Terna's Energy Storage Projects

Bruxelles – 01 July 2016

Rosario Maria Polito
Project Leader – Terna's Energy Storage Projects

Agenda

- *About Terna*
- *The Italian Context*
- *Terna’s Approach to ESSs*
- *Energy Intensive ESS Projects*
- *Power Intensive ESS Projects*
- *Main Lessons Learned*

Agenda

- *About Terna*
- *The Italian Context*
- *Terna's Approach to ESSs*
- *Energy Intensive ESS Projects*
- *Power Intensive ESS Projects*
- *Main Lessons Learned*

About Terna – Company Profile

Terna is

- ...the **largest independent transmission system operator** (TSO) in Europe and the sixth in the world
- ...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

~ 72,000 km of high- and extra-high voltage power lines (123/150 kV, 220 kV, 380 kV)

21 Interconnections lines with neighbouring countries

841 Substations

Assets

8 Transmission Operating Areas

8 Distribution Centers

3 Remote-Control Centers

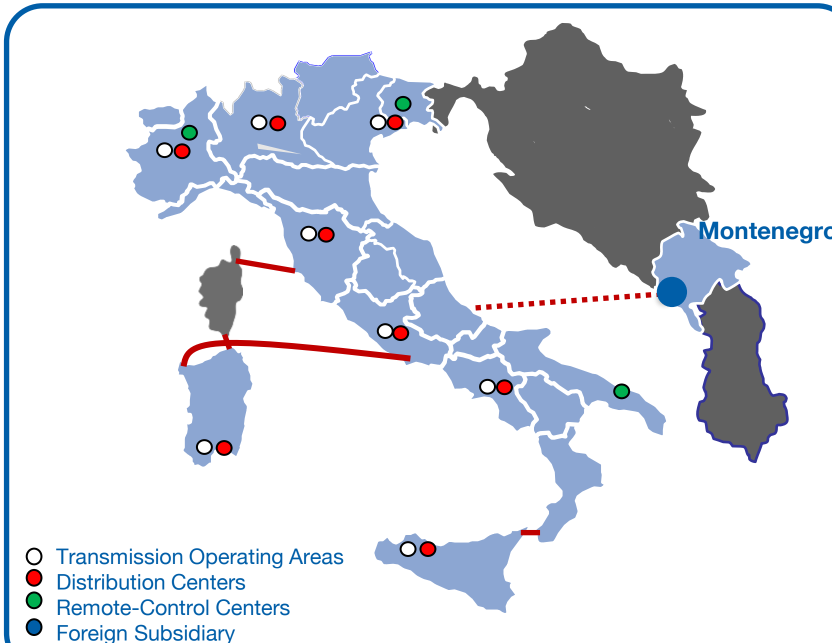
1 Foreign Subsidiary

Electricity Market

310 TWh of energy consumption (2014)

≈**59,400 MW** demand peak (July 2015)

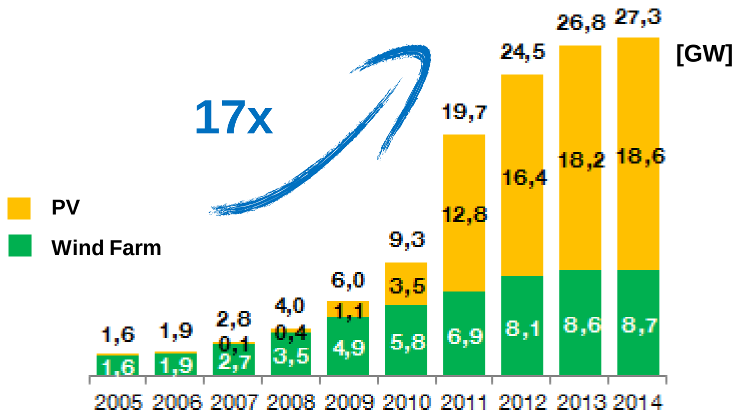
... and premises



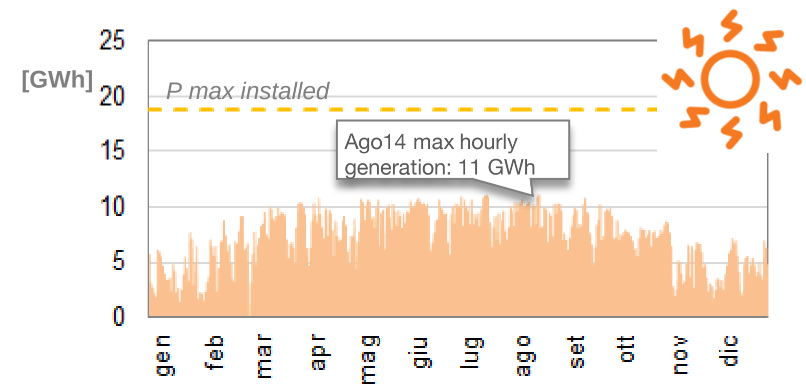
Agenda

The Italian Context – Trend of Renewables

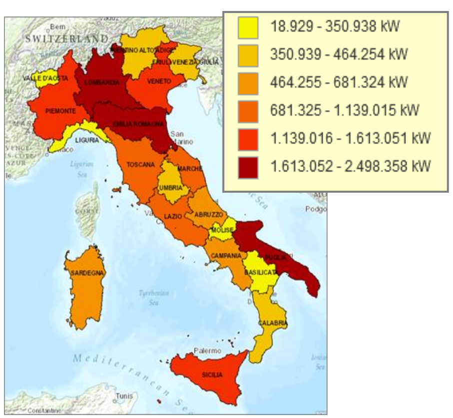
- Aggressive policy of incentives and the imminence of grid parity brought an exorbitant trend of PV and wind farm generation in the last 10 years, achieving over **27 GW of overall capacity** today
- PV generation is almost uniformly distributed over the italian territory; on the contrary, Wind generation is mainly concentrated in Southern Italy and in Italian Main Islands



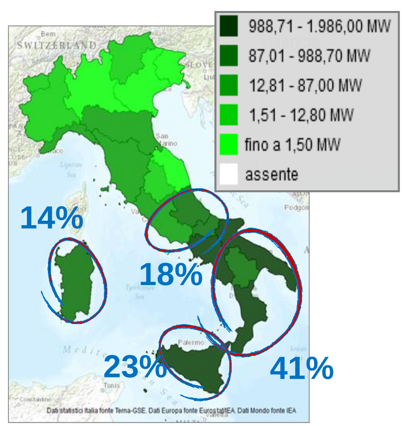
Installed generation of PV and Wind Farm



