New frontiers for grid management: the TSO perspective

Matteo Neri- International Business Development – Terna Group

WORKSHOP

NON-DISPATCHABLE RENEWABLE ENERGIES INTEGRATION INTO THE GRID

Lusaka, 5-6 September 2018

New frontiers for grid management: the TSO perspective

- ✓ **ABOUT TERNA**
- ✓ RENEWABLE ENERGY SOURCES (RES) AND CHALLENGES FOR TRANSIMISSION SYSTEM OPERATORS (TSO)
- ✓ CURRENT GRID BALANCING SERVICES IN ITALY - OVERVIEW
- ✓ BATTERY ENERGY STORAGE SYSTEMS (BESS) – OPPORTUNITIES FOR GRID SERVICES
  - o TERNA'S PILOT PROJECTS ON UTILITY SCALE BATTERIES AND VIRTUAL STORAGE PLANT
- ✓ NEW BALANCING TOOLS: VIRTUAL POWER PLANT (VPP) AND DEMAND SIDE RESPONSE (DSR)
- ✓ 2 TERNA'S PILOT PROJECTS ON BALANCING SERVICES FROM VPP+DSR AND BESS+BALANCING PRODUCTION UNIT

New frontiers for grid management: the TSO perspective

Terna in Italy:

- Is the **owner** and **operator** of the Italian **High Voltage National Transmission Grid, responsible for the transmission and dispatching of electricity** throughout Italy
- Is in charge of the development and maintenance of the HV Grid, employing a **workforce of about 3,800 people**
- Listed on the Italian Stock Exchange since 2004 (one of the leading industrial companies on the FTSE-MIB index)

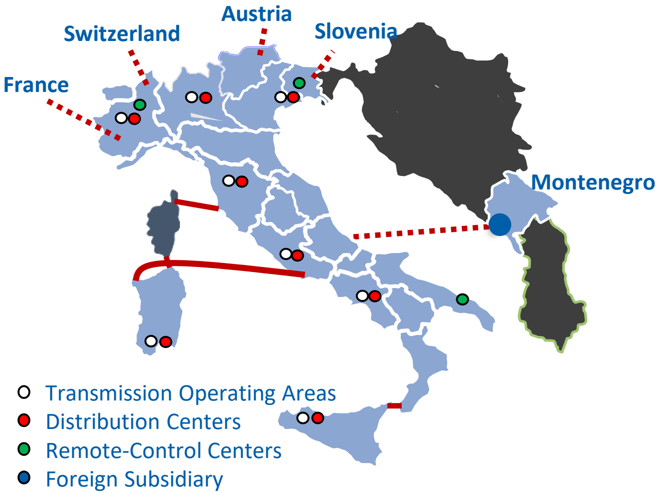
Numbers .....

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

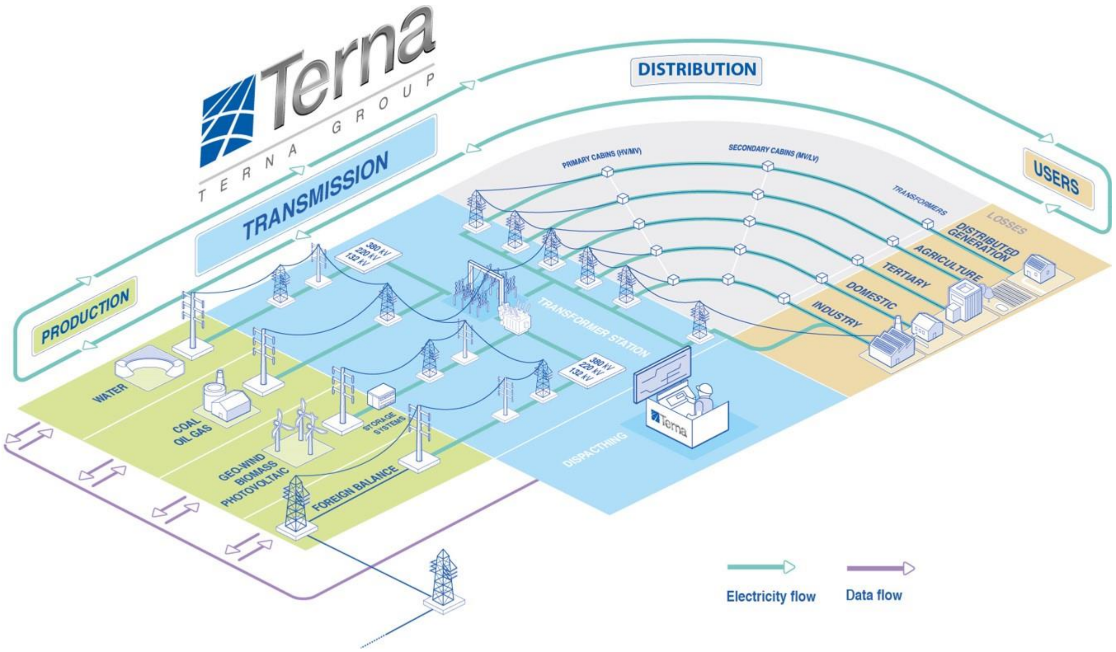
Assets
8 Transmission Operating Areas
8 Distribution Centers
3 Remote-Control Centers
1 Foreign Subsidiary

Electricity Market
315 TWh of yearly energy consumption
60 GW demand peak

... and premises



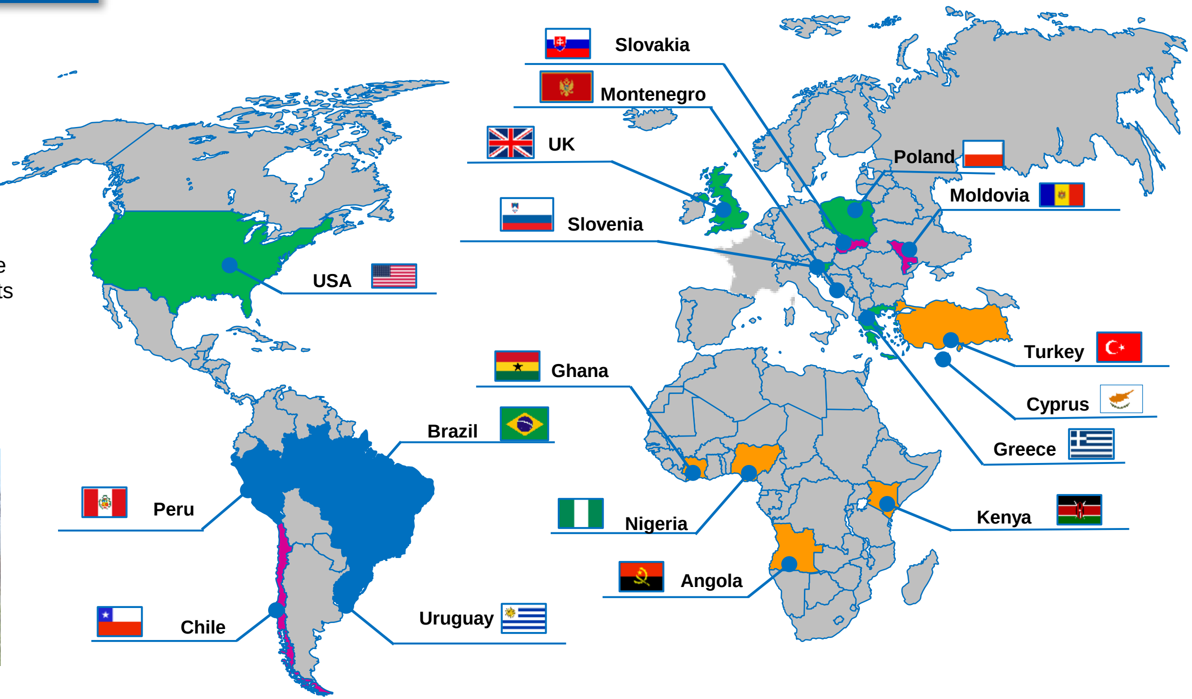
New frontiers for grid management: the TSO perspective



According to EU rules, in Italy Generation Transmission and Distribution are unbundled

New frontiers for grid management: the TSO perspective

Terna abroad:



Brazil

Uruguay

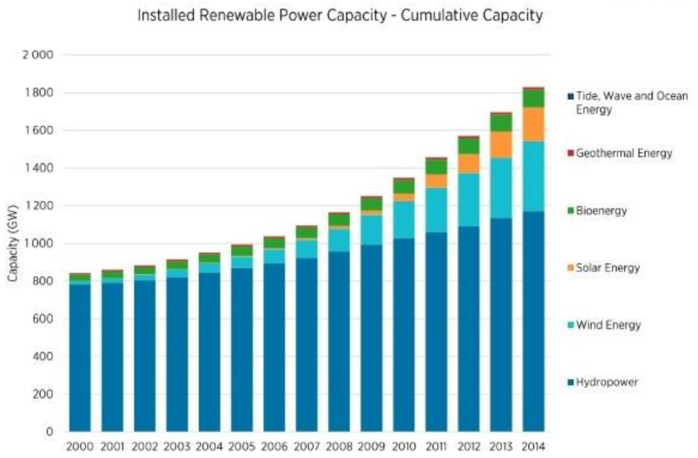
Montenegro

New frontiers for grid management: the TSO perspective

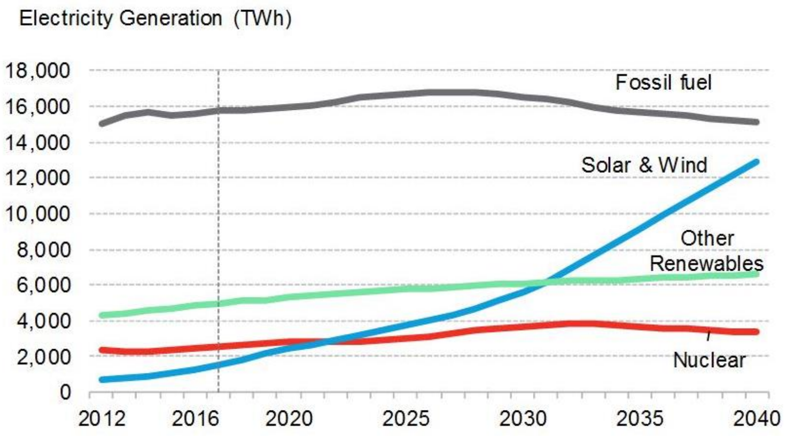
- ✓ ABOUT TERNA
- ✓ **RENEWABLE ENERGY SOURCES (RES) AND CHALLENGES FOR TRANSIMISSION SYSTEM OPERATORS (TSO)**
- ✓ CURRENT GRID BALANCING SERVICES IN ITALY - OVERVIEW
- ✓ BATTERY ENERGY STORAGE SYSTEMS (BESS) – OPPORTUNITIES FOR GRID SERVICES
  - o TERNA'S PILOT PROJECTS ON UTILITY SCALE BATTERIES AND VIRTUAL STORAGE PLANT
- ✓ NEW BALANCING TOOLS: VIRTUAL POWER PLANT (VPP) AND DEMAND SIDE RESPONSE (DSR)
- ✓ 2 TERNA'S PILOT PROJECTS ON BALANCING SERVICES FROM VPP+DSR AND BESS+BALANCING PRODUCTION UNIT

New frontiers for grid management: the TSO perspective

In the last 3 years, global worldwide newly installed electrical generation from Renewable Energy Sources (RES) overtook new traditional generation powered by fossil fuels:



Source: IRENA

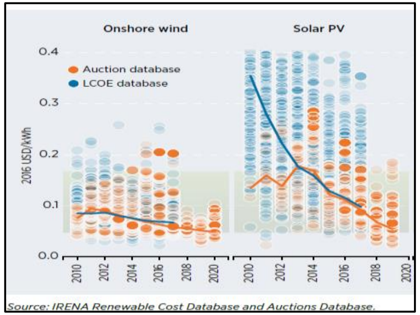


Source: BNEF

The growth of RES is due to raise more steeply in the coming years

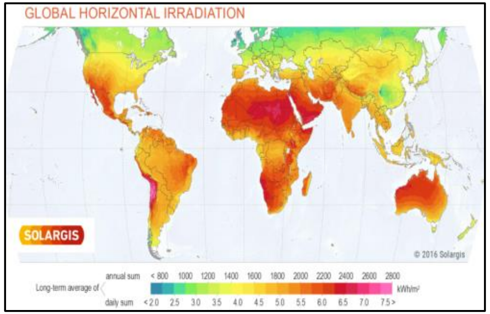
New frontiers for grid management: the TSO perspective

The transition from fossil fuels to RES is due to several convergent factors:



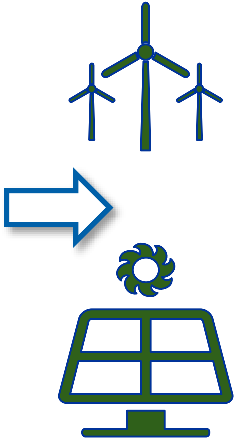
Source: IRENA Renewable Cost Database and Auctions Database.

