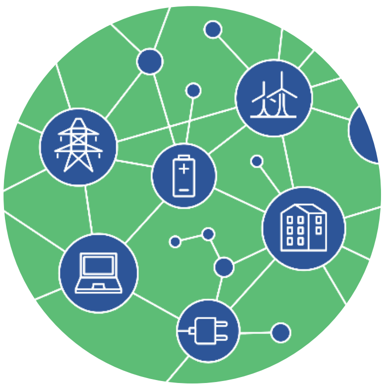
OSMOSE

OPTIMAL SYSTEM-MIX OF FLEXIBILITY SOLUTIONS FOR EUROPEAN ELECTRICITY

Techno-economic analysis of DSR and RES selected services

D5.1



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List of acronyms and abbreviations

In the following table is listed the acronyms and abbreviations used in this document.

Acronym	**Meaning**
aFRR	Automatic Frequency Restoration Reserve
AMI	Analog Measured Values
ARERA	*"Autorità di Regolazione per Energia Reti e Ambiente" (*i.e The Italian Energy Authority*)*
ASO	Analog Sepoint Commands
AVC	Automatic Voltage Control
BESS	Battery Energy Storage System
BMS	Battery Management System
BSP	Balance Service Provider
CA	Consortium Agreement
CHP	Combined Heat Power
CMU	Communication Module Unit
D	Deliverable
DFIG	Doubly Fed Induction Generator
DS	Demand Side
DSR	Demand Side Response
DTR	Dynamic Thermal Rating
EGP	Enel Green Power
EMS	Energy Management System
ERPS	Enhanced Reactive Power Service
FCR	Fast Containment Reserve
FRR	Frequency Restoration Reserve
FSO	Floating point Sepoint Commands
GPRS	General Packet Radio Service
HMI	Human Machine Interface
HV	High Voltage
HVDC	High Voltage Direct Current
IC	Communication Interface

ICT	Information Communication Technology
IED	Intelligent Electronic Device
KPI	Key Performance Index
LCR	Local Control Room
LV	Low Voltage
MFI	Measured Floating point Information
MSD	"*Mercato dei Servizi Ancillari*" (Ancillary Service Market)
MV	Medium Voltage
ORPS	Obligatory Reactive Power Service
PCS	Power Conversion System
PE	Power Electronics
PFC	Power Flow Control
PLC	Programmable Logic Controller
PV	Photovoltaic
RES	Renewable Energy Source
ROCOF	Rate Of Change Of Frequency
RR	Restoration Reserve
RTU	Remote Terminal Unit
RVR	Regional Voltage Regulator
SCADA	Supervisory Control And Data Acquisition
SCI	Substation Communication Interface
SI	Synthetic Inertia
TSO	Transmission System Operator
UVA	Enabled Virtual Unit
UVAC	Enabled Virtual Unit for Consumption
UVAM	Enabled Virtual Mixed Unit
UVAN	Enabled Virtual Nodal Unit
UVAP	Enabled Virtual Production Unit
VPP	Virtual Power Plant
WP	Work Package
WTG	Wind Turbine Generator

0 Executive summary

This deliverable aims to provide a detailed technical description of the flexibility services to be tested within the WP5 demonstrator of the OSMOSE project; furthermore an economic analysis for each service has been performed. The document follows the structure of the project proposal and it recalls the following tasks:

- 5.1.1 “Demo site location and plant assessment”
- 5.1.2 “Analysis and design of RES flexibility services”
- 5.1.3 “Analysis and design of advanced features for dynamic transmission grid management services”

In fact, paragraph 1, “Demo site location and plant assessment”, recalls all the activities done in order to localize the demonstrator area, by identifying the portion of the Italian power system in which the demonstrator will be implemented. The area was identified by looking for a grid portion in which phenomena of power flow inversion, line congestions and wind power curtailment have been relevant. Besides the localization of the demonstrator area, task 5.1.1 identified also the flexibility resources that could be involved in the testing of flexibility services provision, both RES and DS resources. The engaged RES power plants are owned by some of the WP5 partners, which have a clear idea of the potential benefits that could come from the experimentation. A brief description of the involved power plants is included in paragraph 1, with a focus on their control system. On the other hand, industrial customers are currently being engaged as third parties by the WP5 partners, in such a way to explain[1] to them the relevance and the usefulness of the project: they will in fact acquire the know-how necessary to participate in future market scenarios (open to DS resources as well as to RES power plants).

Paragraph 2, “Analysis and design of flexibility services”, analyses the provision of flexibility services, from a technical and economical point of view. First, the current state of the art and regulatory context of the Italian ancillary service market are described, in order to explain the context in which the flexibility services, provided by new actors, could be potentially introduced. Then, a proposal of technical specifications for each service is provided. The starting point was the Italian Grid Code, which prescribes the requirements for the provision of each service.

[1] No remuneration for the provision of flexibility services is envisioned for the involved flexibility resources, while, especially for industrial customers, their priority is to maintain their production chains as much stable as possible.

However, those prescriptions are valid for the generation units already enabled to the ancillary service market. The additional step, taken with task 5.1.2 and task 5.1.3, was to hypothesize innovative services, compliant as much as possible with the Grid Code requirements, but provided by new type of sources. This technical analysis has been followed by an economic estimation, based on market price analyses and European best practices. Finally, a description of the hardware devices and the software components that will enable the service provision by the flexibility resources is presented. In fact, while RES power plants have their own SCADA systems (for which the main control logics are described), DS resources will have to be controlled by an aggregator platform that will combine their regulating capability in order to provide, globally, the services specified in this document.

Deliverable 5.1 aims to provide a shared approach for the introduction of new players in the ancillary service market, by characterizing flexibility services provided by not already enabled resources. As a matter of fact, the WP5 demonstrator perfectly fits in the progressive evolution of the Italian ancillary service market that is currently undergoing[2], in which it is envisioned that new resources (such as the one involved in the demonstrator) could eventually provide flexibility services, especially in a context of high RES penetration.

[2] For more information, see paragraph 2.2.1, "*Market evolution - Resolution 300/2017/R/eel*"

1 Demo site location and plant assessment

The scope of this chapter is to show the current results of Task 5.1.1 "*Demo site location and plant assessment*", in which the demo site location has been identified and characterized, in terms of grid topology and available flexibility resources (RES power plants and industrial loads). A first part is dedicated to the HV grid analysis that allowed the selection of the grid portion in which the flexibility services provision is going to be tested. Then, the industrial customers' identification and engagement processes are described. Finally, a technical overview of the involved RES power plants is given, with a focus on their control systems.

1.1 Demo site description

At a regional level, the demonstrator area was selected by identifying those grid portions in which the testing of flexibility services provision as well as the application of congestion management tools would have been the most effective. According to the 2017 Italy National Grid Development Plan ("*Piano di Sviluppo*"), there is a presence of congestions in both 380 kV and 150 kV HV lines between Apulia and Basilicata regions (*figure 1*), as well as reversed energy flows in the HV / MV primary substations. These effects together contribute to affect the amount of production cuts of wind power generation, increased between 2015 and 2016 from 1.1% to 1.3% of the total national wind power production, confirming the growth trend started in 2014.

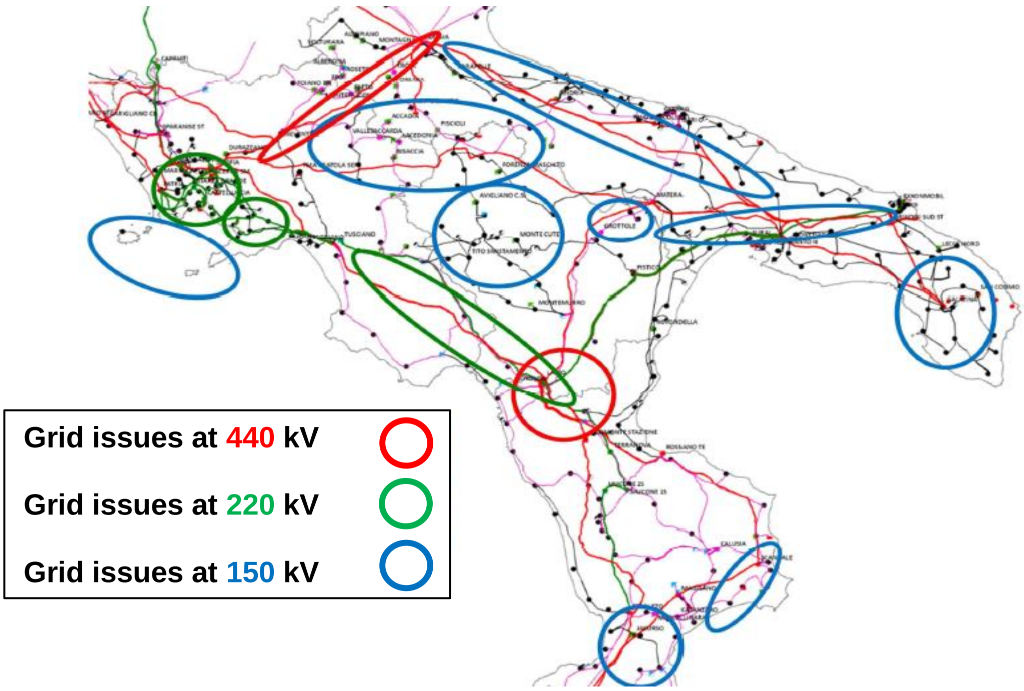


Figure 1 – Main areas in South Italy subjected to congestions on the HV grid

Within the South Italy area, the demonstrator area was selected after a careful HV grid assessment that took into account:

- The occurrence of line congestions and power flow inversion phenomena inside the substations
- The expected number of planned RES power plant connections

The occurrence of congestions was registered especially in the following main lines:

1. lines connecting the 380/150 kV substation of Matera
2. lines connecting the 380/150 kV substation of Troia, Deliceto and Andria
3. 150 kV grid portion between Bari and Brindisi
4. main lines between Brindisi and Galatina 380/150 kV substations

Among those lines, four backbones between the Apulia and Basilicata regions were chosen for the OSMOSE project:

1. Taranto N2 – Taranto E
2. Aviglia C.S. – Avigliano
3. Melfi – Venosa
4. Altamura – Altamura Allacciamento

In parallel to the identification of congested lines, substations interested by flow inversion were identified, by looking at the balance between load and generation in the year 2016. The trend of the load/generation balance has been analysed for some sample substations (Tricarico, Salandra and Avigliano) in order to better characterize the phenomenon and to quantify the number of hours/year during which each substation is working under reverse flow condition. The results showed how each substation worked under these conditions for more than 20÷40 % of the time relative to the period 01/03/2016 – 28/02/2017.

Three additional backbones were selected after considering the most likely evolution of the operating conditions of the selected grid portion, in terms of:

- number of HV connection requests from RES plants, grouped for each backbone and for the next 3 years (short-term scenario) and 5 years (mid-term scenario)
- number of works for grid reinforcement envisioned in the 2017 Development Plan, which completion is expected for 2020-2023

In particular, the installed capacity from RES (especially wind farms) in the selected portion of the grid will increase by 587.3 MVA in the next 5-6 years. The three most affected backbones (figure 2) were selected accordingly:

5. Melfi – Tricarico – Matera SE
6. Melfi – Potenza – Salandra – Matera CP
7. Matera SE – Bari Ovest SE

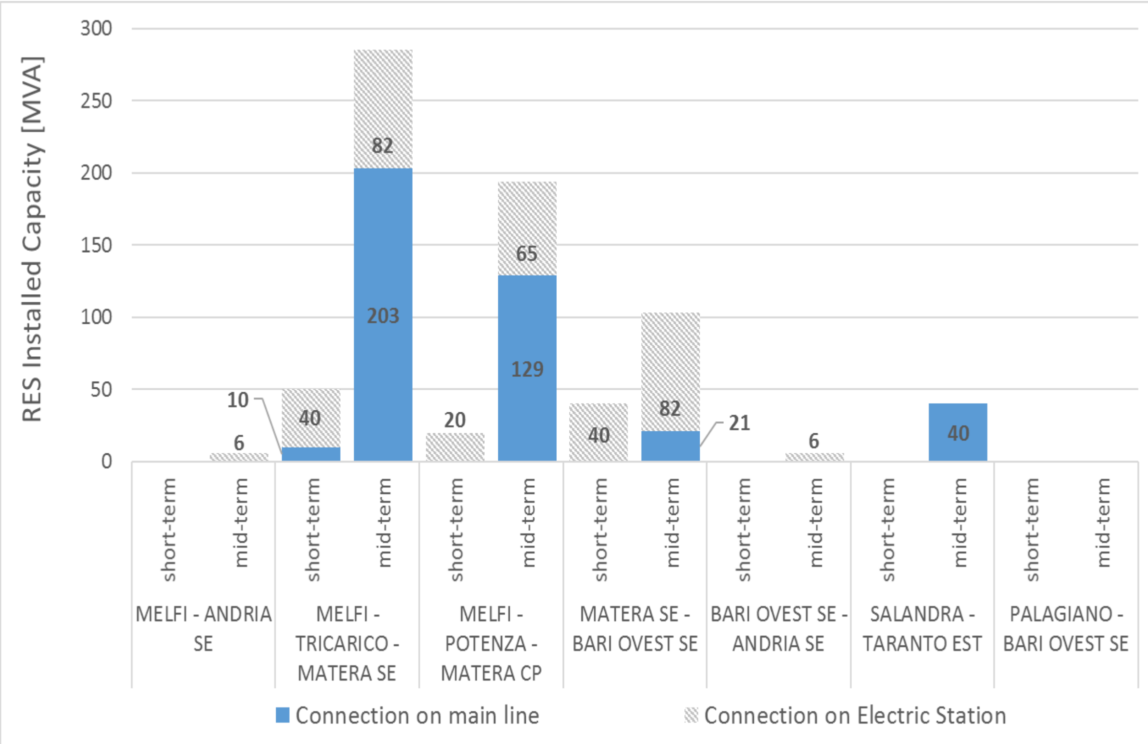


Figure 2 – Subdivision of the new installed capacity from non-programmable RES for each main lines

Finally, the selected HV grid portion consists of portion of seven different 150 kV backbones lines, forming a ring around the area between Apulia and Basilicata regions (figure 3).

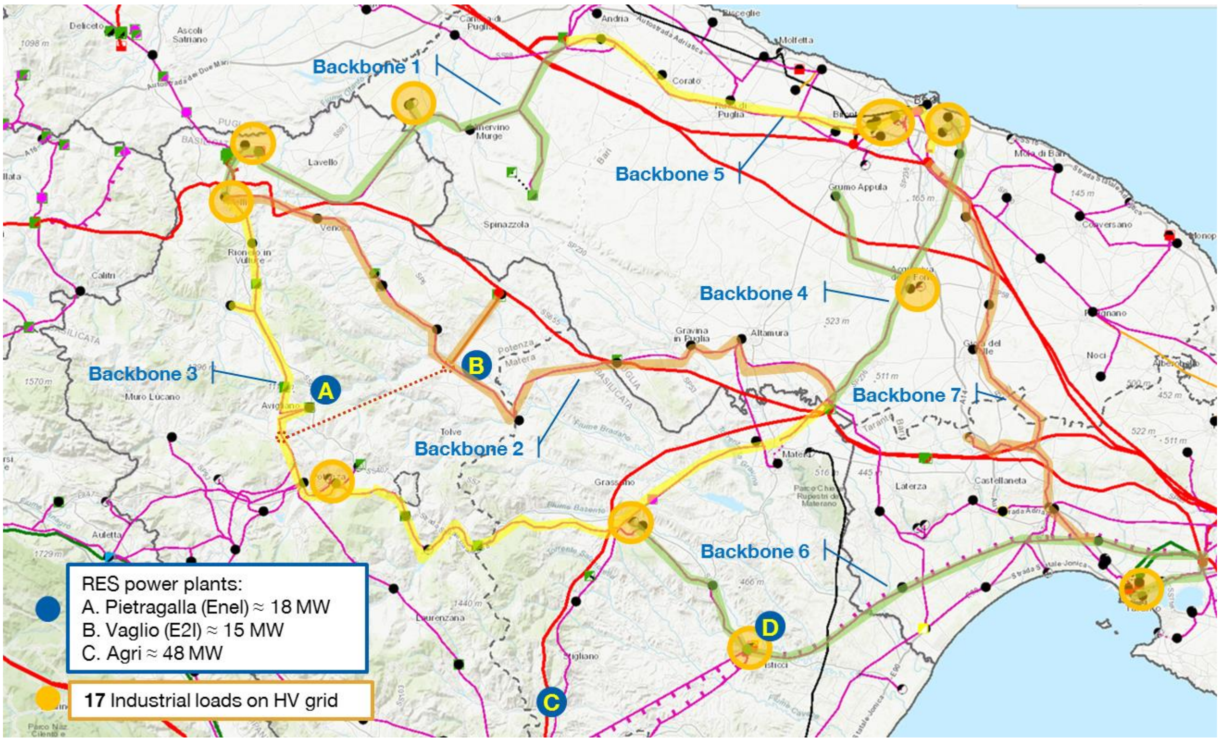


Figure 3 - Demo site location and flexibility resources identification

After the identification of all the flexibility resources available inside the demonstrator area, the WP5 partners have carried out an engagement process in order to involve as many resources as possible.

