IENE Online Webinar

Tuesday 27 April 2021

"The Role of Energy Storage in Advancing Large Scale RES Penetration"

Grid-Scale Storage to support Large Scale RES integration in Power Systems

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Energy storage in power systems: Not a new story

- Energy storage has contributed to the operation of the electricity system already over decades based on the technical and economic grounds of arbitrage, storing electricity during low electricity demand and releasing it back into the grid during high demand, typically over a daily cycle.

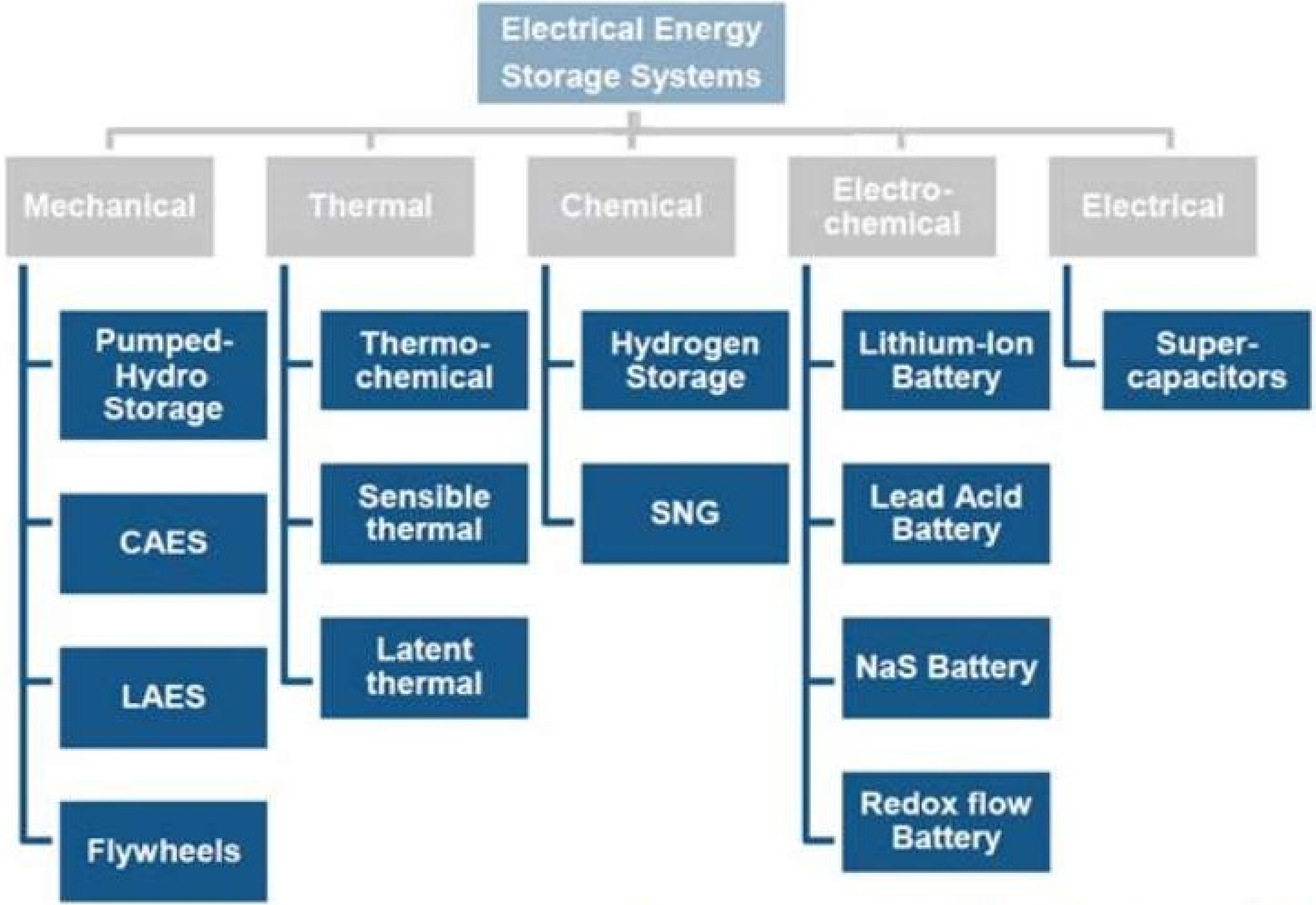
- Given that in the past the electricity generation mix relied almost exclusively on fossil fuels, nuclear and hydro, and variability of generation was not a major challenge, the necessity for energy storage was more limited and less economically attractive.

- However, the situation is changing with the growing share of renewables in electricity generation, and this is particularly the case in Europe.

- The main driver towards larger structural changes in the electricity system is the increasing variable intermittent renewable electricity generation.
  - Pumped storage is well established. Other megawatt-scale technologies are being developed.
  - At household level, behind the meter, battery storage is being promoted

- In November 2016 the European Commission acknowledged energy storage as a key flexibility instrument required in the future

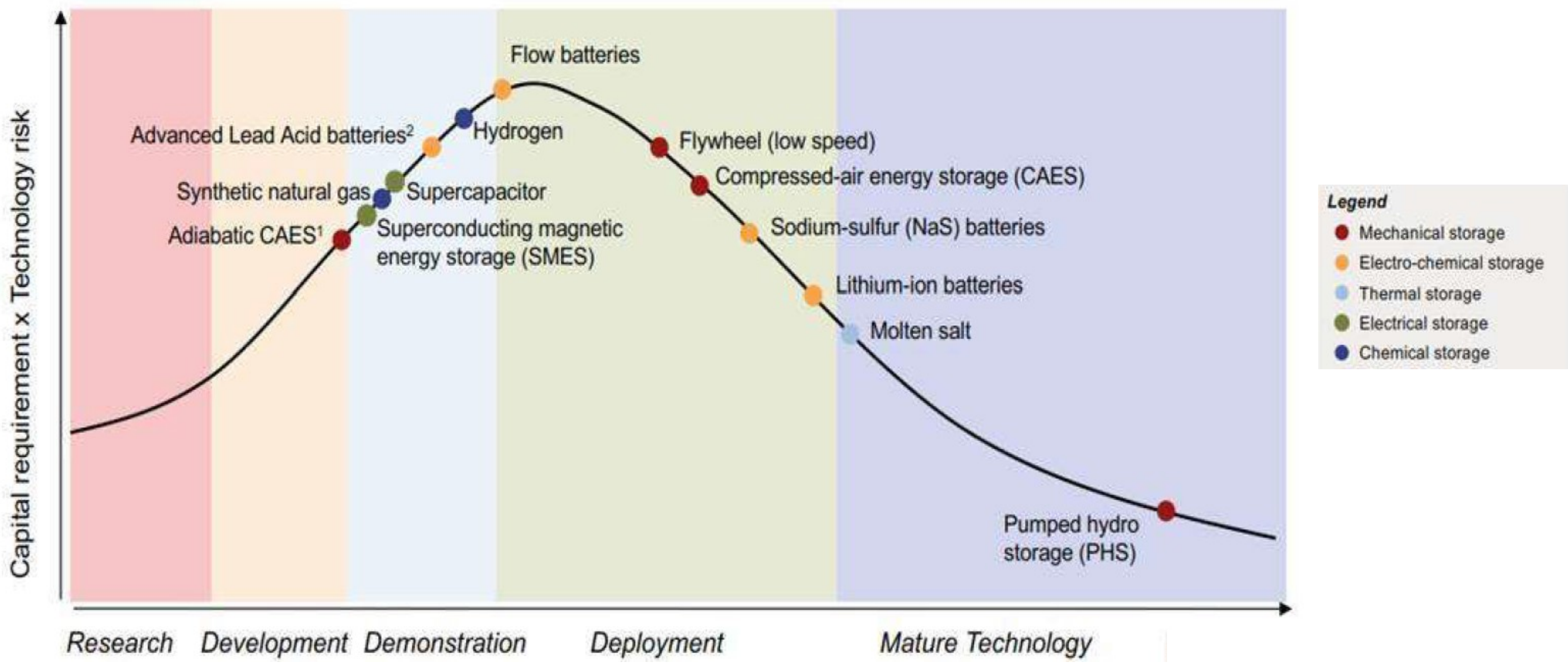
Energy Storage Types



CAES = Compressed Air Energy Storage; LAES = Liquid Air Energy Storage; SNG = Synthetic Natural Gas.