RES costs have decreased drammatically (-85% in the last decade): when available energy from RES is cheaper than energy from fossil fuels



Diffuse availability of RES worlwide: RES can be deployed almost everywhere in the inhabited lands (in particular solar)

Climate change urgency
(a drastic reduction of greehouse gases emissions, in particolar CO_2, is a global priority)

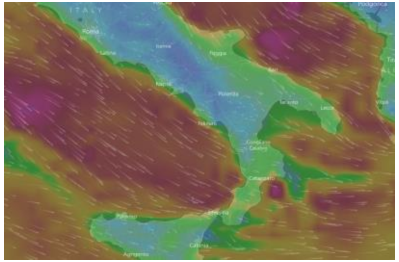


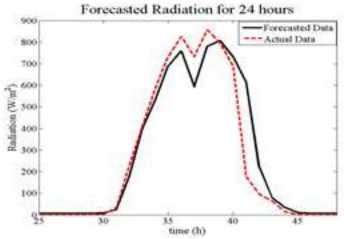
New frontiers for grid management: the TSO perspective

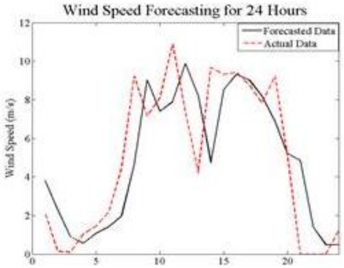
Effects of a high penetration of intermittent RES in the grid

Renewable Energy Sources (RES) into existing grids introduce **high risks of unbalances** due to:

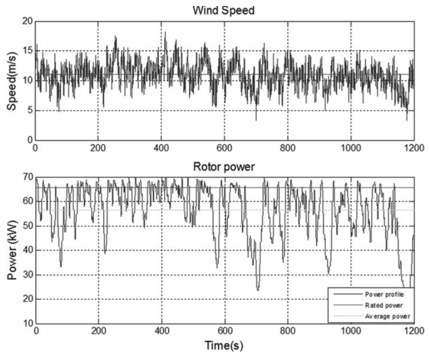
Not fully predictable RES output the day ahead when energy is negotiated (wheather forecasts are not 100% accurate)



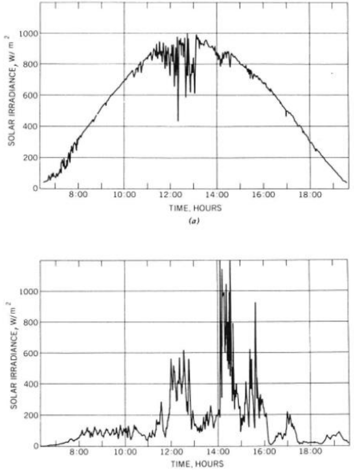




RES instant intermittency during production



20 mins wind profile

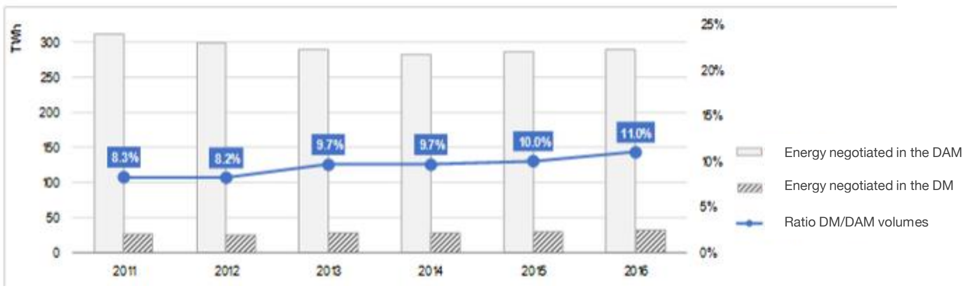


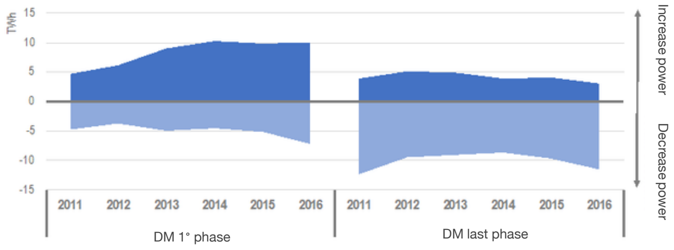
Irradiance daily profiles

In the lack of a clear RES program TSOs need to **activate excess standby reserve power for grid balancing**

New frontiers for grid management: the TSO perspective

Terna’s trend of Dispaching Market in the last years





Due to the **increasigly contribution in the Italian daily energy mix of non programmable RES**:

- ✓ the annual volumes of energy acquired by Terna in the Dispatching Market (DM) has progressivley increased (from 25,8 TWh in 2011 to 31.9 TWh in 2016)
- ✓ the ratio between the energy purchased in the DM and the total volumes of energy negotiated in the Day Ahead Market (DAM) has also increased

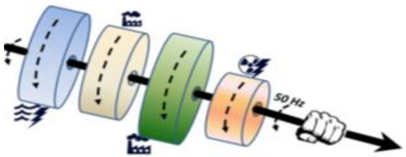
With the purpose of grid security, buys a larger amount of energy in the **first phase of the DM** (especially for the “increase power” services) and then balances it in the **last phase** with more “decrease power” services, when approaching real time grid balancing and unpredictability is lower.

New frontiers for grid management: the TSO perspective

Unbalances effects are worsened by a general decrease of global system inertia due to less availability of rotating masses (lower resilience against grid frequency and voltage unbalances):

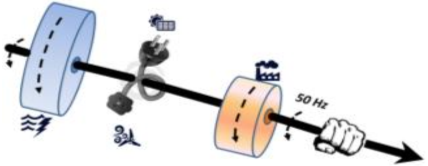
Traditional system generation had more rotating masses

more mechanical inertia

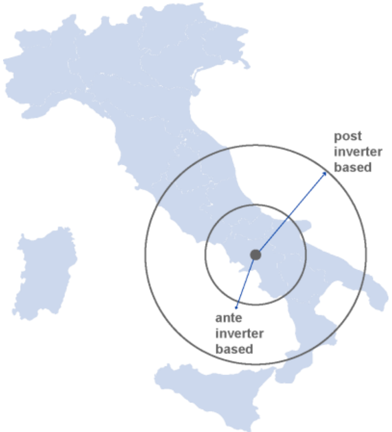


RES systems (inverter based) have less rotating masses

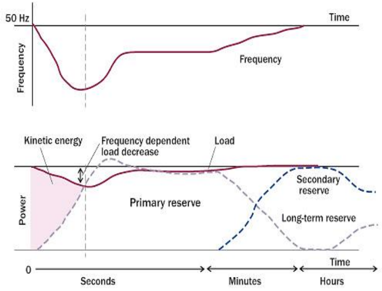
lower inertia

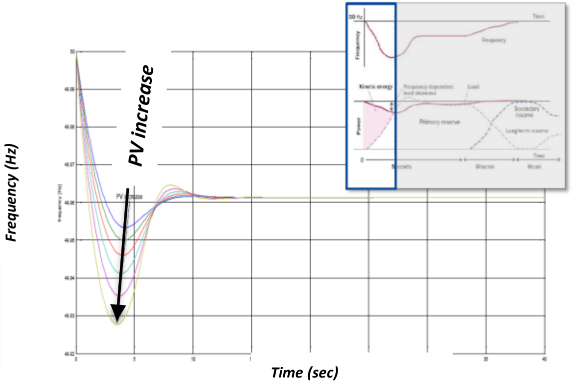


Increase of the frequency change gradient



Replacement of rotating generators with inverter based generators decreases the short-circuit currents and widens the area of disturbance in voltage



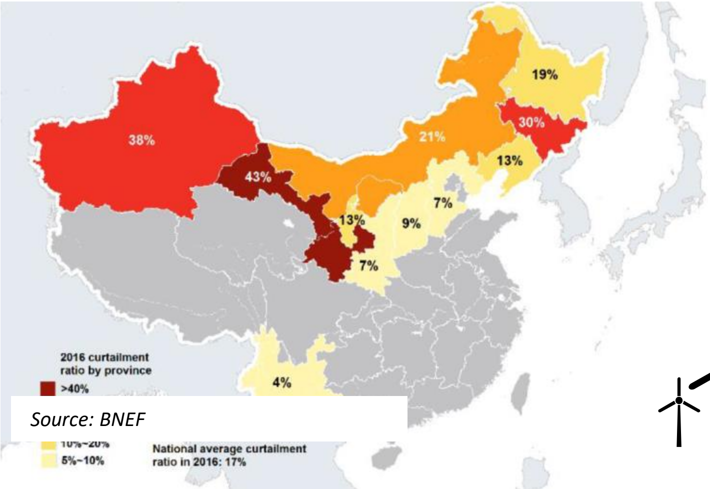


New frontiers for grid management: the TSO perspective

Without an adequate grid planning RES curtailment ratio can be very high

As some grid portions don't have sufficient transport capability in hours of low load **a large diffusion of RES generation could lead to grid bottlenecks** (measured effects are **reverse flows in primary cabins**). Defensive measures include **power curtailments**.

2016 wind curtailments



Source: BNEF

2016 PV curtailments

Source: BNEF

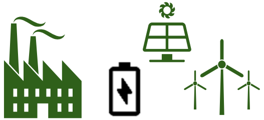
New frontiers for grid management: the TSO perspective

In order to allow for more RES into their gridsTSO's have several options:

Enhance transmission lines capability

- Construction of new HV lines 
- Improve existing HV lines capacity (cable replacement, Dynamic Thermal Rating) 

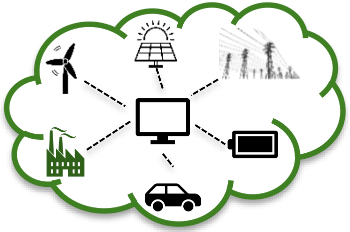
Purchase more instant balancing services (production-side or customer's-side)

- Fast change of production (+ or -) by traditional generation assets and/or grid connected energy storages (single or aggregated through Virtual Power Plants - VPP) 
- Fast reduction of consumption of selected clients in case of excess demand in the grid): Demand Side Response (DSR) 

Invest in proprietary Energy Storage Systems

- Battery Energy Storage Systems (BESS) 
- Pumped Hydro Storage (PHS) 
- Other ESS (CAES, LAES) 

Digitalize the grid (real time data management for a quick interaction between balancing options)



The optimal solution involves a blend of the above solutions

New frontiers for grid management: the TSO perspective

In order to allow for more RES into their gridsTSO's have several options:

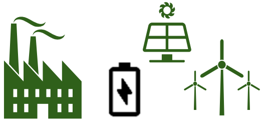
Enhance transmission lines capability

- Construction of new HV lines

- Improve existing HV lines capacity (cable replacement, Dynamic Thermal Rating)

Purchase more instant balancing services (production-side or customer's-side)

- Fast change of production (+ or -) by traditional generation assets and/or grid connected energy storages (single or aggregated through Virtual Power Plants - VPP)



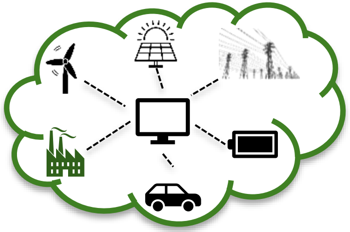
- Fast reduction of consumption of selected clients in case of excess demand in the grid): Demand Side Response (DSR)

Invest in proprietary Energy Storage Systems

- Battery Energy Storage Systems (BESS)
- Pumped Hydro Storage (PHS)

- Other ESS (CAES, LAES)

Digitalize the grid (real time data management for a quick interaction between balancing options)



focus

New frontiers for grid management: the TSO perspective

- ✓ ABOUT TERNA
- ✓ RENEWABLE ENERGY SOURCES (RES) AND CHALLENGES FOR TRANSIMISSION SYSTEM OPERATORS (TSO)
- ✓ **CURRENT GRID BALANCING SERVICES IN ITALY - OVERVIEW**
- ✓ BATTERY ENERGY STORAGE SYSTEMS (BESS) – OPPORTUNITIES FOR GRID SERVICES
    - o TERNA’S PILOT PROJECTS ON UTILITY SCALE BATTERIES AND VIRTUAL STORAGE PLANT
- ✓ NEW BALANCING TOOLS: VIRTUAL POWER PLANT (VPP) AND DEMAND SIDE RESPONSE (DSR)
- ✓ 2 TERNA’S PILOT PROJECTS ON BALANCING SERVICES FROM VPP+DSR AND BESS+BALANCING PRODUCTION UNIT

New frontiers for grid management: the TSO perspective

Terna: Grid management criteria

In the Italian grid, transmission and dispatching activities are characterized by:

- ✓ an **instant and continuous balancing between the energy fed into and taken from the network**, net of transport and distribution losses;

the **maintenance of the frequency and the voltage of the network energy** within a **very narrow range**, to protect the safety of the plants;
the need that the **energy** that flows on each individual power line **doesn't exceed the maximum permissible transit limits of the relevant power line**.

