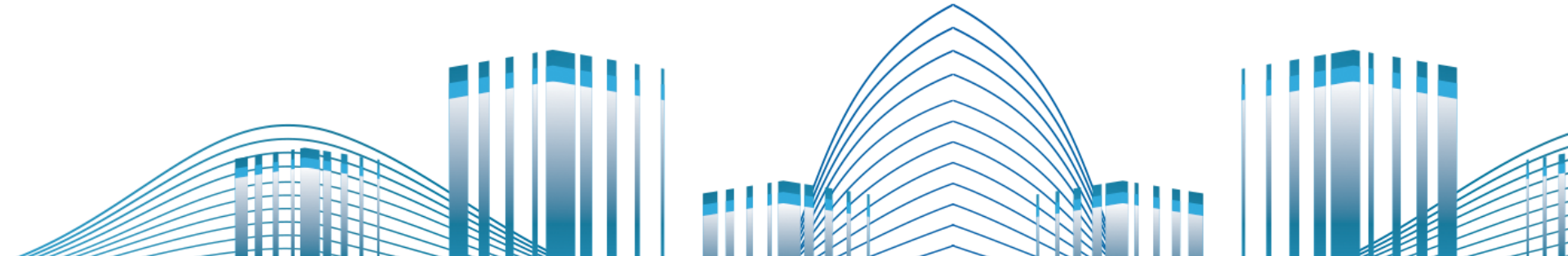
Terna’s Grid-Scale Battery Storage Projects

Results from experimentation

Maura Musio – Innovation & Storage, Terna

Nicosia, November 24th 2017



ABOUT TERNA

CURRENT SCENARIO AND FUTURE CHALLENGES

TERNA'S EXPERIENCE OF ENERGY STORAGE INTEGRATION IN THE TRANSMISSION GRID

LESSONS LEARNED AND FUTURE PERSPECTIVES...

About Terna – Company Profile

Terna is

- ...the **owner** of the Italian High Voltage National Transmission Grid
- ...**responsible for the transmission and dispatching of electricity** throughout the Country
- ...in charge of the development and maintenance of the HV Grid, employing a **workforce of ~3,700**
- ... Listed on the Stock Exchange since 2004, it is **one of the leading industrial companies on the FTSE-MIB index**

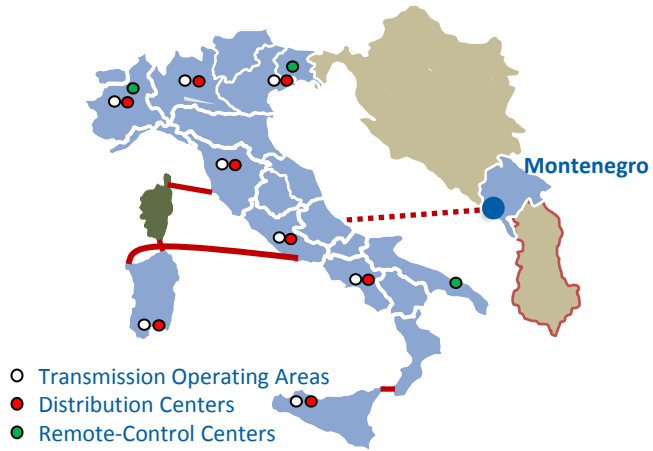
Numbers ...

Grid
~ 72,600 km of high and extra-high voltage power lines
(132/150 kV, 220 kV, 380 kV)
21 Interconnections lines with neighbouring countries
852 Substations

Assets
8 Transmission Operating Areas
8 Distribution Centers
3 Remote-Control Centers
1 Foreign Subsidiary

Electricity Market
316,9 TWh of energy consumption (2015)
≈60,491 MW demand peak

... and premises



ABOUT TERNA

CURRENT SCENARIO AND FUTURE CHALLENGES

TERNA'S EXPERIENCE OF ENERGY STORAGE INTEGRATION IN THE TRANSMISSION GRID

LESSONS LEARNED AND FUTURE PERSPECTIVES...