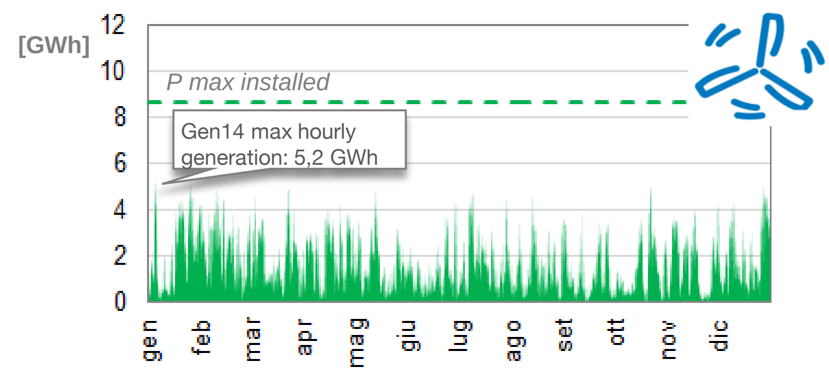
Hourly Production of PV Energy – y 2014



Distribution of PV Generation



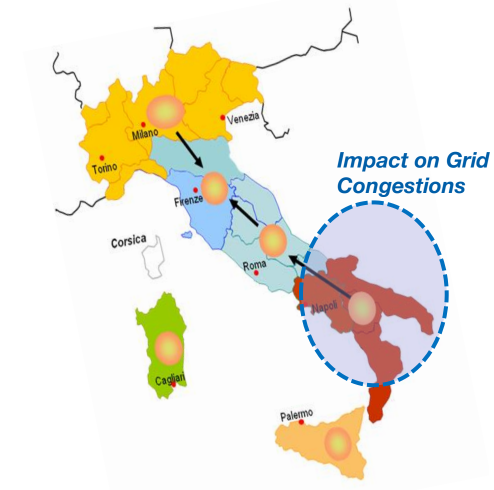
Distribution of Wind Farm Generation

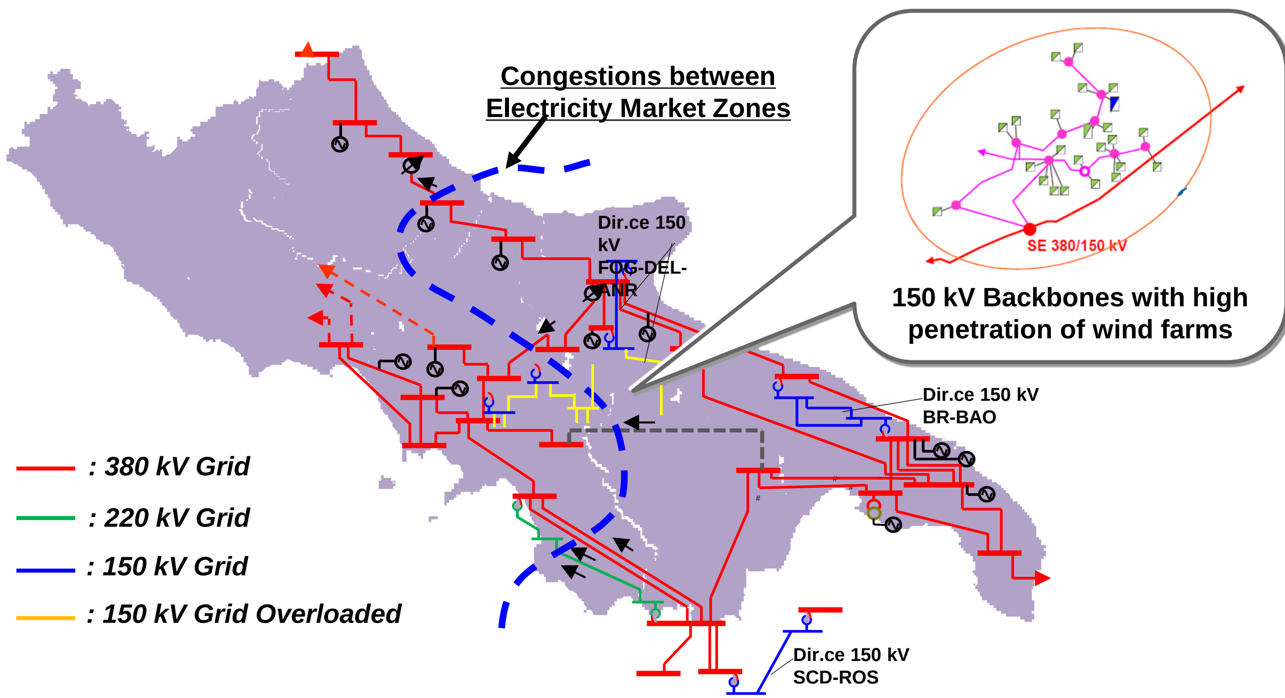


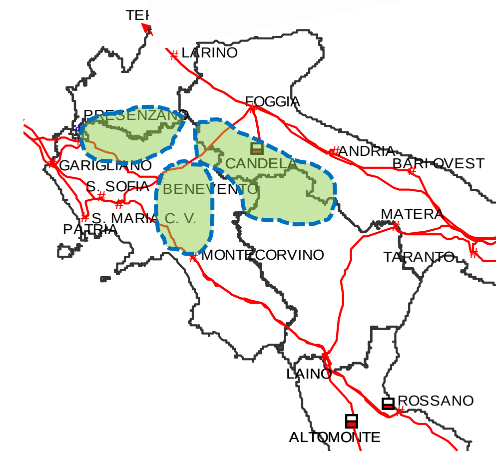
Hourly Production of Wind Farm Energy – y 2014

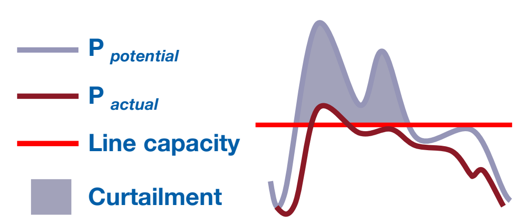
Impact on the Grid Congestions

- Fast penetration trend of wind generation has characterized some HV grid portions in Southern Italy without an adequate and simultenous HV grid development
- Such condition caused an increase in **local congestions** of HV backbones and **congestions between Electricity Market Zones**, forcing Terna to frequently curtail wind energy generation through dispatching orders to wind power producers;
- As a result, in 2010 more than **500 GWh** of potential energy from wind generation is cut by Terna





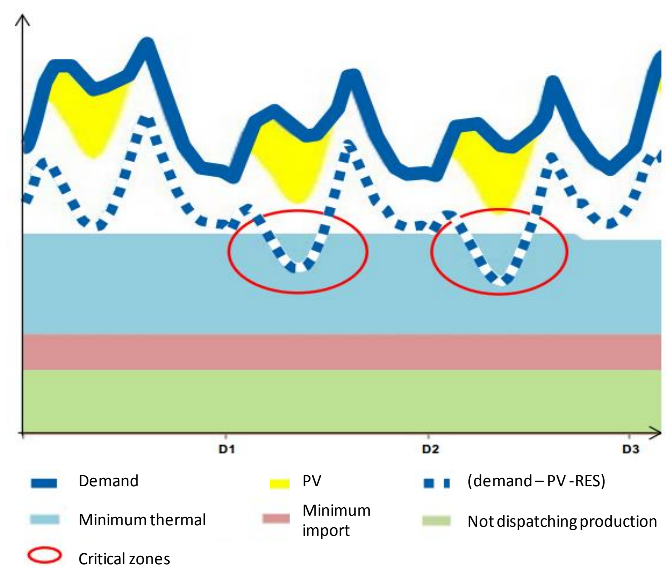




Impact on Spinning Reserve and Frequency Regulation

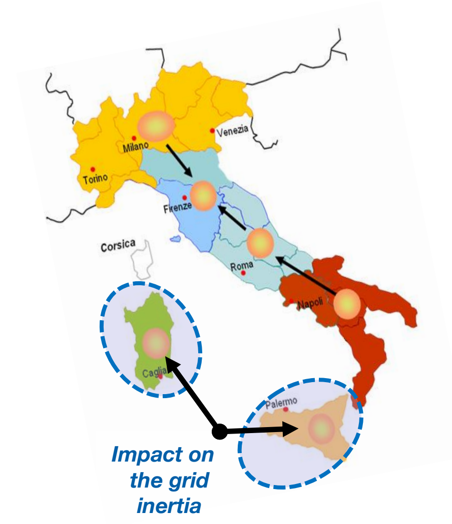
- RES requires an increase of spinning reserve demand because of uncertainty and intermittency of its generation. In addition, RES is excluded from the commitment of primary frequency reserve and is not able to perform ancillary services as well as traditional thermal generation.
- Days of high solar radiation and low energy demand can result in RES generation surplus, because of lack of the minimum amount of thermal power generation to safely cover the demand.
- As a result, the change in energy mix leads to difficulties in balancing grid and a lack of Regulating Reserve. Therefore, RES requires higher flexibility demand of thermal power generation, as frequent stops and starts, capability to hold and release loads during quick ramps, etc.