(source: World Energy Council)

Storage – Technology Maturity Curve



SOURCE : ILF Consulting Engineers Austria GmbH - AT. Kearney Energy Transition Institute analysis

Energy Storage Applications

1) Electric Supply	g) Voltage Support	m) Demand Charge Management
a) Electric Energy Time-shift	**3) Grid System**	n) Electric Service Reliability
b) Electric Supply Capacity	h) Transmission Support	o) Electric Service Power Quality
2) Ancillary Services	i) Transmission Congestion Relief	**5) Renewables Integration**
c) Load Following	j) Transmission & Distribution Upgrade Deferral	p) Renewable Energy Time-shift
d) Area Regulation	k) Substation On-site Power	q) Renewables Capacity Firming
e) Electric Supply Reserve Capacity	**4) End User/Utility Customer**	r) Wind Generation Grid Integration
f) Voltage Support	l) Time-of-use Energy Cost Management	

Source: SNL (2010) Energy Storage for the Electricity Grid

Grid-Scale Storage Key Services – Electric Supply & Renewables Integration

- **Storage of excess RES energy**
  - Avoid curtailments – energy spillage
  - Since this energy would have been curtailed, the value of this energy is the marginal generation cost during the hours when the energy is returned to the grid
  - A remarkable percentage of the energy is lost in the process
  - Business case for storage stations through market driven processes
    - intraday and balancing market
    - High RES production ---> lower SMPs ---> Store Energy from Grid
    - Low RES production ---> higher SMPs ---> Provide Energy to Grid

- **Energy Arbitrage**
  - The traditional function of energy storage (e.g. PSH) was to absorb energy during periods of excess generation or low prices in order to release it back to the electricity system in times of scarcity or high prices. The usage of storage for this basic function provided benefits which enabled a business case.
  - Well established through energy markets

Grid-Scale Storage Key Services – Electric Supply & Renewables Integration

- **Contribution to adequacy**
  - Storage can make renewable energy more "dependable" during periods of peak loads
  - By enhancing the Effective Load Carrying Capacity (ELCC) of the renewable generators, it is possible to avoid (or delay) the construction of additional conventional generation
  - Participation of storage applications in any Capacity Adequacy Remuneration Mechanism that will be established
  - Need to estimate capacity credit per storage technology
  - Possible applications on interconnected islands
    - Islands with limited "interconnection capacity" (interconnection capacity below their maximum load) , storage to operate in parallel with conventional production
    - Islands "fully interconnected" (no conventional unit in service on islands under normal conditions, storage to replace part of strategic "cold" reserve that will remain as emergency backup on islands

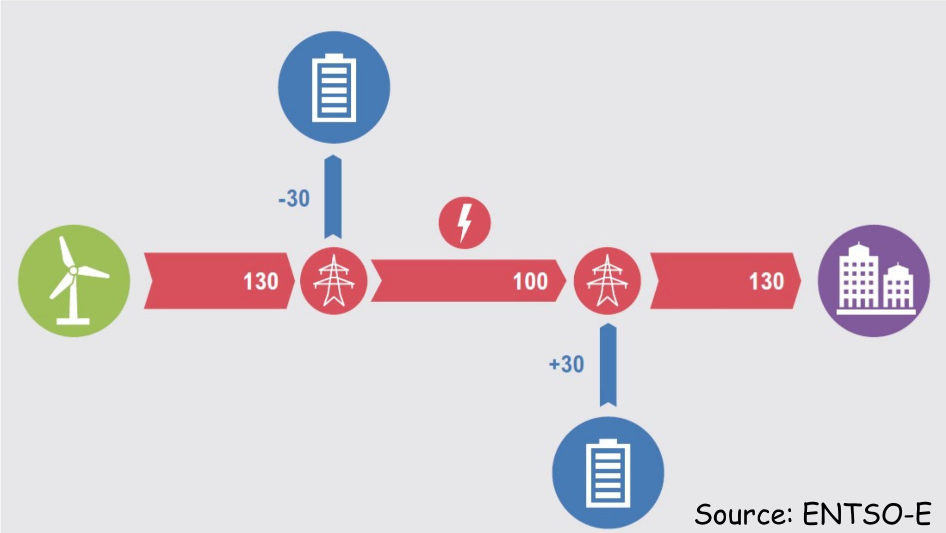
Grid-Scale Storage Key Services – Grid System

- **Congestion management (congestion relief)**
  - On the road to large-scale RES integration levels congestions stands out to be a critical factor
  - Introduce barriers already from the initial stage of connection process since Transmission System Operators restrict new RES connection to fullfill N-1 reliability criterion in Grid
  - Congestion issues strongly related to **local conditions** and having as a root cause RES stochastic production appear with **intermittency**
    - In the existing market, congestion is managed either through the Integrated Scheduling Process (ISP) during the preparation phase of a feasible dispatch schedule with the introduction of appropriate constraints, or through the mFRR process.
    - Not sufficient to fully exploit storage for congestion management

- **Upgrade deferral**
  - Virtual power lines concept makes possible to defer or avoid building new transmission lines or operate existing lines closer to their limits

Grid-Scale Storage – Enhance Transmission System Transfer Capacity

- **Concept of Virtual Power Line**
  - Null net energy balance of the involved storage systems
  - Locally high RES production lead to overload of the transmission "corridor", then first battery charges, while the other discharges at the same time and the opposite during periods of low RES production



Source: ENTSO-E

- In a similar but different case the traditional approach needs additional wires to meet the **n-1 reliability criterion**. The power flow of the system is limited, and the wires are underutilized

- The installation of storage systems with best practices can contribute to a more efficient usage of existing transmission lines while maintaining the N-1 reliability criterion and/or to be an alternative to the construction of new power transmission lines

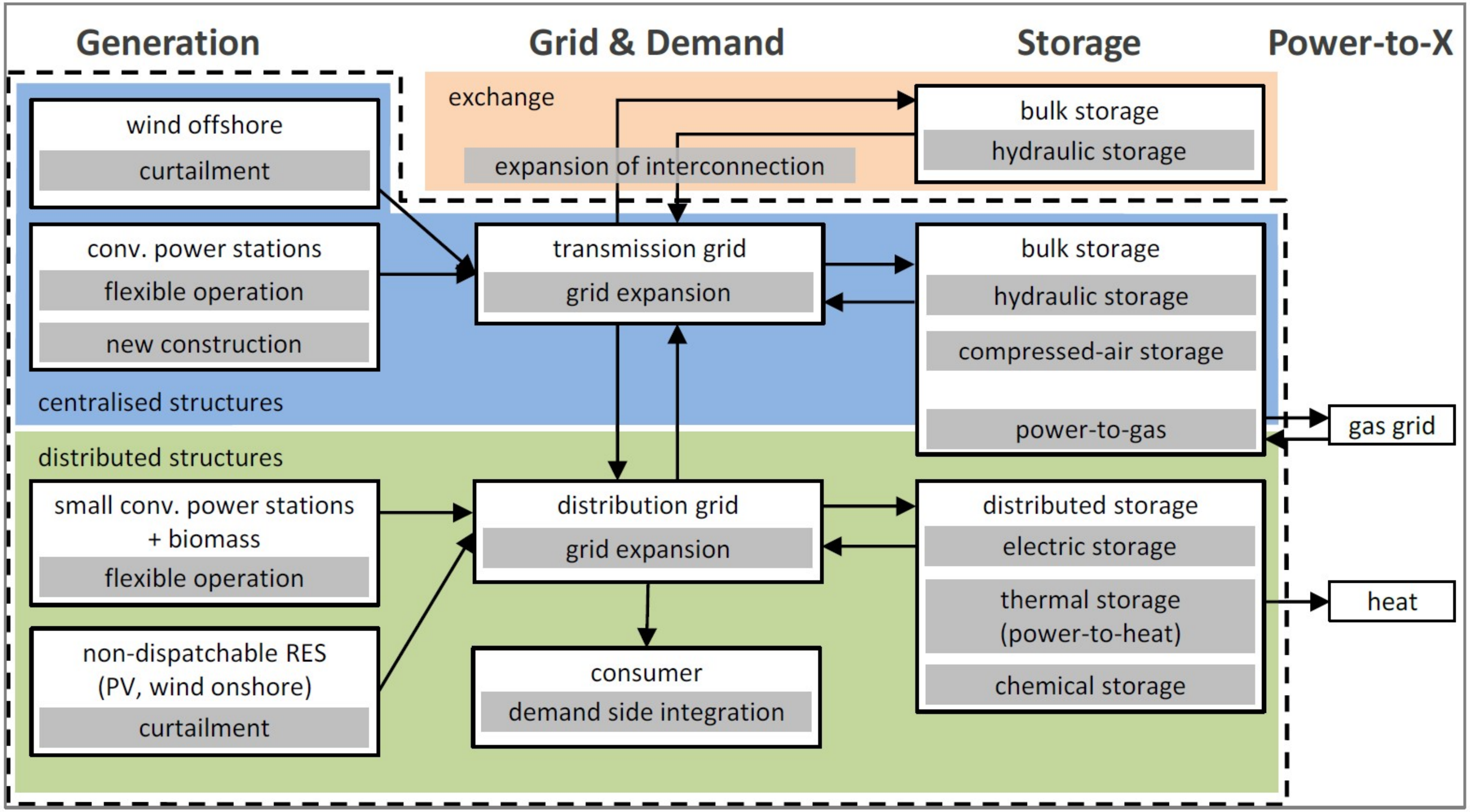
- In general not only two storage units and not only at the terminal of a corridor but a fleet of storage units may be operated at zero overall balance by the TSO and hence with a pure transmission effect.