Terna's National HV grid control room

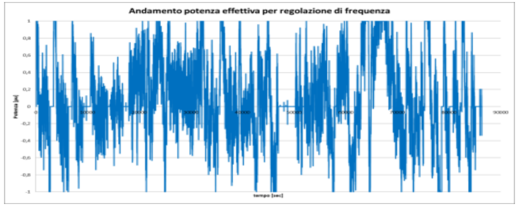
The characteristics of the technologies and the ways in which electricity is produced, transported and consumed make the compliance with these constraints complicated. Minimal deviations from any of the above parameters, for more than a few seconds, can quickly lead to systemic states of crisis.

Terna in order to guarantee the service to Italian grid customers, **performs in real time the System Balancing activity**. The necessary balancing between inputs and load is guaranteed by the **automatic regulation and control systems of the production units** (so-called **primary and secondary reserve**), which increases or reduces the input into the network in order to compensate for any unbalance.

Out of automatic regulation Terna intervenes actively when the operating margins of the automatic control systems are lower than the safety standards in order to reintegrate them - sending to the **tertiary reserve units** orders for ignition, increase or reduction of the power supplied.

New frontiers for grid management: the TSO perspective

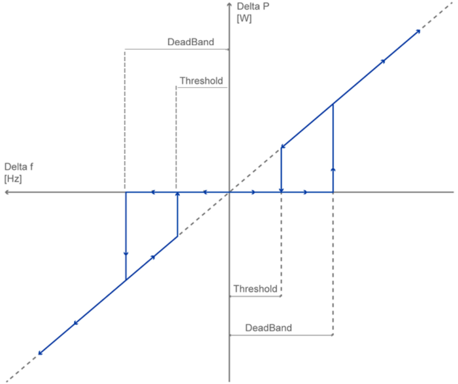
Primary frequency regulation

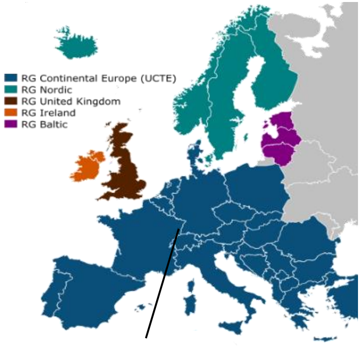


Terna uses the **Production Units with power output bigger than 10 MW to correct the instantaneous imbalances between total production and total requirements** of the entire interconnected European electricity **system** through the intervention of the speed regulators of the power generating turbines, in response to frequency variations. The primary frequancy regulation is carried out simultaneously by all generation groups in parallel on the European interconnected system. It must be continuously available and must be distributed as uniformly as possible in the Electrical System. Producers should make available to Terna a **band of electricity production capacity serviced by an automatic regulation device** able to modulate the power supplied, both increasing and decreasing:

- ✓ In the areas of Sardinia and Sicily must make available an adjustment band of not less than **± 10% of the efficient power (PN)** of each generation group;
- ✓ In the other zones (synchronous with Continental Europe), an adjustment band must not make **up ± 1.5% of the efficient power (PN)** of each generation group.

Terna does not procure the resource through the Dispatching Market (an order is not issued by Terna). The service is mandatory (generally **not remunerated** in Italy).





Synchronous area

$$\frac{\Delta P}{P_N} = -\frac{1}{\sigma} \cdot \frac{\Delta f}{50Hz} \cdot 100$$

ΔP to be fully deployed in 30 sec (of which 0.5 DP in 15 sec) and lasting at least 15 mins.

σ = 4% for hydro, 5% thermoelectric

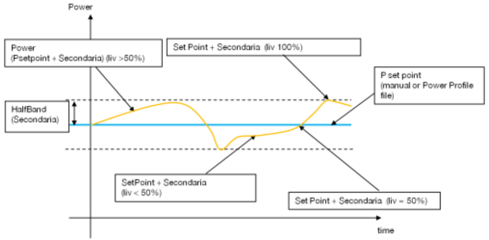
New frontiers for grid management: the TSO perspective

Secondary frequency regulation

Another technical constraint of the network that TERNA must take into account is the **capacity for transport and exchange between the areas** in which the network is divided. In order to avoid congestions, producers are willing to reduce or increase the power to be supplied by their plants in order to solve congestion on the network, ensuring that power flows on the lines always take place within the technical limits. In order **to offset the differences between production and requirements** (and so contributing to the re-establishment of the European frequency after a frequency change) and **bring power exchanges at the borders to the program values** Terna uses **secondary frequency regulation. This automatic function is performed by a centralized controller in the Terna control system.** The provision of this resource consists of:

- ✓ **in the planning and management phase**, in **making available the secondary reserve** half-band in the updated cumulative programs of the Production Unit;
- ✓ **in the real-time management phase**, in securing the secondary reserve band to an automatic regulation device capable of modulating the input of electrical energy of the same generation group on the basis of a signal (called **"level signal" L%**) elaborated and sent by Terna.

The secondary frequency regulation is **purchased on the Dispatching Market by Terna and remunerated.** In general, the unit enabled to supply resources for the secondary power reserve has the obligation to make the service available. In order to participate, **hydropower plants should make available at least ±15% of their maximum output and ± 6% for thermal power plants.**



Automatic level signal

$$\Delta P = 2 \cdot SB \cdot \left(\frac{L\% - 50\%}{100\%} \right)$$

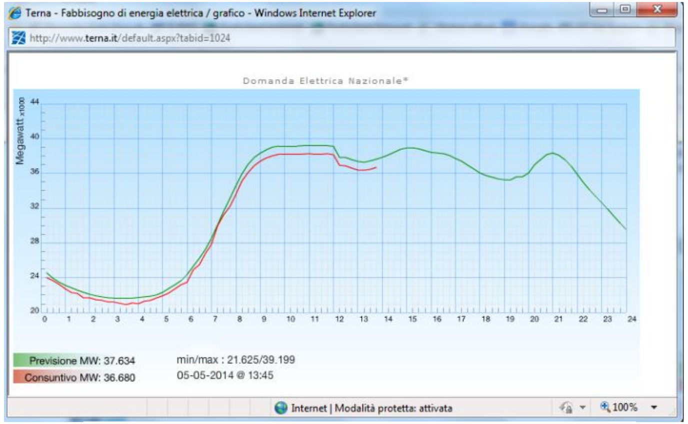
ΔP should be made available completely within 200 sec and should last at least 2 hours from start

SB = half band

Tertiary frequency regulation

Terna uses these resources to establish **appropriate margins with respect to the Minimum or Maximum power purchased from the Production Unit in the dispatching market.** These **margins**, prepared during the programming or management phase in real time, **are activated in real time with the dispatching order**, in the context of balancing services, and not through an automatic adjustment mechanisms (such as in the case of the primary and the secondary power reserve). Type of **dispatching order** can be: **«to increase»** or **«to decrease».** The provision of the power tertiary reserve service consists in the **presence of margins in the programs that allow**, in the context of the real-time balancing service, **the variation of the input or withdrawal, within the activation time and for a duration defined by Terna.** Tertiary frequency regulation means a real-time change to the binding schedule for a producer **aimed essentially at restoring appropriate primary and secondary regulation bands in the system.** Modifications to schedules can be configured either as modifications to generator programs already in service or as generator start / stop

The Production Units have the possibility to make available offers on the market for "**reserve ready**" (which can be activated within 15 minutes) or "**replacement**" (which can be activated within 60 minutes of the request).



Daily plot of expected (green) and measured (red) load

New frontiers for grid management: the TSO perspective

- ✓ ABOUT TERNA
- ✓ RENEWABLE ENERGY SOURCES (RES) AND CHALLENGES FOR TRANSIMISSION SYSTEM OPERATORS (TSO)
- ✓ CURRENT GRID BALANCING SERVICES IN ITALY - OVERVIEW
- ✓ **BATTERY ENERGY STORAGE SYSTEMS (BESS) – OPPORTUNITIES FOR GRID SERVICES**
  - o TERNA'S PILOT PROJECTS ON UTILITY SCALE BATTERIES AND VIRTUAL STORAGE PLANT
- ✓ NEW BALANCING TOOLS: VIRTUAL POWER PLANT (VPP) AND DEMAND SIDE RESPONSE (DSR)
- ✓ 2 TERNA'S PILOT PROJECTS ON BALANCING SERVICES FROM VPP+DSR AND BESS+BALANCING PRODUCTION UNIT

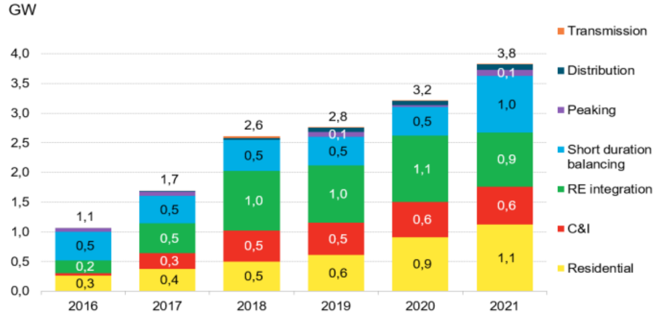
New frontiers for grid management: the TSO perspective

Battery Energy Storage System (BESS) - overview

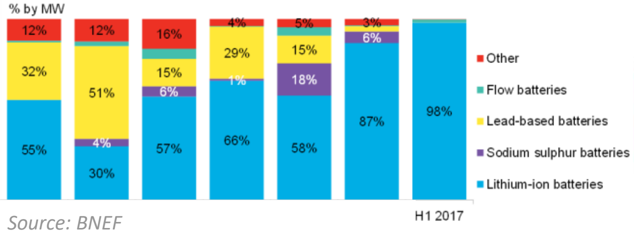
A BESS works on a **chemical reaction** that occurs between the **electrodes** and generates through an external electrical circuit a **flow of electrons**.
BESS can be made of **several chemistries.** After an long period dominated by lead-acid batteries, the market **leading technology** has become **lithium-ion**, due to **high power density, high efficiency, long durability**.

Other chemistries are in the research phase and could supersede in the long time lithium for specific applications. **Flow batteries** for instance, that store the electrolytes separately from the electrodes, can increase their storage capacity by increasing only the volume of the electrolyte's tanks at lower incremental coast (economically viable when energy discharge lasts long time i.e. several hours).