The Italian Context

Causes

- **Economic crisis** and subsequent loss of many big consumers (i.e. national **demand decreased** 12% from **340 TWh to 300 TWh**)
- Aggressive policy of **incentives promoting RES** + imminence of grid parity
- **No time to fortify** and develop the grid to support new scenarios

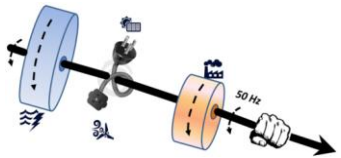
Effects

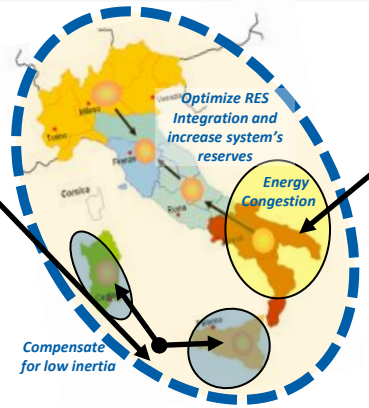
- Fast and massive **growth of RES**:
  - → ***Rise in congestion****-related curtailments (i.e. 2010 ~500 GWh lost)*
- Traditional **power plants** running at **minimum load**:
  - → ***Loss of inertia*** *in smaller insular systems (i.e. Sicily and Sardinia*)
  - → ***Loss of*** *available frequency* ***reserves***

Mitigating actions

Optimize **integration** of RES and increase **flexibility** of national grid (i.e. smarter grid)

Power Problem





Energy Problem

Key Enablers of the energy transition

Capacity Market	• Mechanism aiming at ensuring system **adequacy** by means of long term price signals in the energy market structure
Network Development	• **Transmission capacity** increase and interconnection with other countries
Storage	• **Utility scale** and **distributed** small-medium scale **storage** solutions development
Demand Response	• **Enabling demand** to participate to the market, providing ancillary services
Smart Grid	• Investing in **FACTS** (Flexible AC Transmission System) and **real time grid management system**
Market Evolution	• Driving the evolution of Ancillary Services Market to foster the **participation of new resouces** (demand, distributed generation, storage) and **new actors** (e.g. aggregators)
Data Management	• **Full availability of** metering **data** from any resource/operator and implementation of a **management platform**

It is required to develop the proper mix of actions among which a further increase of storage capacity

ABOUT TERNA

CURRENT SCENARIO AND FUTURE CHALLENGES

TERNA'S EXPERIENCE OF ENERGY STORAGE INTEGRATION IN THE TRANSMISSION GRID

LESSONS LEARNED AND FUTURE PERSPECTIVES...

Storage Terna projects track record

Energy Intensive projects

October 2012
Italian ministry approval

April 2013
Tender started – battery supplier

December 2014
Service started - provisional layout

Testing

2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018

February 2013
Italian energy authority approval

October 2013
First factory test acceptance

December 2015
Testing startup

Power Intensive projects

October 2012
Italian ministry approval

September2013
Tender started – first suppliers

December 2014
Testing startup – first storage systems

Testing

2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018

February 2013
Italian energy authority approval

December 2013
First factory test acceptance

December 2016
Testing startup – last storage systems (flow technology)

2018
Storage Lab Completion

Terna's Energy Storage Pilot Projects

Storage Lab (Power Intensive)

- **Main goal:** increase of grid security
- **Applications:** fast FCR, FRR, Special Protection System (*)
- **Size (MW):** ≈ **16 MW (Phase I)**
- **Technologies:** Li-Ion, Zebra, Flow, other (Supercap…)
- **Number of sites:** **2**

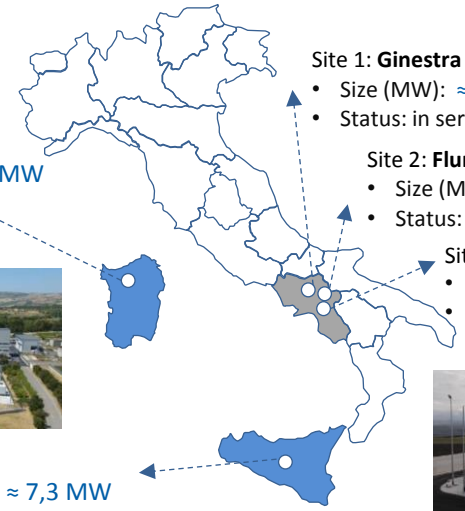
Large Scale (Energy Intensive)

- **Main goal:** reduction of wind energy curtailment
- **Applications:** congestion management, FCR, FRR, TR (*)
- **Size (MW):** **≈35 MW**
- **Technologies:** NaS (Sodium Sulfur)
- **Number of sites:** **3**