Grid-Scale Storage Key Services – Ancillary Services

- **Regulation and Contingency Reserve Services**
  - Change in injected power to ensure real-time balancing
  - Increase in injected power after a disturbance, such as loss of a production unit
  - Ancillary Services from provision
    - FCR (primary regulation)
    - aFRR (automatic Frequency Restoration Reserve)
    - mFRR (manually Frequency Restoration Reserve)

- **Contribution to flexibility of the system**
  - The requirements for flexibility, in terms of quantity and time frame, are significantly different in the new low-carbon energy system
  - More flexible components will be needed in the electricity system to compensate for the increasing amount of variable RES electricity generation
  - Storage is one of these components

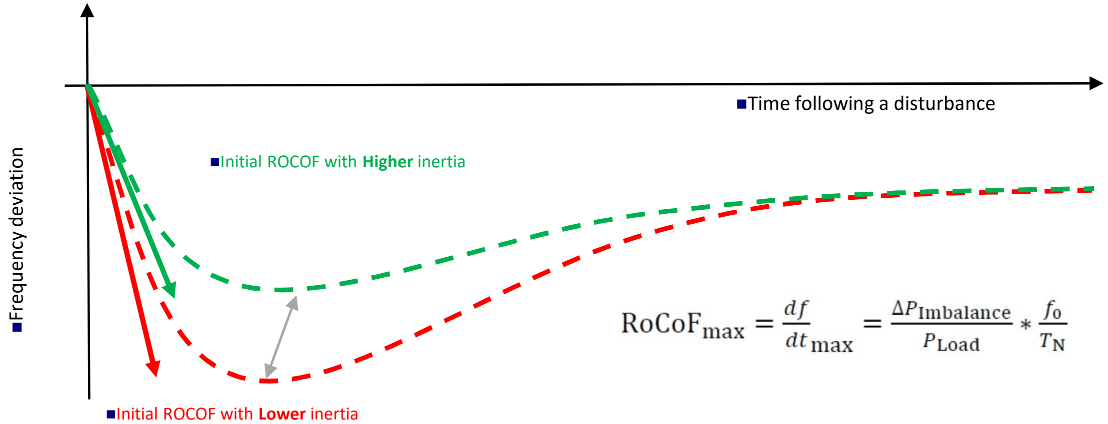
Flexibility options in the electricity market



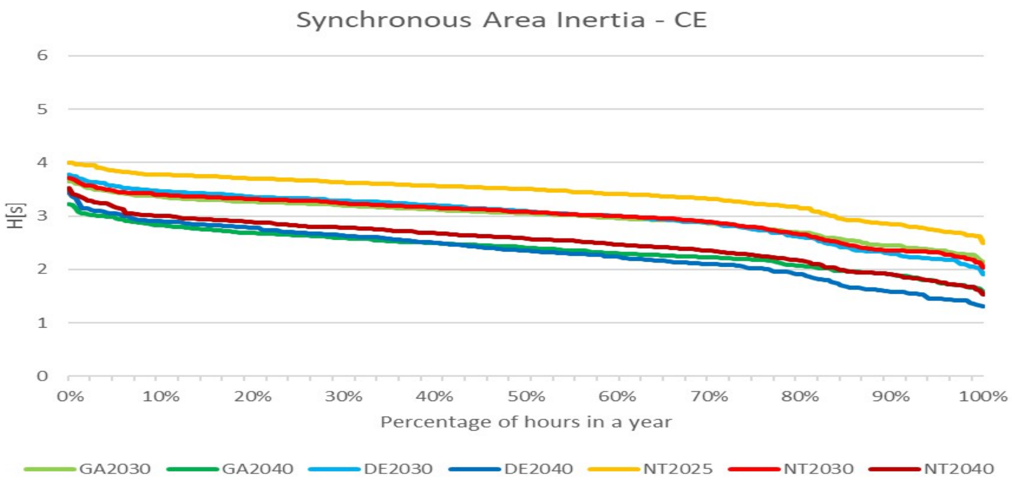
(Hufendiek, 2015)

Grid-Scale Storage Key Services – Ancillary Services

- **Kinetic energy storage**
  - Decommissioning of thermal power plants composed from synchronous generators with high rotating masses lead to critical lack of inertia
  - **Inertia challenge in Europe**
  - **Steady tendency in the reduction of inertia from 2025 to 2040**
  - The higher the amount of converter connected generation in the energy mix, the lower the inertia

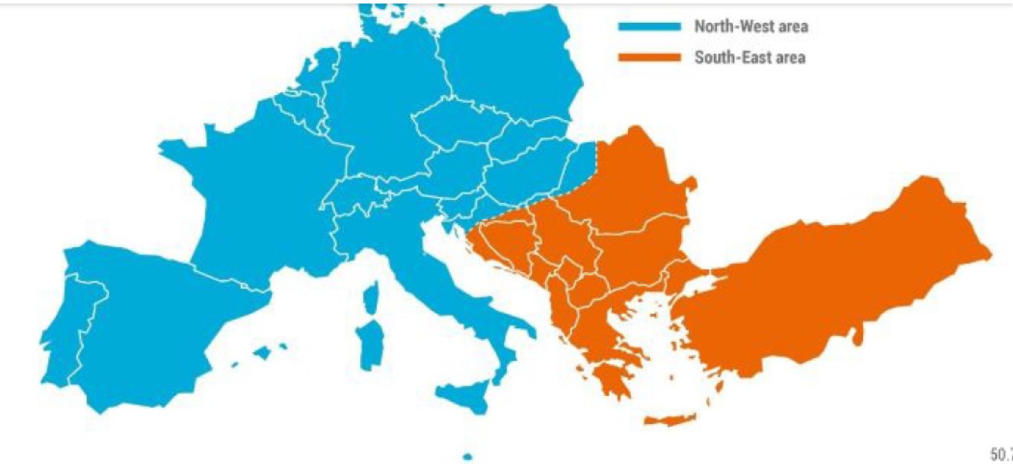


$$\mathrm{RoCoF}_{\max} = \frac{df}{dt}_{\max} = \frac{\Delta P_{\mathrm{Imbalance}}}{P_{\mathrm{Load}}} * \frac{f_0}{T_N}$$



- ✓ Higher inertia means more capability to withstand instantaneous generation and load imbalances while maintaining the system frequency within acceptable variations and limits.
- ✓ Conversely, lower inertia, means lower capability to deal with the same issues.
- ✓ Small synchronous areas would see rapid and large frequency excursions following a normal generation loss, large synchronous areas would not see the same size of frequency excursions unless a significant disturbance occurs such as a **system split**.