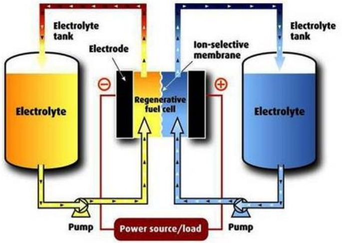
Global annual storage deployments by application, based on power output



Technology mix of utilit commissioned energy storage projects



Source: BNEF

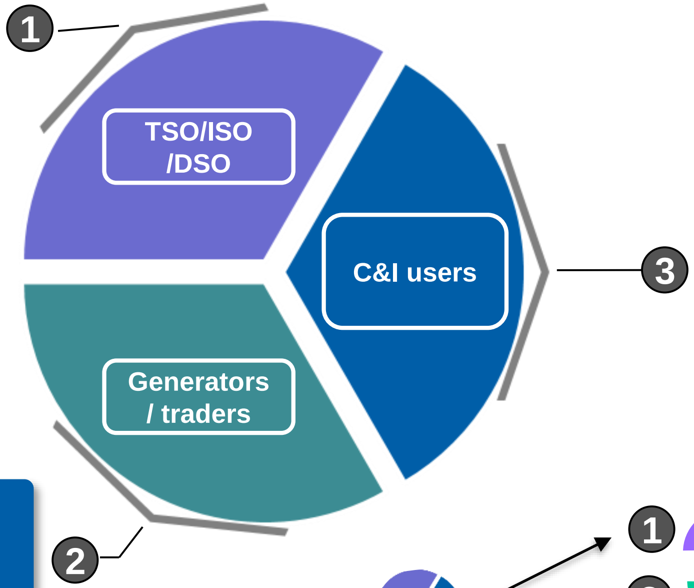


Flow battery

Large Scale BESS for on-grid applications – Services overview and markets

Grid services

TSO/ISO/DSOs are interested in storage applications that perform grid services (frequency response, voltage, demand ramping, etc.) in order to better operate the network, or either using the storage to defer grid enhancements

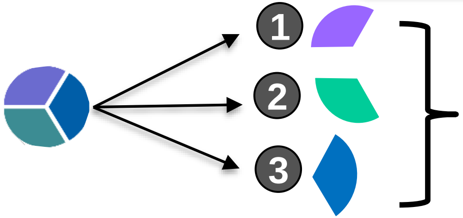


Customer's electricity bill optimization and supply reliability

Storage can also have Commercial and Industrial (C&I) customers in the so –called "behind-the meter" application, pushing toward optimization of electricity bills and, in case of weak grids, answering to the necessity of their reliable electricity provision.

Market services

Generators and traders are using energy storages to exploit market inefficiencies and realize potential gains (time shifts, peak demand "shaving")



Services "stacking": (a battery can perform several remunerated services at the same time)

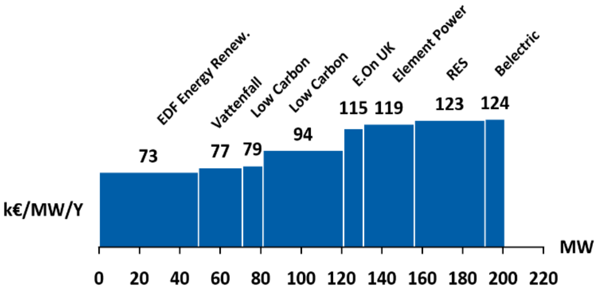
New frontiers for grid management: the TSO perspective

1 Grid services – ancillary services for the TSO

Grid services (“**ancillary services**”): **frequency and voltage regulation**. BESS unbeaten reaction time efficiently contrasts a frequency or a voltage fluctuation in an electrical grid (in less than a second a BESS can inject full power from standby mode as well as reverse its current flow**). Fast reactions and capability of BESS to be overcharged for short durations allow lighter energy injections in order to restore correct grid parameters**.

In the UK in 2016 National Grid (local TSO) issued its first **Enhanced Frequency Regulation (EFR) tender**, main rules being:

- **Power release within 500 ms from frequency deviation**
- **Full output within 1 second**
- Simmetrical service (store/release)
- Full power output for at least 15 minutes
- **18 month to commission the plants from tener award**
- **Contract duration: 4 years**



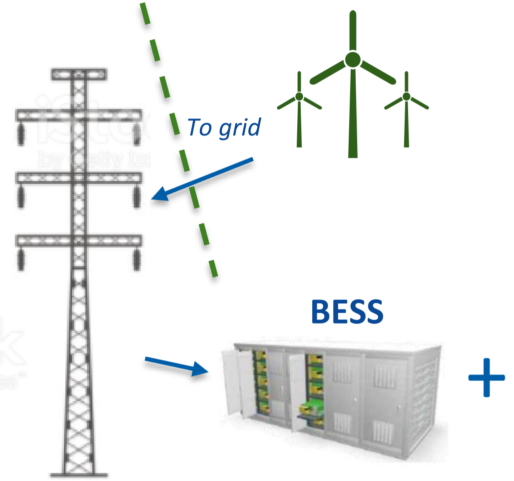
The tender was «technology agnostic» but, due to the superfast response requested, was entirely awarded to BESS

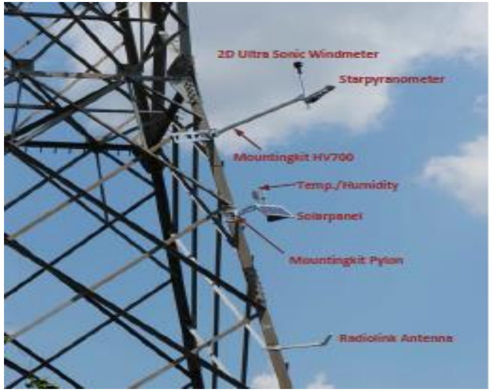
New frontiers for grid management: the TSO perspective

1 Grid services – BESS as a “non wire alternative”

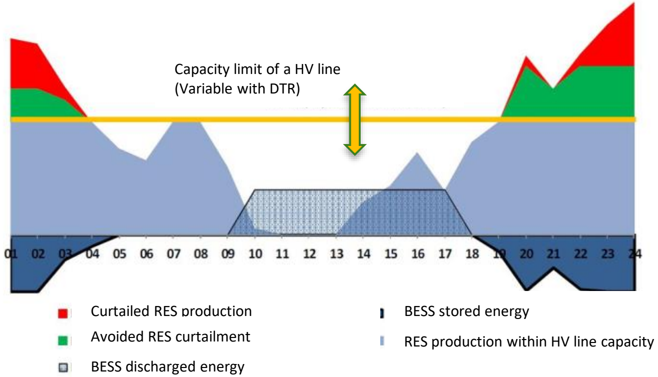
A well designed BESS can allow to **defer a more expensive grid reinforcement** (due for instance to an increase in power demand or in power production).

Terna has implemented large scale BESS in conjunction with Dynamic Thermal Rating (DTR) in order to mitigate wind production curtailments (when production is high and load is low – typically during night hours).



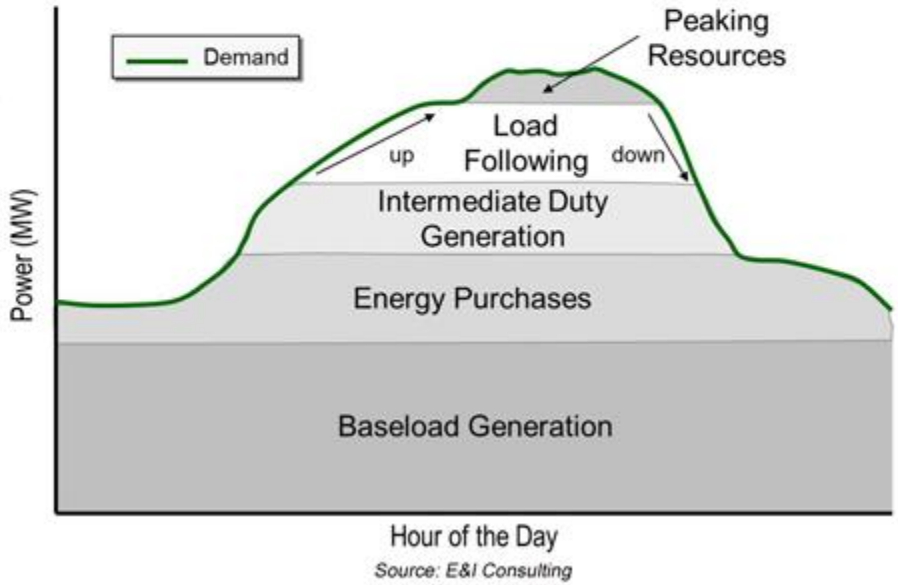


Best reduction of curtailments is achievable by coupling BESS with ***Dynamic Thermal Rating (DTR)*** on relevant HV lines (Terna’s experience)



New frontiers for grid management: the TSO perspective

1 Grid services – replacement of a new peak power plant with a BESS



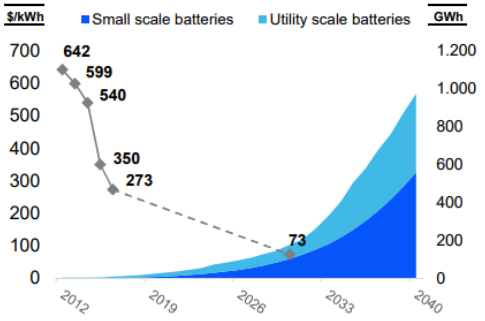
In the traditional energy mix, load following is mostly performed by hydro with reservoir plants and natural gas fired plants. When old gas fired plants reach end of life, **the realization of brand new ones might be more expensive than an alternative BESS of adequate capacity (if the gas plant is expected to work a little % of time during the year)**.

In the US (California) there are several examples of BESS installed as an alternative of new gas fired plants, with economical benefits for final customers' electricity bills. **This phenomenon is predicted to increase as far as BESS price will decline (ongoing process)**.

New frontiers for grid management: the TSO perspective

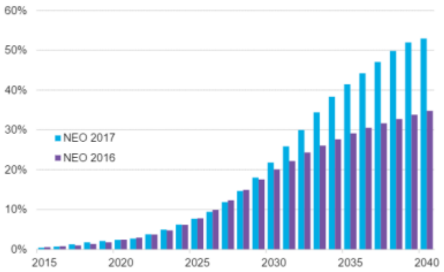
Historical and projected costs of lithium ion Battery Energy Storage Systems (BESS):

Batteries, cumulative installed capacity, 2012-2040 and Lithium-ion battery price



Source: BNEF

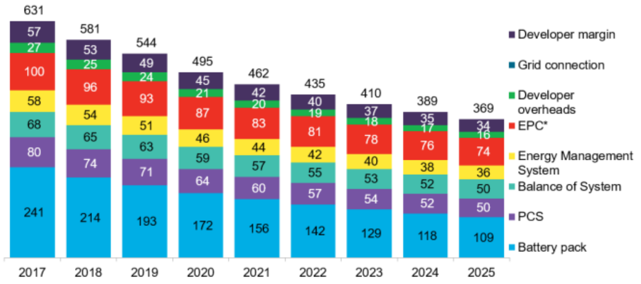
Percentage of EVs sales on total vehicle sales (2015-2040)



Source: BNEF

Benchmark capital costs for a fully-installed energy storage system, of a 1MW/1MWh project

Real 2017 $/kWh



Source: BNEF

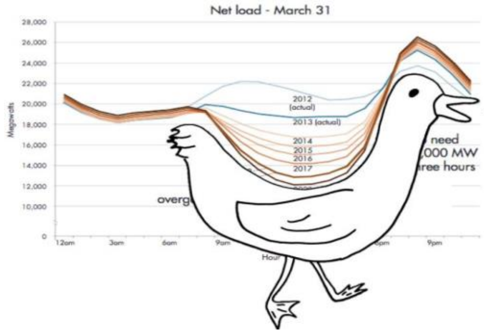
Huge reduction of costs in next years (same path experimented by cost of solar energy in the last decade)

New frontiers for grid management: the TSO perspective

RENEWABLE ENERGY SOLUTIONS FOR THE MEDITERRANEAN

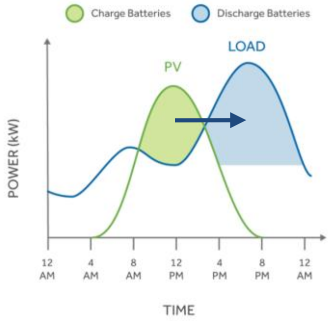
RENEWABLE ENERGY SOLUTIONS FOR AFRICA

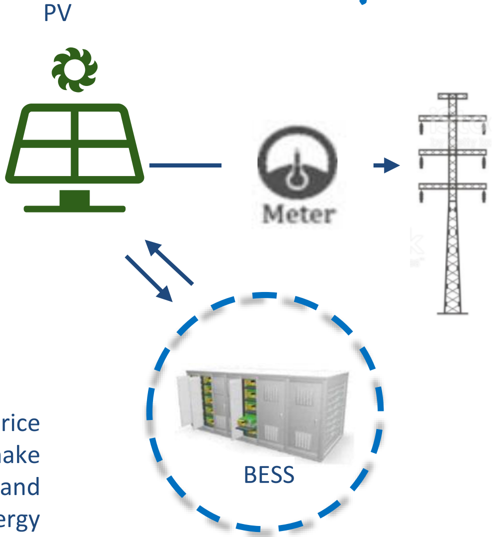
2 Market Services - BESS for time shift (US case study)



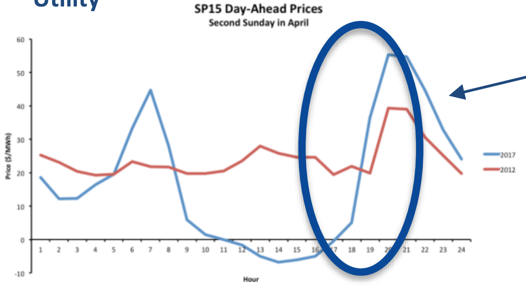
The current ramping needs curve of programmable generation is also known as the «**duck curve**». This steep ramp is mainly due to solar energy (that switches off at night, when demand from customers reaches its peak)

This is reflected in **higher prices for energy during evening hours**





Purchase price 2012-2017 for a Californian Utility



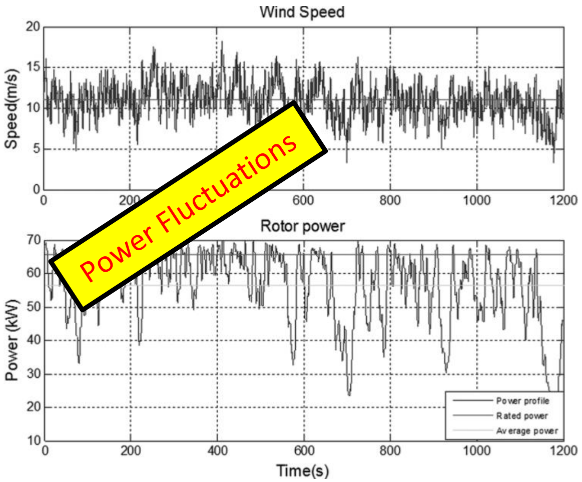
In 3 hours, price of energy rises from negative values up to 60 USD/MWh.