Impact on Spinning Reserve and Frequency Regulations



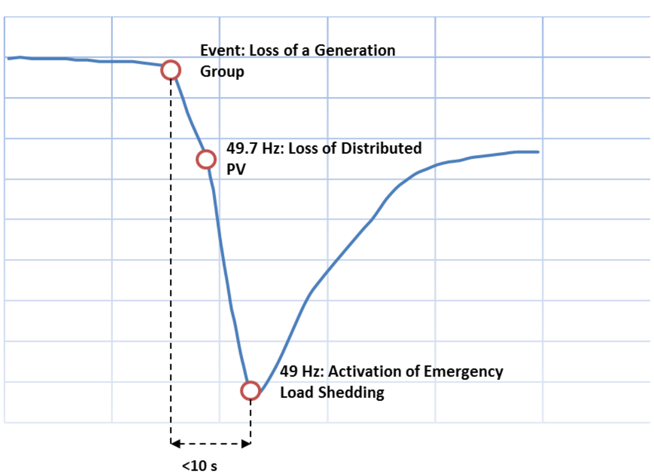
Impact on the Grid Inertia

- High penetration of renewables brought a **lower inertia** of the electrical system.
- **Case study –** HV grid managed with high amount of Distributed Generation and low level of grid interconnection (*real event in Sicily, 2011*): loss of generation group coupled with the system's modest inertia caused a **very fast frequency drop** and **the activation of Emergency Load Shedding**. The net increase in Distributed Generation makes this approach alone ineffective so new methods are necessary.
- New grid code standards and innovative mechanisms for a faster frequency restoration are needed to contain frequency deviation in case of imbalance between generation and demand.



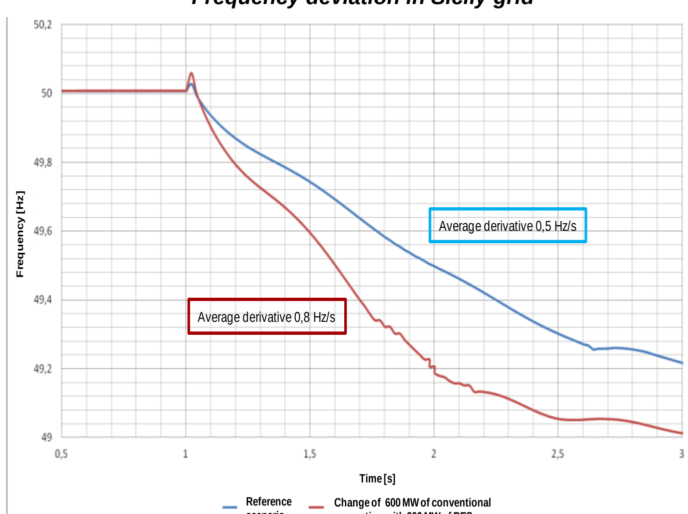
Real case

Loss of generation in Sicily grid (2011)

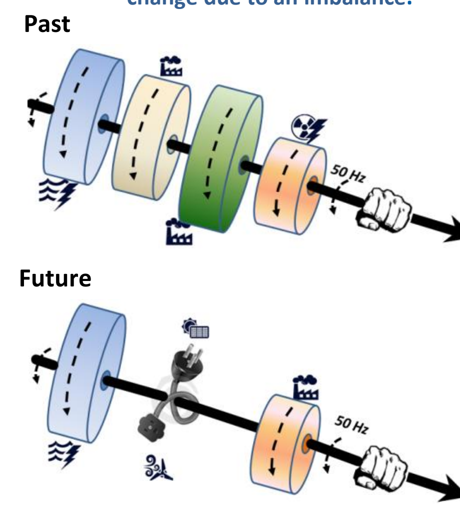


Simulations and analysis of scenarios

Frequency deviation in Sicily grid

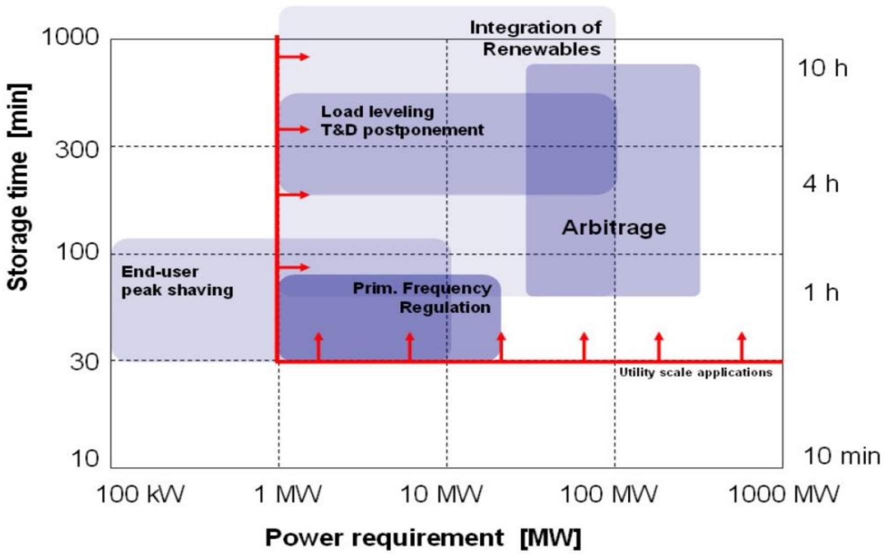


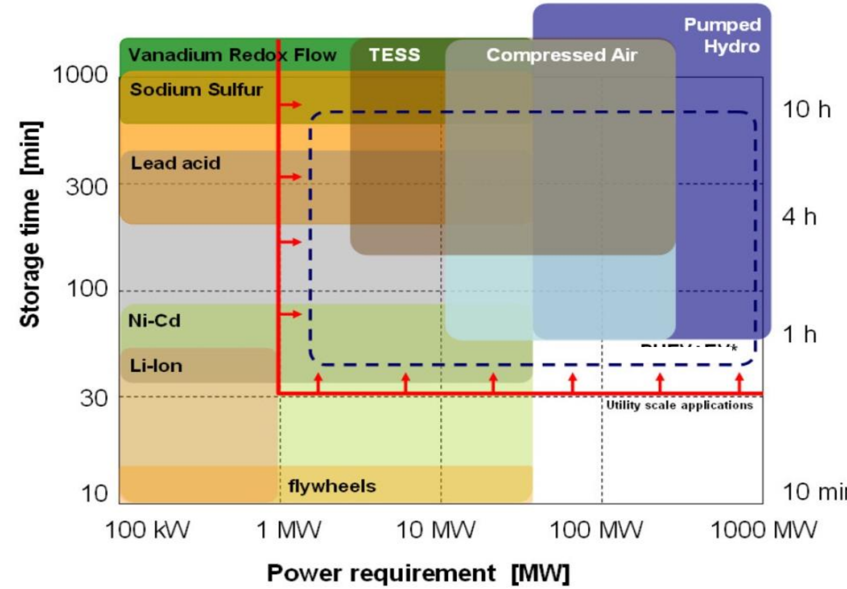
Inertia: the physical resistance of the system against frequency change due to an imbalance.



