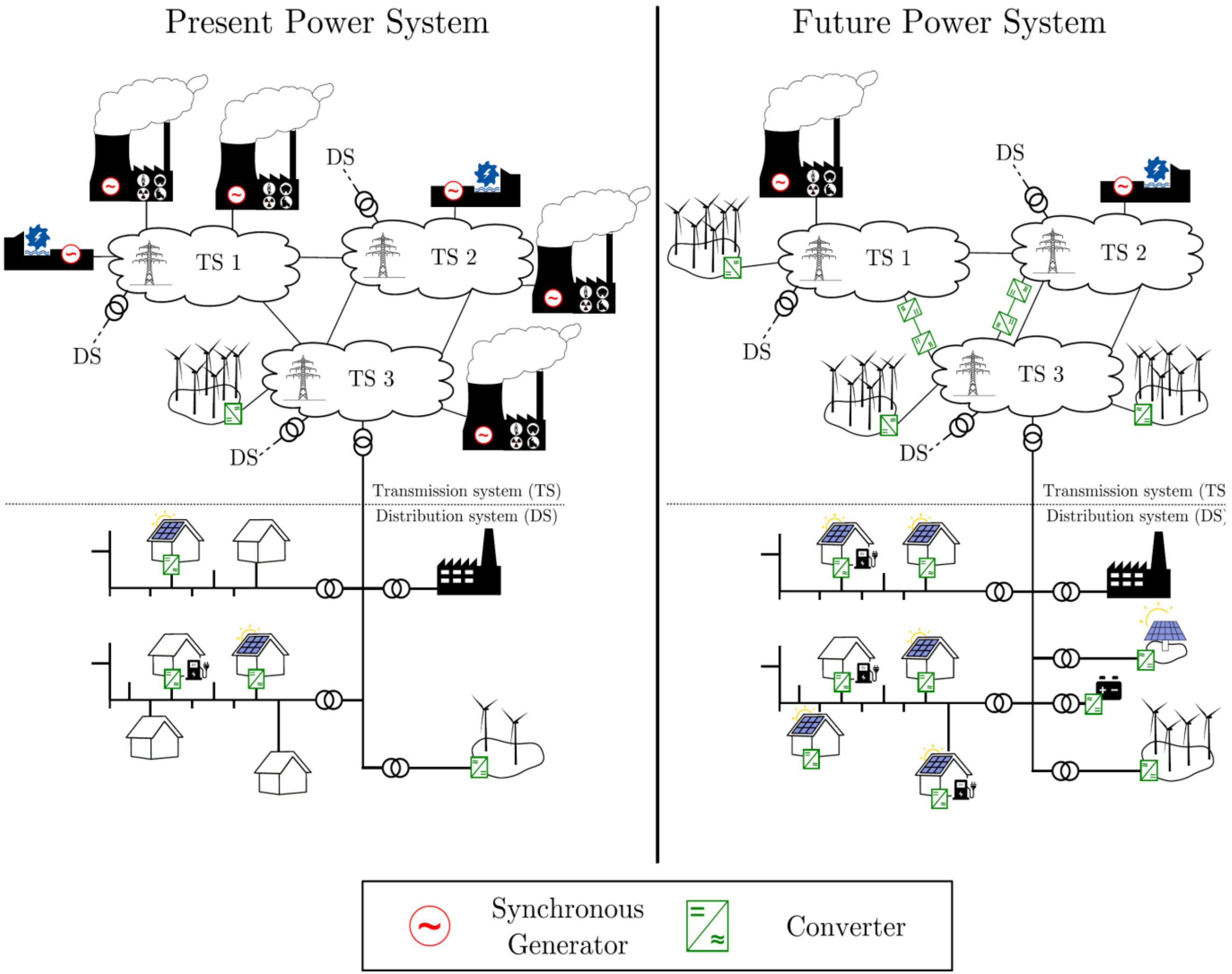


Increased penetration of renewables & converter connected units

- Increasing share of Renewable energy sources (RES-e) in electricity generation mix
  - Intermittent generation output
  - More and more interfaced with a power electronic converter (e.g. PV and Wind power)
  - E.g. EU-28: 2050 ≈ 50% of generation capacity converter connected
- Large synchronous generators are displaced by these converter coupled units
- Also the network (HVDC) and load are becoming converter based



Source: European Commission (EC), "EU energy statistical pocketbook and country data," 2018.



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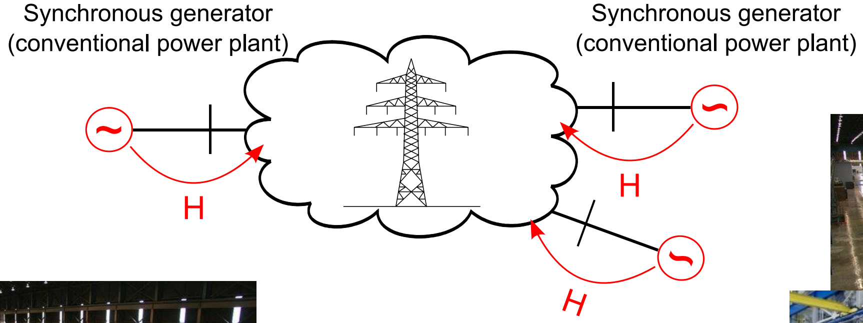
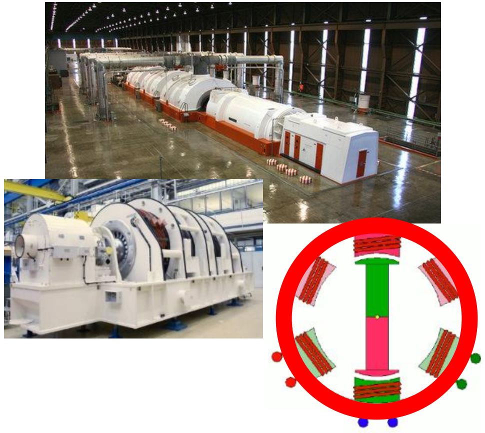
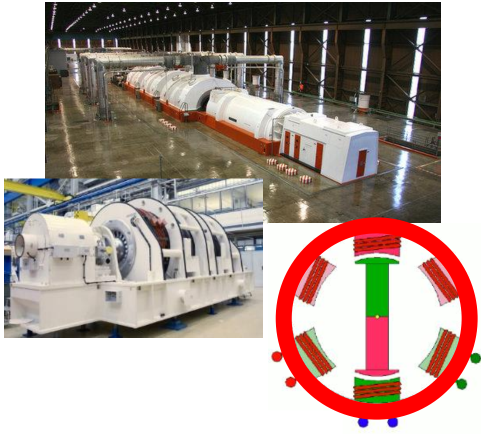
Displacing large synchronous generators results in decreasing system inertia H_{sys}