1.2 Industrial customer engagement

The area of the demonstrator is characterized by a large presence of large industrial loads, such as foundries, factories and water ducts. The selection of the potential customers to be involved was done by taking into account some simple requirements:

- Direct connection to the HV grid
- Direct connection to one of seven main lines, if possible
- Connection to lines topologically close to the seven main lines

Finally, 19 potential industrial customers have been identified and contacted for the participation to the OSMOSE project. The list of the customers is presented in table 1.

ID	Plant name	Voltage [KV]	Region	Province	Power [MW]
1	Car manufacturer	150	BASILICATA	POTENZA	30
2	Water utility	150	APULIA	BARI	11,2
3	Foundry	150	APULIA	BARI	n.d.
4	Tires manufacturer	150	APULIA	BARI	10,9
5	Powertrain industry	150	APULIA	BARI	20
6	Foundry	150	BASILICATA	POTENZA	45
7	Water utility	150	BASILICATA	POTENZA	11,2
8	Packaging industry	150	APULIA	TARANTO	7,5
9	Water utility	150	APULIA	TARANTO	19,9
10	Water utility	150	APULIA	TARANTO	10
11	Wastewater treatment facility	220	BASILICATA	MATERA	16
12	Concrete industry	150	APULIA	TARANTO	27
13	Car frame manufacturer	150	APULIA	TARANTO	N.D.
14	Steel mill	220	APULIA	TARANTO	300
15	Oil company	150	APULIA	FOGGIA	18
16	Aeronautic company	150	APULIA	FOGGIA	14
17	Car manufacturer	150	APULIA	FOGGIA	15,5
18	Aeronautic company	150	APULIA	TARANTO	15
19	Cable manufacturer	60	APULIA	BARI	3,4

Table 1: Customer highlighted in green are directly connected to one of the seven main lines, thus preferred. The yellow ones are still considered relevant, given their proximity to the demonstrator area

After having identified the industrial customers that could provide flexibility services, engagement meetings were held in order to explain the project, the required effort and the benefits coming from taking part to the project, such as:

1. The energy audit of the industrial site for plant's DSR availability assessment will be carried out completely on OSMOSE partner's expenses
2. Free installation of the hardware and software components necessary for the experimentation
3. Know-how acquisition related to new opportunities deriving from the opening of Italian Ancillary Services Market to new resources

After the companies will make their own considerations and evaluations about joining the OSMOSE project as a third party, they should sign a Letter of Interest. The plants that will join the project will be analyzed in order to find out the flexibility they could potentially give to the electric system through DSR services. Then, there will be a hardware and software upgrade, so that the plants could provide the selected services. Finally, the plant will be required to actively take part to the demonstrator execution during the test campaign, by providing flexibility services. The effective duration of the test campaign was sized by assuming a time period of provision that could produce relevant results, in terms of congestion management and flexibility provision, without economically impacting the operation of RES power plants and industrial loads. According to the project proposal, the testing phase overall duration is expected to last for about 10 months. In those 10 months, the testing of flexibility services should be provided according to the following time arrangement:

- In a month, one week out of four
- In a testing week, two days out of seven
- In a testing day, five hours out of twenty-four

Therefore, a total of one hundred hours of provision is expected for each selected service provided by both loads and power plants. Of course, this value is affected by the actual availability of the resources, which will prioritize their core business activities.

1.3 RES power plants engagement

Concerning RES flexibility resources, two wind power plants have been successfully involved in the demonstrator: the Potenza Pietragalla and Vaglio 2 wind power plants. Additionally, the Agri power plant, a 38 MW hydroelectric power plant, will take part in the demonstrator. However, the testing of flexibility services provision from the Agri power plant is still under evaluation, since there is a constraint on the water level stored in the dam: in fact, the water daily release is regulated by a strict program for both drinking and irrigation purposes and it cannot be used arbitrarily within the testing campaign. Still, the integration inside the regional EMS, object of task 5.2 “EMS software planning and specifications”, of the control logics that take it into account such constraint could bring additional value to the project. Nevertheless, the Agri power plant will be involved in the testing of RES generation forecasting algorithms in subtask 5.1.2 “Forecasting models for RES generation and loads”. For the aforementioned reasons, the following paragraphs will cover only the description of the two wind power plants.

1.3.1 Potenza Pietragalla Power Plant

The *Potenza Pietragalla* power plant, owned by *Enel Green Power*, is a 18 MW industrial-scale wind farm (9x2MW – REPower MM92 – HH 78,5m turbines) based in Basilicata. The Potenza Pietragalla system is connected to the primary substation (150kV) of e-Distribuzione in Avigliano (PZ) municipality by a 20/150kV 20-25 MVA transformer.

The wind power plant has been integrated with a 2MW/2MWh Battery Energy Storage System (2x 1MW/1MWh Samsung SDI), in order to increase the programmability of RES and verify the possibility to provide ancillary services.
With reference to figure 4, the main components of the power plant are:

- Containers No. 4 (two identical containers): it contains the Battery Energy Storage System (BESS), subdivided into two subsystems with 1 MWh capacity each
- Container No. 3: it contains, in order: PCS, LV/MV transformer, MV panels (which “collect” contributions from WIND, BESS, and AUXs)
- Building 2: it contains the system for controlling and monitoring the BESS + RES system (i.e. the Master SCADA at the plant)

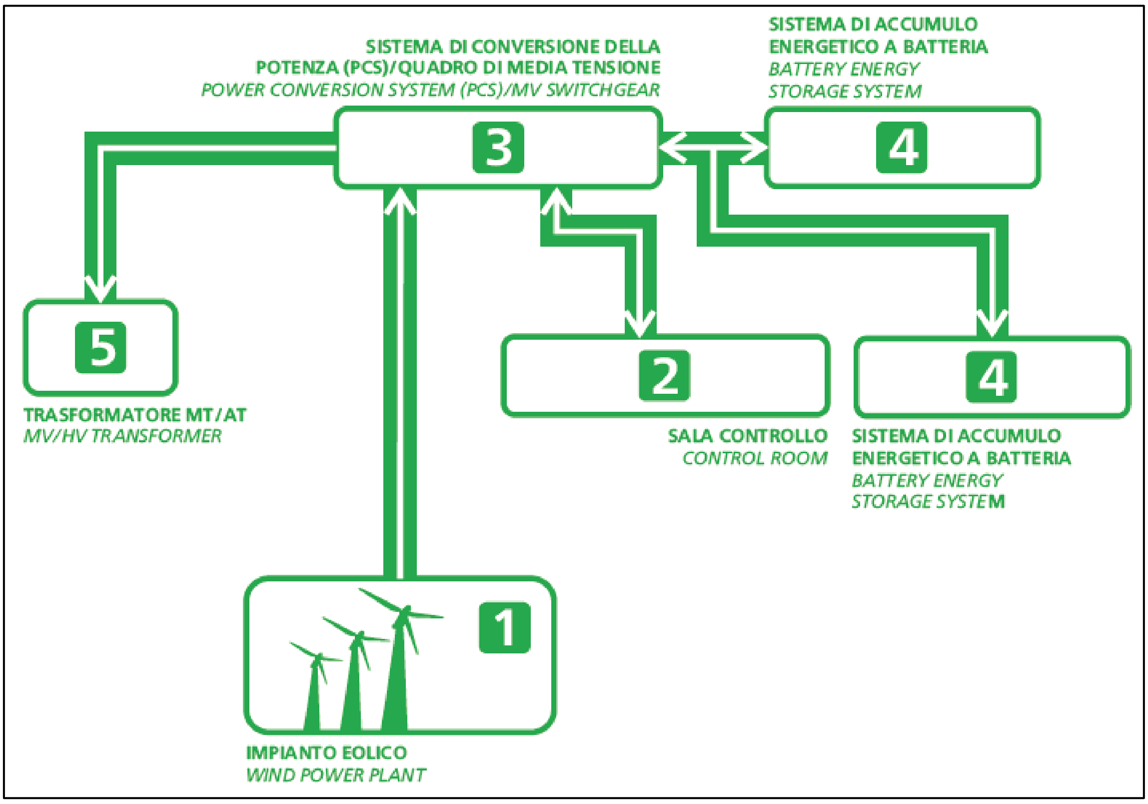


Figure 4 - Layout of the ESS of Potenza Pietragalla wind farm

1.3.1.1 Control system

The battery is managed and controlled by a hierarchical multilayer management system, consisting of a BMS for each rack and for the system as a whole (System BMS), a BESS SCADA and a MASTER SCADA. The charging and discharging cycles are performed by the Power Conversion System (PCS) based upon signal that come from the BESS SCADA controller. At site level, the upper hierarchical level is managed by the MASTER SCADA controller that manage the exchange of energy flows between RES and BESS and implement controls deriving from the upper higher level defined 'Centralized service' (figure 5).

The main services provided through the integration of BESS technology with RES technology can be divided into:

- Site services: The Master SCADA (MS) installed onsite manages the RES + BESS system, which regulates the production and manages several services using dedicated algorithms implemented at the controller level. The abovementioned service, most of which are still under test phase, are:
  - Scheduling and Energy Shifting
  - Reactive Power Q (RES + BESS) set-point regulation
  - Frequency Regulations
  - Synthetic Inertia

- Centralised services: They are not run onsite but are linked to it. The HMI Local Control Room is a user interface, which allows remote monitoring and control of RES and BESS, as well as receiving updates to production plans from centralised services and users. During limitation orders requested by Terna, the EGP operator inserts the instantaneous set point trough the HMI, the system automatically limits the plant's energy production; in the presence of wind or solar resource availability, the excess of energy is stored into BESS as much as possible for the minimisation of possible energy losses.

Terna connection to the EGP LCR should be in IEC-104 protocol and "read only type". In case of necessity (OdB, plant shutdown), Terna will communicate to the EGP LCR.

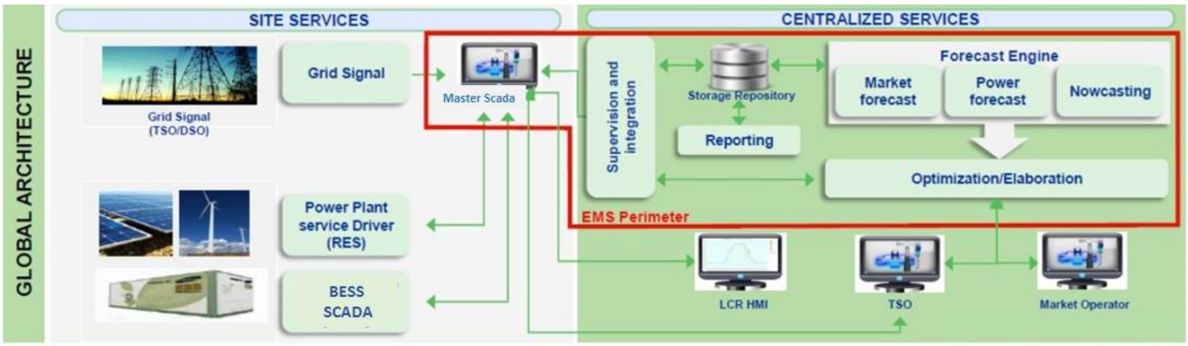


Figure 5 - Description of the Relationships between Website Services and Centralised Services

1.3.2 Vaglio 2 Power Plant

The Vaglio 2 power plant, owned by E2I, is a 15 MW industrial-scale wind farm (6x2.5 MW – Siemens Siemens – Gamesa G114 WTG model with 80 m hub height and 114 m blade rotor diameter), based in Basilicata as well. The WTGs will be connected to a 30 kV medium voltage switchgear that will be connected to the 150 kV HV grid by a dedicated step-up transformer and a 150 kV underground cable to the *Santa Croce* electrical power station, which is connected to the 150 kV *Vaglio* electrical station. The power plant does not include a BESS and the WTGs are featured by a Doubly Fed Induction Generator (DFIG). This system (figure 6) consists of an asynchronous three-phase generator with a coil rotor accessible through slip rings and a power converter (AC/AC). The stator connects directly to the grid and the rotor is connected to the grid through an inverter ("Converter").

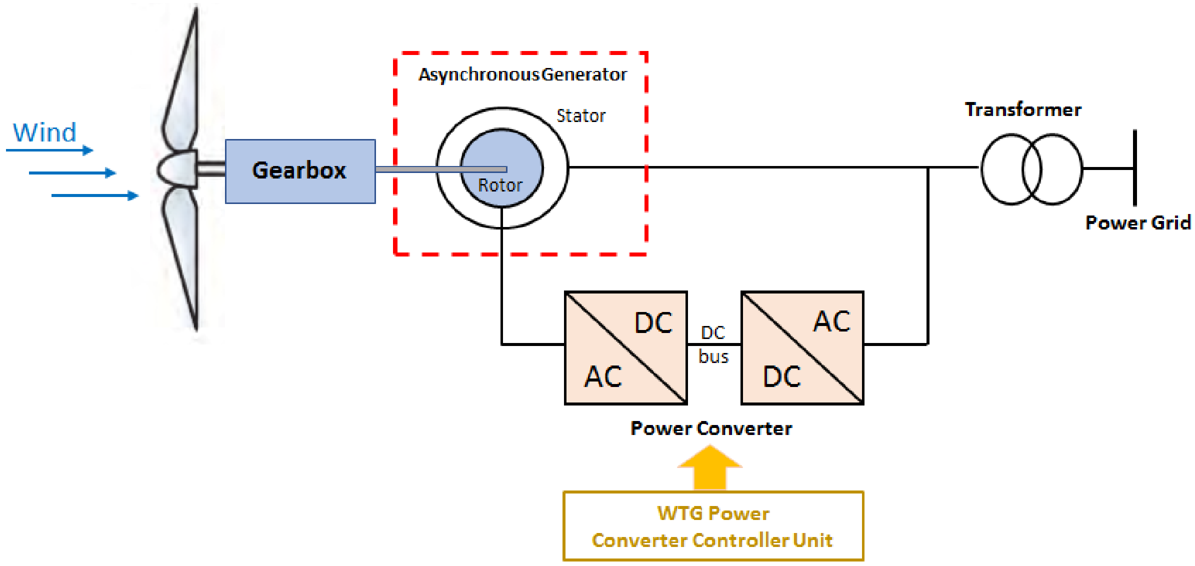


Figure 6– Simplified schematic of a DFIG

The electronic power converter simulates an approximately synchronous-like mode of operation with respect to the grid. The voltage and frequency induced in the stator match the same variables of the grid. If the line voltage or the frequency varies, the voltage and frequency of the generator's stator do so in the same direction and proportion. The converter's behavior in its connection to the grid is identical, adjusting the frequency of the switching so that the resulting voltage waveform always matches the line's waveform.

1.3.2.1 Control system

The control system continuously selects the correct shaft torque values, the blade pitch angle and the power settings, depending upon the wind speed and thus guaranteeing safe and reliable operating in all the wind conditions.

The Siemens-Gamesa first Level SCADA is a supervisory, control and data acquisition system, which allows wind farm data retrieval from a browser.