System Separation in the Continental Europe Synchronous Area on 8.01.21

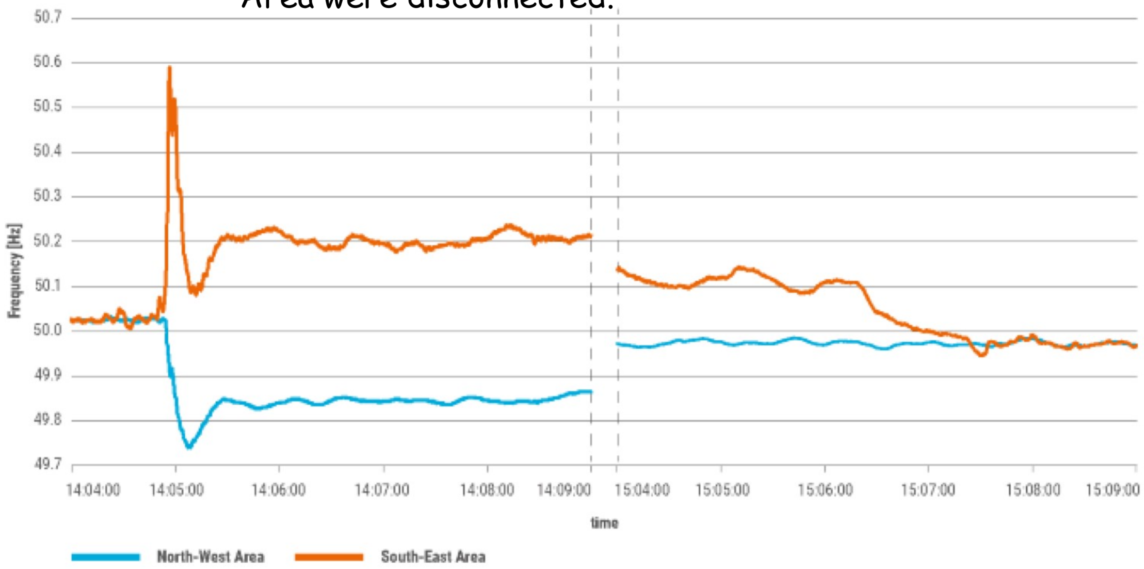


- Separation initiated by a "simple" event in the SS Enerstinovo (Croatia)

- The system separation resulted in a deficit of power (approx. -6.3 GW) in the North-West Area and a surplus of power (approx. +6.3 GW) in the South-East Area

- Frequency in the North-West Area initially decreased to a value of 49.74 Hz while in the South-East Area initially increased up to 50.6 Hz

- Contracted interruptible services in France and Italy (in total around 1.7 GW) were disconnected in order to reduce the frequency deviation
- To reduce the high frequency in the South-East Area, automatic and manual countermeasures were activated, including the reduction of generation output
  - ✓ 1,2 GW of dispersed generation and old Wind farms disconnected in GR
- Customers in the order of 70 MW in the North-East Area and in the order of 163 MW in the South-East Area were disconnected.



Grid-Scale Storage – Ancillary Services

- **Synchronous condenser + flywheels:** Rotate without a prime mover with excitation adjustable over a wide range of values
  - Increase equivalent system inertia
  - Support grid voltage by providing dynamic reactive power regulation
  - Improves grid short circuit strength

- Mature technology that exist in power systems for about a century
  - Projects are now being planned for other reasons than voltage support (inertia, short circuit)
  - **Fully Integrated Network Components: TSOs to develop and operate**

- Many Synchronous condenser projects have been completed in recent years in Germany, Denmark, Italy and USA
  - Project Uchltelfangen (Germany) 330 MVAR Anprion GmbH (2019)
  - Project Bergheinfeld (Germany) 250 MVAR TenneT GmbH (2015)
  - Project Partinico (Italy) 170 MVAR TERNA (2015)
  - Project Favara (Italy) 170 MVAR TERNA (2015)

Grid-Scale Storage Key Services – Ancillary Services

- **Fast Reserve Service**
  - Fast frequency response indend to support frequency stability and act complimentary to the Frequency Containment Reserve, especially in systems with relatively low inertia
  - These services are useful in systems exposed to high frequency disturbances, so that the frequency nadir after a disturbance is kept at sufficiently high levels (e.g. Ireland, United Kingdom)
  - Identification of needs could lead to develop a special remuneration mechanism (similar to capacity mechanisms) for these services
    - In Italy, a relevant mechanism was approved in 2020 for the period 2023-2027 with the product of automatic response of units to frequency deviations within 1 s and a total capacity of 250 MW was assigned to Storage Stations

Energy Storage System Installation Cost

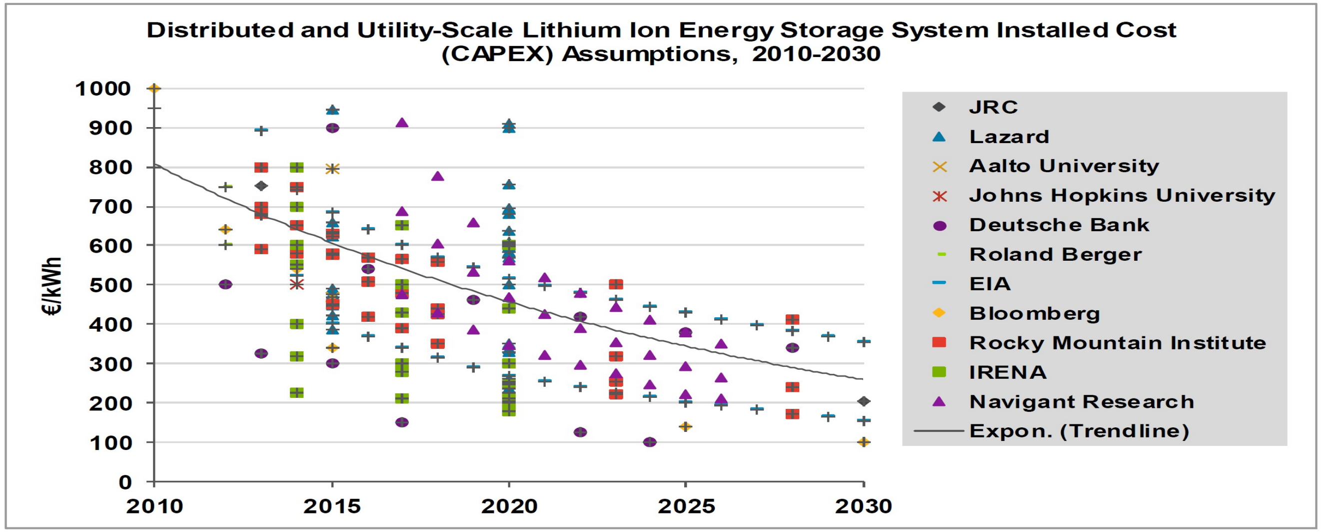


Figure 2. Past and forecasted Lithium-Ion Battery system costs for distributed and utility-scale batteries. Own representation based on [IRENA] [EPRI] [RMI] [Bloomberg] [EIA] [Roland Berger] [Deutsche Bank] [Castillo] [Zakari] [Lazard] [JRC 2014] [Navigant].

- **Revenues of Storage Stations:**
  - Energy revenues from the Day - Ahead, Intra - Day and Balancing Market
  - Ancillary Services from provision of aFRR (automatic Frequency Restoration Reserve) and mFRR (manually Frequency Restoration Reserve)
  - Remuneration of the Projects by other mechanisms (i.e. the Capacity – Flexibility mechanism)
  - **Other non-market, grid related services need further elaboration**

- Li-ion Batteries cost expected to reduce up to 3 times during the period 2010-2030
  - Nevertheless even in 2030 batteries installation cost remain non competitive
- **Storage projects cannot rely on the wholesale electricity market revenues in order to cover fixed and variable costs**
  - Congestion management service remuneration could provide additional revenues to storage stations and in the same time benefit the whole electricity market

Grid-Scale Storage Key Services – Congestion Management

- **An opportunity can be recognized regarding congestion management issue**
  - Clear necessity, due to spread of evolving congestions in the network, to create suitable conditions to advance large scale RES integration and penetration to the system to meet ambitious med & long-term targets
  - Contribute to the storage revenues to support their economic viability
- **Transmission System Operator critical role**
  - TSO to identify local needs and suggest areas/nodes for storage installations to be addressed by tendering procedures
  - In case of own developments, by paying for these strategically located batteries on the grid, the transmission operator could defer much more expensive investment in network upgrades
  - TSO to operate a fleet of storage stations (own and other parties) for congestion relief in a market neutral mode
    - ✓ Need for a Storage Balance Control (SBC) application to act in real time similar to AGC application. As system operators are not allowed to partake in energy markets, it is necessary to implement a particular operational protocol: at timeframe of balancing market, the net energy balance of the involved storage systems has to be null – when one battery discharges, others charge at the same time.
    - ✓ IPTO has designed and proposed in TYNDP "small" pilot projects to experiment and gain experience in this field