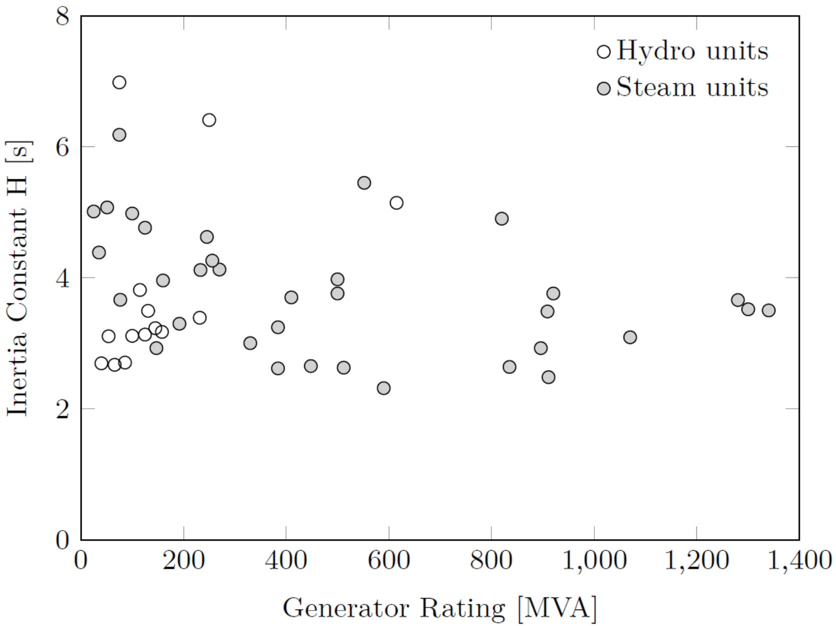






$$H_{sys}[s] = \sum H[s] = \frac{\sum E_{kin}\,[MWs]}{\sum S[MW]}$$

Displacing large synchronous generators results in decreasing system inertia H_{sys}



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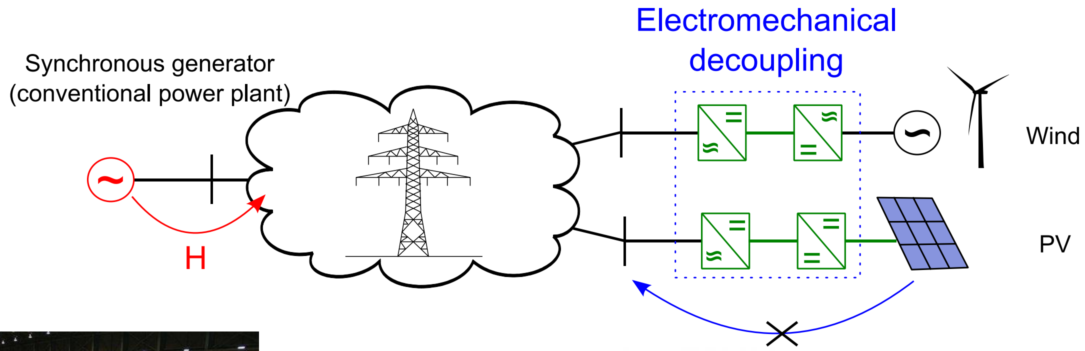
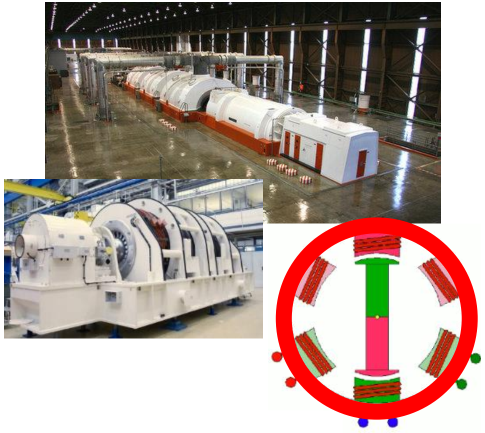
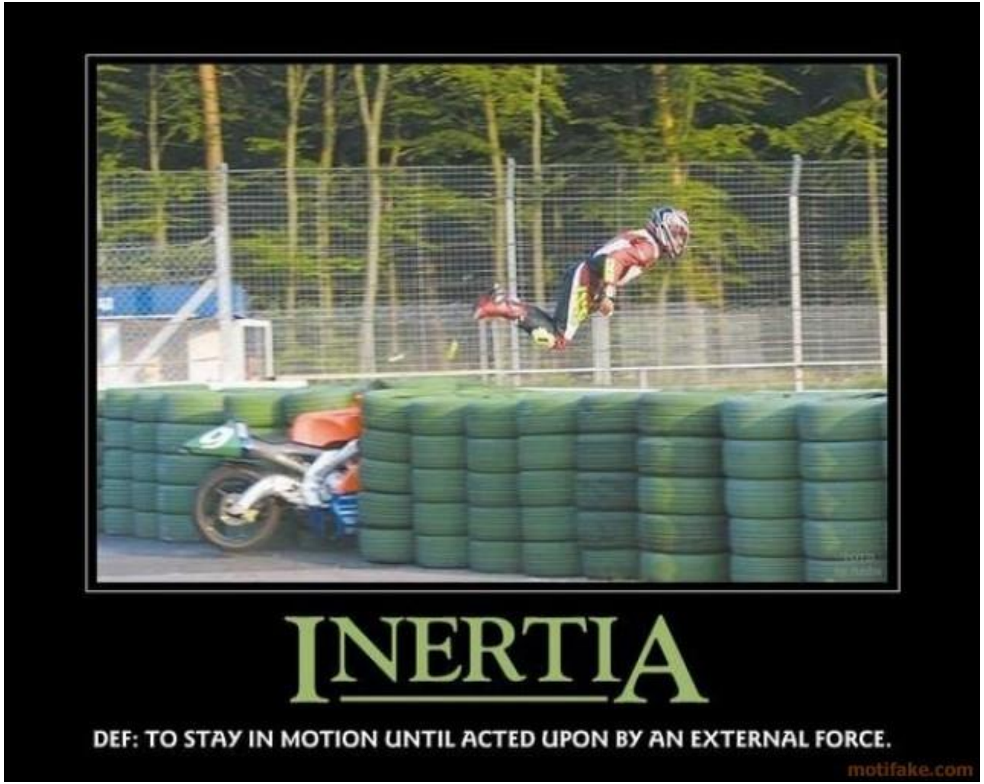