Testing, comparison and evaluation of **different storage technologies**

Advanced control systems for the management of multi-technological battery plants

System characterization both on **"grid scale" size** and **"lab-module scale" size**



Sardegna - Codrongianos
- Final planned size (MW): ≈ 8,65 MW
- Status: in testing ≈ 7,9 MW

Site 1: **Ginestra**
- Size (MW): ≈ 12 MW
- Status: in service

Site 2: **Flumeri**
- Size (MW): ≈ 12 MW
- Status: in service

Site 3 **Scampitella**
- Size (MW): ≈ 10,8 MW
- Status: in service

Sicilia - Ciminna
- Final planned size (MW): ≈ 7,3 MW
- Status: in testing ≈ 5,55 MW

Mono-technological battery solution based

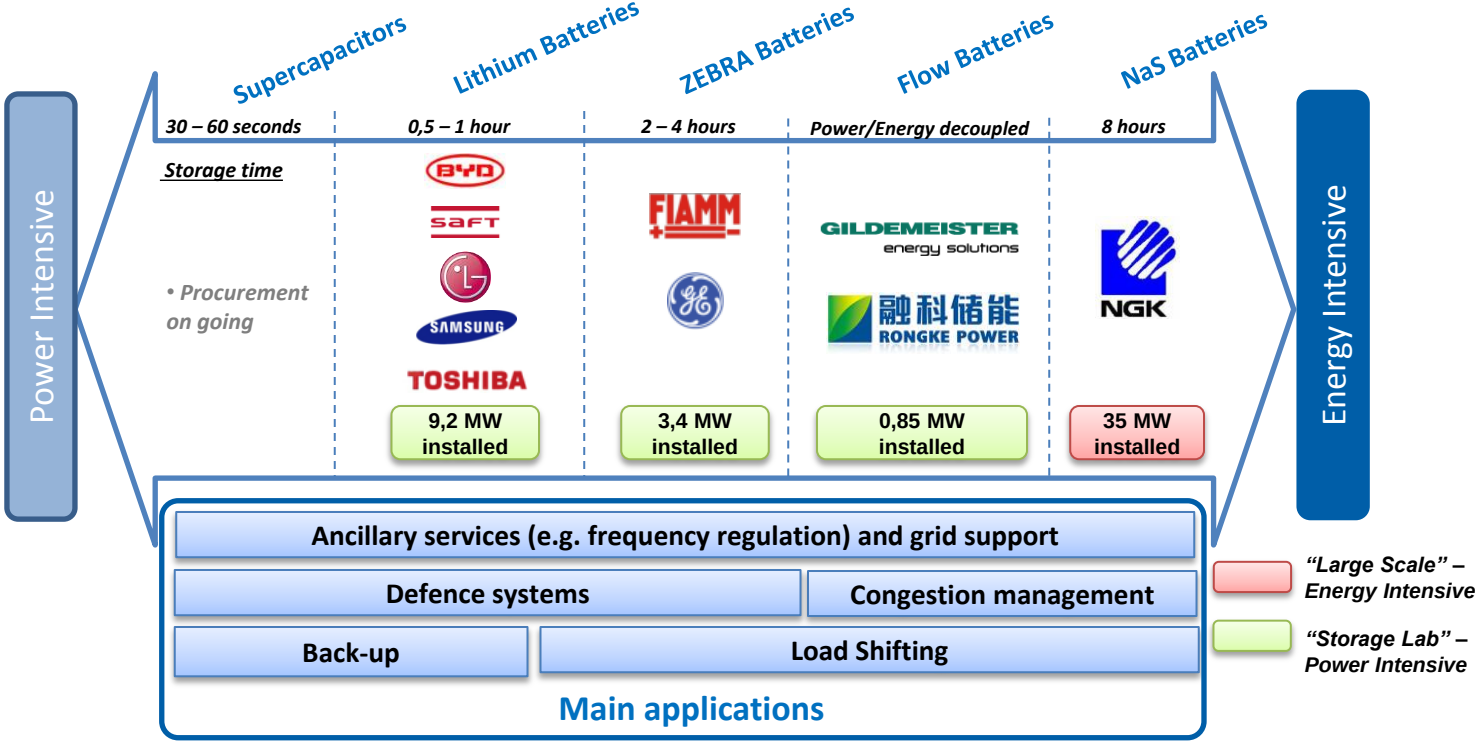
Large scale plants, used to reduce wind energy curtailment