Grid-Scale Storage Key Services – West Macedonia example

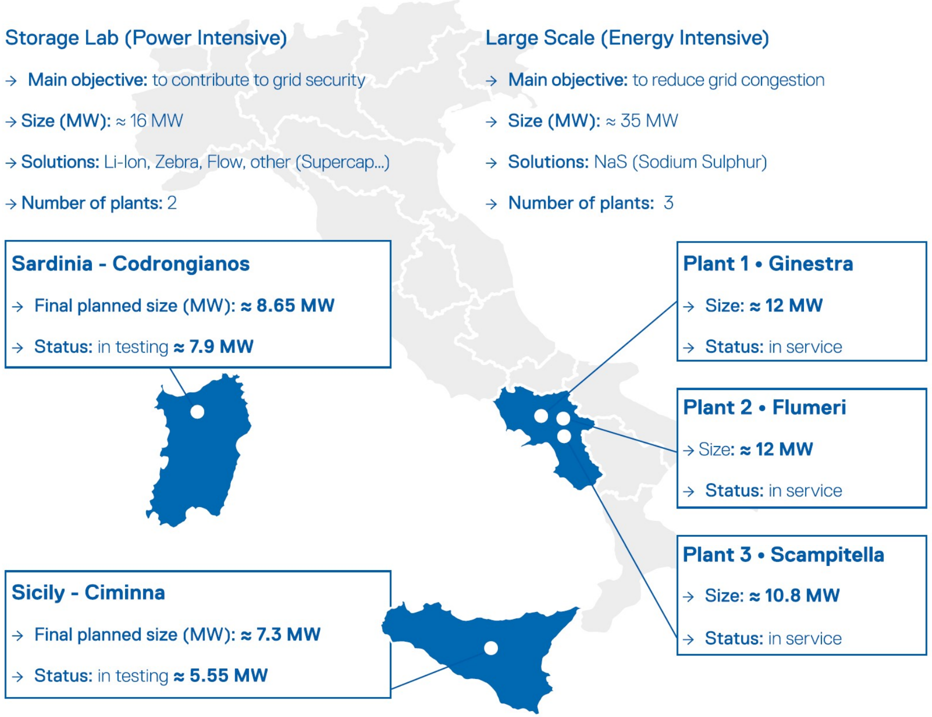
- ~3,7 GW of lignite fired power plants to be decommissioned
- ~4,1 GW existing and future (with bidding connection agreements) RES projects
- Major project (1,9 GW PV parks) related to Road Map for a Managed Transition of Coal-Dependent Regions in Western Macedonia (SDAM)
- Transfer capacity in the sub-transmission grid of 150 kV exhausted ---> **Saturated Network**
- At the same time, already 250 MW BESS project has been approved by RAE and other 700 MW are under consideration
- ***One way direction ---> Exploit BESS projects also for congestion relief purpose***
- Similar cases: Peloponnese, Evia, Thraki areas

Italy – Terna Pilot Storage Projects

- The growing increase in electricity generation plants using non-programmable renewable sources, especially in the Southern regions of Italy and on the two biggest islands have had an increasingly tangible impact in recent years on the dispatching of electricity and in general on the safe operation of the National Electricity System.

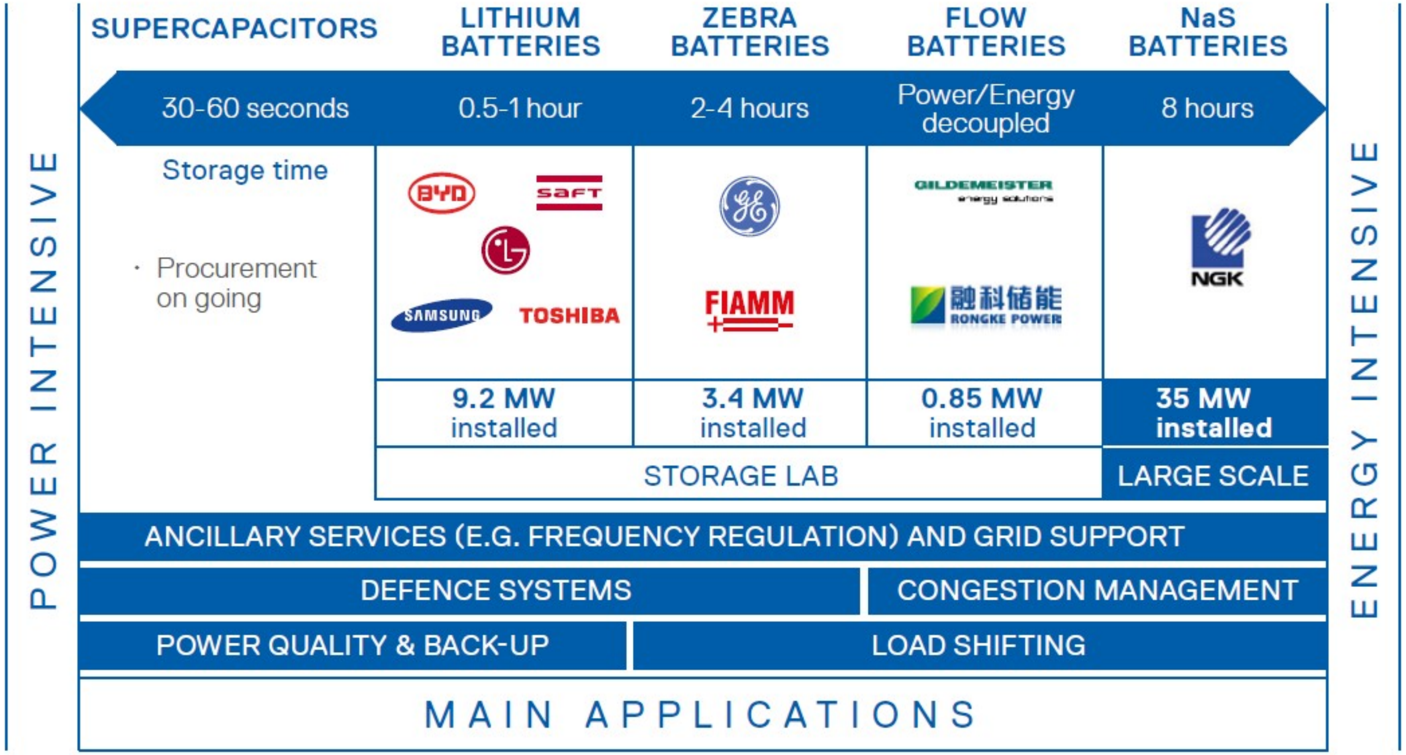
- In order to optimise generation from renewable sources and at the same time ensure increased security management of the Electricity System, Terna has identified energy storage as one of the possible solutions to the problem, planning the installation of new storage technologies connected to the National Electricity Transmission Grid

- **The primary object of the project is to reduce the amount of network congestion in the hours when wind production exceeds the transport capacity in the relative parts of the grid experimenting with additional services and useful applications with the grid operator**



- Terna has planned a highly innovative project based on the use of "energy intensive" electrochemical storage technologies, in other words with a high storage capacity compared to the plant power,
- NAS batteries (sodium/sulphur technology) was selected via tender as the most suitable for the purpose
- The three plants are currently operating under remote control

Italy – Terna Pilot Storage Projects



- The functions developed to conduct and ease the grid services of the storage units not only designed to optimise planned primary objectives (mitigation of grid congestions), but also contribute significantly to maintaining Grid security (e.g. primary frequency regulation) and making the most of the highly innovative nature of the project (e.g. experimental calibration of the primary regulation and easement of the secondary f-P regulation, development of new, advanced conduction, monitoring and dispatching functions etc.)