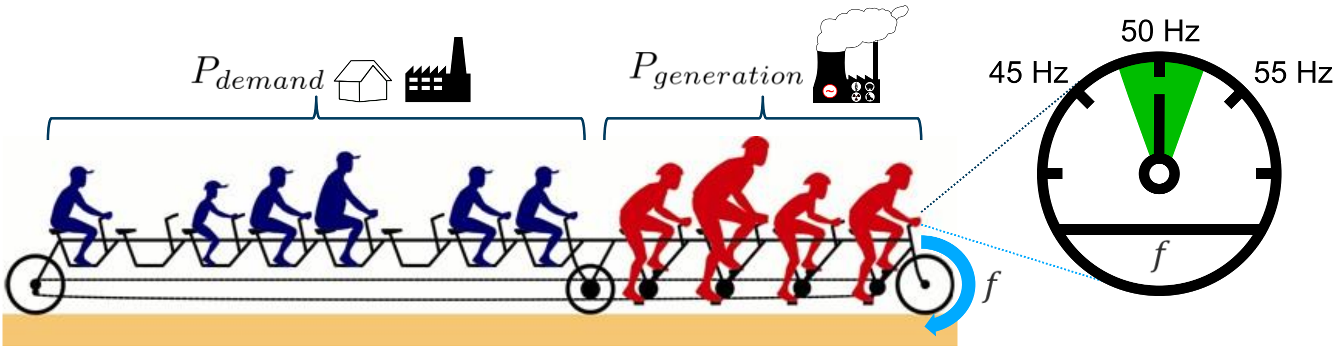


Total inertia (H_{sys}) is reduced: $H_{sys}[s] = \sum H[s] = \dfrac{\sum E_{kin}\,[MWs]}{\sum S[MW]}$

Role of inertia (Hsys)



Role of inertia (Hsys)



In general

Inertia is the resistance of any change in its state of motion

Inertia

Power system

Synchronous inertia (H) is the resistance of a power system to oppose changes in the frequency resulting from power imbalances in generation and demand

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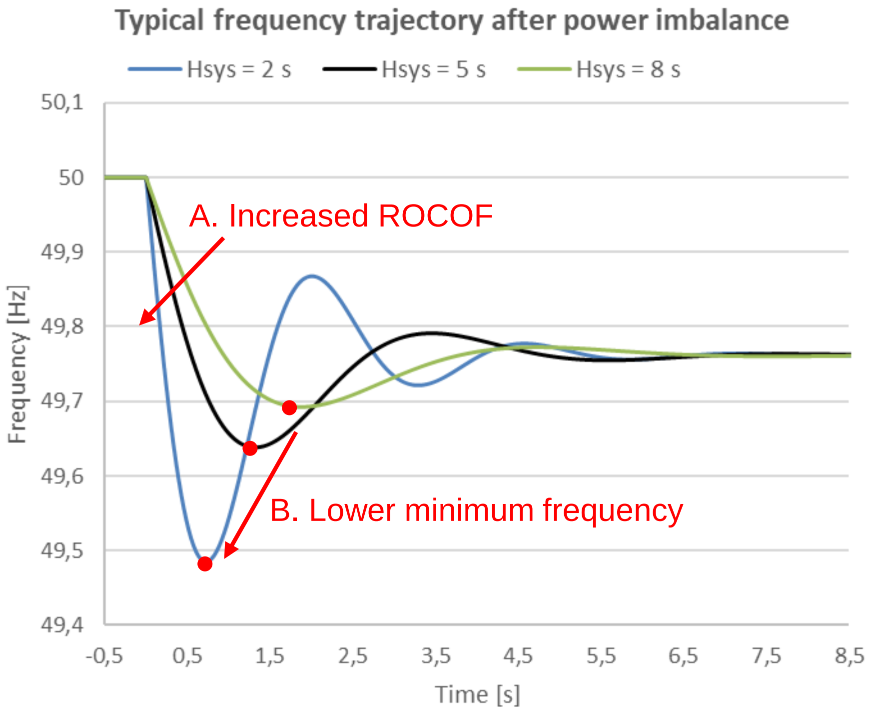
Future systems with low inertia

Foreseen challenges with reduced H_{sys}

- Impact on frequency trajectory after power imbalance (mainly during first seconds)
- Decrease of inertia:

A. Higher Rate Of Change Of Frequency (ROCOF)
  - **Generator compliance: effect on life time?**
  - **Unintentionally activation of ROCOF relays (e.g. GB: 0,125 Hz/s and Ireland 0,5 Hz/s)**
  - **Timing issues related to load shedding schemes**

B. Lower minimum frequency
  - **Activation of load shedding (e.g. 49 Hz CE and 48,8 Hz Nordic)**



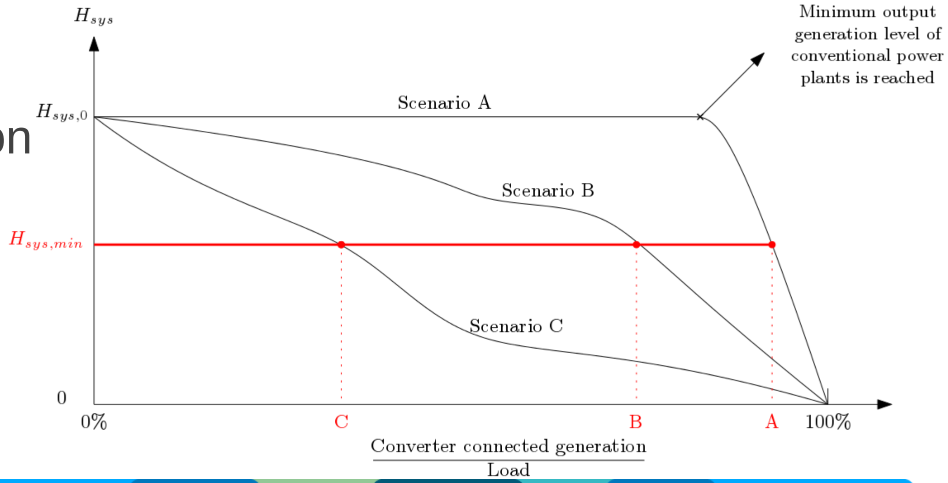
⮑ Problems are often very system specific

When to act?

Synchronous inertia: how low can we go?

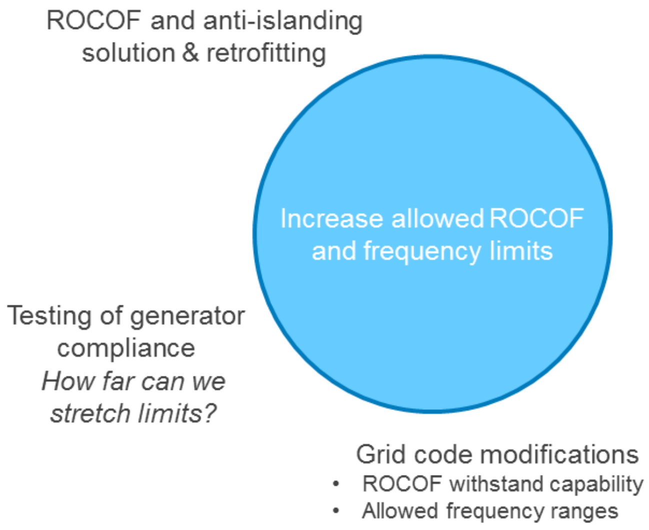
- Minimum inertia for each synchronous area, depending on…
  - Considered reference incident: Take into account system splits?
  - Installed protection devices and settings
  - Allowed ROCOF/frequency ranges (∝ generator, turbine, converter, … compliance)
  - Dynamics of primary control (type, speed, …)