Additional supply of **ancillary services** (FCR, FRR…)

Power and Energy Intensive projects are characterized by different sizes and goals, having each one peculiar experimenting approach

(*) FCR: Frequency Containment Reserve
FRR: Frequency Restoration Reserve
TR: Tertiary Reserve

Terna's technological portfolio



By means of its Pilot Projects, Terna has covered the full range of possible applications for energy storage systems: from power-intensive to energy-intensive ones

Storage Lab – installed technologies

CODRONGIANOS

TECHNOLOGY	SIZE	
Lithium Iron Phosphate	1 MW	1,23 MWh
Lithium Nickel Cobalt Aluminium	1,2 MW	0,93 MWh
Lithium Manganese	1 MW	0,92 MWh
Lithium Nickel Manganese Cobalt	1,08 MW	0,54 MWh
Lithium Titanate	1 MW	1,02 MWh
Nickel-Sodium Chloride	1,2 MW	4,15 MWh
Nickel-Sodium Chloride	1 MW	2,00 MWh
Flow - Vanadium	0,4 MW	1,10 MWh

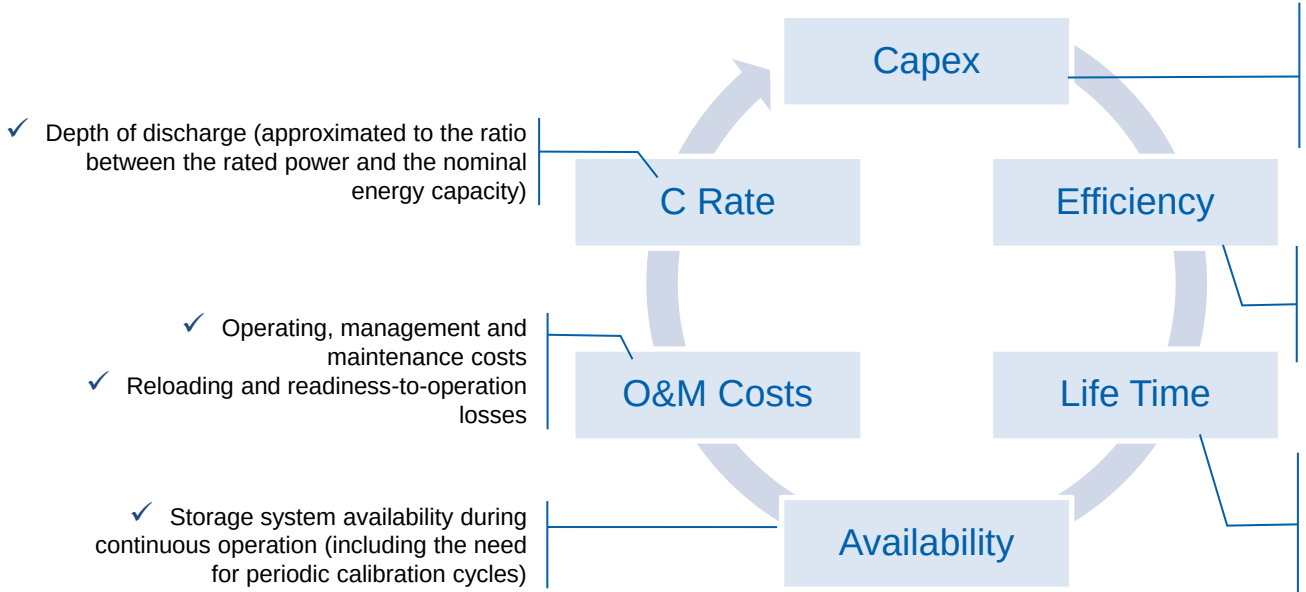
CIMINNA

TECHNOLOGY	SIZE	
Lithium Iron Phosphate	1,0 MW	1,23 MWh
Lithium Nickel Cobalt Aluminium	0,9 MW	0,57 MWh
Lithium Manganese	1,0 MW	0,92 MWh
Lithium Titanate	1,0 MW	1,02 MWh
Nickel-Sodium Chloride	1,2 MW	4,15 MWh
Flow - Vanadium	0,45 MW	1,44 MWh

The project allows hence the testing and performance assessment of most technologies available on the market

Technology assessment, validation and comparison

Key Factors



Investment costs:

- ✓ Upfront
- ✓ Replacement of investments over time

✓ Ratio between the energy in discharge and the energy in charge referred to a reference cycle (depending on the cycle typology and hence on the specific application)

- ✓ Cycles number depending on the maximum tolerable degradation of efficiency, energy capacity and C-Rate, evaluated in operation
- ✓ Calendar Life

✓ Storage system availability during continuous operation (including the need for periodic calibration cycles)

- ✓ Operating, management and maintenance costs
- ✓ Reloading and readiness-to-operation losses

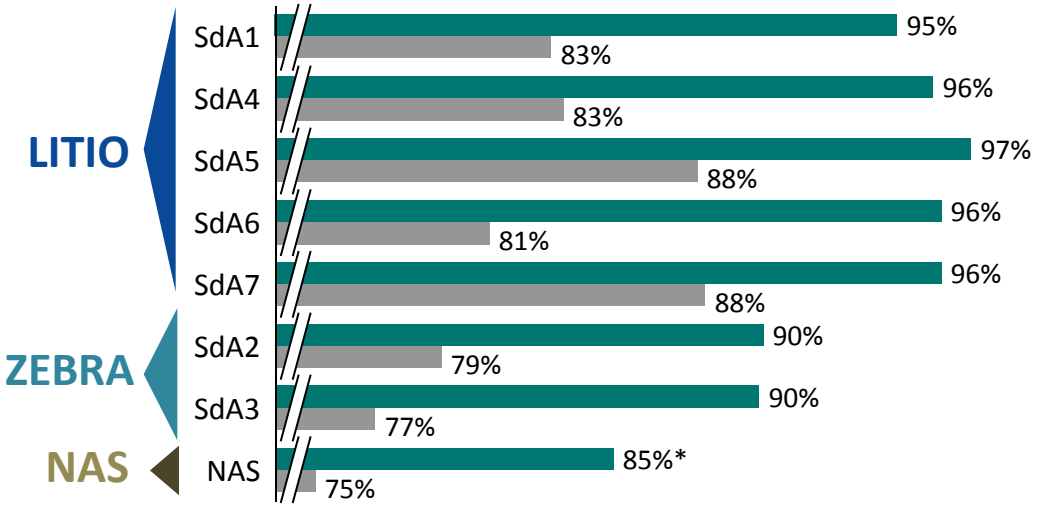
✓ Depth of discharge (approximated to the ratio between the rated power and the nominal energy capacity)

Cost-benefit analysis of energy storage applications should consider at least six key factors. Comparison within the technology portfolio to provide specific applications has to consider each of them

Main results

Efficiency

Round-trip efficiency on the reference cycle (*module scale* VS *grid scale*)



"Module Scale" nominal efficiency evaluated on the reference standard cycle

"Grid Scale" net nominal efficiency evaluated including power converter systems, auxiliaries, transformer, on the reference cycle

Net Efficiency evaluated during continuous operation

- Provision of only primary frequency regulation service (FCR): **15-30%**
- Provision of both primary (FCR) and secondary (FRR) frequency regulation services: **65-80%**
- **ZEBRA** (half-year average values among technologies)
  - FCR **18%**
  - FCR + FRR **67%**
- **LITIO** (half-year average values among technologies)
  - FCR **23%**
  - FCR + FRR **76%**

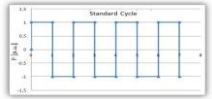
Storage systems have been characterized by high efficiency values close to the nominal ones when used in nominal conditions, that means operations with charging/discharging cycles near to the «standard» cycle. Nevertheless, the efficiency falls dramatically when the cycled energy volumes are lower than standard cycles ones