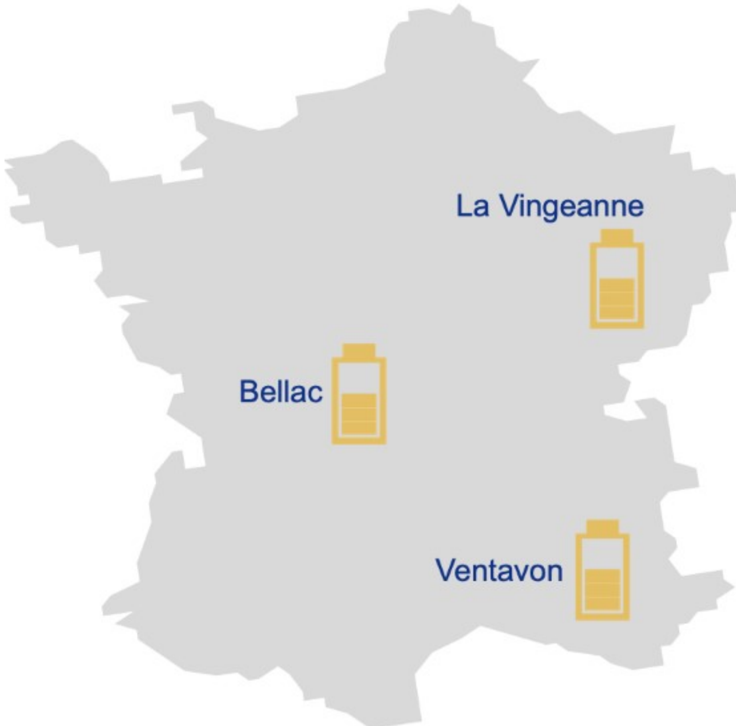
France – RTE Pilot Storage Projects

- RTE first announced the project in March of 2017, using energy storage systems to relieve congestion instead of constructing extra power lines.

- **Battery storage systems will be placed where the lines are congested and absorb large amounts of fluctuating renewable energy resources.**

- The French Energy Regulatory Commission (CRE) has approved a budget of €80 million for this project.

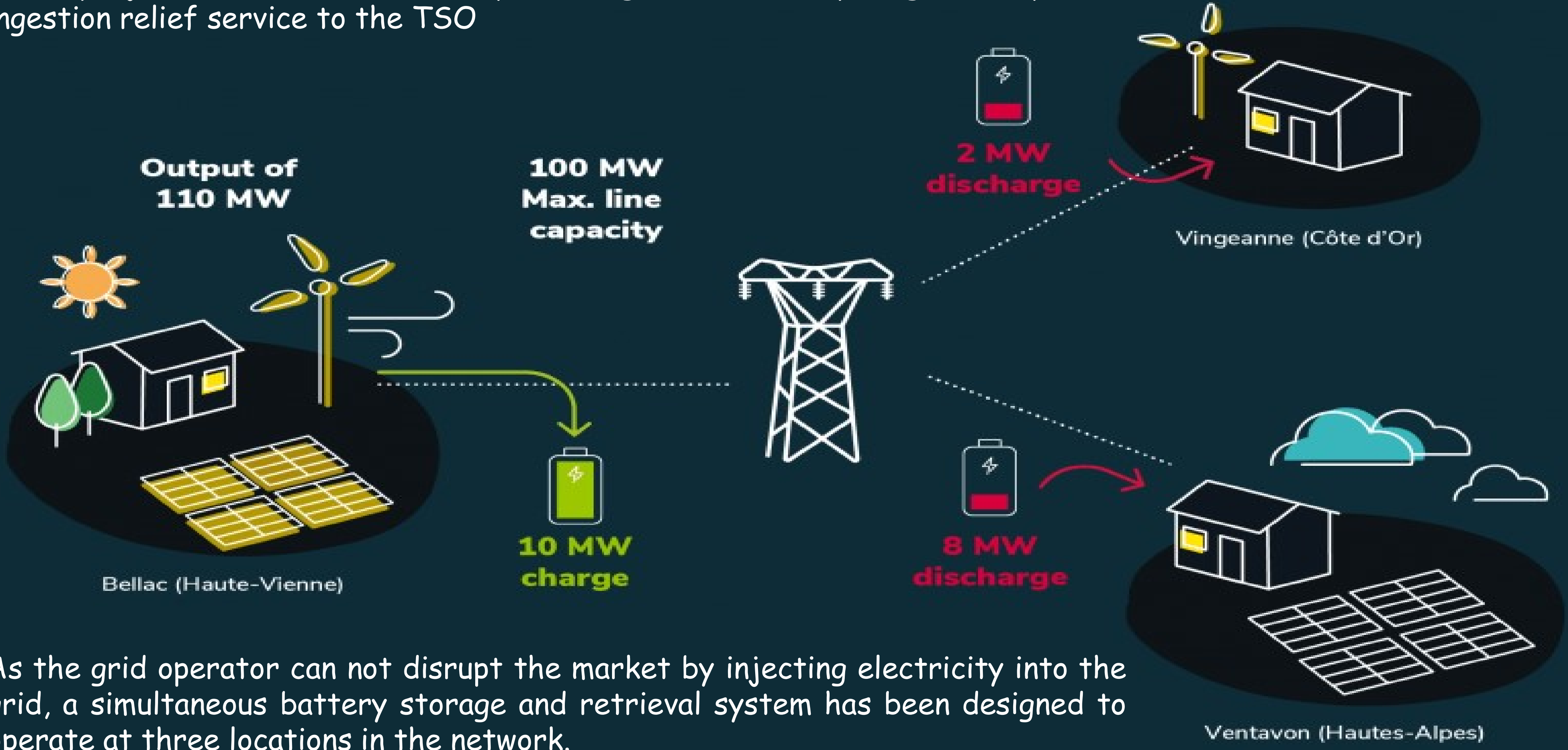
- From 2020 to 2023, the batteries will be operated solely by RTE, as "virtual power lines ". From the beginning of 2023, they will be open to be used by third parties (through contracts with RTE) for potentially multiple uses such as frequency regulation, demand and supply adjustment, congestion resolution and energy arbitrage, among others



Sites	Storage size	Technology providers	Cell manufacturer
Vingeanne	12 MW 37 MWh	NIDEC ASI Fr	Li-ion LG Chem
Bellac	10 MW 30.8 MWh	Saft / Schneider	Li-ion Tianneng
Ventavon	10 MW 30.2 MWh	Blue Solutions / SCLE SFE / INEO	LMP Bolloré

France – RTE Pilot storage project using virtual RINGO power lines

RINGO project from RTE aims at experiencing virtual lines, paving the way for congestion relief service to the TSO



As the grid operator can not disrupt the market by injecting electricity into the grid, a simultaneous battery storage and retrieval system has been designed to operate at three locations in the network.