Among other services, this control system can allow:

- Active power limitation module
- Generated reactive power control module
- Frequency regulation module

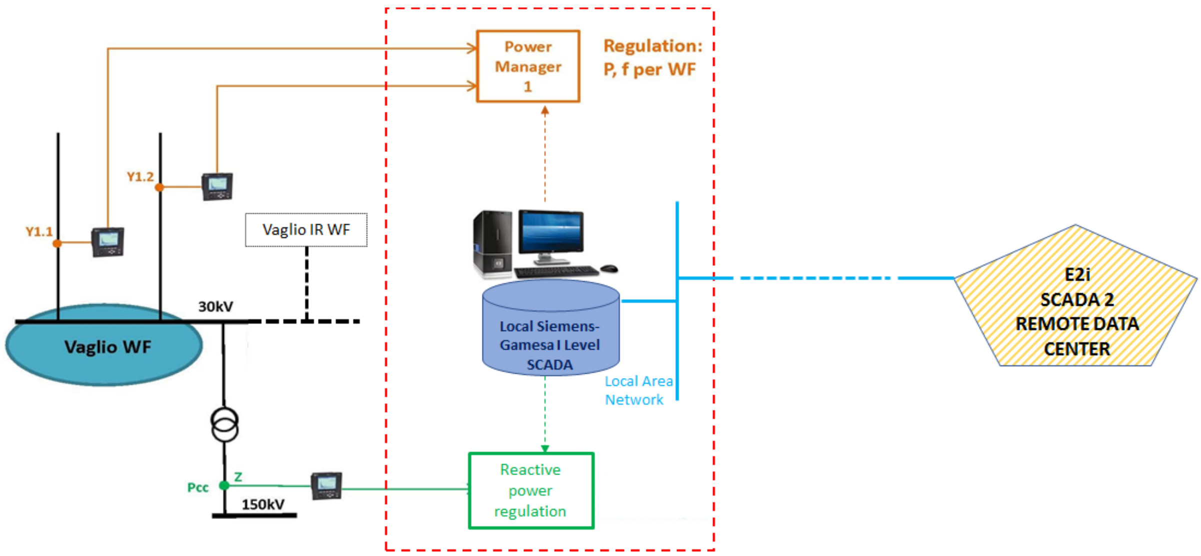


Figure 7– Simplified schematic of Vaglio 2 control system

E2i is also implementing a second level SCADA (SCADA 2 System) for monitoring (see figure 7), assessing and managing its power plants, implementing homogenous processes among different sites.

The SCADA 2 System will be a platform constituted by hardware and software, able to connect in real time to the power plants, to gather all the data measured from several sources, to analyze the big data collected and to produce report and KPI.

The SCADA 2 System will also allow to curtail the power production of any cluster of WTG in any moment and in the most efficient way. This function is required for the curtailments required by the grid operator or any additional curtailments to fulfil potential emergency events or regulatory requirements.

2 Analysis and design of flexibility services

This chapter summarizes the activities performed in subtask 5.1.2 "Analysis and design of DSR flexibility services" and subtask 5.1.3" Analysis and design of RES flexibility services".
For both subtasks, the first step was a research of the state of the art about the provision of flexibility services according to the national Grid Code (*Codice di Rete*) standards. This research was used as a starting point in order to define the functional specifications for each of the selected flexibility services, that are currently not provided by the resources involved in the demonstrator. After the specifications, an economic analysis for the services provision was hypothesized. This analysis was based on the bidding prices of the Italian ancillary service market. Where such data could not be retrieved, the analysis was based on international best practices. Finally, it is provided an overview of the functional specifications and the control logics of the software platform and of the hardware devices that should enable the flexibility services provision from both loads and RES power plants.
In the Deliverable 5.2, which is due to February 2019, both subtasks will receive the inputs from this document, in order to address the sizing of PE devices necessary to enable RES and DSR resources for the provision of flexibility services.

2.1 Selected flexibility services within Demo 5

The flexibility services to be tested within the WP5 demonstrator are the following**:**

- **Congestion Management**: the service can be provided by exploiting the regulation capacity offered by loads, taking into account the improved estimation of the lines capacity thanks to the deployment of DTR technology
- **Synthetic inertia**: the provision of this service will be developed, tested and validated for wind and wind+BESS power plants. Since wind power plants are connected via power converters or with DFIG configuration, their rotational speed is decoupled from the system frequency. The provision of inertia could be done by mimicking the release of kinetic energy from a rotating mass, thus providing an electrical torque, which is proportional to the frequency variation (this can be called a "fast primary regulation"). A more appropriate inertial regulation would require the variation of active power in response to the rate of change of frequency (the so called "ROCOF"). However, this inertial regulation would imply the application of an electrical torque to the WTG shaft in a very short amount of time. Such operation could cause excessive loads to the machine. The OSMOSE project will represent an opportunity to verify the possibility to

provide synthetic inertia either via the wind turbine themselves and with the integrated electrochemical storage

- **Automatic Voltage Control** (**AVC**): RES power plants, RES+BESS power plants and industrial loads can be used to increase or decrease the reactive power that flows out of the plants itself
- **Frequency Restoration Reserve** (**FRR**): industrial loads can be equipped with specific devices in order to provide the active power reserves needed to restore the system frequency to the nominal frequency

The aforementioned services will be tested in different use cases (UC), as established in the project proposal (figure 8). A brief description of the use cases is here recalled:

- **UC1**: Improve congestion management on HV grids and maximize RES production by coordinated use of Dynamic Thermal Rating (DTR) short-term forecasts, and Demand Side Response (DSR) resources. Additionally, the deployment of Power Flow Control (PFC) devices is under evaluation
- **UC2**: Demonstrate the reliability of provision of Synthetic Inertia (SI) and Automatic Voltage Control (AVC) by single or aggregated large wind/solar power plants
- **UC3**: Demonstrate the reliability of provision of Frequency Restoration Reserve (FRR) and AVC by single or aggregated large industrial loads in coordination with traditional power plants

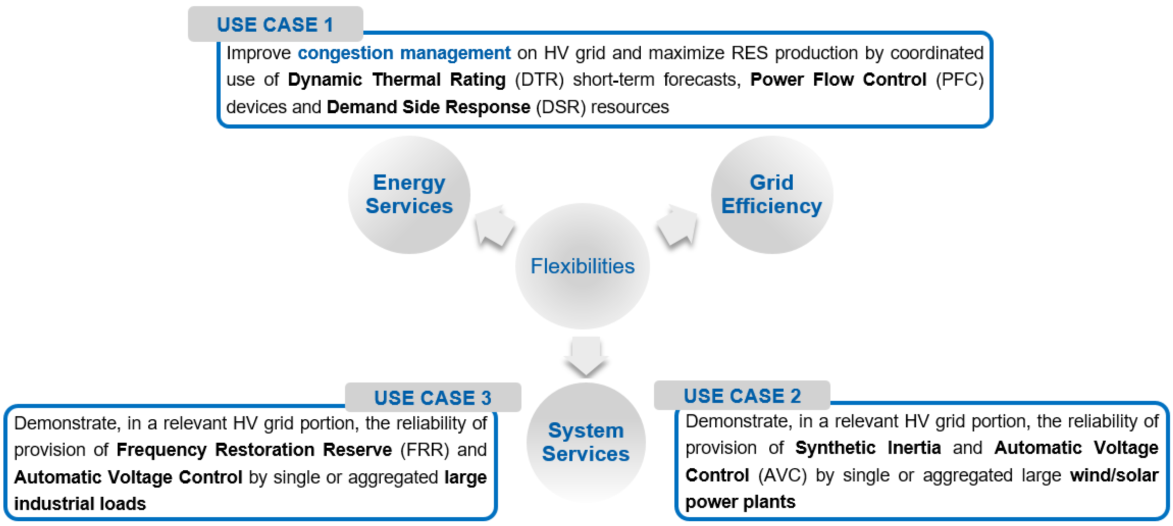


Figure 8: Use Cases for WP5

2.2 Flexibility services in Italy: state of the art and market regulation

Before describing the technical specifications and the valorization of the selected flexibility services, an overview of the state of the art of the Italian ancillary services market is here provided: Italy has an Ancillary Services Market (MSD), where Terna operates as a single counterparty in order to procure the resources needed to ensure system security, adequacy and quality of supply.

MSD is a pay-as-bid market where all programmable production units with a minimum installed capacity of 10 MVA and the needed technical requirements are requested to participate in, by offering all their upward and downward regulation intervals.

On MSD, the following ancillary services are procured with a mechanism of remuneration:

- infra-zonal congestion relief
- secondary reserve, which is comparable to the Frequency Restoration Reserve with automatic activation (aFRR)
- tertiary reserve, which is divided into ready tertiary reserve ("*riserva terziaria pronta*"), spinning tertiary reserve ("*riserva terziaria rotante*"), and tertiary replacement reserve comparable to the Replacement Reserve (RR)
- real-time balancing

Furthermore, there is a series of services that are provided without remuneration, as their provision is mandatory. The mandatory services are the followings:

- Primary reserve, which is comparable to the Frequency Containment Reserve (FCR)
- Primary Voltage Control, which is the regulation of reactive power production of a generation group performed by an automatic voltage regulator (RAT), which responds to the variation of the voltage at the terminals of the generation group
- Secondary Voltage Control, which consists in the regulation of reactive power production of the generation groups of a power plant performed by a local and automatic voltage regulator (SART). The SART can change the voltage set point of each RAT in response to the variation of reactive power injected into some predefined nodes of the power systems

Particularly, MSD is divided into two sub-markets:

1. MSD ex–ante, which is the planning phase where Terna accepts energy demand bids and supply offers in order to relieve residual congestions and to procure both secondary regulation reserve and tertiary regulation reserve intervals

2. Balancing Market (MB), which is the real-time phase where Terna uses both secondary regulation reserve and tertiary regulation reserve intervals and balances injections and withdrawals in real time

Not all power plants can provide resources for ancillary services. In particular, all plants must have an installed capacity equal or higher than 10 MVA (i.e. the relevant units). Furthermore, the primary source must be programmable, therefore RES are excluded, except for hydroelectric power plants (run off the river are however considered as “non programmable”). These are only the minimum requirements in order to bid in MSD. In fact, not all relevant units can provide all the ancillary services, but must be compliant to specifics connection requirements, prescribed in the Grid Code, for each ancillary service. In conclusion, the following resources cannot participate to MSD:

- PV power plants
- Wind power plants
- Geothermal power plants
- Run-of-the-river hydroelectric power plants
- Wave power plants
- Distributed generation and load units

2.2.1 Market evolution - Resolution 300/2017/R/eel

Since there is no such a thing as an Italian market in which loads and non-programmable RES plants are enabled to provide ancillary services, the Italian regulator ARERA has envisioned, with the Resolution 300/2017/R/eel [1], the possibility of realizing pilot projects in order to define the criteria to allow those subjects to take part in the ancillary services market.

In particular, the resolution defines that the pilot projects may concern:

- the participation in MSD of the demand and production units not yet enabled (including the accumulation systems)
- the use of storage systems, in particular in combination with relevant production units enabled to participate in MSD in order to optimize the supply of dispatching resources in compliance with the requirements set by the Grid Code
- the aggregation modalities of the production and consumption units, according to geographical aggregation perimeters consistent with the network model. With reference to the possible aggregations, the resolution provides that aggregates, called UVA (virtual units enabled), may be established in compliance with the perimeter defined by Terna. UVA are classified as follows:

  - enabled virtual production units (UVAP), characterized by the presence of only non-relevant production units (either programmable or non-programmable), including storage systems
  - enabled virtual units for consumption (UVAC), characterized by the presence of only consumption units
  - mixed enabled virtual units (UVAM), characterized by the presence of non-relevant production units (either programmable or non-programmable), including storage systems, and consumption units
  - enabled virtual nodal units (UVAN), characterized by the presence of relevant production units voluntary and/or non-relevant (either programmable or non-programmable), and possibly also consumption units, connected to the same node of the transmission network national
- the procedures for the remuneration of ancillary services currently not explicitly remunerated (for example, voltage regulation); therefore, primary reserve services, secondary reserve, tertiary reserve, resolution of congestion and balancing are excluded.

The provision also highlights the minimum criteria that must be respected for the eligibility of pilot projects relating to the participation of consumption units and production units subject to voluntary authorization. It is also defined for the different cases which is the counterpart for the supply of dispatching resources (coinciding or not with the aggregator, i.e. the Balance Service Provider - BSP) and the modalities for the valorisation of the actual imbalances are made explicit. The Resolution provides that the pilot projects identified by Terna are subject to prior consultation with the operators; the consultation must contain the regulation according to which the pilot project will be managed (including technical requirements and procedures for requesting new resources to MSD) as well as a technical report illustrating the project and the reasons for the choices made. At the end of the consultation, the pilot projects are sent by Terna to the Authority for approval. The pilot projects, unless otherwise specified, are based on the current classification of the production and consumption units, including the concept of relevance for participation in the markets, in order to allow it to start quickly without requiring significant interventions. In table 2, the main results of the pilot projects for UVAC and UVAP, carried out in the year 2017, are listed.

Pilot Project	*Consumption enabled in MSD*	*Services provided*
UVAC	516 MW	▪ Tertiary reserve (upward) ▪ Balancing (upward)
UVAP	116 MW	▪ Congestion management (upward and downward) ▪ Tertiary reserve (upward and downward) ▪ Balancing (upward and downward)

Table 2: Resolution 300/2017/R/eel pilot projects results in 2017

The OSMOSE project – WP5 perfectly fits in this context of the Ancillary Service Market reforms, as it offers the chance to already enabled participants and new users to exploit new potential opportunities to the take part in the MSD. In addition to that, the project results could suggest a new evolution of market designs and regulatory frameworks that could enable new flexibility resources.

2.3 Selected flexibility services technical specifications

2.3.1 Synthetic inertia

Compared to the conventional bulk power plants, in which the synchronous machine dominate, the RES units, interfaced by means of power electronics, do not provide any inertial response to grid frequency. The intrinsic kinetic energy (rotor inertia) and damping properties (due to mechanical friction and electrical losses in stator, field and damper windings) of the bulk synchronous generators play a significant role in the grid stability.

With the growing penetration level of RES, the impact of low inertia and damping effect on the grid dynamic performance and stability increases. Voltage rises due to reverse power from PV generations, excessive supply of electricity in the grid due to full generation by the RES, power fluctuations due to variable nature of RES, and degradation of frequency regulation can be considered as some negative results of the mentioned issue.

A solution towards stability improvement of such a grid is to provide virtual (or synthetic) inertia by storage and RES power plants, by using proper control mechanisms to be investigated during the experimental phase. In general, an inertial frequency regulation, or Synthetic Inertia (SI), could be provided by static components like batteries, HVDC connection converters and, under certain conditions, generators interfaced with inverters, such as wind power and solar photovoltaic panels.

Conventional synchronous generators show an inertial response to network frequency transients that is related to the kinetic energy of the rotating mass. The inertial behaviour of a synchronous generator is described by the following equation:

$$\frac{d}{dt}\left(\frac{1}{2}J\omega^2\right) = P_m - P_e \tag{2.1}$$

where J is the moment of inertia, ω the angular rotation speed and P_m and P_e the driving mechanical power and the resistant electric power applied to the rotor.

Computing the first term of the equation (2.1), and considering the *starting time* T_a of a generator as a characteristic parameter at nominal operating frequency, defined as follows:

$$T_a \triangleq \frac{J\omega_n^2}{P_n} \tag{2.2}$$

Where P_n is the generator nominal installed capacity. Then, the inertial response of a conventional generator to a certain $ROCOF = \frac{df}{dt}$ can be derived as follows:

$$(P_m - P_e) = \frac{T_a P_n}{f_n} \cdot \frac{df}{dt} = \frac{T_a P_n}{f_n} \cdot ROCOF \tag{2.3}$$

Assuming that the driving mechanical P_m does not change, the conventional generator responds to an electric network frequency variation with a change of the injected electric power as follows:

$$\Delta P_e = -\frac{T_a P_n}{f_n} \cdot ROCOF \tag{2.4}$$

A device providing SI must be able to emulate the same behavior changing the injected power in a way proportional to the ROCOF:

$$\Delta P_{SI} = -k_{SI} \cdot ROCOF \tag{2.5}$$

This is assumed as a basis to define the technical requirements of SI provision to the power system. A study on impact of inertial regulation on the behaviour of the electrical system with the contribution of synthetic inertia can be found in [2] [3] [4] [5].

According to annex 17 of the Italian Grid Code [6], which prescribes the connection requirements for wind power plants, the fitted wind turbine must be prepared in order to provide, upon request of TSO operator, an active inertial response in case of sub-frequency transients in the interval [49.5 Hz; 50 Hz] with 0.05 Hz step and default value of 49.8 Hz. The regulation for a predefined time, have to provide higher power values exploiting the blades inertia and decreasing blade speed (operating zone for power less than nominal power P_n) or by varying the pitch angle (constant P_n zone).