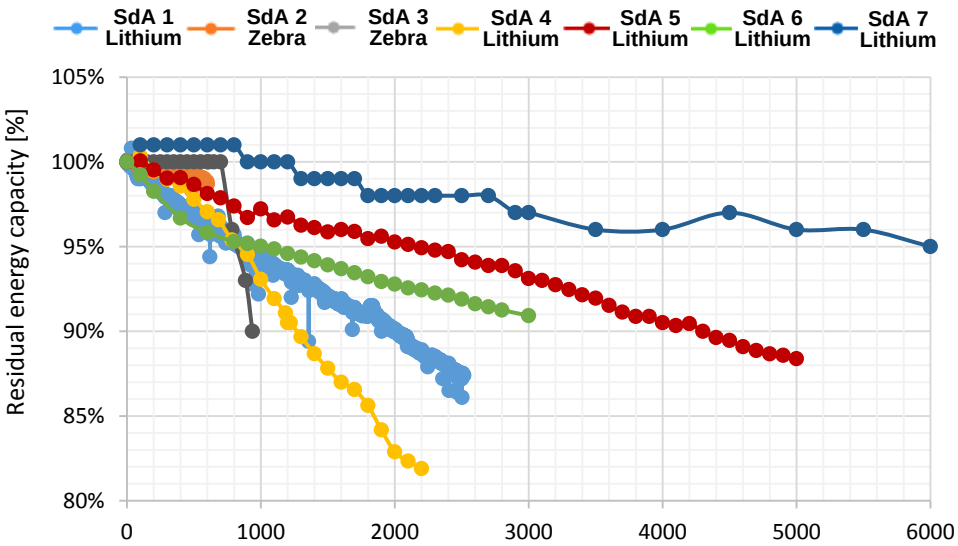
(*) Battery efficiency evaluated for the «grid scale» system

Main Results
Ageing

AGEING DEGREE: STANDARD CYCLE

Std cycle





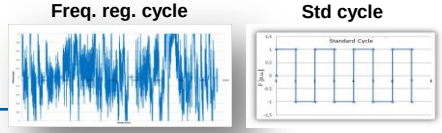
Battery energy capacity measured after every reference cycle and referred in percentage to the nominal battery capacity

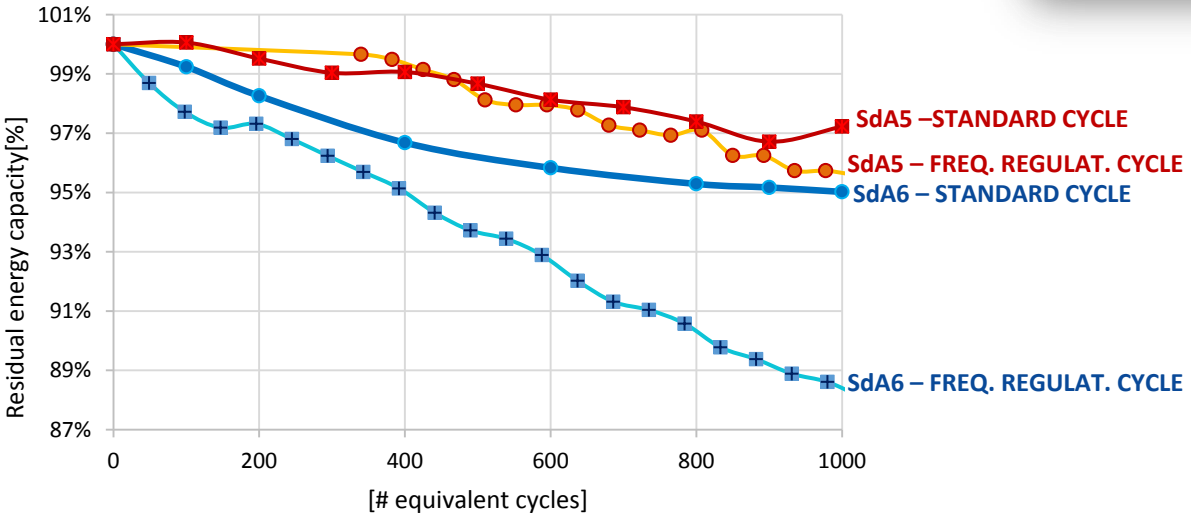
- The results of the cycling test indicate that **some technologies can tolerate more than 5000 cycles showing a very low performance degradation**:
  - The Lithium SdA 7 showed **a 5% reduction** of its nominal capacity after **6000 cycles**.
- On the contrary, other technologies showed **high ageing degrees even from 1000 cycles**:
  - The Lithium SdA 4 proves to be **near to the 80% limit** of residual capacity **just after 2000 cycles**

The different electrochemical storage technologies, tested on the same cycle, show an ageing degree substantially different from one other