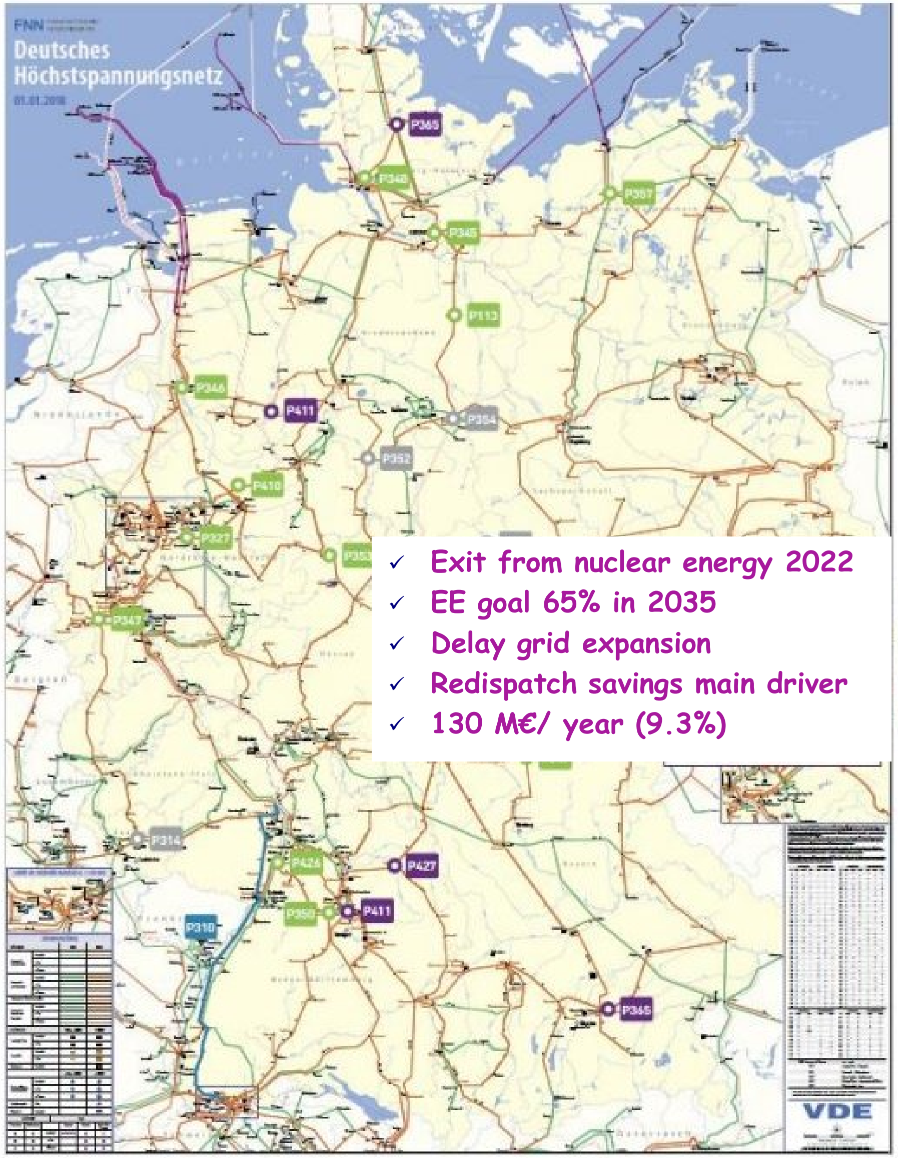
Germany – Grid Booster concept

- In Germany, the power generating landscape is changing fast in the course of the energy transition and increasingly large amounts of renewable electricity must be transmitted from the north and east to the south and west

- At the same time, the grid infrastructure needs to expand. As a result, the German power grid is reaching its thermal and stability limits. Consequently, congestion measures like redispatch are needed. If the generated electricity exceeds line capacities, the four German transmission system operators (TSOs) have to perform costly redispatch measures.

- To cope with these challenges, as so to minimise the need for grid extension and cut redispatch costs, the idea is to use unexploited transmission capacities. Among the most promising of these concepts (power-to-X, monitoring systems etc.) is the Grid-Booster.

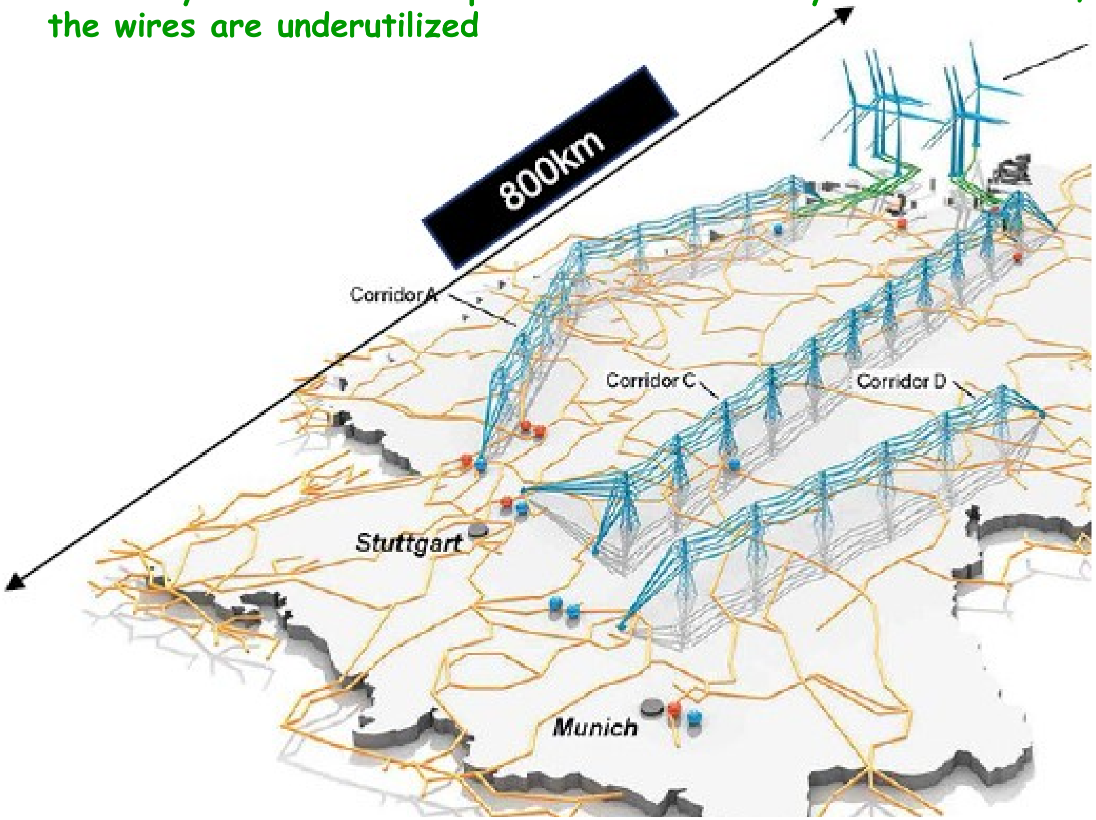
- The Federal Network Agency, the competent authority, has approved the booster plan. The concept includes fast power sources in the shape of a large battery at the ends of a line section that is subject to frequent overload.



- ✓ Exit from nuclear energy 2022
- ✓ EE goal 65% in 2035
- ✓ Delay grid expansion
- ✓ Redispatch savings main driver
- ✓ 130 M€/ year (9.3%)

Germany – Grid Booster concept

The traditional approach needs additional wires to meet the n-1 reliability criterion. The power flow of the system is limited, and the wires are underutilized

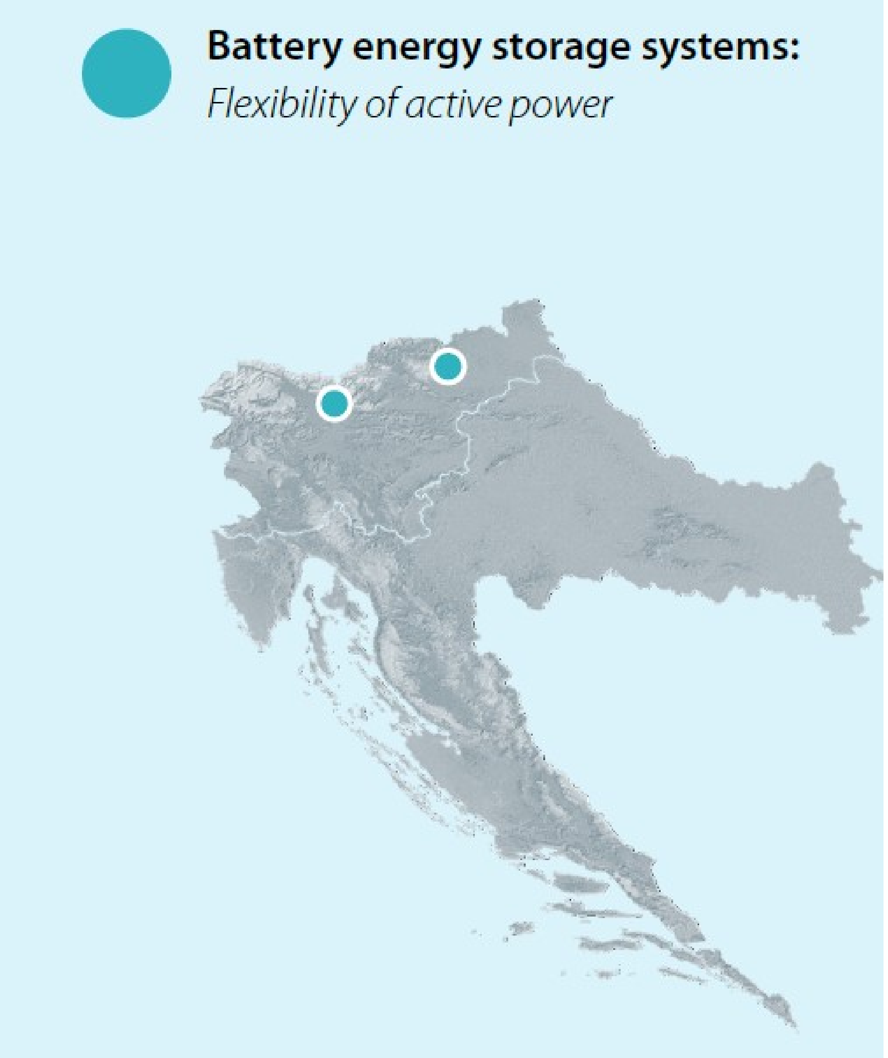


The new approach utilizes a storage system to meet the n-1 criteria as Back-Up. The power flow of the existing system is massively enhanced.