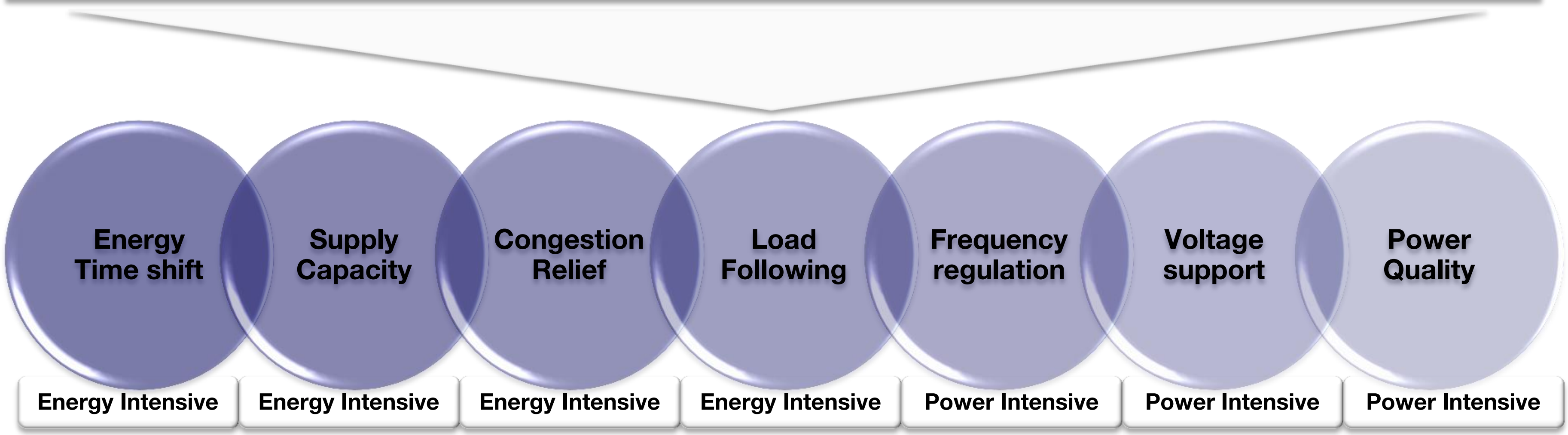
Agenda

Market Analysis for Energy Storage Systems





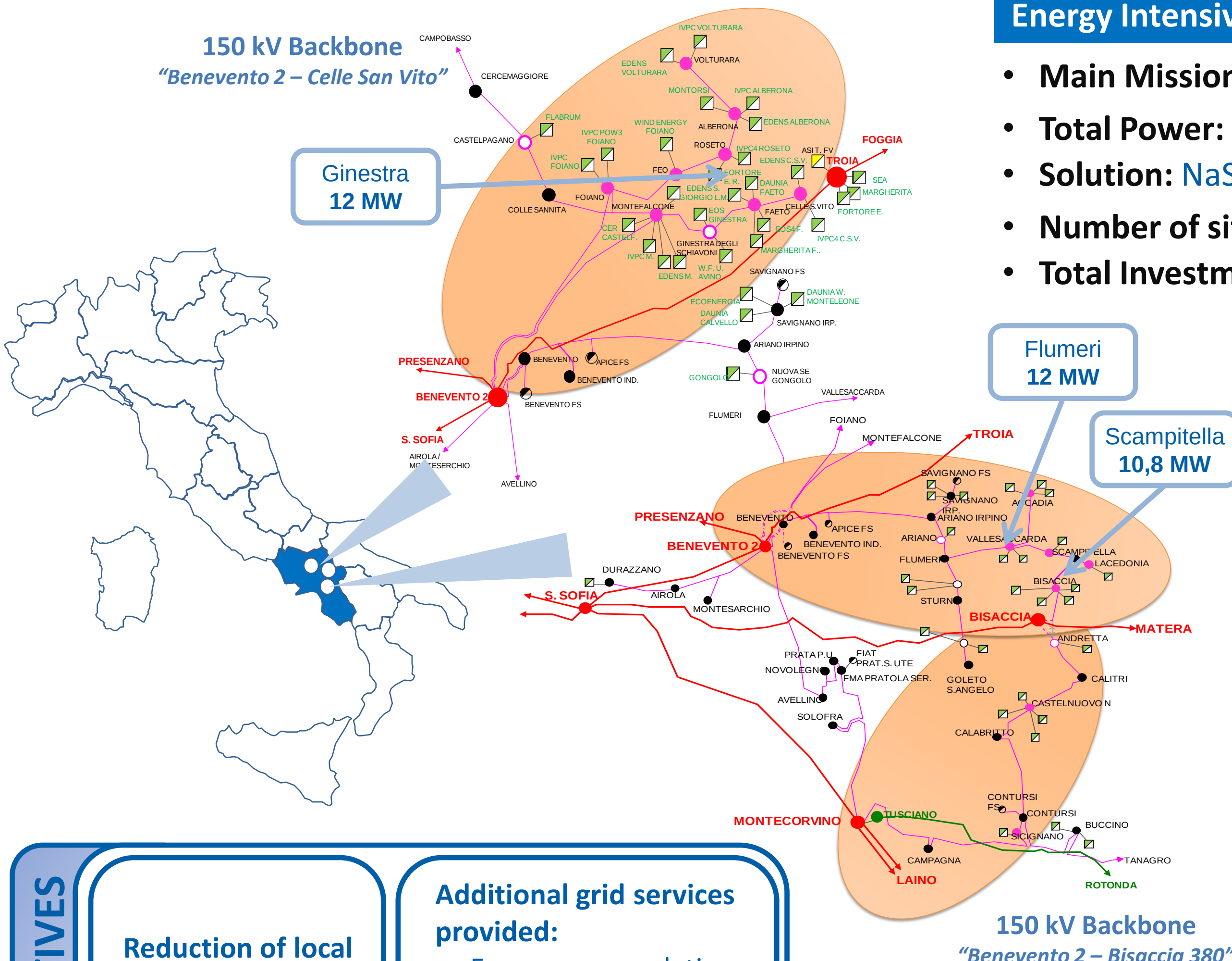
…several technologies are available to better adapt specific type of applications….



Terna's Projects of Energy Storage Systems

Total €300 Million	Energy Intensive (35 MW) Grid Development Plan 2011	Power Intensive (40 MW) Grid Defense Plan 2012
Critical issues	• Local congestions on the HV grid and wind curtailment • Support to primary reserve and frequency regulation • Support to tertiary reserve and system balancing • Voltage support	• Tools inadequate to control frequency transient • Low primary reserve • Low inertia of the system due to the increase in static generation • Difficulties in the management of low-load operation due to RES generation
ESS Technical Features	• Energy to Nominal Power ratio ≥ 7 MWh/MW • AC roundtrip efficiency ≥ 75% • Rapid response time	• Ultra-rapid frequency regulation • High Power to Energy Ratio • AC Roundtrip Efficiency >85%

Energy Intensive Storage Projects



Energy Intensive

- **Main Mission:** reduce wind curtailment
- **Total Power: ≈35 MW**
- **Solution:** NaS *Sodium Sulfur*
- **Number of sites: 3**
- **Total Investment Size: 160 €mln**

Site 1*: Ginestra*
- **Total Capacity: 12 MW**
- **Status: in operation (by dec-2014)**

Site 2*: Flumeri*
- **Total Capacity: 12 MW**
- **Status: in operation (6 MW by dec-2014 + 6 MW by oct-2015)**

Site 3*: Scampitella*
- **Total Capacity: 10,8 MW**
- **Status: in operation (by dec-2015)**