In the WP5 demonstrator, a new innovative proposal for the SI is presented: this service will be provided by exploiting the electrochemical storage of Potenza Pietragalla and by the inertia of the WTG of Vaglio 2, provided that the additional mechanical stress are compliant with the mechanical properties declared by the manufacturer. Such limit is represented by the saturation level (A) in figure 9, and it is going to be thoroughly investigated during the upcoming months. Parameter B represents instead the maximum value of ROCOF below which the WTG could provide a proportional regulation.

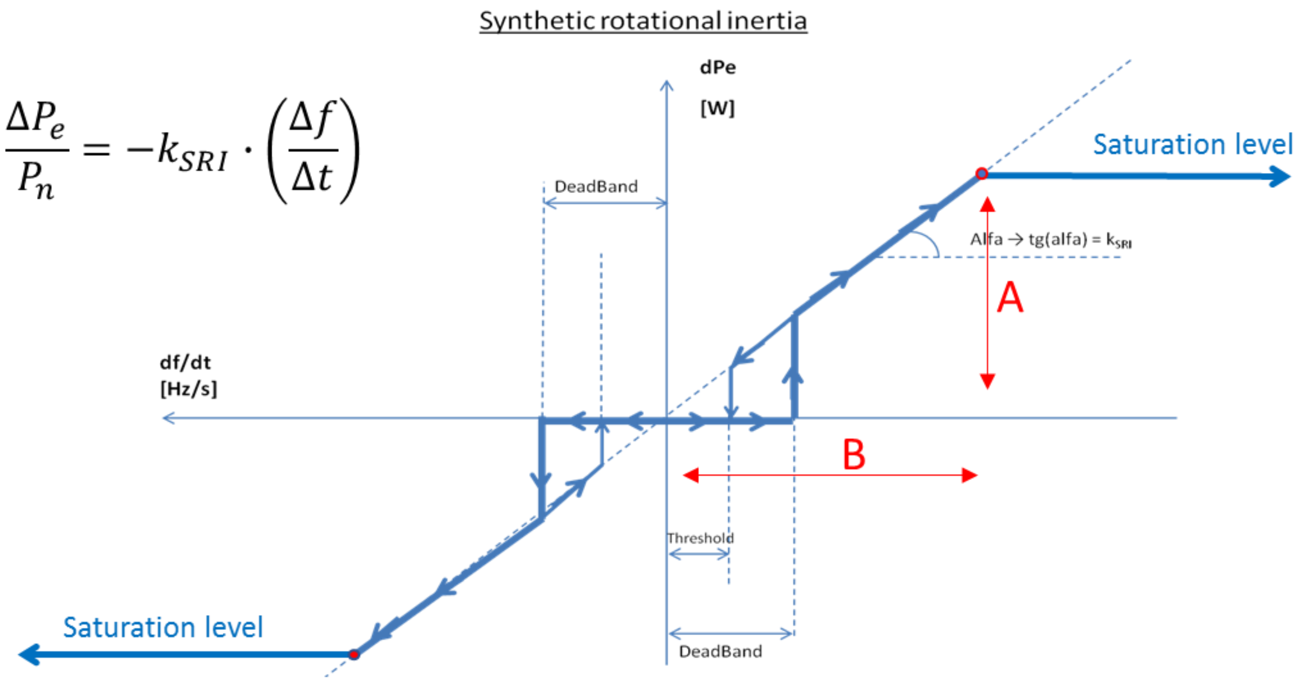


Figure 9 – Synthetic inertia control

Of course, for a correct functioning of the control it is critical to calculate the derivative of the frequency gradient.

2.3.2 Automatic Frequency Restoration Reserve

The TSO uses the automatic Frequency Restoration Reserve (aFRR), or secondary power reserve, to compensate for the deviations between demand and production in the Control Area, to restore the power exchanges at the border to their planned values, and consequently to contribute to reestablishing the European nominal frequency. In the Grid Code, annex 15 [7], it is prescribed that this automatic operation is carried out by a central regulator installed in the operator's control system. Normally Sardinia and Sicily, when the latter is not synchronized with the mainland, perform the secondary power reserve operation locally.

The secondary reserve band of each energy resource connected to the grid must be made subject to an automatic regulating device which is able to regulate the energy production or demand, based on the level signal calculated and sent by the TSO.

The governors of the power units participating in the secondary regulation aFRR, in addition to the characteristics required by the primary regulation, must:

- be able to receive remote commands from the centralized network regulator in the form of a percentage level, variable between 0 and 100%, referred to the available secondary regulation reserve
- in the case of power plants consisting of multiple units, be equipped with a device capable of distributing the active power requested between the units in regulation

Nowadays, power plants enabled to supply the aFRR service must make available a secondary power reserve equal to:

- the greatest between ± 10 MW and ± 6% of the maximum power for thermoelectric units. In the case of combined cycle power units the value of the reserve refers to the overall power of the unit
- ± 15% of the maximum power for hydroelectric generating units

The units participating in the aFRR must make available a total power given by the sum of the primary and secondary reserve.

For the provision of the secondary reserve, the power variation gradient must be not less than the rate of change of the remote control level signal. This rate of variation is communicated by the TSO and is a function of an integral time constant, set in the network controller. The requested secondary reserve should be supplied for not less than 2 hours.

In the WP5 demonstrator, the provision of the aFRR from aggregated industrial loads (figure 10) will be tested so that the service is compliant with the grid code. Additionally, it will be pondered whether the service should be customized for each individual industrial loads, as to adopt the technological solution that respects the Grid Code requirements as well as the production constraints (e.g. it will be considered whether the individual industrial loads will provide an asymmetrical service or not).

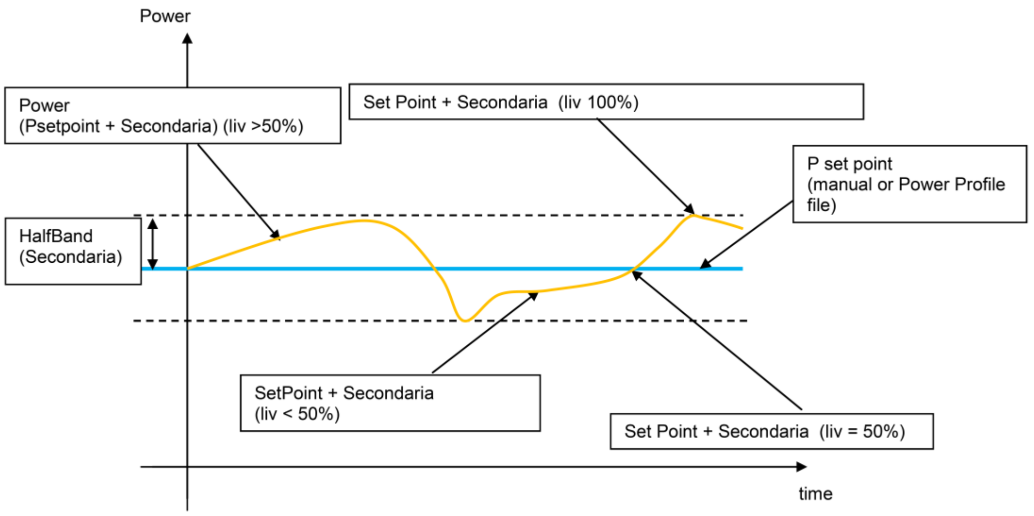


Figure 10 – aFRR service provision from industrial loads

2.3.3 Congestion management

Referring to the proposed regulation for UVAM (mentioned in paragraph 2.2.1), which are the most generic type of virtual units, the WP5 demonstrator aims to follow their technical requirements for the participation to the ancillary services for the provision of the congestion management service from industrial loads. The technical requirements are the followings [8] [9] [10] [11] (see also figure 11):

- every unit included in the UVAM must be located in the same aggregation perimeter, defined by the TSO
- the whole Virtual Unit must be able to increase or decrease its power injection or consumption at least by 1 MW. A Virtual Unit can decide to provide its flexibility in both directions or only in one of them
- for the congestion resolution service, the UVAM must be able to implement the power injection or consumption modification within 15 minutes of receiving the dispatching order
- for the congestion resolution service, the UVAM must be able to maintain the modulation for a period of 120 minutes
- the variations of power injection or consumption are calculated with respect to a *baseline*, whose profile is calculated in advance by the aggregator

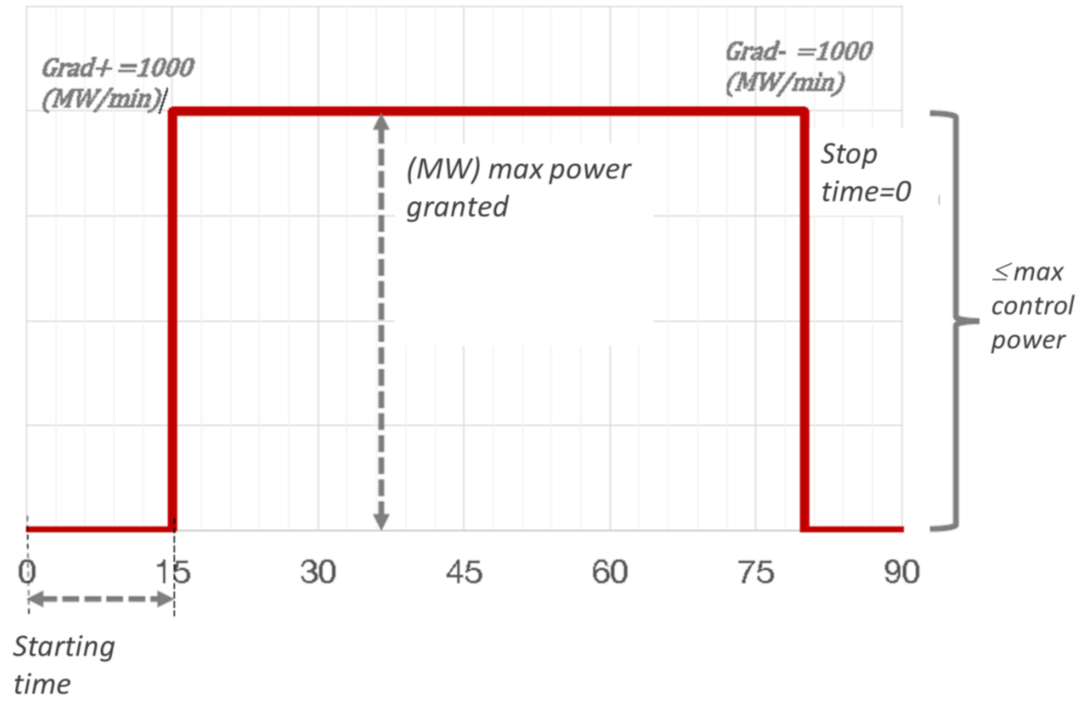


Figure 11 - UVAM - Loads minimum technical requirements

2.3.4 Automatic Voltage Control

The nodes voltages of the national power system are essentially determined by the reactive power transits on the lines. Therefore, it is possible to regulate the voltage in the network nodes setting the production (or absorption) of the reactive power of the generators [12].

Automatic voltage control (AVC) in OSMOSE will be provided by both loads and wind power plants, with or without BESS, either by the WTG itself or by the BESS. However, since the involvement of industrial customers is still ongoing, their capability of providing reactive power regulation is still unknown and it will be investigated during the upcoming months. As far as wind power plants are concerned, the AVC will be enforced at two levels:

- Primary regulation: the terminals voltage is regulated to a preset value V_{rif} (local regulation)
- Secondary regulation: the TSO send a reactive power Q_{rif} set point to the aggregator or to the power plant SCADA, that will then command the flexibility resources according to predefined regulation logics (centralized regulation)

Primary regulation

The injection and the absorption of reactive power should follow the characteristic curve Q = f (ΔV), as illustrated in Figure 12.

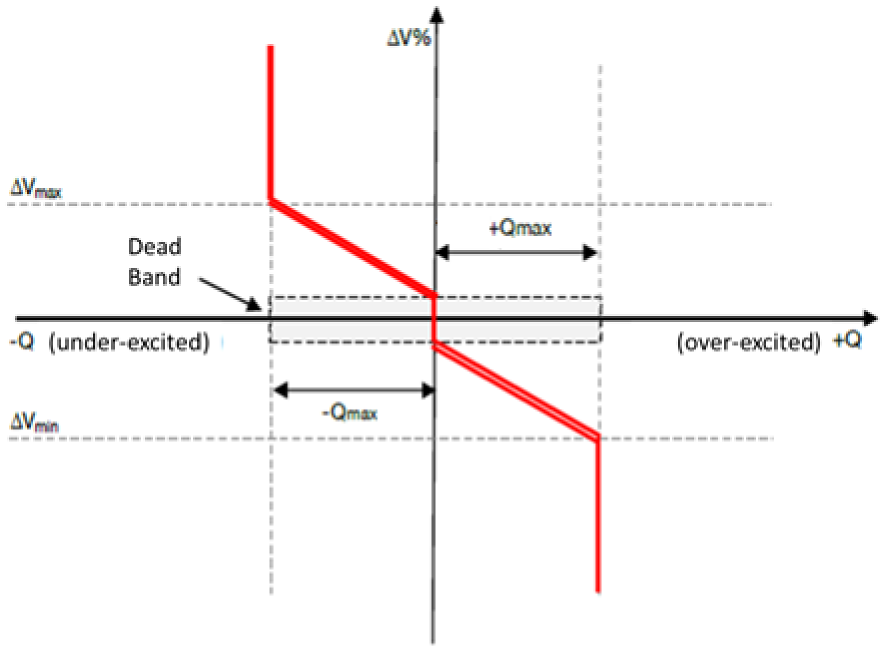


Figure 12 - Wind turbine generator characteristic curve Q = f (ΔV)

In order to avoid instability phenomena on the reactive power regulation cycle, a proportional/integral closed loop regulation (figure 13) will be tested.

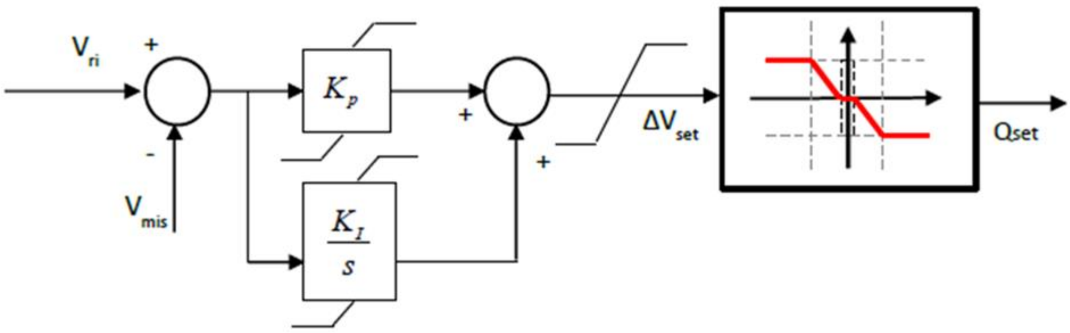


Figure 13 – closed loop regulation on the V_{rif} setpoint

The V_{rif} value is set manually on the unit voltage controller, where available, according to the prescriptions of the TSO operator. As a rule, two different values for V_{rif} should be prescribed: one to be used during high load hours and another for low load hours.

Secondary voltage regulation

It consists in a centralized regulation of the voltage of some relevant network stations, called *pilot nodes*. The *pilot node* voltage is controlled by a Regional Voltage Regulator (RVR) installed at one of the TSO regional control centers, which controls multiple pilot nodes and the power plants which perform the secondary voltage regulation. In the WP5 demonstrator, the RVR should transmit the Q_{rif} value to the aggregator platform or to the power plants SCADA, that will then decide how to provide or absorb the necessary reactive power. The wind power plants should be set up to receive this set-point reference, which should be followed by wind turbines up to their capabilty curve limits. In order to allow the most precise computation of the control signal to be sent, the power plant should send to the TSO the maximum reactive power limits available in real time.

2.4 Economic analysis of selected flexibility service provision

2.4.1 Synthetic Inertia

Since there is no market for system inertia, in order to evaluate the economic benefits to the power systems, derived from the potential contribution of Synthetic Inertia coming from RES power plants, only existing system costs can be considered as a proxy for an economical evaluation of SI provision. In order to estimate this economical value, it has been considered that to provide additional amount of inertia to the system, it is needed to start a certain amount of synchronous generators. By considering the startup cost of synchronous generators as reference, an economical evaluation of the service provision has been obtained.