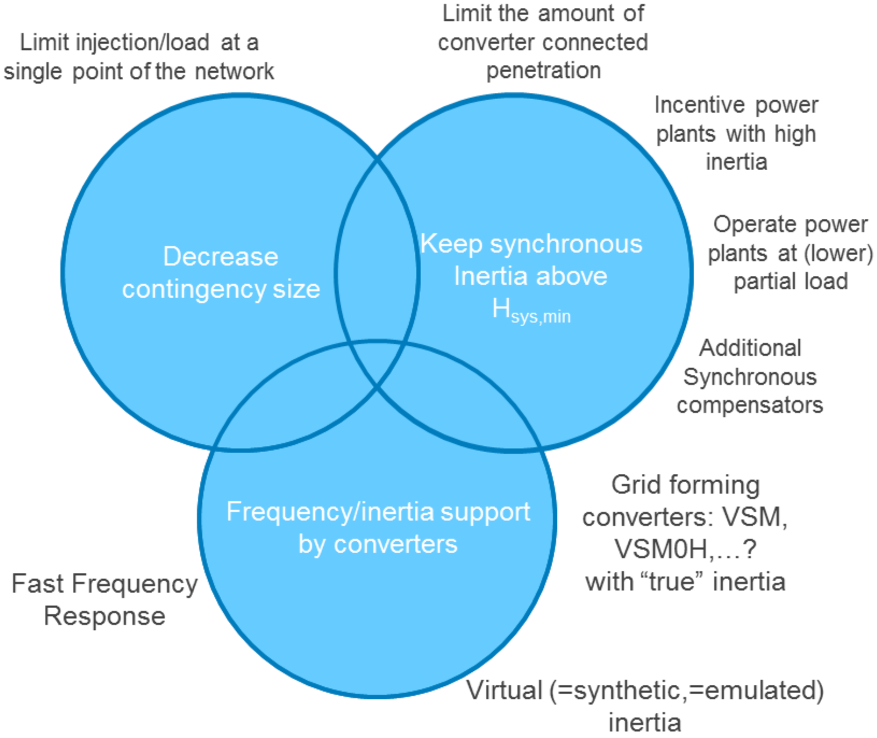
- Inertia vs converter connected penetration
  - Dispatch of remaining conventional power plants
  - Type and size of spinning power plants



Proposed solutions

MANAGE | ADAPT



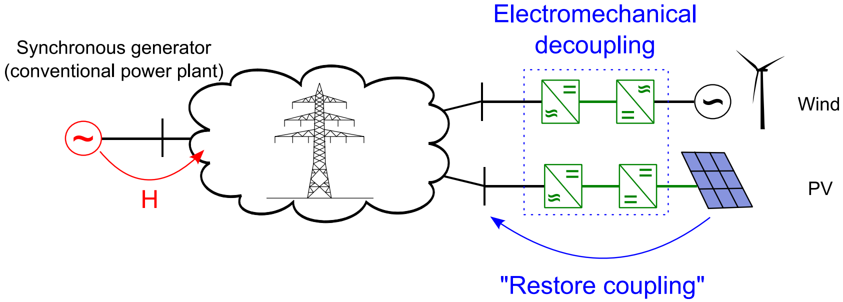


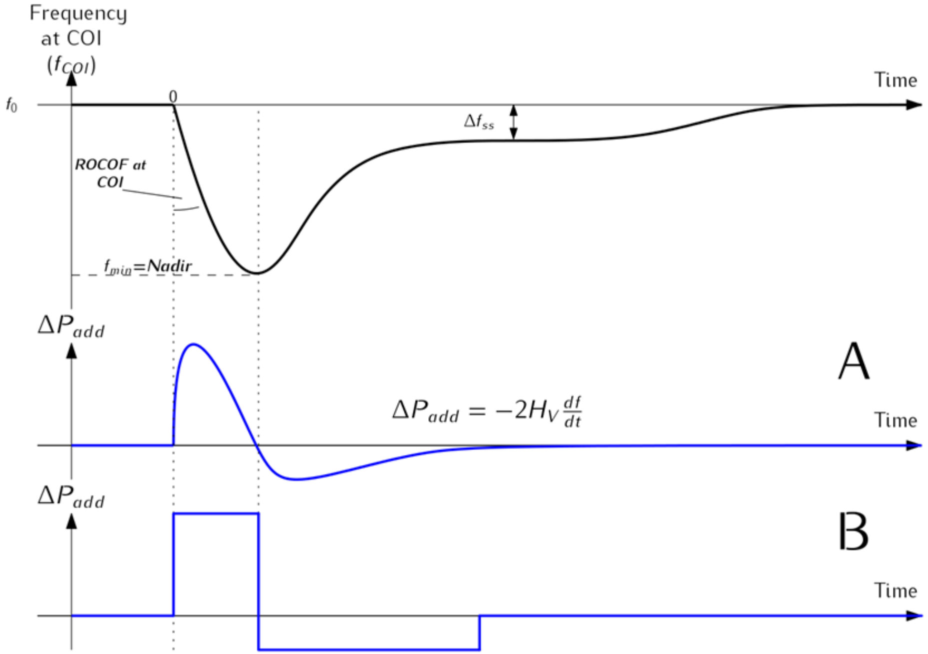
Proposed solutions

Frequency/inertia support by converters

- Virtual (=synthetic,=emulated) inertia:

Power output of converters becomes “coupled” to the measured grid frequency





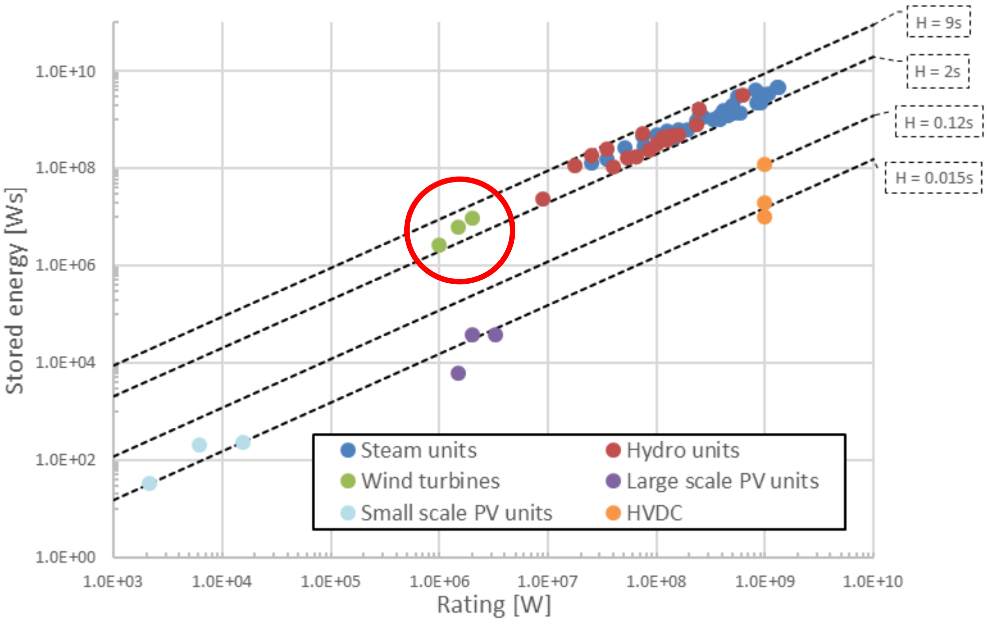
Proposed solutions

Frequency/inertia support by converters

- Virtual (=synthetic,=emulated) inertia:
  - ∝ ROCOF response (A)
  - Step response (B)
  - Droop response ∝ Δf