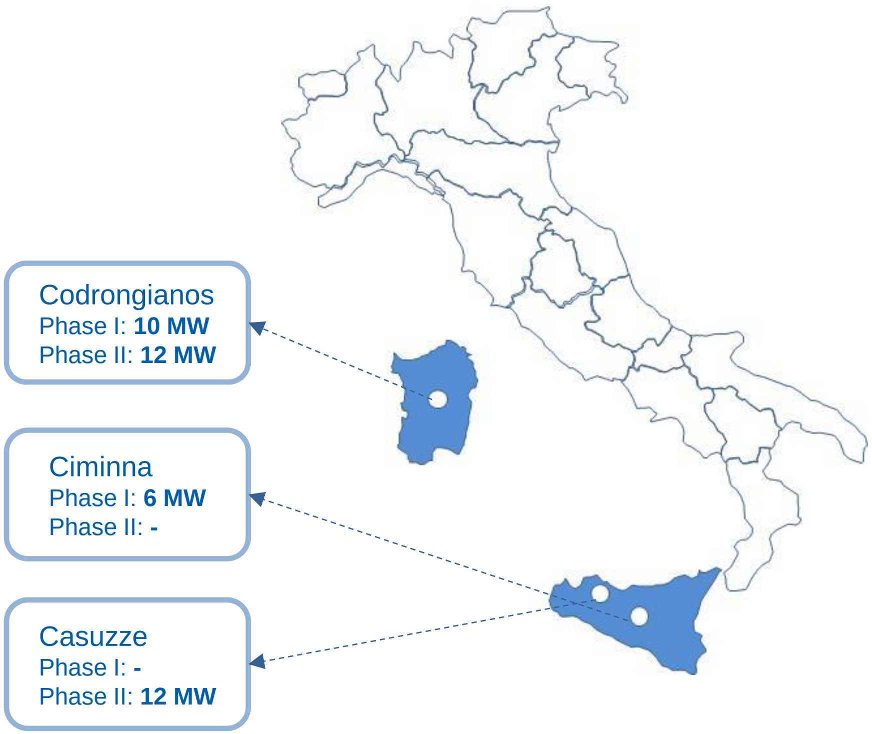
Ginestra SANC – 12 MW

OBJECTIVES

Reduction of local congestions and wind curtailment

Additional grid services provided:
- Frequency regulation
- Secondary Regulation
- Tertiary reserve
- Voltage support

Power Intensive Storage Projects



Power Intensive

- **Main Mission:** increase safety of the grid
- **Total Power: ≈ 40 MW**
- **Solutions:** Li-Ion, Zebra, Flow Batt, Supercaps
- **Number of sites: 2**
- **Total Investment Size: 93 €mln;**

PHASE I: 16 MW – STORAGE LAB

Site 1: ***Codrongianos (Sardinia)***
- **Total Power: ≈ 9,15 MW**
- **Status: operational ≈ 5,4 MW**

Site 2: ***Ciminna (Sicily)***
- **Total Power: ≈ 6,8 MW**
- **Status: operational ≈ 5,1 MW**

PHASE II: 24 MW

Sites: ***Codrongianos (Sardinia) and Casuzze (Sicily)***
Status: ***to be initiated***

OBJECTIVES

Grid support provided:
- Frequency regulation
- Secondary regulation
- Synthetic Inertia
- Integration in TSO's Defense Plan
- Power Quality

Assessing the performance characteristics of multiple Energy Storage Systems

Developing an Advanced Control System for the management of multiple EESS Technologies **(Virtual Storage Plant)**

STORAGE LAB: Codrongianos

Terna's Technology Portfolio

Power Intensive → Energy Intensive

Storage time

	Supercapacitor	Lithium batteries	ZEBRA batteries	Flow batteries	NAS Batteries
Storage time	*30 – 60 seconds*	*0,5 – 1 hour*	*2 – 4 hours*	*P & E are decoupled*	*8 hours*
Suppliers	• *Procurement on going*	BYD, SAFT, LG, SAMSUNG, TOSHIBA	FIAMM, GE	GILDEMEISTER energy solutions, 融科储能 RONGKE POWER	NGK
Capacity		9,2 MW installed	3,4 MW installed	0,85 MW in commissioning	35 MW installed

Grid support and ancillary services (e.g. frequency regulation)

Grid Defense System | Congestion management

Power Quality & Back-up | Load Shifting

Main applications

Agenda

- *About Terna*
- *The Italian Context*
- *Terna's Approach to ESSs*
- ***Energy Intensive ESS Projects***
- *Power Intensive ESS Projects*
- *Main Lessons Learned*

Requirements for Energy Intensive Projects

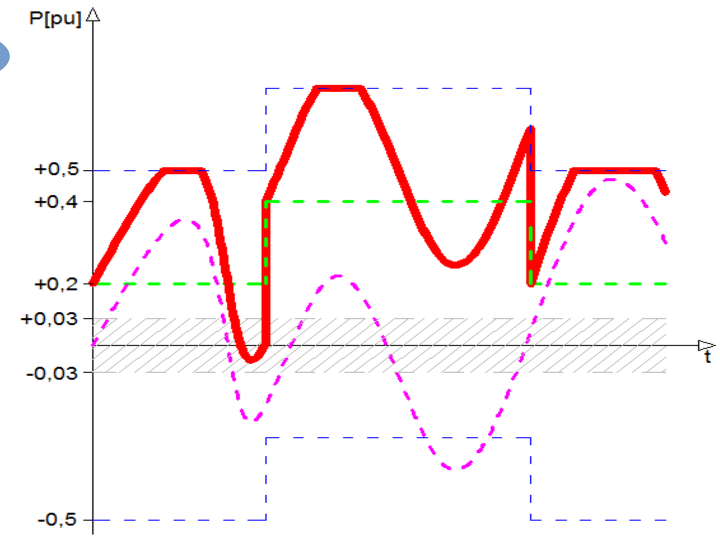
Benefits and Ancillary Grid Services	ESSs Requirements / TSO System integration
Wind Curtailment Reduction and grid congestion reduction	• *Energy intensive: charging phase at rated power for a large amount of consecutive hours (> 8 hours)* • *Integration with wind generation forecast systems* • *Integration with Dynamic Thermal Rating*
Tertiary and spinning reserve **Tertiary regulation** **Frequency secondary regulation**	• *Integration with Terna's Energy Management System (EMS)* • *Definition of procedures for Short Term Scheduling and Dispatching* • *Dispatching Centre integration (setting dispatching order and schedules)* • *Integration with Central Area Regulator (remote signal of power set-point)*
Frequency primary regulation	• *Fast response time (< 1 sec)* • *Local automatic regulators* • *Set and activation from local and remote control system (dead band, ..)*
Voltage regulation **Reactive power regulation**	• *Local voltage regulators activated from local voltage deviation or coordinated by a reference signal sent from the Remote Centre*
Special Protection System **Teletripping support**	• *Time to phase inversion < 100 msec* • *Integration with Special Protection System (Defense Plan)*

Main set of functionalities and application required
Optional functionalities provided

Terna's Innovation: grid services providing together

Deployed

- Each Energy Storage Unit (1,2 or 2,4 MW "UAC") for 12 MW ESSs exchanges active power with HV Grid to provide mainly the following grid services: **Wind Curtailment Management, Primary Frequency Regulation, Secondary Frequency Regulation, System Balancing**.
- In addition, ESS can exchange reactive power with HV grid in order to provide **voltage regulation**.
- The ancillary services can be provided: a) **exclusively** or b) **simultaneously**. In case of a), only one function is active (ON) while the others are kept on (OFF) state. In case of b), more than one function is kept active
- In order to manage the ESS Unit Capability for the operational active and reactive power range among the functions simultaneously activated, the operator can set a "**priority index**" (from "1" to "4", "1" being highest priority) for each one of four functions, defining the merit order to deliver simultaneously more ancillary services
- Minimum and maximum active power contribution for primary and secondary frequency regulation can be manually set by the Grid Operator **fixing an operational range** of active power variation



Dispatching Functions	Status	Priority Index
Primary frequency Reg	ON	1
Balancing (P set-point or schedule)	ON	2
Secondary frequency Reg	OFF	3
Voltage regulation	OFF	4