In order to assess an economical value to the inertial response of a synchronous generator, equation (2.4) can be rewritten as follows:

$$\Delta P = -k_{SG} \cdot ROCOF = -\frac{T_a P_n}{f_n} \cdot ROCOF \qquad (2.6)$$

Where the constant K_{SG} is defined as:

$$k_{SG} \triangleq \frac{T_a P_n}{f_n} \qquad (2.7)$$

Using actual costs payed for turning on synchronous generators in the Italian power system, an equivalent economic value for K_{SG} can be evaluated.

The starting time T_a can be expressed by means of the *inertia constant* H, defined as the ratio between the stored rotational energy and the plant nominal power:

$$H \triangleq \frac{1}{2} \cdot \frac{J\omega_n^2}{A_n} \tag{2.8}$$

Where A_n is the nominal apparent power of the generation unit. Recalling the definition of T_a in equation (2.2) and substituting $P_n = A_n cos\varphi$, T_a can be expressed as:

$$T_a = 2 \cdot \frac{H}{cos\varphi} \tag{2.9}$$

and finally:

$$k_{SG} = \frac{2HA_n}{f_n} \tag{2.10}$$

The inertia constant for some types of conventional generators is known from the literature (Table 3).

Generator type	H [MW·s/MVA]
Coal (old)	4
Coal (new)	2
OCGT	6
CCGT	9
Cogeneration	2
Biomass	2
Hydro	3
Nuclear	5
CSP	2.5

Table 3 - Inertia constant for conventional generators

Using the values reported in Table 3, and the generation plants nominal data, the value of k_{SG} $[MW \cdot s/Hz]$ for each generator was obtained. Next, analyzing the awarded prices for synchronous generators start up on the Italian balancing market during year 2017, the statistics of price per unit of k_{SG} were obtained. The mean, minimum and maximum prices computed on the whole 1.770 accepted bids in 2017 are reported in Table 4.

	Mean	Min	Max
K_{SG} Price [€·Hz/MW·s]	572	3	6.332

Table 4 - Price per unit of $\boldsymbol{k_{SG}}$ (Italy - 2017)

Moreover, in Table 5 are reported the actual costs for starting a synchronous generator split by generator type.

Generator type	n. bids	K_{SG} Price [€·Hz/MW·s] Mean	K_{SG} Price [€·Hz/MW·s] Min	K_{SG} Price [€·Hz/MW·s] Max
Fossil Gas	1.216	453	7	2.468
Fossil Oil	74	3.378	671	6.332
Fossil Hard coal	14	1.201	431	3.017
Other	466	416	3	1.887

Table 5 - Price per unit of $\boldsymbol{k_{SG}}$ (Italy - 2017) per generator type

Table 4 gives an idea of a possible economical evaluation of actual inertia response capacity of synchronous generators.

Thanks to the equation (2.4) and (2.5), representing respectively the inertial response of a synchronous generator and that of a SI provider, it will be computed the amount of synthetic inertia needed to substitute a conventional generator and obtain also an economic valorization of this service. The real capacity of RES generators to offer inertial response and the determination of k_{SI} will be one of the objectives of demo activities.

On a side note, the prices showed in table 4 and table 5 are not uniquely related to the provision of inertia, as the production units operation, once turned on, might provide simultaneously other benefits to the power system (e.g. voltage regulations). Therefore, only a portion of those values is related to the provision of inertia.

2.4.2 Automatic Frequency Restoration Reserve

For an economic evaluation of the benefits to the power system of aFRR, derived from the availability of new flexible energy resources, the current prices payed for this service have been analyzed. Then, the possible impacts on the current market have been considered.

2.4.2.1 Historical price analysis

The current prices of bids for the aFRR in the Italian market has been analyzed. The time profiles of average bid prices for one year for continental Italy, Sicily and Sardinia, are reported and compared in Figure 14, Figure 15 and Figure 16 for the period July 2017 – June 2108 [15].

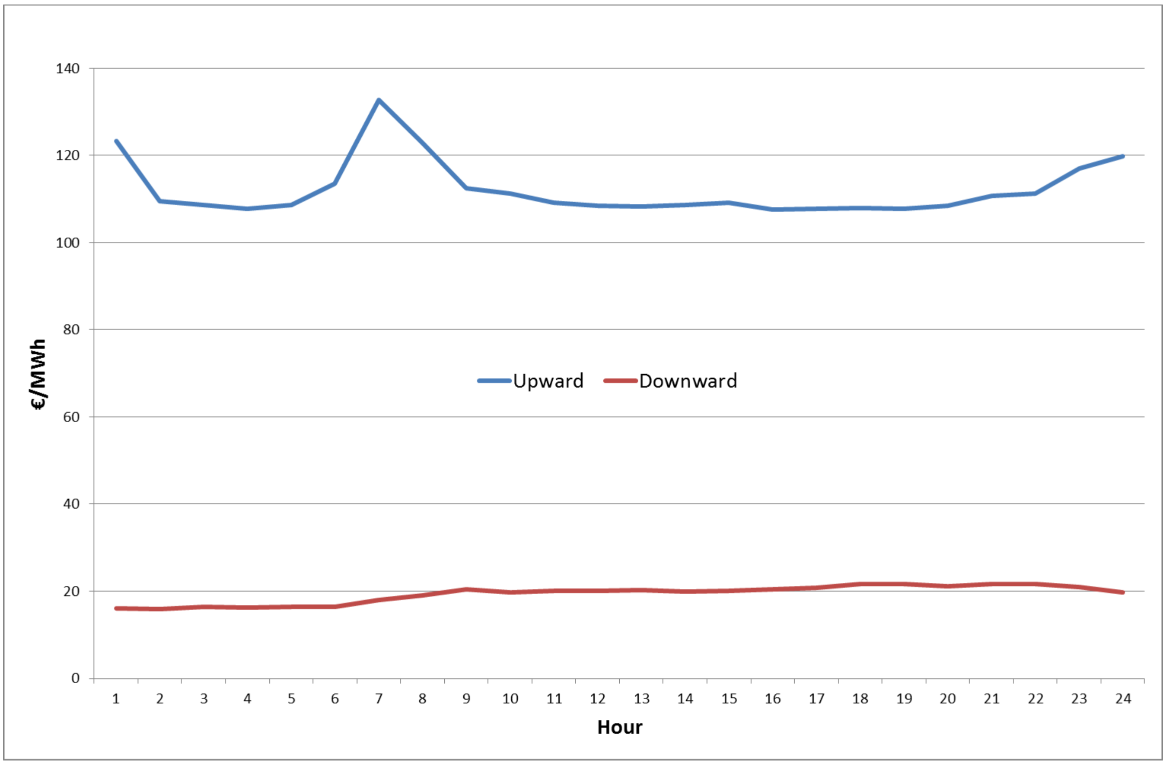


Figure 14 - Average aFRR price in continental Italy (July 2017 - June 2018)

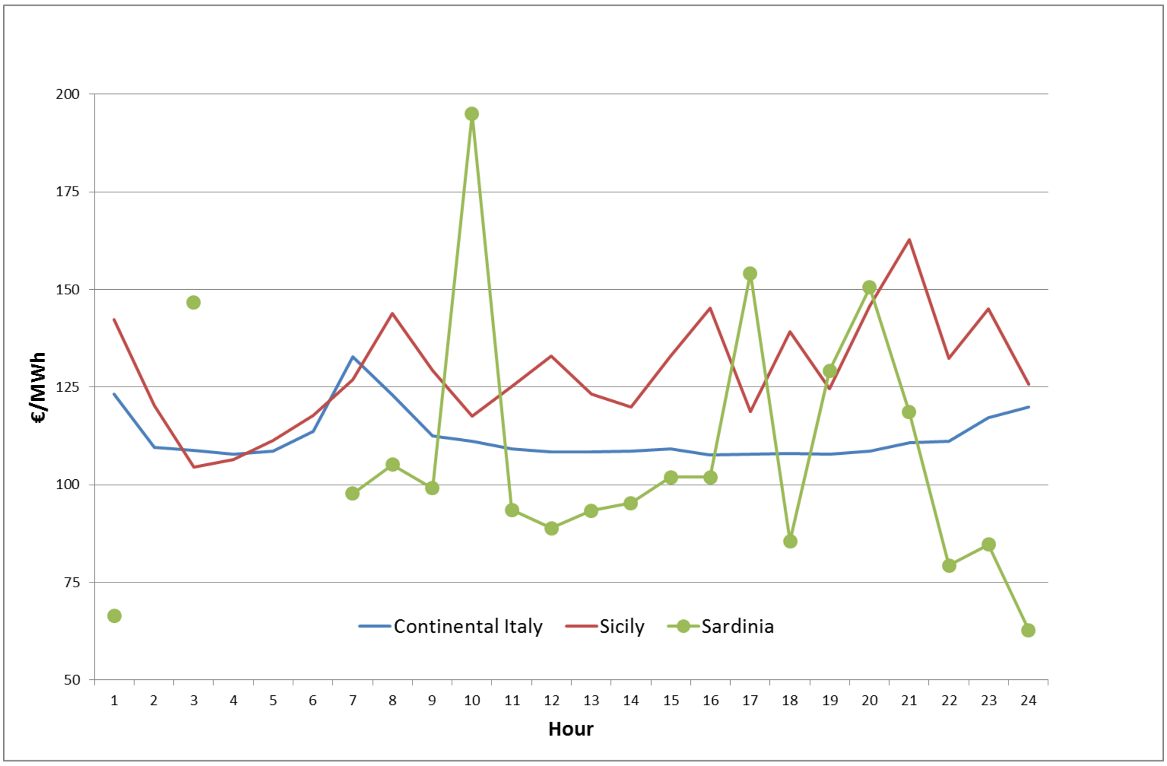


Figure 15 - Average aFRR upward price in continental Italy, Sicily and Sardinia (July 2017 - June 2018)

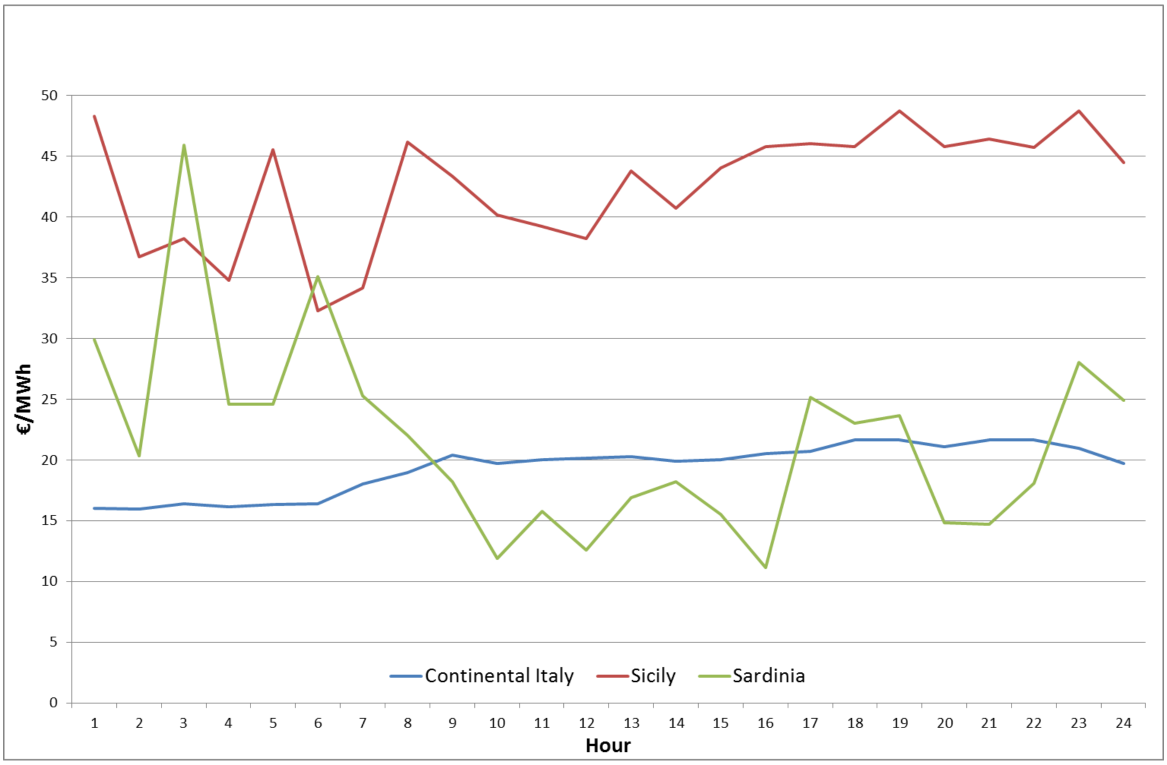


Figure 16 - Average aFRR downward price in continental Italy, Sicily and Sardinia (July 2017 - June 2018)

In addition, the analysis of bid prices is detailed for continental Italy in order to highlight the minimum and maximum range of bid prices (Figure 17) and investigate possible correlation of mean prices with holyday/working days (Figure 18) and seasons (Figure 19, Figure 20).

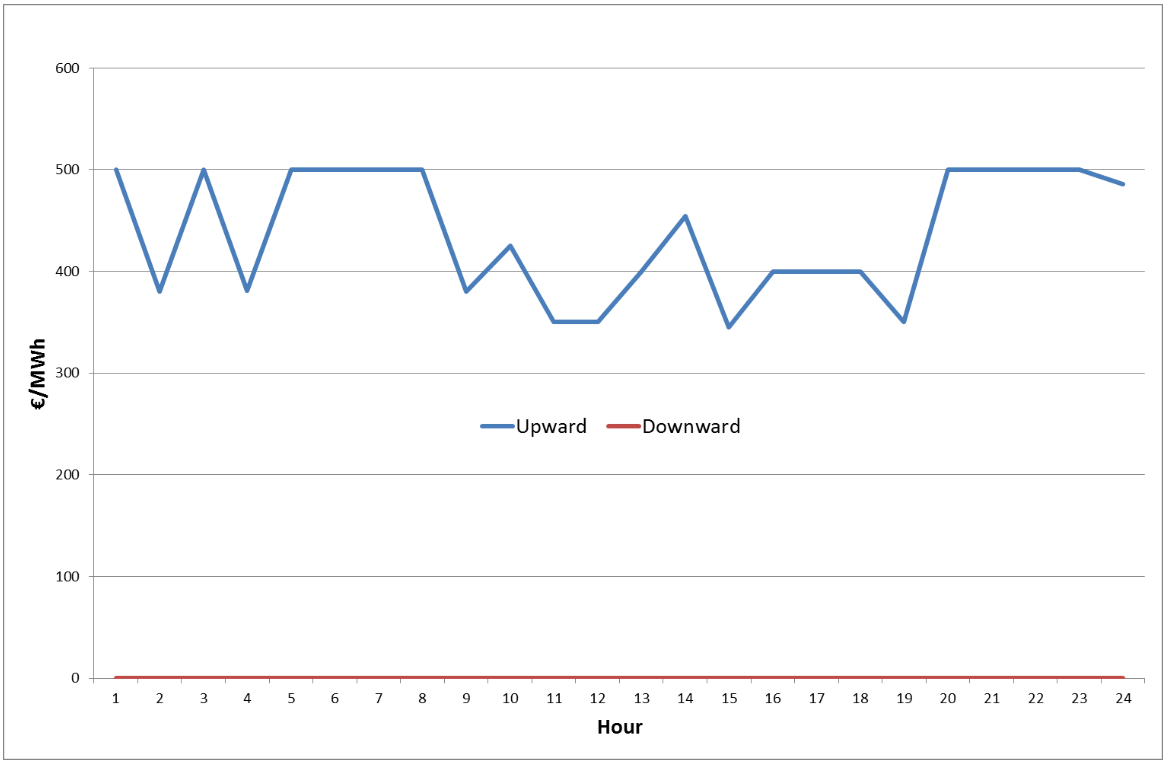


Figure 17 - Max (up) and min (down) aFRR price in continental Italy (July 2017 - June 2018)