  Also sometimes defined as "Fast Frequency Response (FFR) "

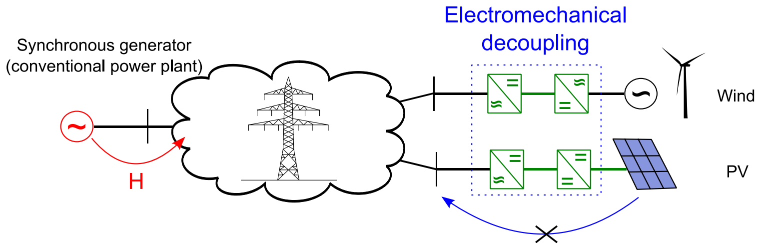
- Which units?
  - Wind turbines (deloading or using stored kinetic energy)
  - PV (with storage or deloading)

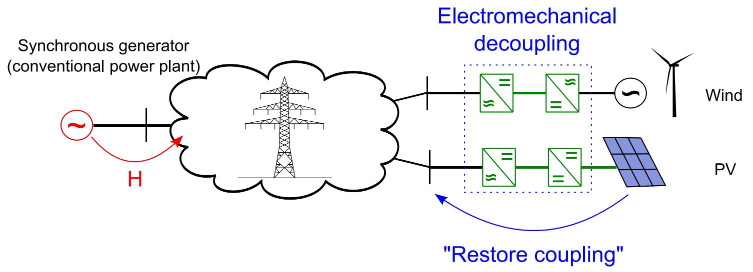


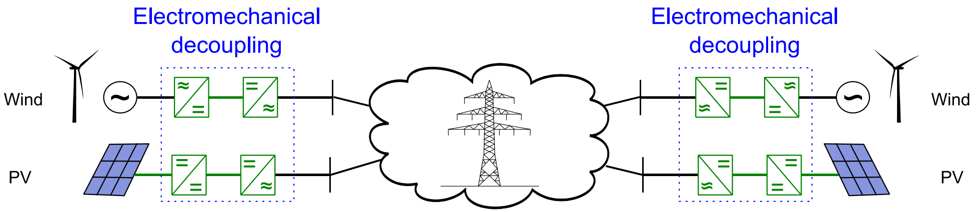
- Implementation in power systems:
  - **Synthetic inertia** by wind turbines in Hydro-Québec's electricity transmission system → Not for inertia issue, but mainly to compensate for slow hydro governor response
  - **Fast Frequency Response** as a new product in Ireland

Proposed solutions
Grid forming converters

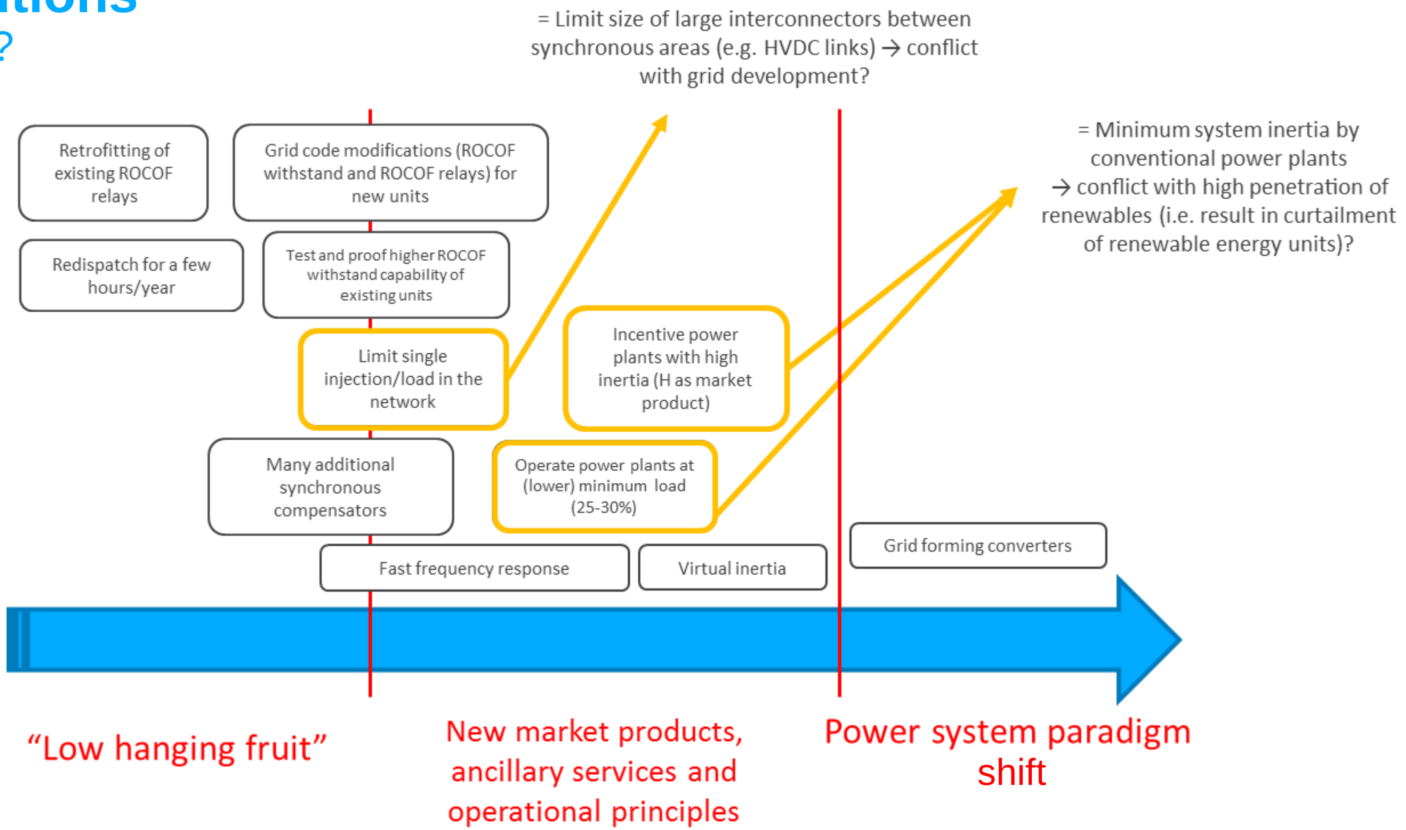
- Towards a power system without synchronous machines
- Grid forming converters
  - Set the frequency
  - Share load imbalances with each other using droop control
- Already implemented?
  - (Small) microgrids
  - Offshore wind power plants with HVDC connection
- Not yet considered for large power systems
  - Protection?
  - Additional communication layer required?
- Energy storage required!