Main Results
Ageing

AGEING DEGREE: STANDARD CYCLE VS FREQUENCY REGULATION CYCLE





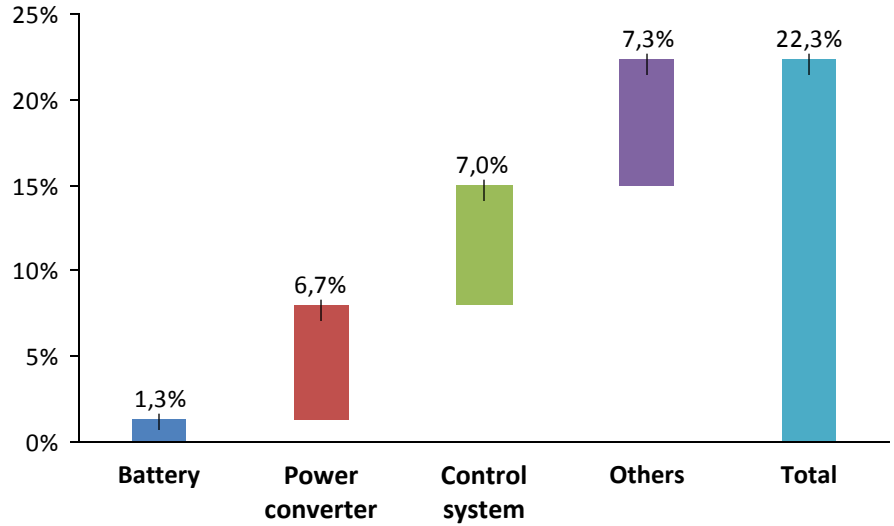
Battery energy capacity measured after every reference cycle and referred in percentage to the nominal battery capacity

- In general, **the frequency regulation cycle causes a higher battery degradation than the standard cycle**, even if the former is characterized by a lower total energy exchange
- **The effect on the capacity degradation is however strongly dependent** on the tested technology

For each technology, the number of equivalent cycles is strongly dependent on the cycle characteristics (power profile, inversions number, continuous cycling or with stand-by phases, …)

Main Results
Availability e Reliability

Average availability of the Energy Intensive plants – First half 2016



- **Average plants availability: 70-91%, characterized by a constant growth in the half-year periods** after the start of operations
- Most of unavailability is due to **failures and malfunctions of the power conversion system**, as well as related to **adjustments on the innovative control logics and functionalities presently implemented**

Considering the experience acquired so far, it can be highlighted that battery modules have the minor impact on the whole unavailability of the storage plants

ABOUT TERNA

CURRENT SCENARIO AND FUTURE CHALLENGES

TERNA'S EXPERIENCE OF ENERGY STORAGE INTEGRATION IN THE TRANSMISSION GRID

LESSONS LEARNT AND FUTURE PERSPECTIVES...

Lessons learnt

- Storage technologies tested by Terna have shown efficiency similar to the nominal one when used in nominal conditions. **The real efficiency can be much lower than the nominal one and strongly depends on the application**
- So far, it is not possible to highlight any conclusion **about expected lifetime** of these technologies, but it is clear that **important differences exist among similar technologies, depending on the application**
- Using a storage plant providing only one application can reduce its potentiality exploitation. It is very important **to design a storage system able to provide multiple services**, considering technical limits of each electrochemical technology
- In order to foster the sector, it is very important to ensure a regulatory framework where **an energy storage resource can carry out benefits for more than one player of the electricity chain**. **Grid codes should be adapted properly** to maximize the capabilities of these resources

Next Steps

Pilot Projects for participation of new flexibility resources to the Ancillary Service Market

AEEGSI Resolution 300/2017/R/eel

The Italian Regulator has defined the criteria to allow demand, production units not already enabled to ancillary service market (such as RES and DER) and storage plants to provide flexibility services by means of "pilot projects". These pilot projects are meant to allow the acquisition of useful elements for the organic reform of the ancillary service market in accordance with the "European Balancing Code".

Consumption Virtual Units enabled

- Market participation of aggregated loads ensuring a reduction of the consumption of at least 5 MW within 15 min by Terna signal, able to provide the decrease of consumption for at least 3 hours.
- New role of the Balance Service Provider as an indipendent player.

Production Virtual Units enabled

- Market participation of aggregated non-relevant production units (whether programmable or non-programmable) **including storage systems**, able to provide flexibility to increase and/or decrease at least 5 MW within 15 min by Terna signal, and keeping the state for at least 3 hours.
- New role of the Balance Service Provider as an indipendent player.

In accordance with the Italian Regulator, Terna has been promoting new initiatives aiming at enabling a larger number of resources to provide flexibility to the electric system.
In 2017 Terna has launched pilot projects about both consumption and production virtual units aggregated

Thank you

www.terna.it