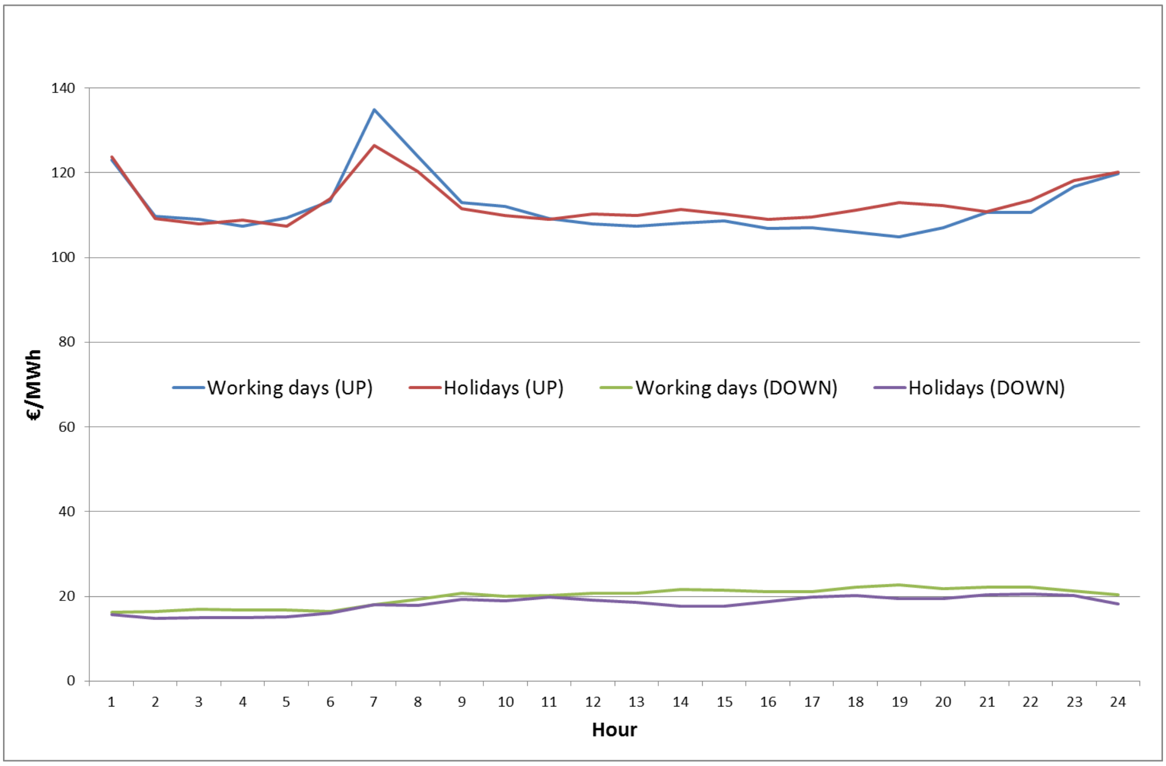


Figure 18 - Average aFRR price during working days and holidays in continental Italy (July 2017 - June 2018)

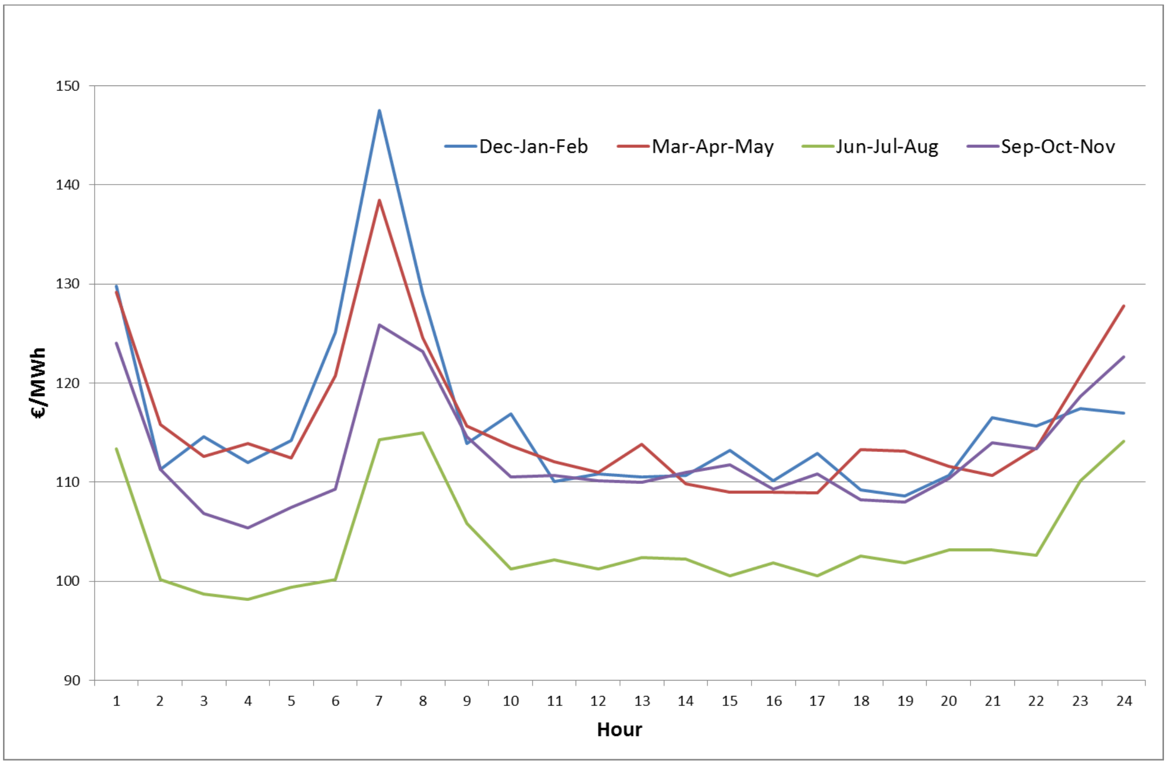


Figure 19 - Average aFRR upward price in the different seasons in continental Italy (July 2017 - June 2018)

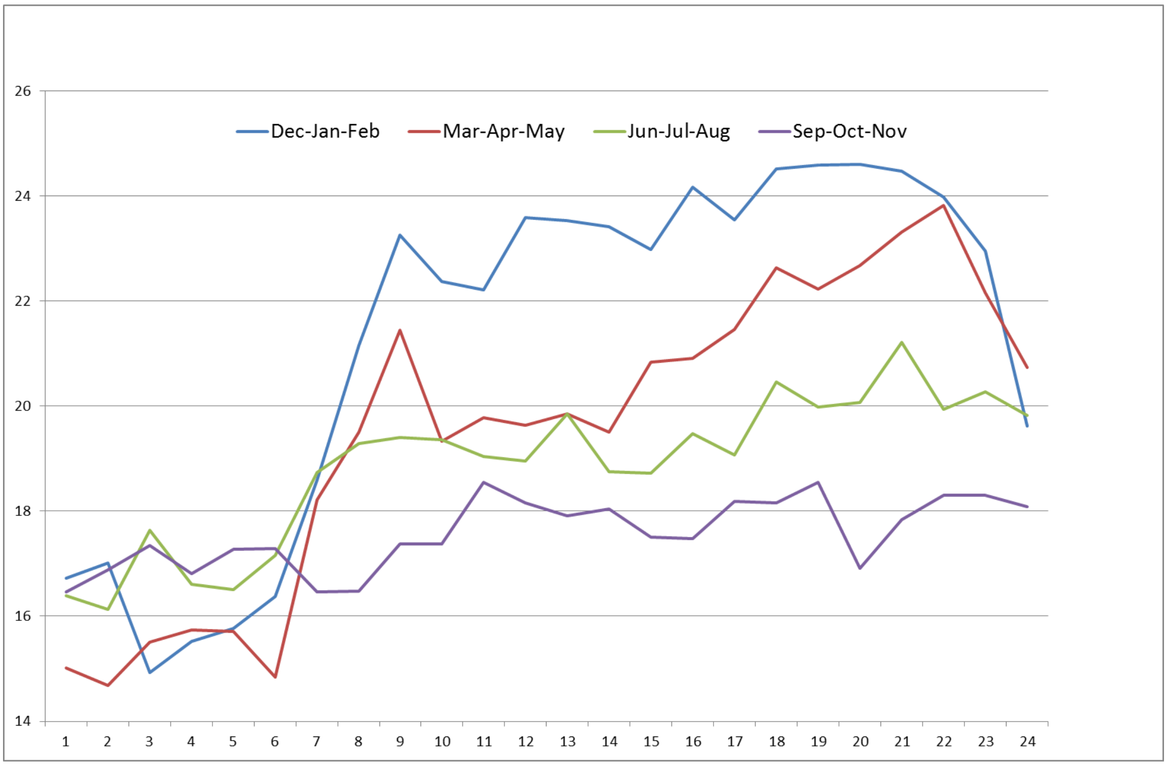


Figure 20 - Average aFRR downward price in the different seasons in continental Italy (July 2017 - June 2018)

The main conclusion from the current aFRR Italian market analysis can be summarized as follows:

- The average upward price is around 110 € / MWh, with a peak in the hour 7 around 130 € / MWh and values around 120 € / MWh in the hours 1, 23 and 24
- The average downward price is around € 16 / MWh from 1 to 6 hours, then goes up to stabilize on € 20 / MWh from 9 am onwards
- The maximum upward price varies between 350 € / MWh and 500 € / MWh in the various hours
- The minimum downward price is always zero
- There is no particular difference between average prices both upward and downward between weekdays and holidays
- As for average upward prices in the various seasons, summer prices are always lower than those of the other seasons, which, from the 9th hour onwards, substantially coincide. At the peak of the 7th hour, the highest average prices occur in the winter, followed by spring, autumn and summer. In the hours from 1 to 7, autumn average prices are placed at an intermediate level between summer and those of the other two seasons
- As for downward average prices in the various seasons, if from 1 to 7 hours they are not significantly different, from 8 onwards they differ with, in descending order, winter, spring, summer and autumn
- Comparing the average upward prices between the Continent, Sicily and Sardinia, one can see that Sardinia's prices are quite different (both higher and lower in the different hours) compared to those of the other two areas. Moreover, at hours 2, 4, 5 and 6 there were no offers accepted in Sardinia. Regarding the Continent and Sicily, the prices of the latter are higher from 8 onwards
- Comparing the average downward prices between the Continent, Sicily and Sardinia, you can see prices of Sicily much higher than those of the Continent and those of Sardinia closer to those of Sicily in the hours from 1 to 7 and closer to those of the continent in remaining hours

The analysis performed gives an idea of the economic value currently assigned to the aFRR services.

2.4.2.2 Impact of new market players

Today, the economic value of FRR used for secondary frequency control is determined in Italy by a 'pay as bid' market mechanism that collects all bids for this service from available resources and pays the accepted bids at bid price. The power system FRR needs are fulfilled by accepting all the necessary bids starting from lower prices. With this procurement mechanism, bids with very different prices may be accepted. In fact, if lower price bids are not sufficient to fulfill the total needed reserve, also higher price bids will be accepted, increasing the total cost of this service for the power system.

From a system point of view, the benefit from the participation of new actors in the aFRR market can be evaluated in term of total cost reduction of the aFRR service. Thus, the question is if this wider market, with actors of different types, can guarantees a total cost reduction in the frequency reserve procurement.

The impact of participation of new energy resources in the current aFRR market cannot easily be predicted and a quantitative analysis would require complex simulations of different market scenarios with reliable data. However some general consideration can be done: it can be assumed that renewable energy sources and loads, thanks to their flexibility, could offer services for secondary frequency control, in the aFRR market, at lower price with respect to traditional plants. In a 'pay as bid' market, the market price is normally influenced by higher cost bids because, in order to maximize their income, actors that can offer the service at very low price succeed in selling the service also if they align their offers at a price, even if slightly lower than the maximum price in the market.

Two major aFRR market scenarios can be identified, corresponding to two snapshots in possible evolution path:

- Minimum impact: if the total amount of reserves offered by the new actors at low cost is little in respect to the quantity required, the market price will be mainly influenced by higher cost plants and the impact of new actors on average market price will be limited. The total cost of the aFRR service will diminish only for the amount acquired at lower prices. The benefits will increase with the increasing of number and size of the new actors
- Major impact: If the high penetration of RES and full deployment of loads flexibility makes possible to cover the total system needs of aFRR, at least in some hours of the day, the prices will be determined by the new market player at lower cost with high economic benefit for the power system

2.4.3 Congestion management

Similarly to what has been done for the aFRR, an hystorical price analysis is here presented. Then, the possible impacts on the current market have been considered.

2.4.3.1 Historical price analysis

Since the resources used for the congestion management are procured on the MSD, the analysis took into account all the accepted bids for one year, excluding those dedicated to the aFRR. All the market zones were examined together, calculating average prices. The time profiles of average bid prices for one year for all the market zones are reported and compared in the following figures for the period Sep 2017 – Aug 2108 [15].

In particular, Figure 21 and Figure 22 display the overall mean value for each hour of the day, together with the working days and holidays groupings, for upward and downward direction respectively.

Figure 23 and Figure 24 display the same upward and downward bids, grouped by season, in order to investigate the price seasonality.

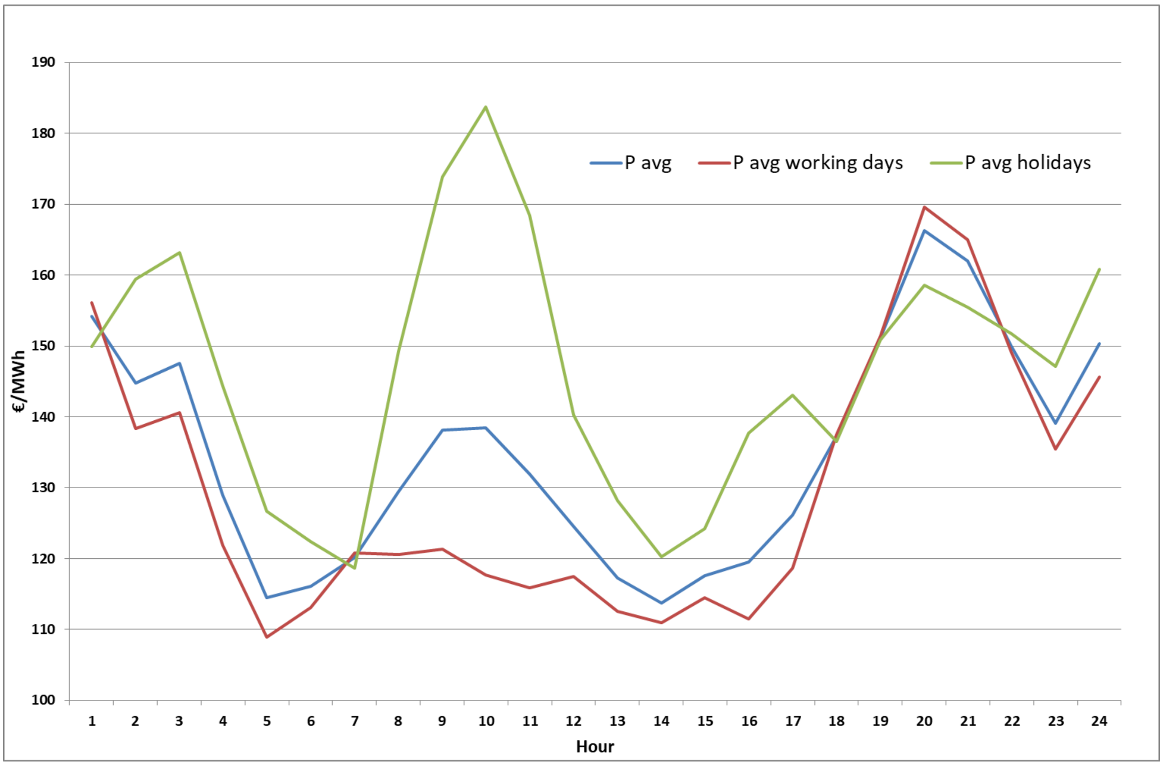


Figure 21 - Average upward balancing market price (Sep 2017 - Aug 2018 / excluding aFRR)