- In contrast to the classic preventive approach, the GridBooster ensures a (n-1) secure grid operation reactively, i.e. after fault occurred. Therefore, the power load of existing power lines can be increased beyond presently valid stability limits saving preventive redispatch. In order to implement and test the Grid-Booster concept a pilot project has been started. Specifically, two spatially separated energy storage devices are planned to be installed in the north and south of the main grid congestions which act as source and sink of a "virtual power line" in case of emergency

- The grid booster that is envisaged will have an output of 250MW. The booster battery can supply energy within a few seconds. In periods of high grid load, the booster is intended to relieve the system in case of disturbances until the bottleneck can be eliminated in a targeted manner by the system management.

Slovenia (ELES) & Croatia (HOPS) – SINCRO.GRID project



- The increasing integration of decentralised renewable energy sources (RES) both in the regions of Slovenia and Croatia has led to a lack of flexibility resources needed to regulate the electricity system.

- In 2014, the transmission system operators (HOPS and ELES) and distribution system operators (HEP ODS and SODO) of Croatia and Slovenia began to search for joint solutions. The most promising appeared to be the establishment of international cooperation in setting up smart grids – and the idea of the SINCRO.GRID project was born.

- Croatia and Slovenia decided to present the project to the European Commission (EC) as a proposal for a Project of Common Interest (PCI) in the field of smart grids.

- Within the framework of the SINCRO.GRID - Phase 1 project, two battery storage units (Li-ion Batteries) with a capacity of 5 MW will be installed at the existing substations of Okroglo and Pekre. Their main purpose is to increase the flexibility of active power and thus enhance adaptation of the electricity system to modern challenges in operation.

Large Scale Grid Energy Storage – A discussion on a fundamental question

- **How much storage is needed for the Greek Power System ?**
  - There is no direct answer to this question as the amount of storage that the system "needs" is not a technical magnitude for which the need for the system can be assessed, e.g. the firm power deficit to meet system adequacy or the size of a specific type of reserves (which can be dimensioned based on reliability criteria)
  - Storage is a category of (flexibility) options available to be applied in order to satisfy the system needs, such as generation adequacy, ramping capability and reserves. The total size of storage that should be integrated into the system depends on which solutions are considered more economical.
    - storage
    - flexible thermal units,
    - flexibility from RES units, including curtailment,
    - increased interconnectivity,
    - demand response
  - Since any storage service on the system can come from other sources, the question is how much cheaper is the system for each storage size compared to other solutions and therefore in general which storage sizes offer enough benefits to be the best solution

Large Scale Grid Energy Storage – IPTO study to support NECP

- In the framework of NECP IPTO has conducted a **technical study on the operation of Greek Power System for year 2030 to assess the expected generation shares (including imports/exports) and the size of curtailments, as well as to investigate the benefits of different sizes of storage stations and the alternative technologies of pumped storage and batteries**, that are considered to be the short-term prospect of possible applications in Greece. The study was based on NECP forecasts and ENTSO-E methodology and data, with a regional model of South-East Europe, in order to adequately take into account the contribution of international interconnections to the flexibility of the system. According to the conclusions of the study:

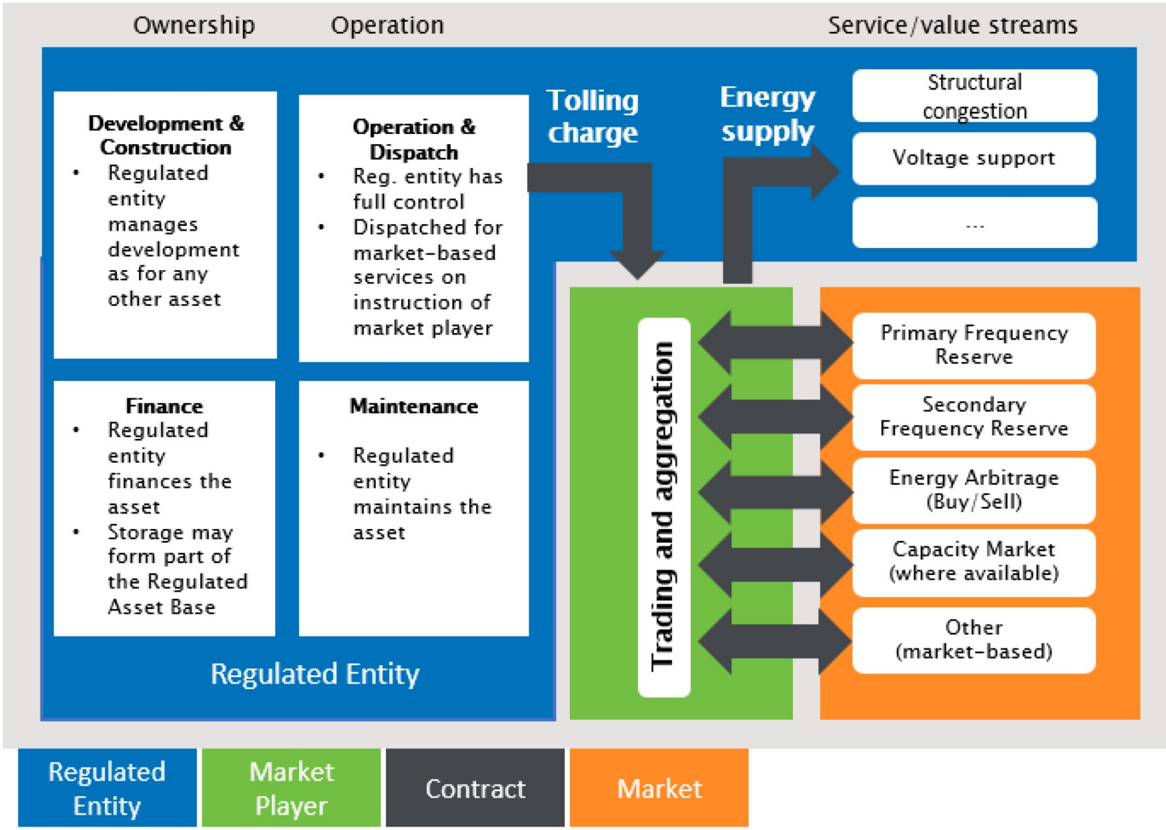
    - The mixture of production and storage devices considered in NECP for the year 2030 results in small sizes of curtailed RES energy, of the order of 0.5% of the total available wind and solar production.

    - The benefits for the system from the storage that were quantified in the study (system operating costs, decrease of curtailed energy, contribution to the adequacy of power) from the installation of 1,4 GW storage was calculated in the range 40-46 M€ per year. The overall benefits are expected to be higher due to the contribution of storage stations to cover part of the reserves needs.

    - Comparatively considering pump storage and batteries technologies, it seems that to the extent the system needs important contribution to the generation capacity adequacy, pump storage technology has a significant advantage. Once generation capacity adequacy is not the main concern, the integration of BESS becomes more advantageous, for addressing mostly other flexibility needs.

Large Scale Grid Energy Storage – What business model we need?

- A **two-sided multi-service business model is needed to maximise the social welfare of storage facilities**:
  - Storage owned by third parties providing also services to the grid
  - Storage owned by TSOs with tolling contracts (following transparent procedures) with market players to provide market services



Source: Overview of Multi-Service Business Case Involving a Regulated Entity and a Market Player EASE, 2019.

Thank you for your attention

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