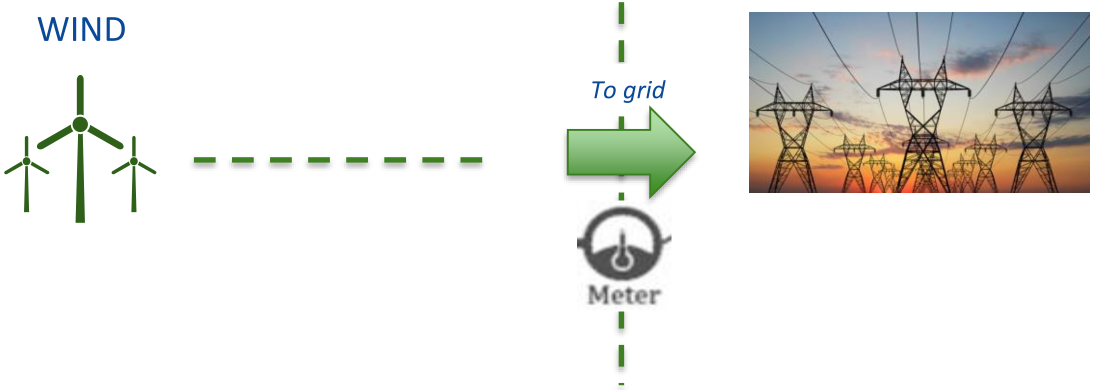
Huge variations in energy price within few hours can make convenient to store energy and release it few hours later (energy «**time shifting**»).

New frontiers for grid management: the TSO perspective

Progressive stacking of services of a on grid BESS associated with RES (example):

Traditional connection of a RES plant (e.g wind power):

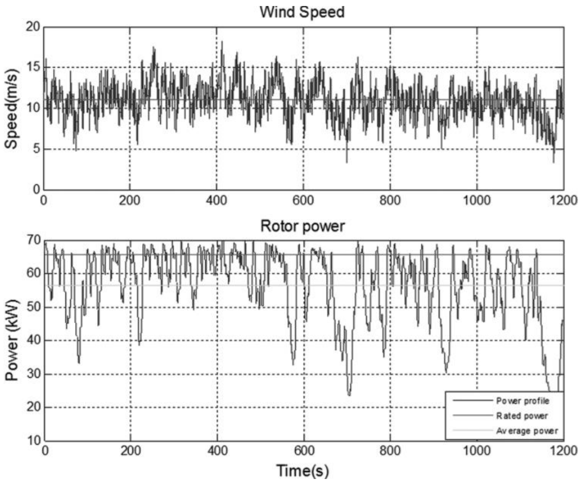


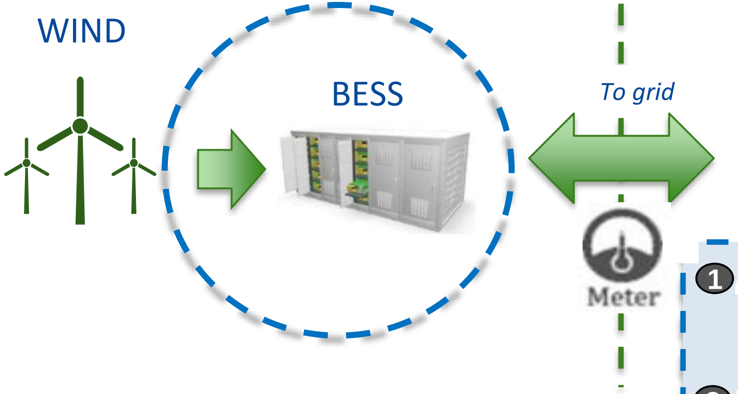


New frontiers for grid management: the TSO perspective

Progressive stacking of services and revenues for a on grid BESS installation:

Introduction of a "behind the meter" BESS:



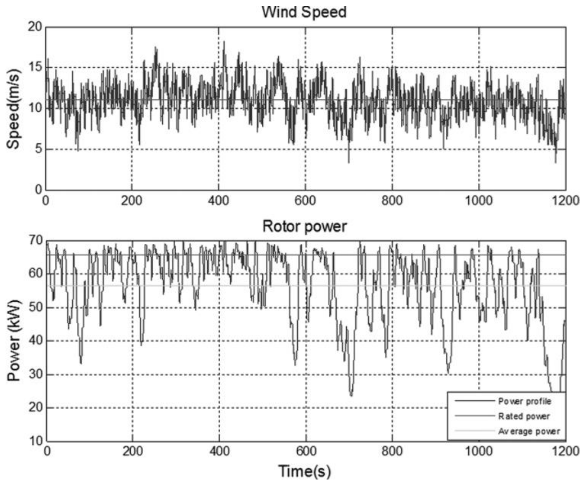


1. Frequency/voltage regulation services to TSO («remunerated **grid balancing services**»)
2. Sale of energy in more rentable hours of the day («**power arbitrage**») and more stable output

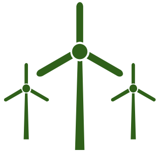
Revenues

New frontiers for grid management: the TSO perspective

If the RES plant is installed at a C&I customer premise, additional revenues for the owner:

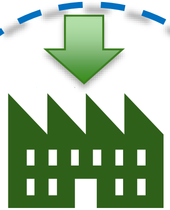


WIND



BESS

To grid



C&I Customer

1 Frequency/voltage regulation remunerated services to TSO («**grid balancing services**»)

2 Sale of energy in more rentable hours of the day («**power arbitrage**») and more stable output

3 Smart purchase of energy in low cost hours «**Electricity bill optimization**»

More revenues

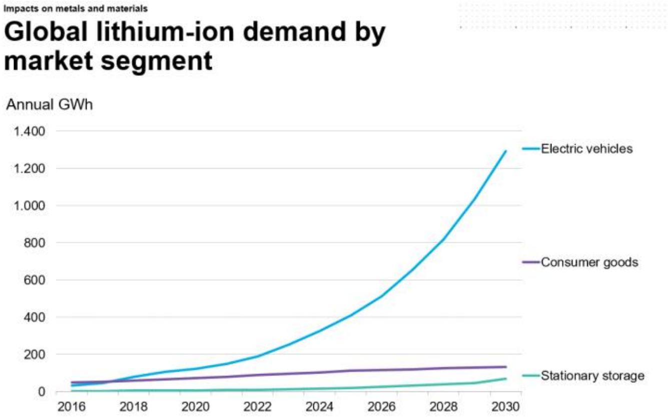
New frontiers for grid management: the TSO perspective

Opportunity for futher cost savings: second-hand Battery Energy Storage System (BESS) from electric vehicles

«In 10 years, more than a half of new vehicle production will be electric in the United States…”
Elon Musk CEO Tesla - July 2017

«Our top priority is electric mobility ….”
Harald Krueger CEO BMW - October 2017

«Electric mobility is and will be the future… »
F. Starace CEO Enel – November 2017



Source: BNEF

In the next 15 years the majority of new BESS will be installed on electric vehicles. A huge amount of second hand batteries from the automotive industry will therefore become available, suitable for stationary applications at very accessible cost (expected < 100 USD/kWh).

New frontiers for grid management: the TSO perspective

- ✓ ABOUT TERNA
- ✓ RENEWABLE ENERGY SOURCES (RES) AND CHALLENGES FOR TRANSIMISSION SYSTEM OPERATORS (TSO)
- ✓ CURRENT GRID BALANCING SERVICES IN ITALY - OVERVIEW
- ✓ BATTERY ENERGY STORAGE SYSTEMS (BESS) – OPPORTUNITIES FOR GRID SERVICES
  - o TERNA'S PILOT PROJECTS ON UTILITY SCALE BATTERIES AND VIRTUAL STORAGE PLANT
- ✓ NEW BALANCING TOOLS: VIRTUAL POWER PLANT (VPP) AND DEMAND SIDE RESPONSE (DSR)
- ✓ 2 TERNA'S PILOT PROJECTS ON BALANCING SERVICES FROM VPP+DSR AND BESS+BALANCING PRODUCTION UNIT

New frontiers for grid management: the TSO perspective

Terna’s BESS proprietary pilot projects in Italy

Storage Lab (Power Intensive)

Main goal: increase of grid security

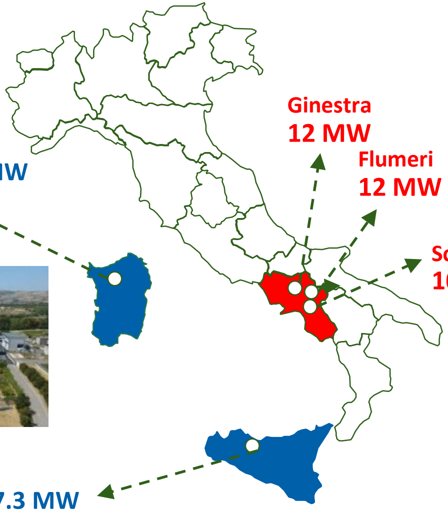
Applications: Frequency, Special Protection System
Technologies: Li-Ion, Zebra, Flow, Supercapacitor
Number of sites: 2

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**

Sardinia - Codrongianos
- Final planned size (MW): ≈ **8.65 MW**
- Status: in testing ≈ 7,9 MW



Sicily - Ciminna
- Final planned size (MW): ≈ **7.3 MW**
- Status: in testing ≈ 5,55 MW

Ginestra
12 MW

Flumeri
12 MW

Scampitella
10.8 MW

Large Scale (Energy Intensive)

Main goal: reduction of wind energy curtailment

Applications: Grid deferral
Technologies: NaS (Sodium Sulfur)
Number of sites: 3

Mono-technological battery solution based

Large scale plants, used to reduce wind energy curtailment

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

These projects are characterized by different sizes and goals, having each one peculiar experimenting approach

New frontiers for grid management: the TSO perspective

CODRONGIANOS

	TECHNOLOGY	SIZE	
BYD	Lithium Iron Phosphate	1 MW	1,23 MWh
SAFT	Lithium Nickel Cobalt Alluminium	1,2 MW	0,93 MWh
SAMSUNG	Lithium Manganese	1 MW	0,92 MWh
SIEMENS	Lithium Nickel Manganese Cobalto	1,08 MW	0,54 MWh
TOSHIBA	Lithium titanate	1 MW	1,02 MWh
FIAMM	Nickel-Sodium Chloride	1,2 MW	4,15 MWh
GE	Nickel-Sodium Chloride	1 MW	2,00 MWh
GILDEMEISTER energy solutions	Flow - Vanadium	0,4 MW	1,10 MWh

CIMINNA

	TECHNOLOGY	SIZE	
BYD	Lithium Iron Phosphate	1,0 MW	1,23 MWh
SAFT	Lithium Nickel Cobalt Aluminium	0,9 MW	0,57 MWh
SAMSUNG	Lithium Manganese	1,0 MW	0,92 MWh
TOSHIBA	Lithium titanate	1,0 MW	1,02 MWh
FIAMM	Nikel-Sodium Chloride	1,2 MW	4,15 MWh
融科储能 RONGKE POWER	Flow - Vanadium	0,45 MW	1,44 MWh