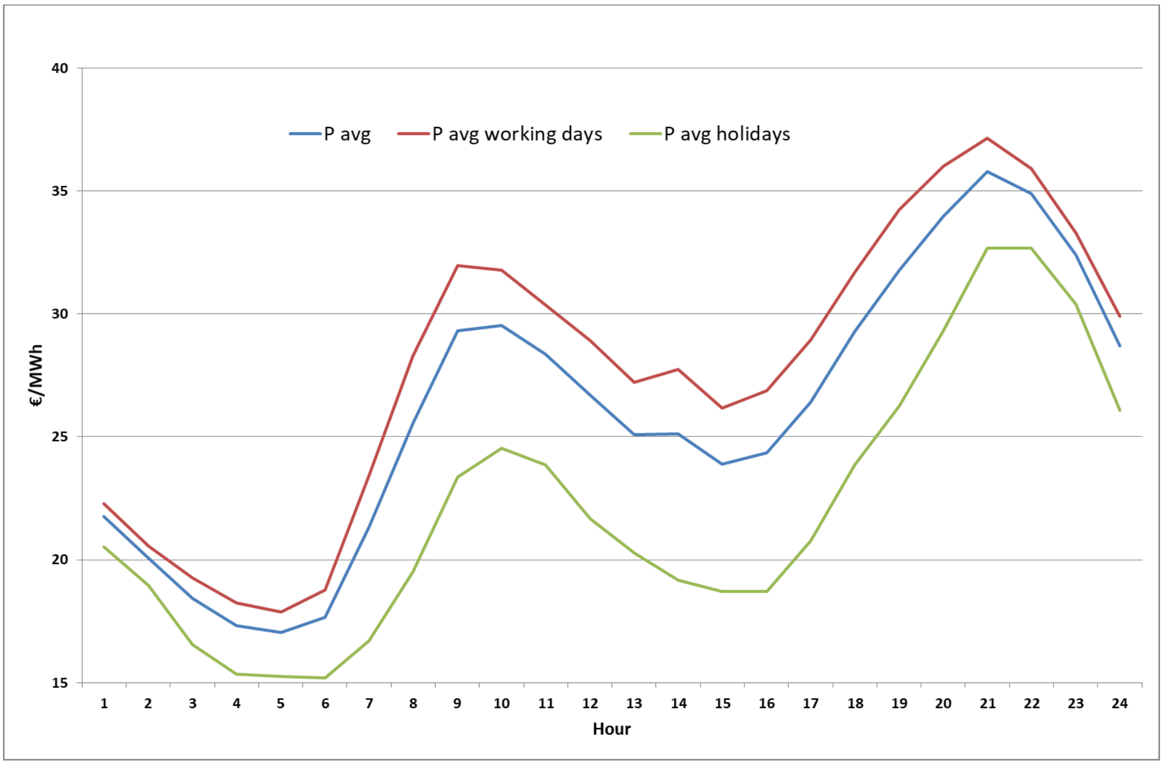


Figure 22 - Average downward balancing market price (Sep 2017 - Aug 2018 / excluding aFRR)

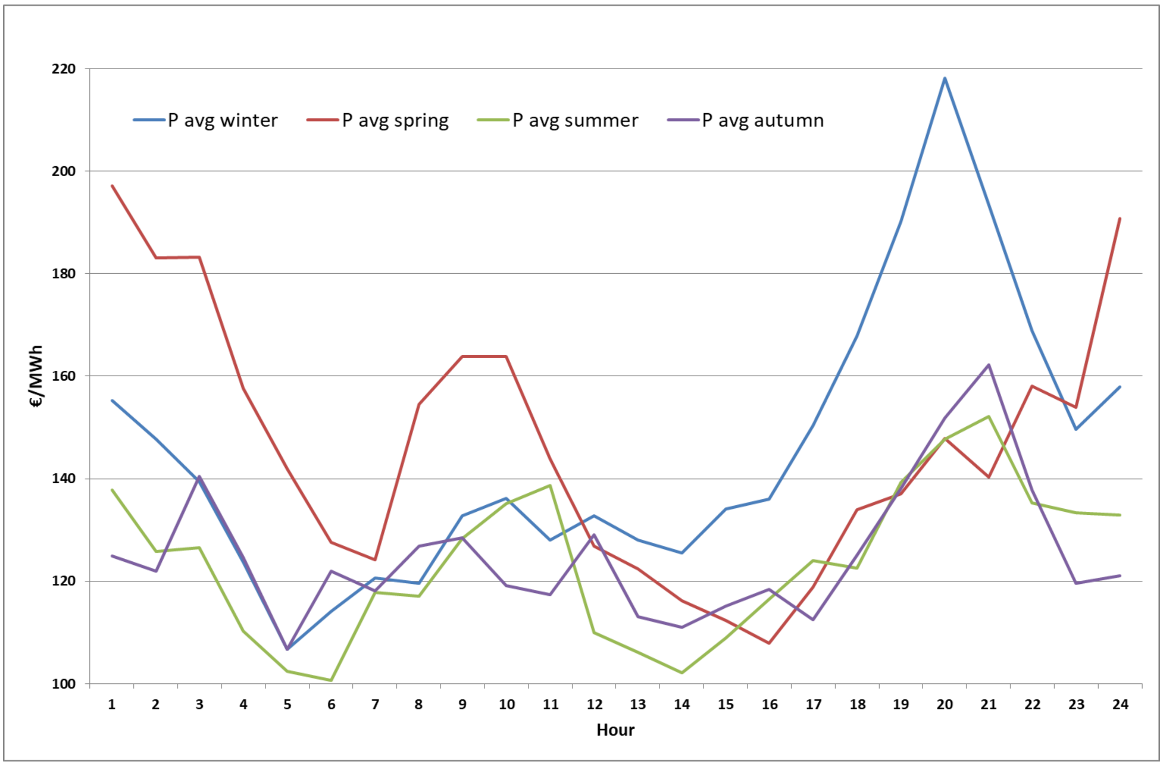


Figure 23 - Average upward balancing market price (Sep 2017 - Aug 2018 / excluding aFRR)

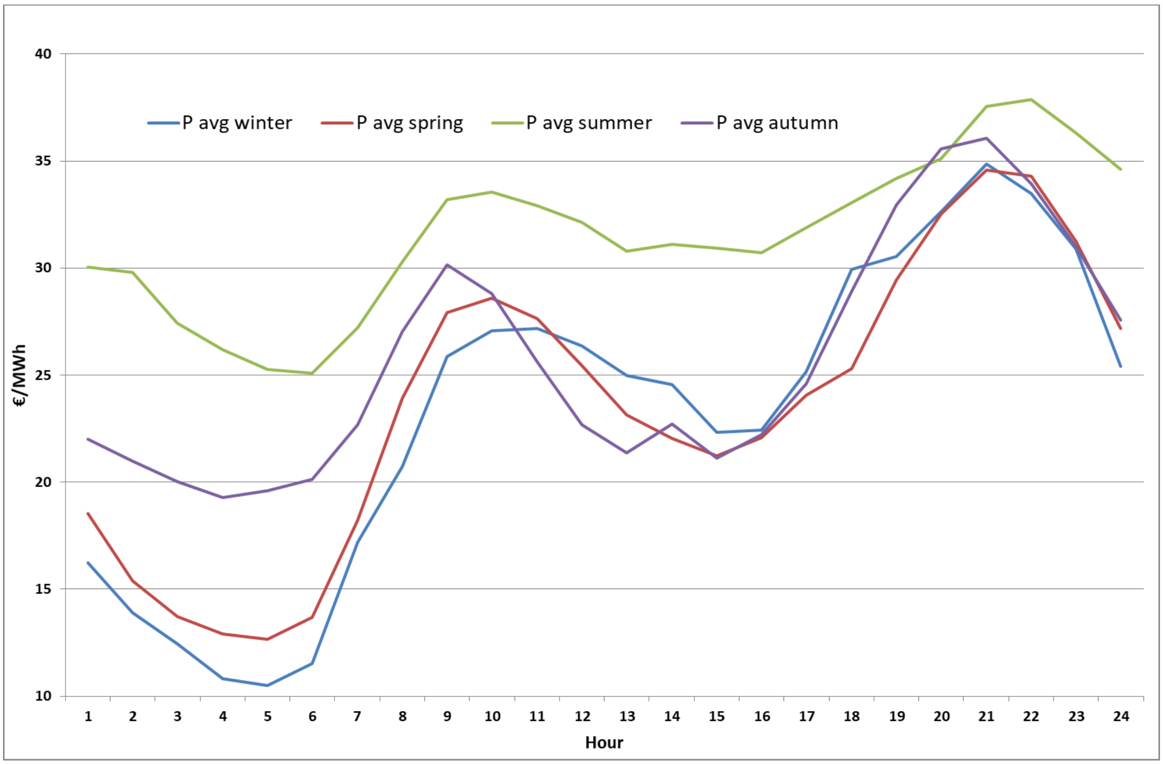


Figure 24 - Average downward balancing market price (Sep 2017 - Aug 2018 / excluding aFRR)

The main conclusions from the analysis (excluding aFRR service) can be summarized as follows:

- The average upward price is around 125 € / MWh, with a peak in the hour 21 around 162 € / MWh and values greater than 135 € / MWh in the hours between 19 and 22
- The average downward price is around € 26/MWh, with values greater that € 30 / MWh from 19 to 23
- The maximum upward price varies reaches 3000 € / MWh between 11 and 23.
- The minimum downward price is always zero
- Holidays have a much higher upward price peak around hour 10 (€ 184 / MWh vs € 118 / MWh), while downward prices are rather the same
- As for average upward prices in the various seasons, the differences are rather small, with average spring prices higher than in other seasons between 1 and 11, and average winter prices higher from 12 to 23
- As for downward average prices in the various seasons, the time profiles are quite the same in each season, except for the average summer prices that are always higher than other seasons

2.4.3.2 Impact of new market players

The analysis performed gives an idea of the economic value currently assigned in the Balancing Market. Congestion management procures its resources in the Balancing Market, but, since it is a pay-as-bid market, and only a few units can help in order to solve a certain local congestion, their price can be higher than the average value. Moreover, the fewer are the locally usable units, and the more frequent are the local congestions, the higher will be the prices.

The system benefit from the participation of new actors in the congestion management service can be evaluated in terms of total cost reduction for the resolution of local congestions. As for the aFRR service, the question is thus if this wider market, with actors of different types, can guarantees a total cost reduction in congestions resolution. Since the technical requirements of the two services are similar, once again it can be assumed that RES and loads, thanks to their flexibility, could offer services for congestion management at lower price in respect to traditional plants. Therefore, drawing similar conclusions to what has been done for the aFRR service, if the total amount of reserves offered by the new actors at low cost is a small portion of the required quantity, the market price will be manly influenced by higher cost plants and the impact of new actors on average market price will be limited. However, for the resolution of a local congestion, a quite small amount of energy is necessary to fulfill the local needs, and the new flexible actors, if properly located, could suffice it entirely. Thus, in this case the price will be determined by the new market players at lower cost, with high economic benefits for the power system.

2.4.4 Automatic Voltage Control

In Italy, the AVC is a mandatory service and it is not remunerated, so it is difficult to estimate the economic benefit at system level. An international comparison, using the British system as a reference case, is here proposed.

2.4.4.1 Reactive Power Service in United Kingdom

In the United Kingdom, the Electricity System Operator (National Grid ESO) defines two types of reactive power services [13]:

- Obligatory reactive power service (ORPS): the obligatory reactive power service is the provision of varying reactive power output between the limits 0.85 power factor lagging and 0.95 power factor leading. Generally, all power stations connected to the transmission network with a generation capacity of over 50 MW are required to have the capability to provide this service. ORPS is paid via the default payment mechanism: all service providers are paid for utilisation in £/MVArh

- Enhanced reactive power service (ERPS): the enhanced service is suitable for generators who can provide reactive power over and above the Grid Code and obligatory reactive power service (ORPS) requirements. Any site that has plants or apparatus that can absorb or inject reactive power can provide ERPS. This could come from synchronised plant that provides ORPS and would like to provide a level of voltage support that is above the minimum requirements. It could also be provided by any other site that has the ability to generate or absorb reactive power, such as synchronous compensators and static devices. The participation and the payments are based on tenders, that allow the generator to request both an available capability price (£/MVAr/hr) and/or an utilisation price (£/MVArh).

Unfortunately, the ERPS has not received any tender since 2011, so no data about capacity price for reactive power is currently available.

Since the ORPS service fulfils all the reactive power needs in UK, the prices and quantities for the period from September 2017 to August 2018 have been analysed and collected in Table 6.

	Reactive Energy provided [MVArh]	Reactive Energy price [£/MVArh]	Reactive Service Cost [£]
Sep-17	2,197,027	2.761807	£ 6,067,765.87
Oct-17	2,176,552	2.976133	£ 6,477,707.94
Nov-17	2,107,880	3.015411	£ 6,356,123.63
Dec-17	2,148,380	3.189798	£ 6,852,898.20
Jan-18	2,050,641	3.263184	£ 6,691,617.33
Feb-18	1,766,158	3.29124	£ 5,812,848.41
Mar-18	1,934,311	3.087256	£ 5,971,714.29
Apr-18	2,115,438	3.089897	£ 6,536,485.38
May-18	2,364,237	3.067452	£ 7,252,184.83
Jun-18	2,412,139	3.143368	£ 7,582,241.96
Jul-18	2,087,881	3.239749	£ 6,764,209.77
Aug-18	2,105,511	3.272756	£ 6,890,824.45
Total	**25,466,155**		**£ 79,256,622.05**

Table 6 - Reactive energy quantities and prices for ORPS

For the reference period, the total reactive energy need was 25.5 TVArh and it costed 79 million £, leading to an average reactive energy price of 3.11 £/MVArh, that corresponds to 3.55 €/MVArh[3]. In order to have an idea of the reactive power needs in UK, the total active energy supplied from from Jul-17 to Jun-18 is 333.69 TWh [14].

2.4.4.2 Italy

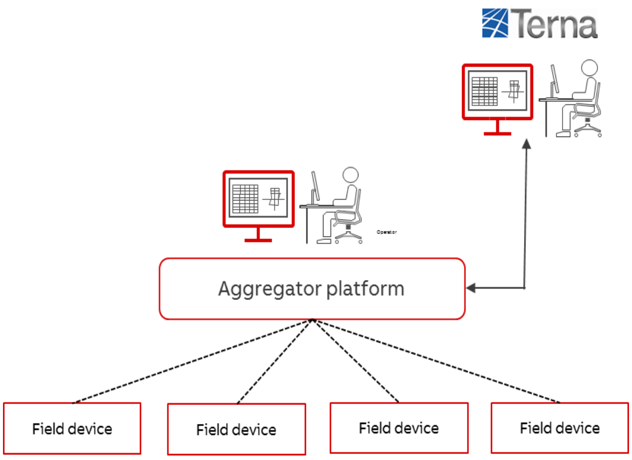
As mentioned above, in Italy the voltage regulation is a mandatory service, not remunerated. So the economic value of this service can be indirectly evaluated, using other indicators.

A study carried out by *Terna* and *Politecnico di Milano*, published in a consultation document by ARERA [16], calculated that, during year 2014, the total reactive energy amount exchanged between the transmission grid and the primary substations, including the high voltage customers, is 33.5 TVArh. The net active energy supplied in Italy during 2014 is 266.8 TWh [18]. The same study calculates that the total sustained costs in 2014 on the MSD for the dispatching orders due to voltage regulation is 150 million €, that leads to 4.48 €/MVArh. Terna has also estimated that, in order to provide a relevant voltage variation (i.e. 1 kV) in the selected grid portion, a provision of 40 MVAr is required. This value can be of course subject to variations due to the considered grid conditions (e.g. high load, low load, specific node, etc.).

2.5 Technical specifications of hardware and software components

As mentioned in paragraph 2.2.1, until 2017 Terna purchased flexibility services from singular programmable production units. Then, Resolution 300/2017/R/eel opened the Italian Ancillary services market to all the other resources, included loads and generators with a nominal power < 10MVA, which have to be aggregated and properly managed by a BSP (Balance Service provider) in a so-called Virtual Power Plant (VPP), in order to provide a relevant service. This subject will aggregate a certain number of units, receive dispatching orders and control the resources in order to satisfy TSO’s requests.

Therefore, for the WP5 demo purposes, is important to test an aggregator platform, which receives the dispatching orders, smartly understands how to move the underlying resources and sends signals to the field devices which enable communication between single resources. At the same time, the field devices need to



[3] Reference exchange rate on Oct 12, 2018: EUR 1 = GBP 0.8764. Source: ECB Statistics.

bring to the aggregator platform the information needed for an optimal management of the plant and the re-dispatching orders.

In the following paragraphs, a general description of platform and field devices architecture and functionalities are provided. The actual aggregators' setup in the WP5 demo will reflect the following description, respecting each plant's peculiarities. Furthermore, a brief description of the control logic of the RES power plant is presented at the end of the paragraph.

2.5.1 VPP platform

Dispersed resourced can be managed in one or multiple pools, as a single *Virtual Power Plant* through an ICT platform that enables their connection, control, aggregation and optimized dispatching and participation in power markets.