Proposed solutions
Easy to implement?



03

European system

Current practice (ENTSO-E)

A. Committee on System development & design

— Studies on long term system development: Ten Year Network Development Plan (TYNDP)

— Legislative obligations defined in the Grid connection Codes (CNC) & their corresponding implementation guideline documents

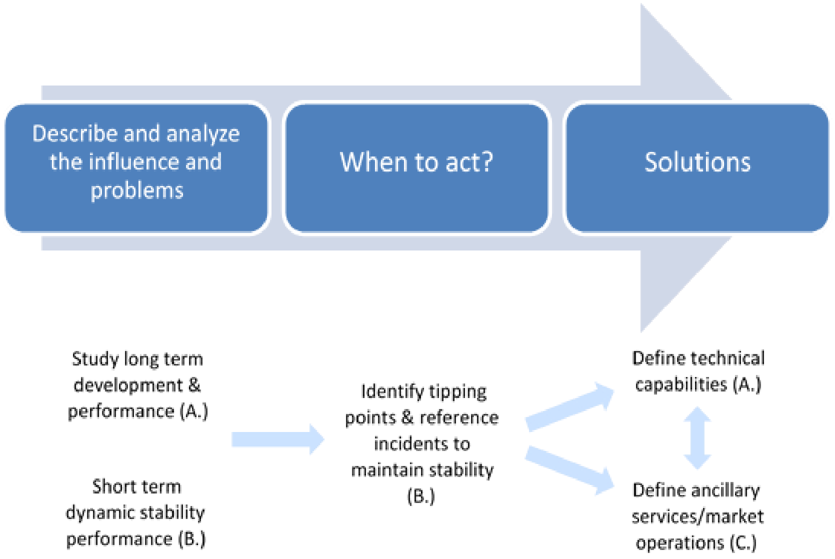
B. Committee on System operation

— Legislative obligations defined in the system operation guideline/codes (SO GL)

— Specific studies performed by the regional working groups

C. Committee on Markets

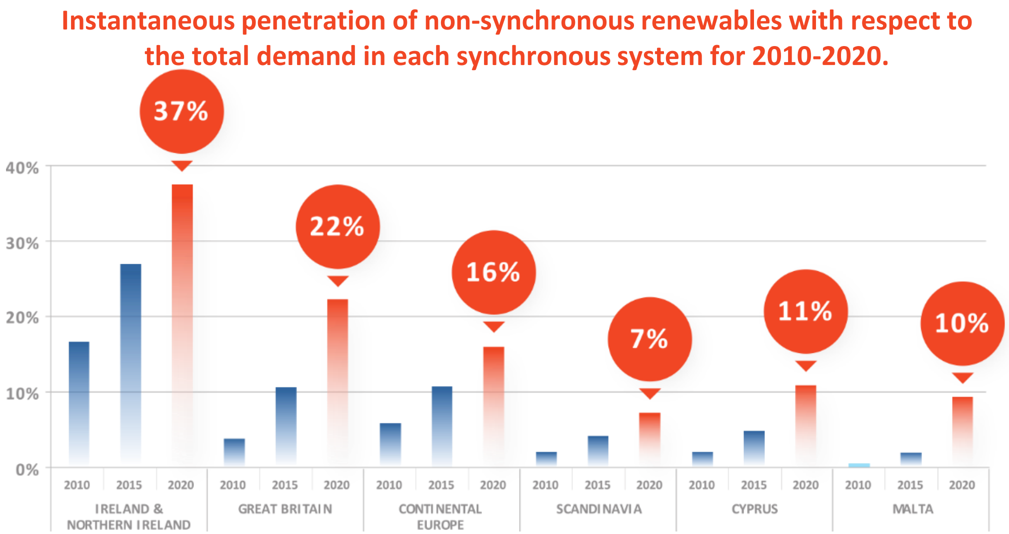
— (No specific market design/product yet, but internal considerations on inertia as a future ancillary service)



Current practice (ENTSO-E)

- ENTSO-E tries to harmonize rules and coordinate the implementation
  - Network codes related to inertia: mostly non-exhaustive and non-obligatory
  - System operation: inertia studies on synchronous area level
- Each synchronous area tackle the issue of low inertia in their own way:
  - Continental Europe
    - TSOs often apply conservative approach
    - General trend: higher ROCOF withstand capability and ROCOF relay settings (>1 Hz/s over 500 ms)
  - Other synchronous areas
    - Small areas are in general more prone to inertia issues
    - Ireland and Great Britain: forerunners in the implementation of new services!

Current practice (GB and Ireland)



Source: EirGrid,SONI &SEMO, "The DS3 Programme: Delivering a Secure, Sustainable Electricity System," The EirGrid Group, Brochure, 2011.

Current practice (GB and Ireland)

- Great Britain (GB)
  - — Limiting the largest credible loss
  - — Increase ROCOF relay settings
  - — New frequency control services & additional synchronous compensators
- Ireland
  - — DS3 programme to cope with high penetration of renewables (mainly wind)
  - — Increase ROCOF relay settings
  - — New services:
    - Fast frequency response
    - Synchronous inertia as a system service!
    - …

Source: EirGrid,SONI &SEMO, "The DS3 Programme: Delivering a Secure, Sustainable Electricity System," The EirGrid Group, Brochure, 2011.

Inertia assessment for Continental Europe (2030)

Approach and methodology

- Input data
- Hourly dispatch of generation per country
- Determine active units per country
- Inertia calculation
- Results: Post processing & analysis

- Input data: EUCO30 policy scenario & TYNDP2018
- Inertia calculation using:

Generation technology	Typical rating [MW]	Typical inertia constant H [s]
Biofuels	208	3.3
Hard coal	361	4.1
Gas	168	4.3
Lignite	310	3.9
Nuclear	869	6
Oil (THN)	153	4.3
Hydro-pump	140	4
Hydro-run	59	2.7
Hydro-dam	140	4
Other non-RES	104	3.7
Solar-thermal	150	3

Inertia assessment for Continental Europe (2030)