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

New frontiers for grid management: the TSO perspective

BESS technological portfolio

	Supercapacitors	Lithium Batteries	ZEBRA Batteries	Flow Batteries	NaS Batteries
Storage time	30 – 60 seconds	0,5 – 1 hour	2 – 4 hours	Power/Energy decoupled	8 hours
	• Procurement on going	BYD, Saft, LG, Samsung, Toshiba	FIAMM, GE	GILDEMEISTER energy solutions, 融科储能 RONGKE POWER	NGK
		9.2 MW installed	3.4 MW installed	0.85 MW installed	35 MW installed

Power Intensive ← → Energy Intensive

Main applications

- Ancillary services (e.g. frequency regulation) and grid support
- Defence systems
- Congestion management
- Back-up
- Load Shifting

"Large Scale" – Energy Intensive

"Storage Lab" – Power Intensive

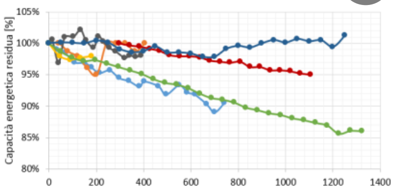
By means of its Pilot Projects, Terna has covered the full range of possible applications for BESS (systems and chemistries): from power-intensive to energy-intensive

New frontiers for grid management: the TSO perspective

In the Storage Lab tests Terna has tested all type of BESS extreme operating conditions:

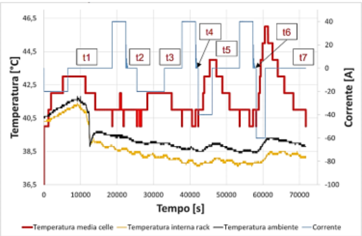
1

- **Standard cycle** tests
- **Frequency regulation** tests
- **Current steps** tests



2

Thermal tests



Thermal and electric modeling

Ageing models

Failure behaviours

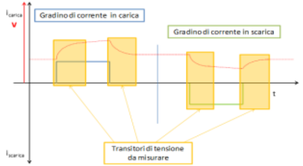
Only on lithium-ion BESS

Behaviour in non standard conditions

Only on lithium-ion BESS

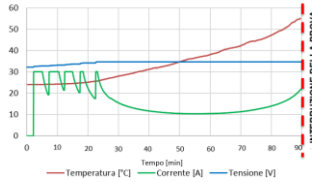
4

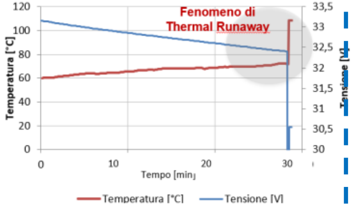
- **Performance** tests
- **Shorter cycles performance** tests
- **Equivalent circuits** calibration



3

- **Overcharge** tests
- **Overdischarge** tests
- **Short circuit** tests





New frontiers for grid management: the TSO perspective

Performed test on Power Intensive (✓) and Energy Intensive (✓) BESS

Grid Scale
(~1MW)

Tests on grid connected BESS

Test	Power Intensive	Energy Intensive
Frequency primary regulation	✓	✓
Frequency secondary regulation	✓	✓
Voltage regulation	✓	✓
BESS and system efficiency	✓	✓
Rated/Overload Capability curves	✓	
Black Start	✓	
Addition of BESS to existing Defense System	✓	
Capacity to reduce power curtailment		✓
Reverse flow time measurement		✓

Module scale
(~100kW)

Tests in laboratory

Test	Power Intensive	Energy Intensive
Ageing	✓	
Peformance test	✓	
Thermal test	✓	
Overcharge/discharge tests	✓	
Surcharge tests	✓	
Short circuit tests	✓	
Equivalent circuit calibration	✓	

Targets

Grid services

Ancillary services (frequency regulation, voltage regulation)

Increase of HV grid security

Reduction of RES curtailments

Technology assessment

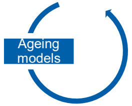
Performance comparison of the different «utility scale» BESS and identification of best suitable chemistry for each application

Operation optimization and value maximization

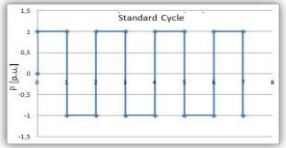
As TSO: development of an Advanced Control System for future management of multi-technological Storage platforms (Virtual Storage Plant)

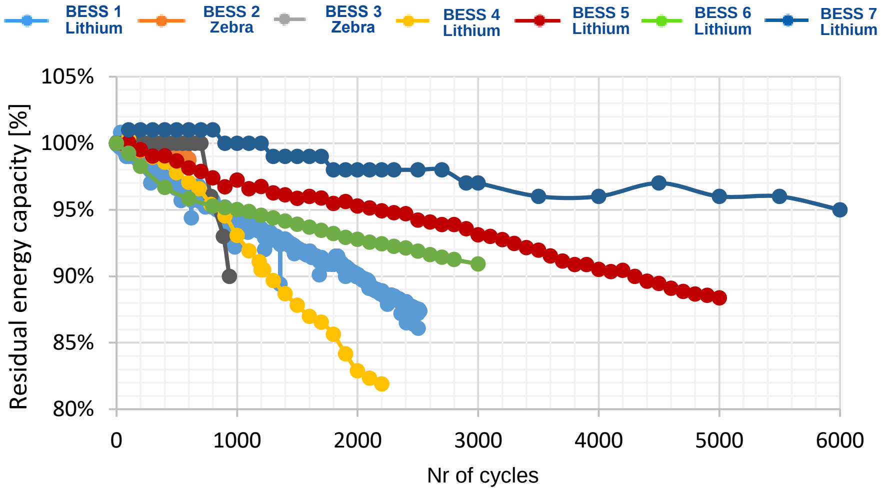
New frontiers for grid management: the TSO perspective

Example: BESS ageing tests for Standard cycles



Standard cycle





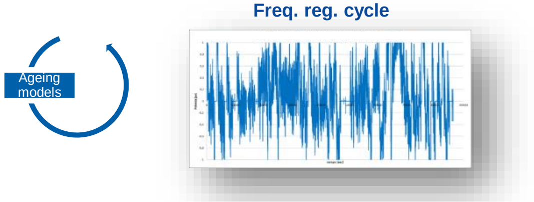
The results of the cycling test indicate that some technologies can tolerate more than 5000 cycles showing a very low performance degradation (Lithium BESS 7 showed a 5% reduction of its nominal capacity after 6000 cycles).

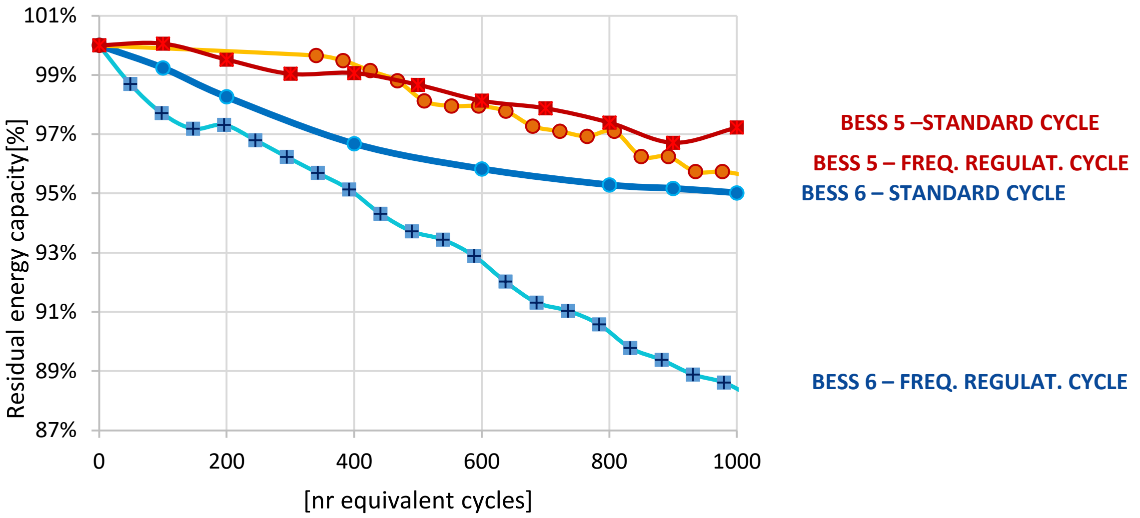
On the contrary, other technologies showed high ageing degrees even from 1000 cycles (the Lithium **BESS 4 proves to be near to the 80% limit of residual capacity just after 2000 cycles notwithstanding the higher warranty guaranteed by the manufacturer**).

The different electrochemical storage technologies, tested on the same cycle, show ageing patterns substantially different

New frontiers for grid management: the TSO perspective

Example: BESS ageing tests for grid frequency regulation





The **normal 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, temperature…)

Terna’s Virtual Storage Plant, a BESS “aggregation”

The **Virtual Storage Plant (VSP)** is an ongoing pilot project. It will allow to control and conduct Terna’s BESSs in 2 ways:

- ✓ at single BESS level (as of today);
- ✓ as an Equivalent single Storage Unit by implementing virtualization and aggregation algorithms.

The logics for aggregation will be based on nominal characteristics and operating states of each storage unit, allowing a **more coordinated and effective management of the whole storage plant**.

The **Virtualization functionality** combined with the **Optimization layer** will allow the optimal use of each technology and the maximization of operational benefits.

The Optimization layer represents indeed the most experimental and pioneering functionality of the VSP, allowing the integration of several storage technology models and different optimization algorithms into the Control, Management and Switching system of the TSO’s plant.

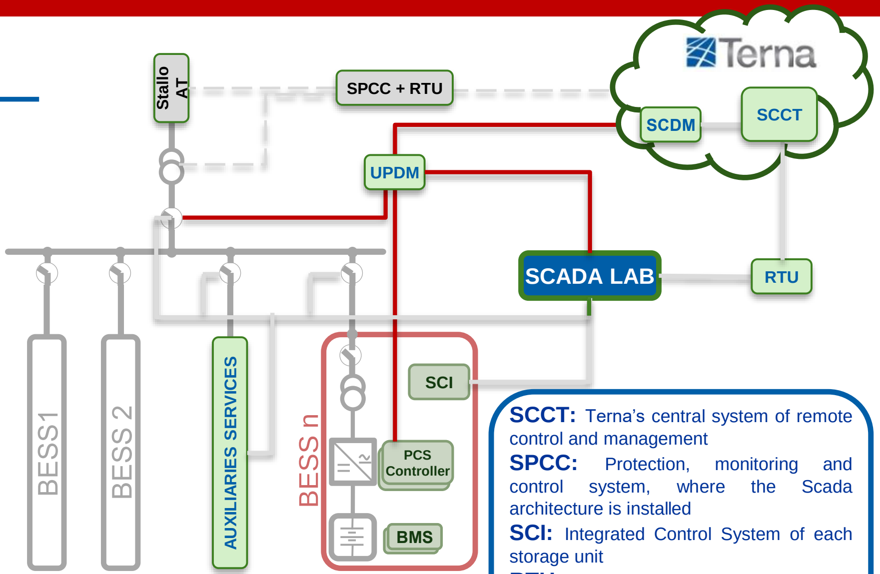



New frontiers for grid management: the TSO perspective

Present Control System

SCADA LAB

- The local control system where the control, management and monitoring functions of the Storage Lab plant are implemented.
- The main functionalities are:
  - Local **control and management** of each BESS **individually**
  - **Communication gateway** to send/receive data from **the Terna's central system of control - SCCT**
  - **Overall monitoring**
  - **Management data flow** to/from the Integrated Control System – SCI of each storage unit
  - **Implementation of Terna's Defense Plan**



SCCT: Terna's central system of remote control and management
SPCC: Protection, monitoring and control system, where the Scada architecture is installed
SCI: Integrated Control System of each storage unit
RTU: Remote Terminal Unit
UPDM: Peripheral Unit of Terna's Defense System by which the functionalities for the security of the Electric System are implemented

The existing configuration of the Scada Lab implies a decentralized management of the Storage Lab since each BESS is controlled on its own and independently from the others.