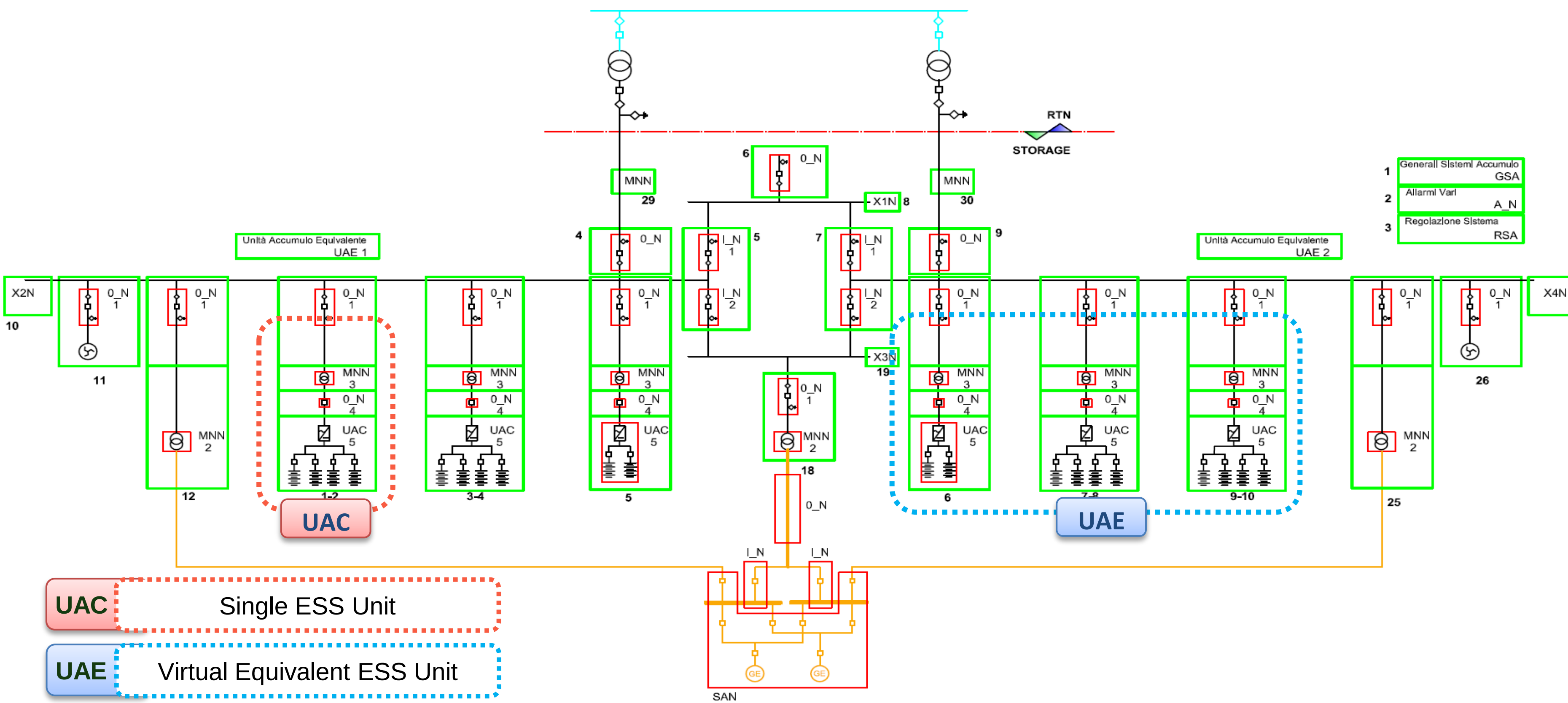
Legenda

- Battery Limitation Band
- Active Power required by Primary Reg.
- Power limits of Primary Reg.
- Active Power scheduled (or P set-point)
- P_{act} - Actual power profile

Terna's Innovation: Equivalent Energy Storage Unit

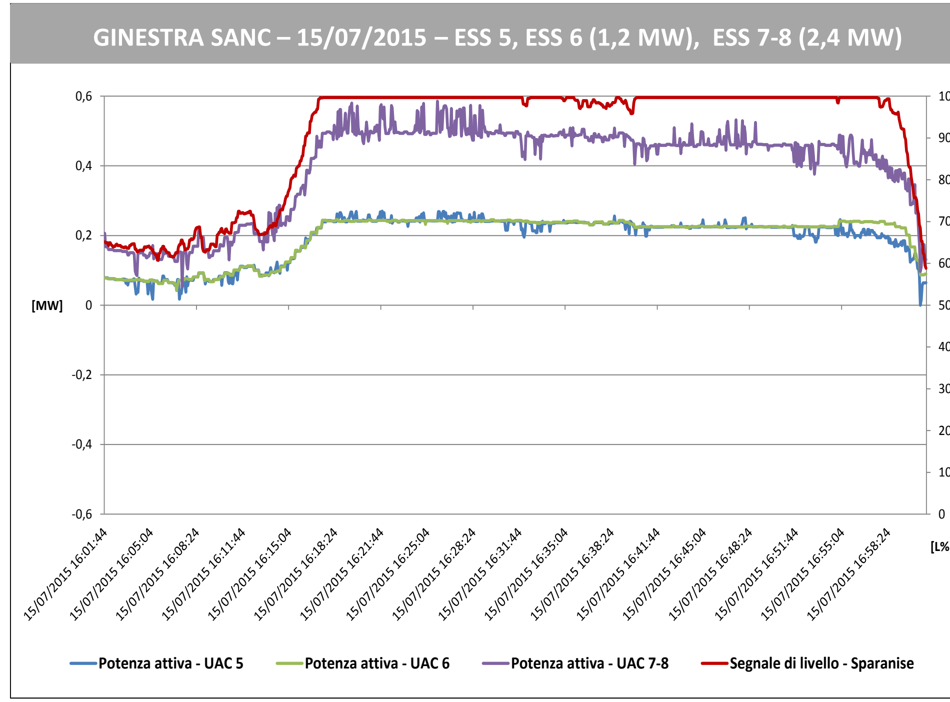
Under test

- Grid Operator can operate single ESS (1,2 MW or 2,4 MW) or an Equivalent ESS, defining the size of the Equivalent Unit
- In case of Equivalent ESS Dispatching Mode, local control systems automatically aggregate signals and commands to/from each ESS, in order to provide to the grid the equivalent contribution of Virtual ESS
- Equivalent ESS Dispatching Mode can simplify the switching, control and monitoring of ESSs (e.g. avoiding to activate and to manage each dispatching functions for each ESS Unit)



Energy Intensive Projects: Example of real operation

- 1,2 MW – UAC 5 (blue colour in figure): secondary and primary frequency regulation are activated concurrently
- 1,2 MW – UAC 6 (green colour in figure): secondary frequency regulation is the only function activated
- 2,4 MW – UAC 7-8 (violet colour in figure): all active power functions are activated
- Half-Band of secondary frequency regulation sets equal to 20% for all ESS Unit
- Red colour in figure: reference signal of the secondary frequency regulation (sent by the Continental Central Area Regulator)



Dispatching Functions	UAC 5	UAC 6	UAC 7-8
Secondary Frequency Regulation	ON	ON	ON
Primary Frequency Regulation	ON	OFF	ON
System Balancing	OFF	OFF	ON

Agenda

- *About Terna*
- *The Italian Context*
- *Terna's Approach to ESSs*
- *Energy Intensive ESS Projects*
- ***Power Intensive ESS Projects***
- *Main Lessons Learned*

Key factors affect "Battery Value"…

C-rate

- **Ratio** between nominal **power exchanged with grid for discharging/charging** and battery **energy capacity:**
- Depends on technology:
  - >100 for Supercaps
  - < 8 for Li-ion batteries,
  - 0.2 – 0.5 for Zebra batteries**,**
  - <0,2 for NaS batteries,
  - Flow batteries, power and energy can be decoupled

Capex

- Overall investments, including:
  - **Upfront** system costs (battery, control systems, civil works, services)
  - **Replacement** of investments over time (if/ when needed, depending on the **life cycle**)

Evaluating the best solution

Efficiency

- Rate of **energy dissipated** every cycle
- Depends on technology/usage, in the **range of 80% AC/AC**

O&M costs

- Operations and maintenance costs:
  - Yearly **fixed** component
  - **Variable** components based on energy exchanged

Life Cycle

- **Degrading capacity/efficiency curve** over number of cycles run
- Depending on batteries, in the **range of 80% of capacity at the 3.000-6.000 cycle mark**

Overview of testing activities of Terna’s Storage LAB

START

- Grid Scale(>1MW)
- Module scale (<100kW)

Focus on EESS’s testing (site tests)

- Frequency Regulation
- Voltage Regulation
- Power Quality
- Increase in Reliability
- Grid Stabilization
- Efficiency analysis

Focus on Modules’ Testing (lab tests)

- Aging Test
- Performance Test
- Thermal Test
- Overcharge/discharge Test
- Overload Test
- Short Circuit Test

The purpose of testing is to collect enough know-how to be able to select the best technology provided according to the desired application

The Storage Lab project has been designed to analyze the performance of selected technologies when used to solve Network issues

?