Approach and methodology

- EUCO30 policy scenario

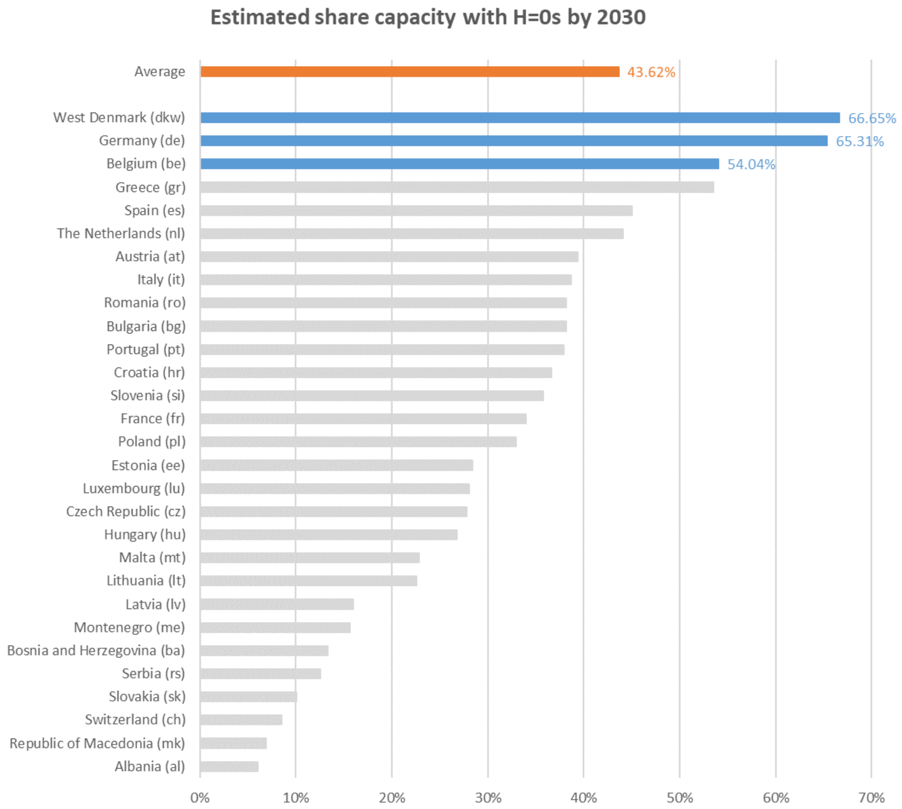
Green house gasses compared to 1990:
40% down in 2030
80-85% down in 2050

ETS (Emission Trading scheme) emissions: 43% less in 2030 than in 2005
Non-ETS emissions: 30% less in 2030 than in 2005

Targets

RES in 2030:
27% of gross final energy demand

Energy efficiency:
Reduced primary energy by 27% in 2030 compared to 2007



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Inertia assessment for Continental Europe (2030)

Results: Post processing & analysis

Maximum available kinetic energy

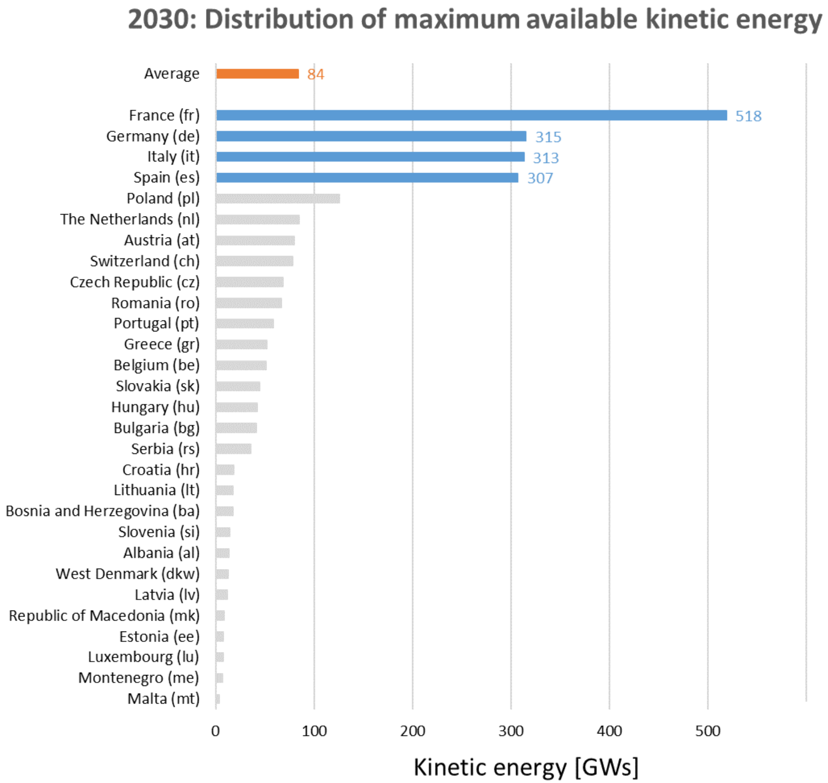
In 2020:

2633 GWs

-9%

In 2030:

2422 GWs



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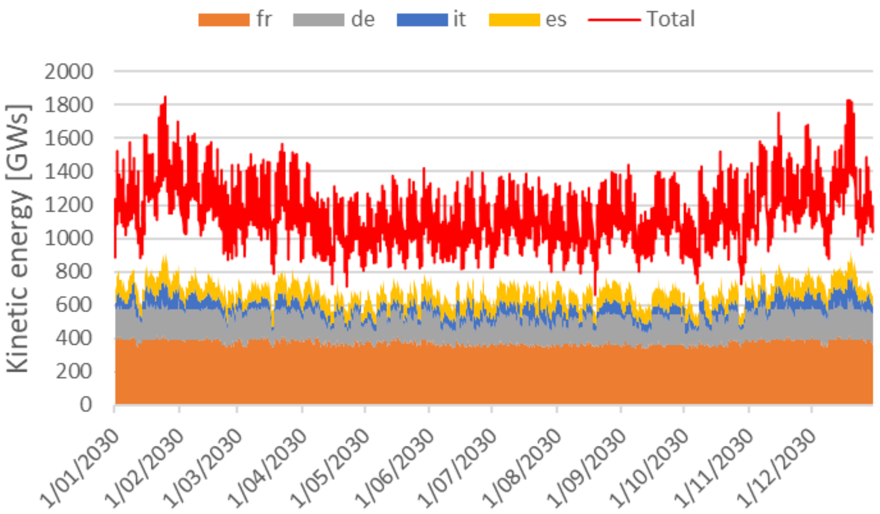
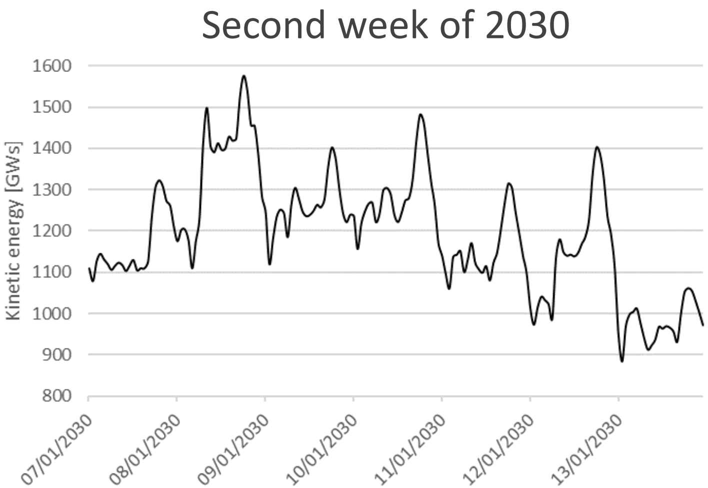
Inertia assessment for Continental Europe (2030)