This results in a non-optimal use of technologies due to the lack of an aggregation tool able to exploit synergies among the installed storage technologies and maximize the performance of each one

New frontiers for grid management: the TSO perspective

- BESS 1
- BESS 2
- BESS n

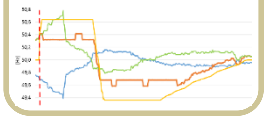
Today

Virtual Storage Plant

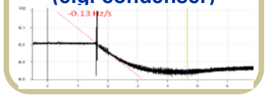
- BESS 1
- BESS 2
- BESS n

Tomorrow

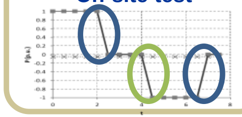
Service details



Special tests (e.g. condenser)



On-site test



Laboratory tests

ENEA CESI RSE

INPUT

VSP - Virtual Storage Plant

CONTROL & SWITCHING

- Plant service with **innovative dispatch and switching functions**

ADVANCED MONITORING

- **Greater observability** of system service and operating methods

VIRTUALISATION

- **Aggregation and virtualisation** of different energy storage systems, simplifying switching and dispatching activities

TESTING & TECH-ASSESSMENT

- **Dedicated testing environment** and **KPI evaluation**

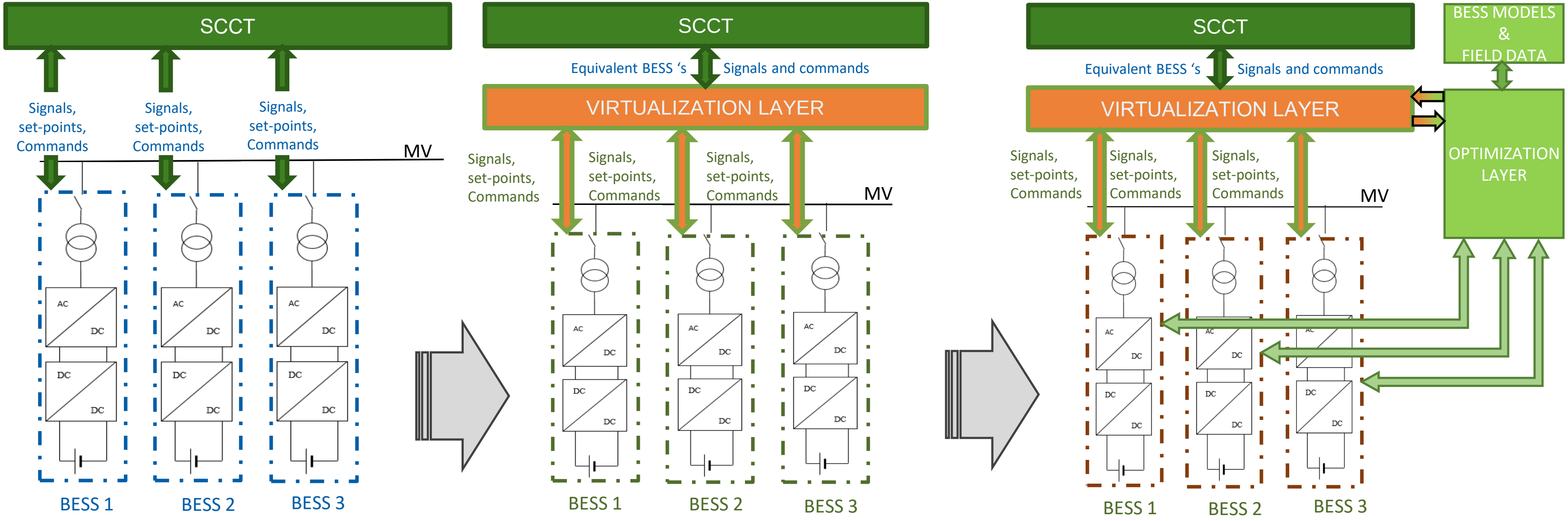
OPTIMIZATION

- **Integrating the model of each technologies** in order to provide real-time system optimization

Virtual Storage Plant is an advanced integrated control system designed to manage several storage units in a virtualized and optimised way, integrating specific technological characteristics and reducing overall constraints

New frontiers for grid management: the TSO perspective

Focus: Virtualization and Optimization Functionalities

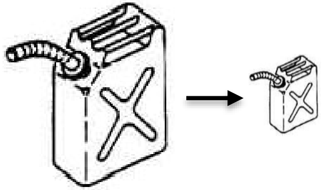


Main concern about BESS: capacity degradation during time

In April 2018 they stated *(source: Norton Rose Fulbright):*

Raphael Declercq (vice president of portfolio strategy for EDF Renewable Energy, the North American arm of EDF) : ……"Our industry is still in its infancy. ***There are a lot of things, like rate of degradation, that we do not know. Degradation is the biggest risk****"…….*

Sam Jaffe, managing director of Cairn Energy Research Advisors : ……."Former US defense secretary Donald Rumsfeld said there are things I know I don't know and things I don't know I don't know. In this sector, there is a lot of not knowing what we don't know. ***We do not know how long the batteries will last****"…*



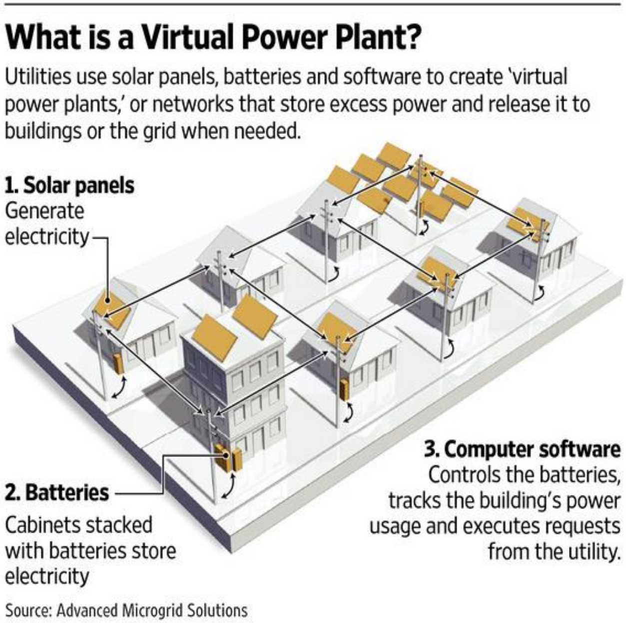
With Storage Lab and Large Scale **Terna has acquired a deep understanding on operational benefits and limits for the whole range of current available BESS**. In particular it has developed the ability to evaluate expected performance and durability of each selected technology depending on the services the battery is expected to perform and developed accordingly **calibrating proprietary ageing models for each chemistry studied**.

New frontiers for grid management: the TSO perspective

- ✓ ABOUT TERNA
- ✓ RENEWABLE ENERGY SOURCES (RES) AND CHALLENGES FOR TRANSIMISSION SYSTEM OPERATORS (TSO)
- ✓ CURRENT GRID BALANCING SERVICES IN ITALY - OVERVIEW
- ✓ BATTERY ENERGY STORAGE SYSTEMS (BESS) – OPPORTUNITIES FOR GRID SERVICES
    - o TERNA'S PILOT PROJECTS ON UTILITY SCALE BATTERIES AND VIRTUAL STORAGE PLANT
- ✓ **NEW BALANCING TOOLS: VIRTUAL POWER PLANT (VPP) AND DEMAND SIDE RESPONSE (DSR)**
- ✓ 2 TERNA'S PILOT PROJECTS ON BALANCING SERVICES FROM VPP+DSR AND BESS+BALANCING PRODUCTION UNIT

New words: «Virtual Power Plant», «Aggregators» and «Prosumers»

In particular in the EU and US, with the **explosion of decentralized small units of production and consumption** (i.e. household PV plants with or without batteries, electric vehicles charging/discharging onboard batteries) a **new fleet of actors** (called "**prosumers**") is emerging, with a high aggregated installed capacity potentially **able to provide important balancing services to the grid operators**. Prosumers, due to their small single capacities, need intermediation means in order to negotiate services with the TSOs/DSOs. Intermediation is normally offered by entities called "**Aggregators**" or in few cases directly by DSOs through **dedicated software platforms**. The contribution of hundreds or thousands of prosumers, from a TSO/DSO perspective, is the same as if the service would have been provided by a single larger unit (what is called a "**Virtual Power Plant" - VPP**). **Aggregators** (mainly software companies) stipulate an individual contract with the prosumer and provide it with a **control unit** that, based on parameters measured locally and production forecasts, **manages the plant within the boundaries of the stipulated agreements**. A proprietary software optimizes the different prosumers contributrions in real time in order to **guarantee as an aggregate the contracted service to TSO/DSO**.



New frontiers for grid management: the TSO perspective

Examples of VPP pilot projects in the UK (at the distribution network level)

Piclo Flex software platform for aggregation

Dubbed as an **"online dating service between Distribution Network Operators (DNOs) and Distributed Energy Resources (DERs)"**. UKPN has placed 4 (of the 10 locations it previously sought 14MW of flexible capacity for) onto Piclo Flex for an auction to take place in Q4 2018

Oxford City Council trial project

Oxford City Council deployed **82 systems in homes alongside solar**, as well as in a school and a community building. Running between 2015-17 as the UK's first **large-scale domestic solar-and-storage project with around 500kWh** of storage capacity, the project aimed to reduce the average peak grid load and increase solar consumption with the added benefit of lowering household bills. It enabled to **test and manipulate the whole fleet together to optimize its software, hardware and asset management services in a wide range of real world scenarios**.

Cornwall (Online virtual market + blockchain)

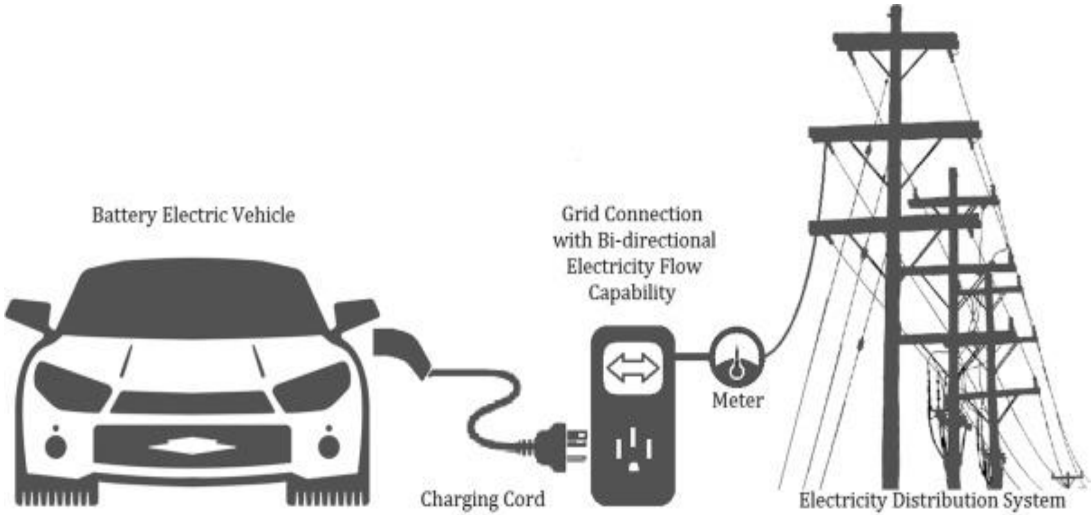
The project will connect hundred of homes and businesses in Cornwall (UK) served by, alongside local **blockchain-enabled smart meters renewable generators**, to an online virtual market place, allowing them to sell energy capacity to the grid and the wholesale

energy market .The distribution company will create a bid around 10 days ahead when it foresees a need for flexibility (e.g. weather forecasting showing increased output from solar and wind, or low demand or network outage). Business and aggregators will create an offer their own operational availability alongside with a price. If accepted, a contract between the utility and the seller will preview:

- ✓ an **arming fee**, as an availability payment.
- ✓ a **dispatch fee** if the service will be finally called (it will be known only few hours before the event).

New frontiers for grid management: the TSO perspective

Electric vehicles = “batteries on wheels”



In the mix of energy resources forming a VPP, electric vehicles are going to play an incrementally important role. For the DSO/TSO **electric cars, when connected to the grid through recharging stations or domestic electric plugs, in order to provide grid services can not only recharge the battery but discharge it depending on the grid needs**. As the majority of the vehicles are parked 90% of their time, if they stay connected to the grid they can contribute significantly to the grid stabilization as other stationary batteries.

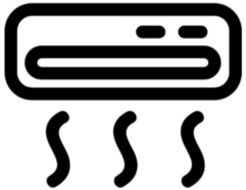
New frontiers for grid management: the TSO perspective

«Demand Side Response»

From *Wikipedia*:
"**Demand Side Response (DSR)** is the modification of consumer demand for energy through various methods such as financial incentives and behavioral change through education. Usually, the goal of demand-side management is to **encourage the consumer to use less energy during peak hours**, or to move the time of energy use to off-peak times such as nighttime and weekends. Peak demand management does not necessarily decrease total energy consumption, but could be expected to **reduce the need for investments in networks and/or power plants for meeting peak demands**".