Technologies:

- Lithium-Ion
- Zebra
- Supercaps
- Flow

Lab

Module Tests executed by:

RSE Ricerca Sistema Energetico

CESI

Consiglio Nazionale delle Ricerche

ENEA Ente per le nuove tecnologie, l’energia e l’ambiente

Grid Scale Tests – AC/AC round trip efficiency test

Targets

Definition and validation of procedures

Test Execution

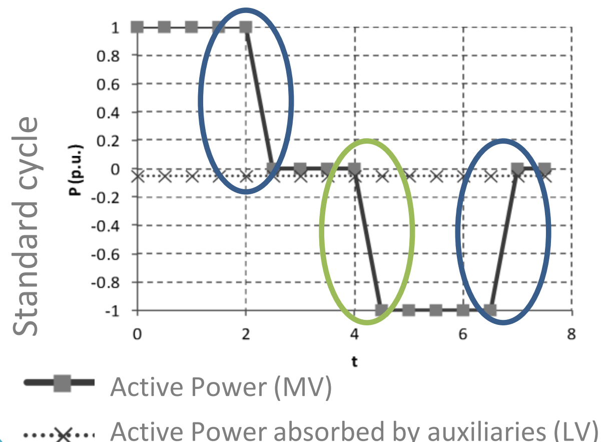
Validation

Analysis and Comparison

Purpose of testing

Validate the performances of each EESS in terms of:
Nominal Energy
Efficiency of the system

$$\eta = \frac{E_{out} - E_{aux,out}}{E_{in} + E_{aux,in}}$$



Standard cycle: the cycle used consists in a discharging phase followed by a charging phase; during the test it is admitted the interposition of stand-by phases

Each technology supplier is requested to propose the profile of the cycle to be used during the test session (*)

Discharging Phase
Charging Phase

Acceptance criteria

•Correct execution of the cycle proposed without any interruption or abnormal behavior
•Discharge energy and efficiency of system (including auxiliaries consumption) should be compliant with the Technical Specifications requests

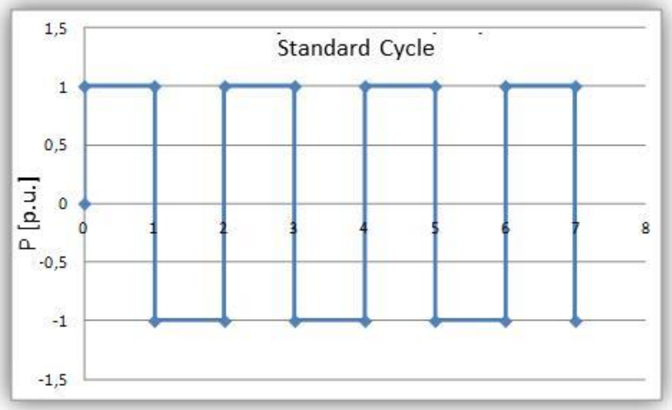
Results

FIAMM SAMSUNG BYD TOSHIBA SAFT

Round trip efficiency measured: **within the range 80-86 %**

Lab Scale Tests – Aging Test, Procedures

During the tender phase it became necessary to create a standard cycle in order to effectively compare and rank the different technologies

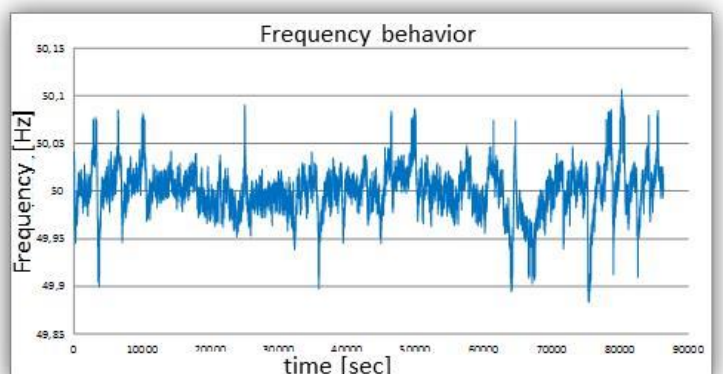


Test Procedure

- ***Discharge @ Pn, DOD 80%;***
- ***Complete Charge @ Pn;***
- ***No resting time (idle) between the cycles (*)***

*** This procedure adapted for each supplier in order to account for the specifications and limitations of each technology**

Furthermore, comparing each technology against the frequency regulation service, another cycle profile was identified: it was obtained by taking a real continental 24h frequency signal, filtered and compressed in order to attain a meaningful and challenging power profile (average value 50 Hz, max frequency deviation > 100 mHz)



Test Procedure

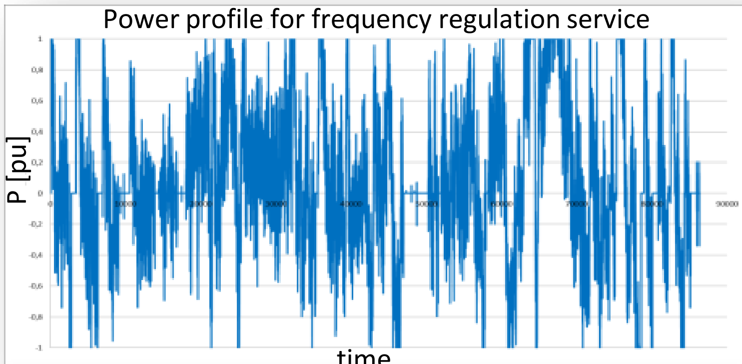
***Service parameters*:**
•Frequency droop 0.075%;
•Deadband 0 mHz.
•***Starting SOC*:** 100%;
•***SOC max*** :100% (no over-charge);
•***SOC min:*** 0% (no over-discharge);

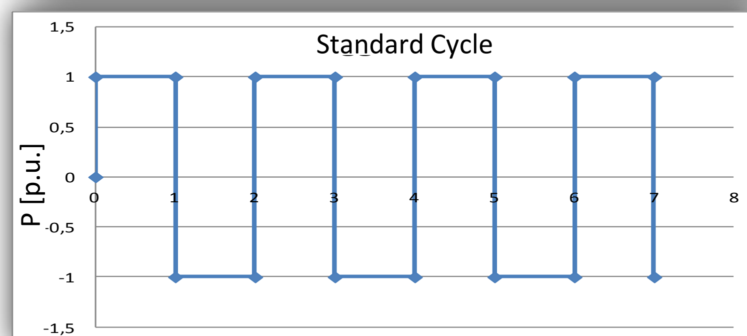
•If SOC min is reached: recharge the battery and nominal power and continue with the power profile

•Every10 days the reference cycle will be performed in order to determine the electrochemical parameters of the battery

Lab Scale Tests – Aging Test, Comparison of cycles

Compared to the standard cycle, **the frequency regulation cycle is**, from a thermal and energetic point of view, **less stressful and yet**…





Comparison between cycles

- **Average power:**
  - •Standard Cycle: **Pn**
  - •Regulation cycle: **0.4 Pn**

  Lower Power demand!

- **•Daily equivalent (*) cycles:**
  - •Standard cycle: **5-12**
  - •Regulation cycle: **≈5**

  Lower Energy demand!