Results: Post processing & analysis

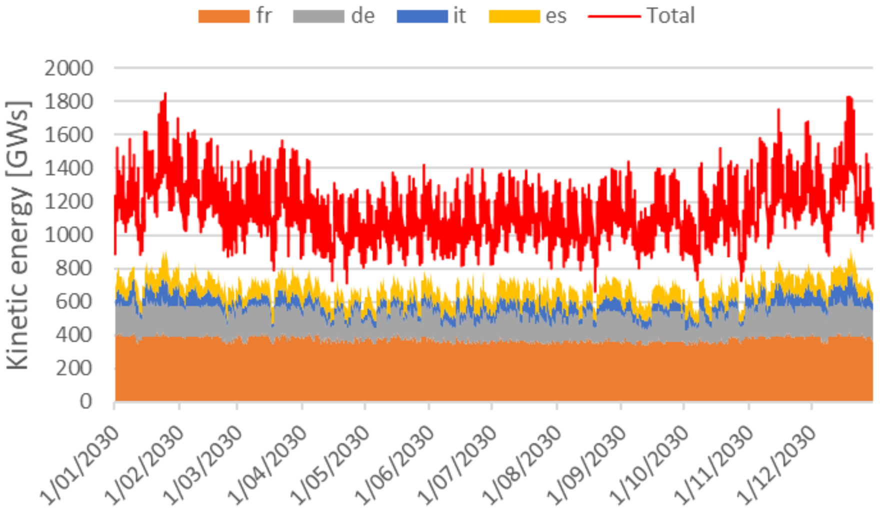


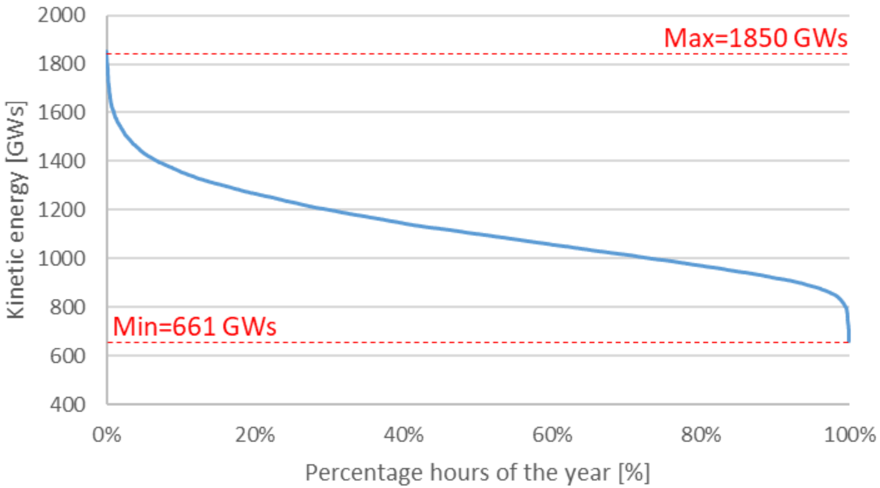


Inertia is highly depending on the load

Inertia assessment for Continental Europe (2030)

Results: Post processing & analysis





Current reference incident is 3 GW:

- Only 37,5 GWs required to keep ROCOF below 2 Hz/s
- Only 75 GWs required to keep ROCOF below 1 Hz/s

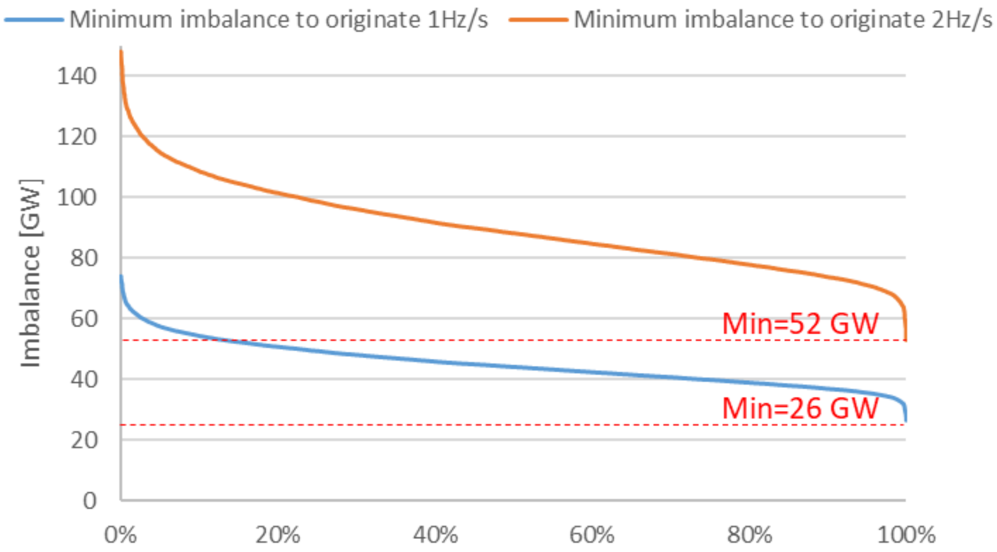
Inertia assessment for Continental Europe (2030)

Results: Post processing & analysis

Sufficient inertia/kinetic energy is <u>always</u> available to cover:

- imbalance of 26 GW and keep ROCOF below 1 Hz/s
- imbalance of 52 GW and keep ROCOF below 2 Hz/s

Large system splits are not considered!



04

Conclusions

Conclusions

- Higher converter connected penetration leads to a reduction of synchronous inertia
- Lower inertia will impact the frequency response
  - Higher ROCOF
  - Lower minimum frequency
- Myriad theoretical solutions exist in order to tackle the issue related to low inertia
  - Take into account complexity and impact of the implementation!
  - Very system specific approach often required
- Although ENTSO-E tries to harmonize rules and coordinate the implementation, currently each synchronous area tackles the issue of low inertia in their own way
- Continental Europe in 2030: Sufficient inertia available

Recommendations

- For **Continental Europe** *(Low inertia situations are very unlikely but not impossible in the far future!)*
  - Gradually put in place a tool to monitor and forecast the inertia at operational level (cooperation between all TSOs within Continental Europe required)
  - Define procedures to cope with the lack of inertia (for now: just apply redispatch to increase the inertia)
  - Review regularly the long-term needs to check if other measures to cope with the reduce inertia are necessary

- For **other (smaller) synchronous areas** within Europe
  - Detailed studies have been carried out and solutions are being implemented (see Ireland and GB)
  - They can be considered the European forerunners with respect to operating a power system with low inertia: it is therefore important to share the main outcomes, problems and experience with the TSOs from other synchronous areas.

- For **small islanded systems**
  - Local, ad-hoc solutions are required which are very system specific. No coordination between different operators is normally needed.

Thank you for your attention

Questions?

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