Example: electric vehicles

Example: supermarkets refrigeration



Example: air conditioning

Example: factories

Providers of DSR services can be **single large consumers or aggregated smaller customers**. The TSO publishes competitive bids for the service. In Italy Terna asks consumers to engage to **reduce their load profile in 15 mins from the order received**.

New frontiers for grid management: the TSO perspective

- ✓ ABOUT TERNA
- ✓ RENEWABLE ENERGY SOURCES (RES) AND CHALLENGES FOR TRANSIMISSION SYSTEM OPERATORS (TSO)
- ✓ CURRENT GRID BALANCING SERVICES IN ITALY - OVERVIEW
- ✓ BATTERY ENERGY STORAGE SYSTEMS (BESS) – OPPORTUNITIES FOR GRID SERVICES
    - o TERNA'S PILOT PROJECTS ON UTILITY SCALE BATTERIES AND VIRTUAL STORAGE PLANT
- ✓ NEW BALANCING TOOLS: VIRTUAL POWER PLANT (VPP) AND DEMAND SIDE RESPONSE (DSR)
- ✓ **2 TERNA'S PILOT PROJECTS ON BALANCING SERVICES FROM VPP+DSR AND BESS+BALANCING PRODUCTION UNIT**

New frontiers for grid management: the TSO perspective

Pilot project #1: more resources admitted to grid balancing

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**. These included:

- ✓ small production units previously not admitted to the Dispatching Market
- ✓ large energy consumers

In 2017 and 2018 Terna has launched **pilot projects** regarding **consumption and production aggregated virtual units**:

Consumption Virtual Units (CVU) enabled

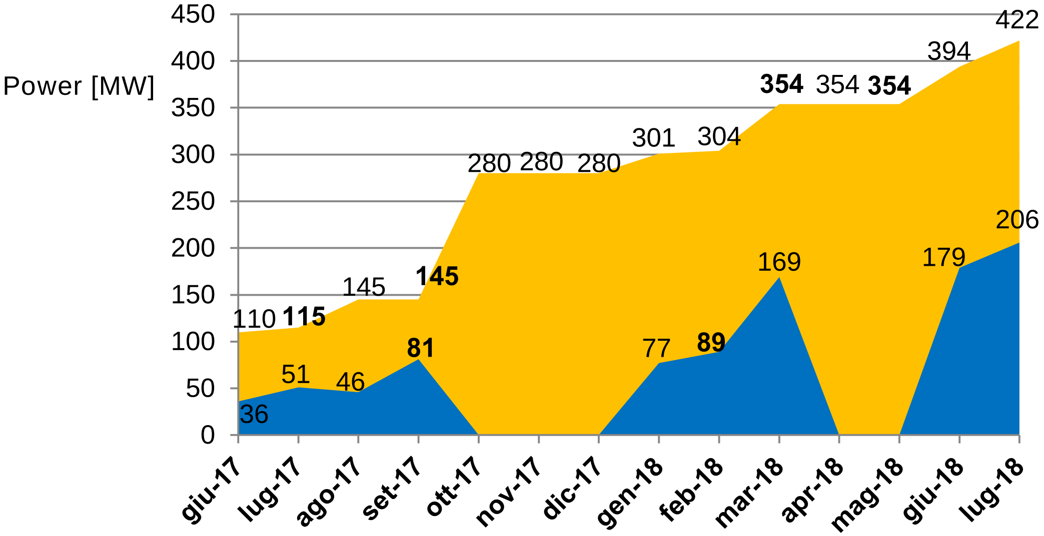
- Market participation of aggregated loads ensuring a reduction of the consumption of at least 5 MW within 15 min by Terna signal, able to provide the **decrease of consumption** for at least 3 hours.
- New role of the Balance Service Provider as an indipendent player.

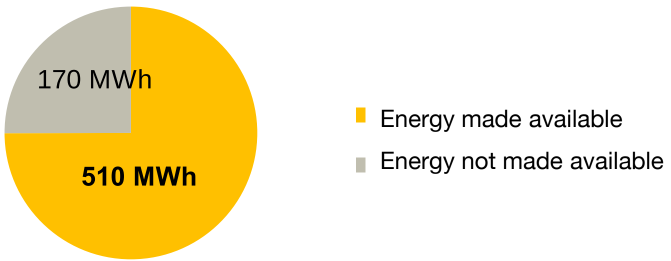
Production Virtual Units (PVU) enabled

- 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.

New frontiers for grid management: the TSO perspective

Results after first DSR tenders:

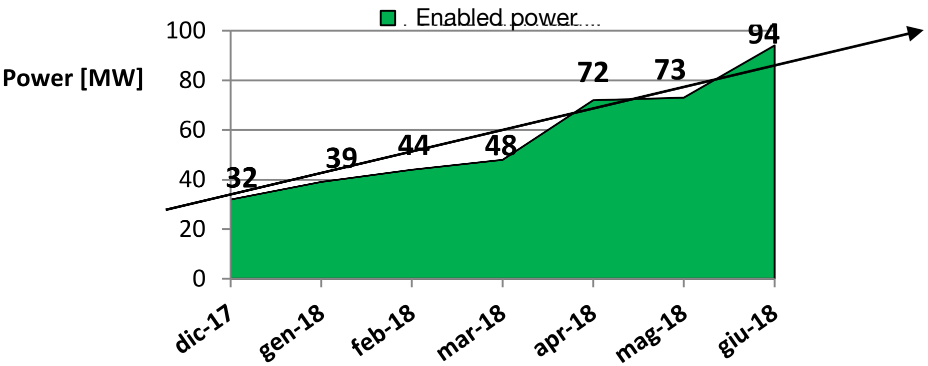


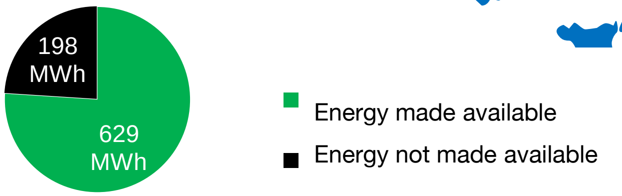


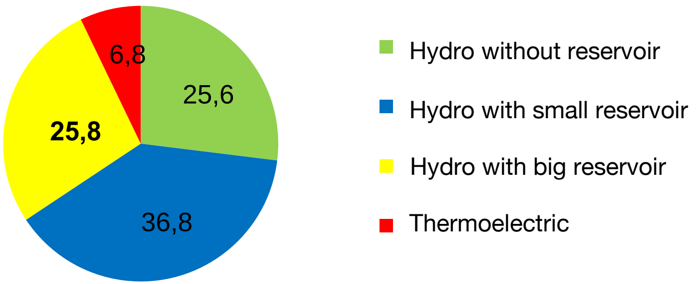
In the period from June 2017 to April 2018 the enabled CVUs averaged 75% of the volumes traded on the Dispaching Market

New frontiers for grid management: the TSO perspective

Results of the implementation after first tenders for PVU:





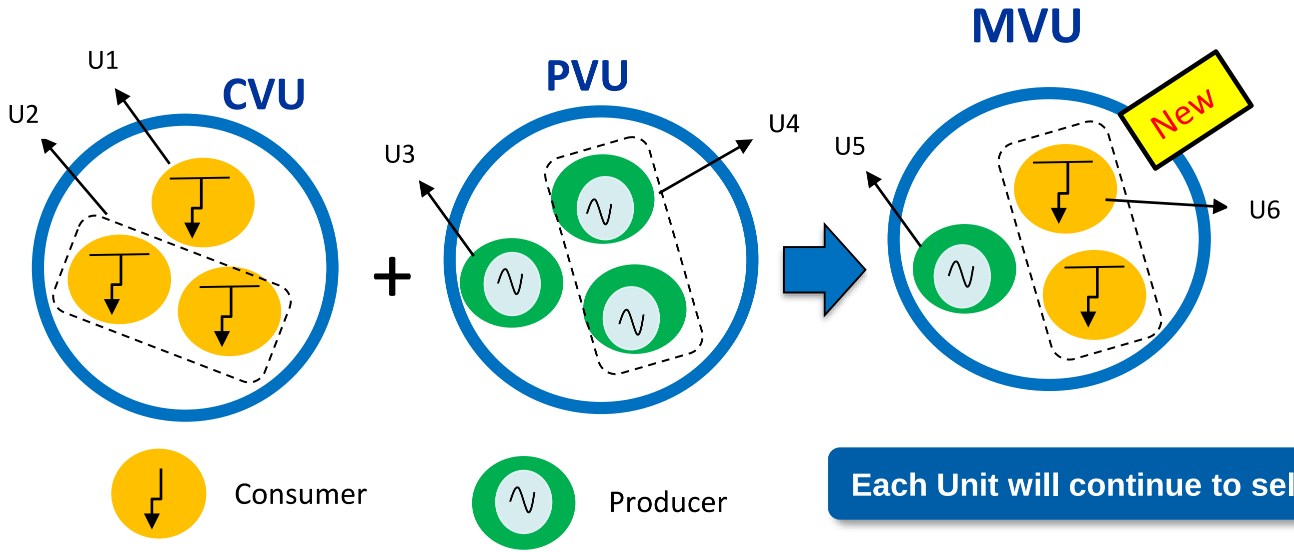


In the period from December 2017 to April 2018 the enabled PVUs averaged 76% of the volumes traded on the Dispaching Market

New frontiers for grid management: the TSO perspective

Next phase: MVU admitted to next tenders

In the next flexibility tenders Terna will admit also **Mixed Virtual Units (MVU)**, that aggregate in the same balancing entity consumers and producers. The **threshold** to provide balancing services has been lowered to **1 MW**.

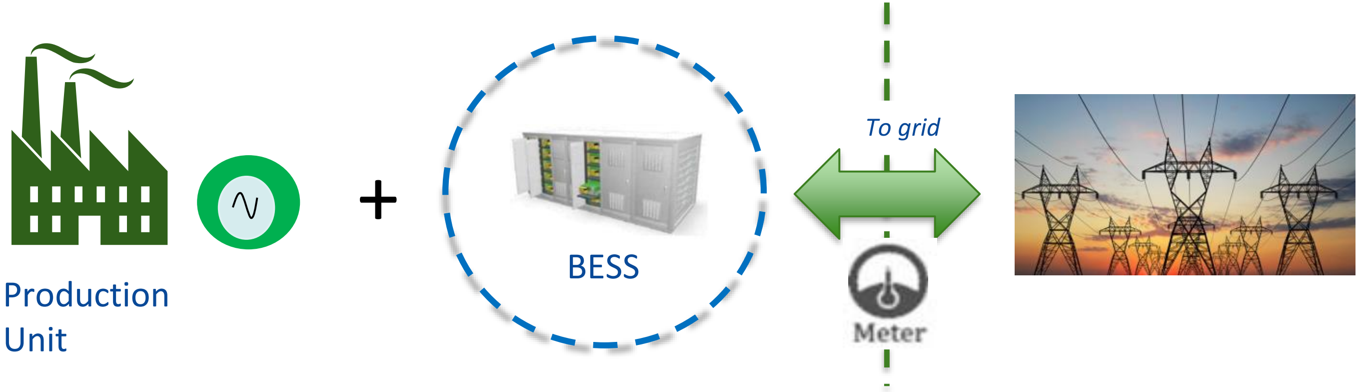


The **Balancing Service Provider (BSP)** - normally an aggregator - will be the responsible of the MVU, selling the balancing services to the TSO.

Each Unit will continue to sell or buy separately its electricity

New frontiers for grid management: the TSO perspective

Pilot project #2 : BESS associated to a main Production Unit already providing balancing services



The **Production Unit** already participating to the Dispatching Market, **will be able to sell to the energy market an additional 1.5 % of its production capacity** (previously dedicated to primary frequency regulation) **if the newly installed BESS will guarantee the same power output and the previously minimum requested duration** for primary frequency regulation. In exchange for this extra marketable capacity for the Production Unit, **the BESS will have to intervene at full power in 1 second instead of the normal 30 seconds.**

Thank you

Matteo Neri
International Business Development
Terna SpA - Viale Egidio Galbani, 70- 00156 Roma - Italia
Tel. +39 06 8313 8665 Mob. +39 342 7752157
www.terna.it