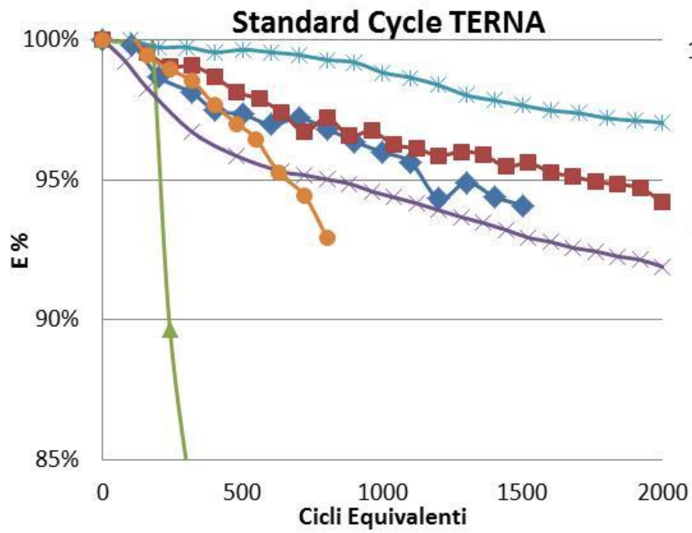
- **•Daily power inversions:**
  - •Standard cycle : **max 24**
  - •Regulation cycle : **over 1000**

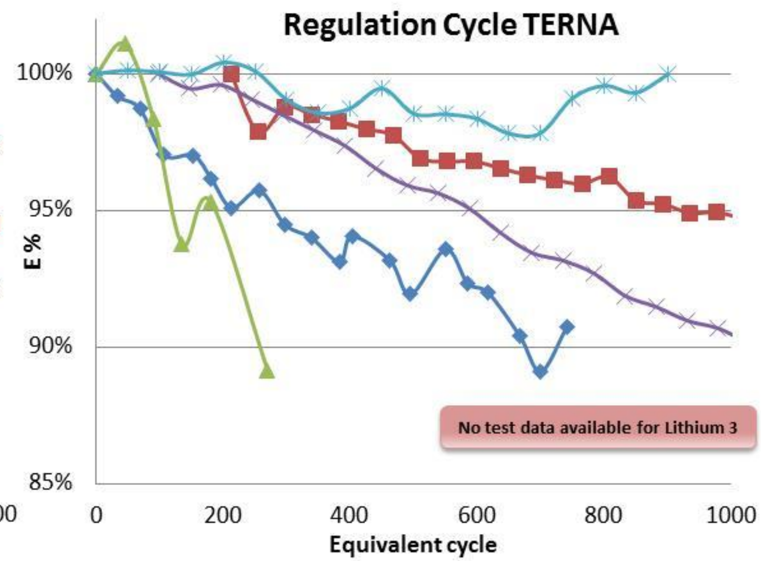
  More inversions!

…Tests have shown that **frequency regulation cycle causes the batteries to age much more than the standard cycle**

*** Equivalent cycles are obtained dividing the daily energy discharged, by module's nominal energy**

Lab Scale Tests – Aging Test, Results





E%: energy capacity measured after a reference cycle divided by the rated capacity

Module under test	Cycle	Number of cycles													
		100	200	300	400	500	700	1000	1500	2000	2500	3000	4000	5000	6000
Lithium 1	Standard Cycle Terna	100%	95%	85%	75%	-	-	-	-	-	-	-	-	-	-
	Regulation Cycle Terna	98%	95%	88%	-	-	-	-	-	-	-	-	-	-	-
Lithium 2	Standard Cycle Terna	99%	98%	97%	97%	96%	95%	94%	93%	92%	91%	-	-	-	-
	Regulation Cycle Terna	100%	100%	98%	97%	96%	93%	90%	-	-	-	-	-	-	-
Lithium 3	Standard Cycle Terna	100%	99%	99%	98%	97%	94%	-	-	-	-	-	-	-	-
	Regulation Cycle Terna	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithium 4	Standard Cycle Terna	100%	99%	98%	97%	97%	97%	96%	94%	-	-	-	-	-	-
	Regulation Cycle Terna	97%	95%	94%	94%	92%	90%	-	-	-	-	-	-	-	-
Lithium 5	Standard Cycle Terna	100%	99%	99%	99%	98%	97%	96%	96%	94%	93%	91%	-	-	-
	Regulation Cycle Terna	100%	100%	99%	98%	97%	96%	95%	-	-	-	-	-	-	-
Lithium 6	Standard Cycle Terna	100%	100%	100%	100%	100%	100%	99%	98%	97%	96%	96%	95%	95%	94%
	Regulation Cycle Terna	100%	100%	99%	99%	99%	99%	99%	-	-	-	-	-	-	-

Agenda

About Terna

The Italian Context

Terna’s Approach to ESSs

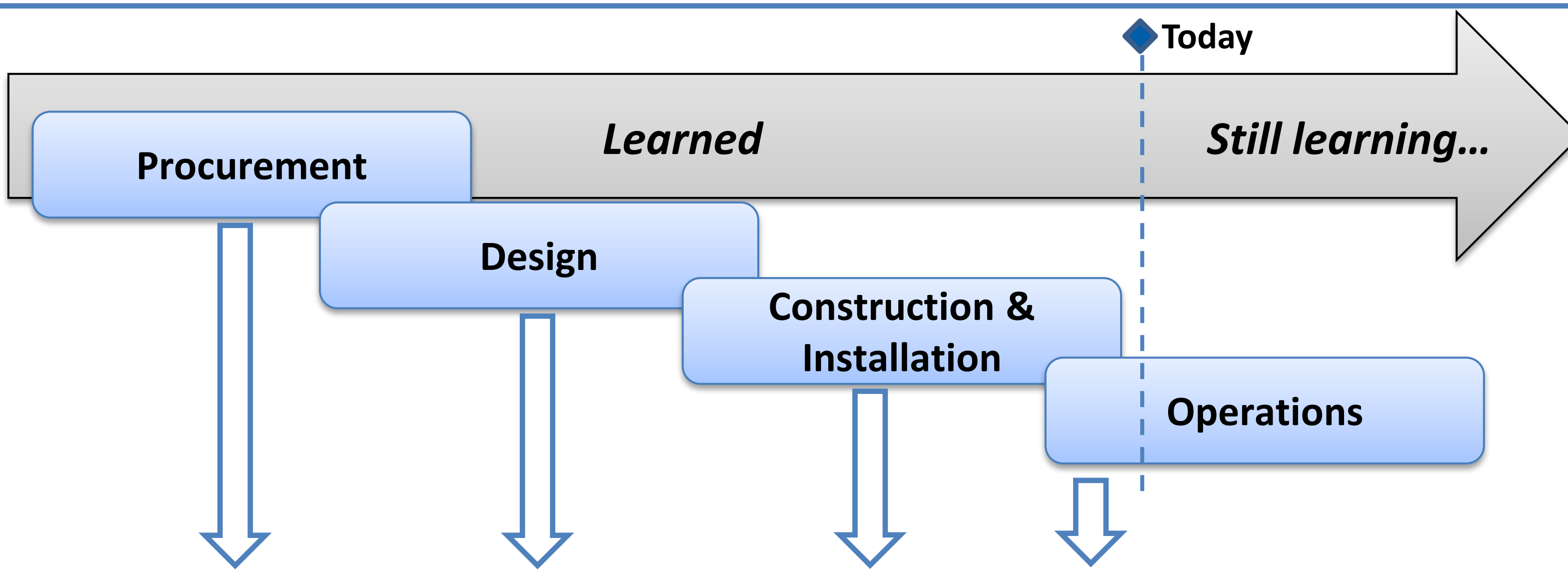
Energy Intensive ESS Projects

Power Intensive ESS Projects

Main Lessons Learned

Main Lesson Learned

To date Terna has commissioned more than 47 MW / 270 MWh of storage systems.
Thanks to this experience, Terna has achieved a significant amount of learning and expertise.



Lessons learned

- *How to better specify what we need*
- *How to improve the control of the system*
- *How to calculate the real cost of the different technologies*
- *Know-how in maintenace and management*

Thanks for your attention