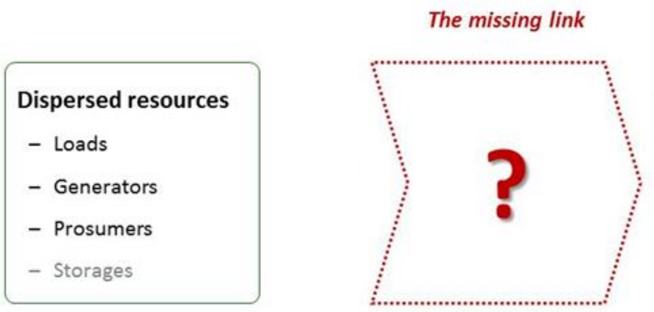


Figure 25: The missing link

The virtual power plant (VPP) includes everything that is necessary to connect, optimize and dispatch resources that is:

- centralized (e.g. VPP software that manages bundled resources) and/or distributed (e.g. on-field software that manages a single resource)
- required centralized (e.g. network operating center) and distributed hardware, essential to run software (e.g. computing resources, data storage, …)
- hardware and software adapters needed to connect and control dispersed resources and relevant data acquisition tools (e.g. *on-site resource connection boxes, that enable communication between platform and single resources or local PLC/BMS*)
- user interfaces both for the trader (*Aggregator*) and for the resource provider (C*ustomer*);
- required data and physical connections to connect users (e.g. aggregator and customers), centralized and decentralized software/hardware and managed resources

Through these, the WP5 demonstrator's platform is able to control and dispatch aggregated resources in order to perform the planned tests, eventually through appropriate modelling and/or forecasting tools.

The VPP platform main dispatching capabilities are:

– *Profiled aggregation and dispatching* (e.g. "tetris" algorithm). To compete with traditional plants on a level playing field, flexibilities embedded in dispersed resources need to be bundled to emulate standard products (e.g. using four resources for a quarter of hour in order to emulate a standard grid service requiring one hour of continuous operation, see Figure 26)

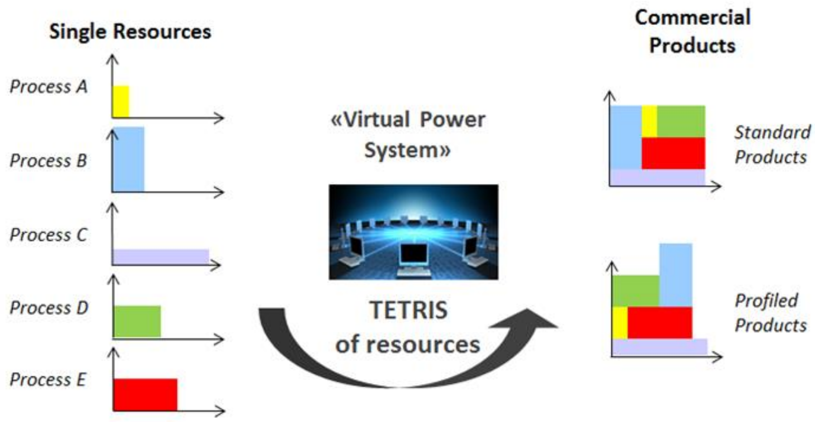


Figure 26: Example of TETRIS of resources

– *Redundancy management* (e.g. "back-up" algorithm). In case of response failure, the VPP needs to replace any resources in order to guarantee a level of reliability in line with that of traditional resources. In particular, the VPP platform must be able to evaluate the reliability of dispatched resources in order to identify the amount of back up resources that are necessary to guarantee a defined VPP reliability target

The VPP resources can be loads (e.g. commercial and industrial processes, with or without back-up generators), programmable generators (e.g. CHP, small hydro, batteries), intermittent generators (e.g. wind, PV, small hydro) and prosumers (i.e. consumers with at least one behind-the-meter generator).

The VPP can be divided in three layers: the bottom layer is the physical device layer and consists of all appliances that provide means for commands, control and metering (e.g. the UPM devices used in Terna's UVAM pilot projects). These devices are triggered through the functionalities in the second layer, the aggregator services layer, which is responsible for linking the physical enablers of electric flexibility with the applications processed at the utility control center. The uppermost layer, the aggregator application layer, provides tools for implementation of flexibility services. Second and third layer compose what has been called so far the VPP platform. Figure 27 shows the division described, with a detail on the functionalities of each one.

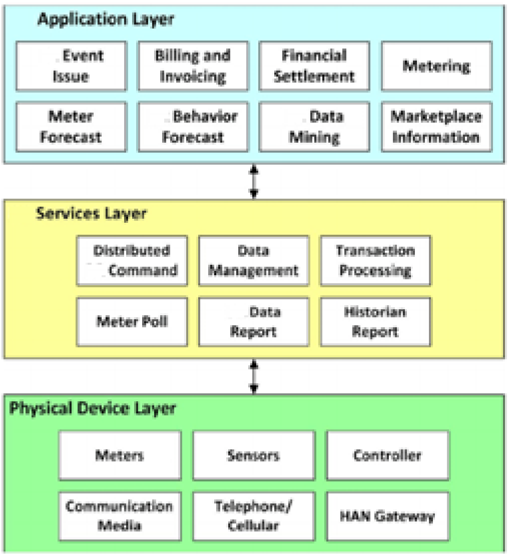


Figure 27: VPP layers and functionalities scheme

In the first two boxes of Figure 27, some of the platform functionalities are listed. A successful aggregation infrastructure must be able to serve all users, promote interoperability and open standards, provide high quality services, create an efficient information marketplace and protect the rights and privacy of its users.

To achieve that, the platform should have the following features:

- Measures and alarms acquisition from RTUs, measurements aggregation and real-time communication with Terna systems
- Dispatch reduction/increase signals for load and/or production
- Field devices diagnostic
- TSO's dispatching order reception and optimal management
- Data storage and reporting (remuneration, financial settlement, penalties, billing and invoicing…)
- Analytics, fault prediction and consumption/production forecasting tools
- Performance analytics

From an interface and communication point of view, the platform has to interact with field devices and TSO systems through:

- IEC-870-5-104 protocol to communicate with Terna
- Private connection to manage the communication with field devices

For the communication between the platform and field devices, requirements for communication protocols are softer, provided that the aggregator is able to send the required measures to the TSO with the desired accuracy. Figure 28 summarizes in a logical scheme the data acquisition/transmission interfaces that have to be developed in order to integrate the on-field devices.

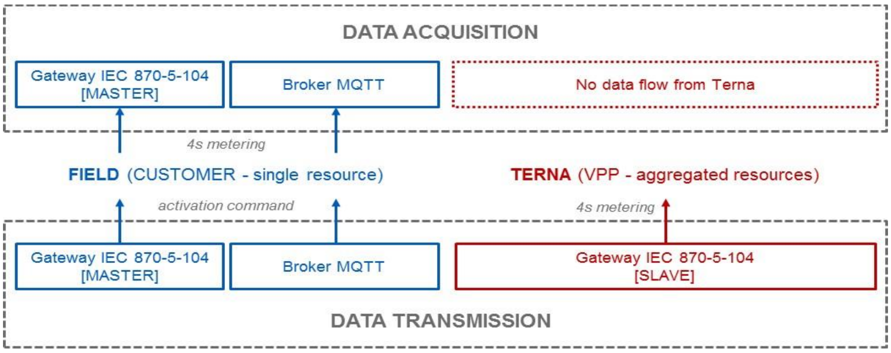


Figure 28: Data acquisition/transmission logical scheme

2.5.2 DSR plants setup

In order to assure the command and control of the industrial loads involved in the WP5, ABB devices will be implemented in the industrial plants participating to the demo. As stated in paragraph 2.1, industrial loads will provide the following flexibility services:

- Congestion Management
- aFRR
- Voltage Regulation

In this paragraph, the main functionalities about the hardware solution, to be deployed on each site, in order to enable the services provision from single and aggregated loads are presented.

The proposed hardware is characterized by the compact form (DIN rail mounting) and has been designed to be modular, in function to the needs of the applications where it will be installed.

Figure 29 highlights the main internal components of the ABB's RTU, which in the case of WP5 demonstrator will connect the field devices to the aggregator's platform. The HCI (Host

Communication Interface) show connectivity with an upper level of controllers (RTU act as controlled role), typically local EMS, using advanced protocol for electrical application through WAN networks. The SCI (Substation Communication Interface) show connectivity with lower layer in Electrical Substation (RTU act as controlling role), typical Protection Relay, IED as Intelligent Electronic Device, other RTU locate remotely, protocol gateway on Transformer, PLC, Meteo Station or Sensors. SCI and HCI are connected by a Communication Interface (IC). PDP icon in the figure 29 shows also the possibility to acquire hardwired Process Data, where status, measures can be connected, commands and setpoint can be given to the process. Cards deputy to the hardwired connection can be deployed in function of the real needs of the application case by case.

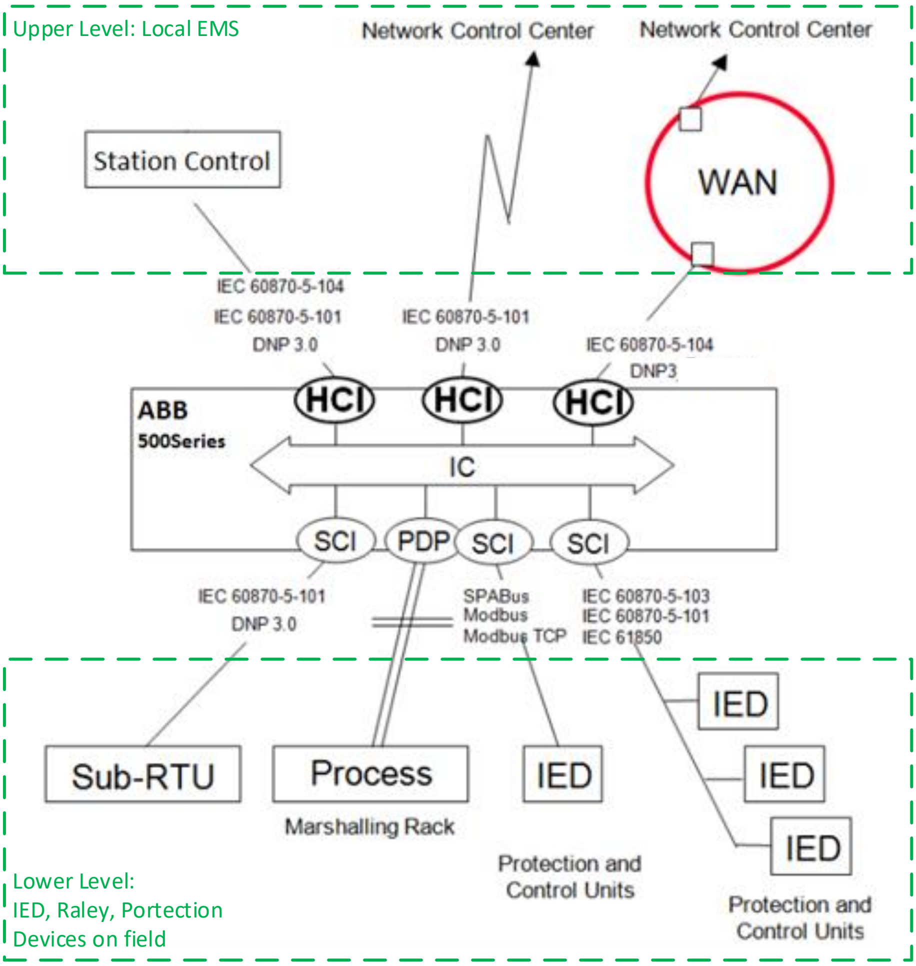


Figure 29: Physical layer architecture

Processing

In order to assure communication with the RTU, devices on field necessarily need a processing module to control the configuration of modules, implement the connectivity and manage database configuration and all mandatory processing task.

This role has been implemented in the CMU Communication Module Unit, where the follow functions are managed:

- Managing and controlling of the I/O modules via the serial I/O bus
- Reading Process events from the input modules
- Send commands to the output modules
- Communicating with control systems and local HMI systems via the serial interfaces (RS232) and the Ethernet 10/100BaseT interface
- Communication with Sub-RTU's, IED's or multimeter devices via the interfaces (RS485) and the Ethernet interface
- Managing the time base for the product line station and synchronizing the I/O modules
- Handling the dialog between CMU product and Web-Browser via the LAN interfaces
- Execution of PLC, logic function implemented and deployed on the local configuration
- Implementing gateway protocol controls

Firmware

A special mention must be dedicated to the firmware: the operating system loads the protocol implementation on the CMU, where is available. The firmware runs the configuration and executes the machine status of the protocol configured. Typical protocols useful for this project will be the IEC 60870-5-104, certified by KEMA for this ABB hardware..

Data Acquisitions

ABB's devices will enable to provide hardwired analog and digital data acquisition.
Concerning analog data acquisition, current and voltage measurement are available. The module is able to process Analog Measured Values (AMI) and Measured Floating point Information (MFI)
The module for the analogue acquisition function can collect up to six measures and can be coupled with other modules to extend the capacity of data acquiring. Digital acquisition is available, and the module is able to process different types of signals or a combination of them.

Following the acquisition, a binary input module unit can execute the following processing functions for the different types of signals:

- Digital filtering to suppress contact bounce
- Validity check and suppression of intermediate input states for double indications
- Consistency check for all channels allocated to digital measured values or step position information
- Summation of increment pulses to form integrated totals in registers of 31 bit resolution
- Copying of integrated totals values into freezing registers for data conservation

Control

Controls are implemented by ABB's devices modules, where the entire system can send digital command and or dispatch the curtailment on fields by setpoint.

Is possible to have two analog output channels (current and voltage) and the module is able to process Analog Setpoint Commands (ASO) and Floating point Setpoint Commands (FSO)

Digital commands are implemented by the ABB module with different types of signals inclusive of Command monitoring functions.

Connectivity

Plants belonging to a DSR program shall be able to communicate with the upper level system to send cyclical measures and statuses, receive plans, setpoints and commands to be applied on the process. The communications between parties shall be implemented and configured to be compliant with the framework for providing cyber security, implementing VPN based on encryption of data flow, adopt authentication, accounting and authorization in all the processes. Physical connectivity can be deployed by GPRS Module, if a network link cannot be host the proposed devices.

2.5.3 RES power plants service provision

In this paragraph, the main logics of regulation are presented for the two RES power plants involved in the demonstrator. As stated in paragraph 2.1, RES power plants will provide the following flexibility services:

- Synthetic Inertia
- Voltage Regulation

Therefore, regulation logics are required for the regulation of both active and reactive powers.

2.5.3.1 Potenza Pietragalla

Referring to the control system of Potenza Pietragalla, which is described in paragraph 1.3.1.1, the voltage regulation is already implemented at Master SCADA level and it can be carried out at the TSO level in different ways, by means of reactive power regulators at the point of delivery with the reactive power set point supplied by TSO. The main logic of regulations are the followings:

- Voltage Regulation from TSO through Reactive Power set point: The Reactive power set point is provided by TSO in percentage to the availability of reactive power of the plant. Properly converted into a signal expressed in kVAr, the set point sent by the TSO goes as an input to the reactive power regulator running inside the MASTER SCADA. For the implementation of this regulation mode, it is necessary to export from Master SCADA to TSO at least the following signals:

    - Analog input - HV bus bar voltage
    - Analog input - Capability curve of total Reactive power available in Pietragalla power plant
    - Analog input - Reactive power at the point of delivery as a percentage of the capability
    - Analog input - Reactive power set point at the point of delivery as a percentage of the capability
    - Analog output - Reactive power set point output at the point of delivery as a percentage of the capability

- Voltage Regulation from TSO by means of Q = f (V) statism on board of Master SCADA*:* the reference voltage V_{RIF} is provided by TSO. The presence of statism Q = f (V) on board of Master SCADA allows the regulation of voltage even in the presence of an occasional change of the reference voltage (for example 2 times a day). For the implementation of this regulation mode, it is necessary to send from the Master SCADA to TSO of at least the following signals:

- Analog input Reference voltage
- Analog input for return of reference voltage set point
- Analog output of the reference voltage set point

On the other hand, how to implement and provide the Synthetic Inertia service is currently under deep analysis.

2.5.3.2 Vaglio 2

The main regulations provided by the control systems of Vaglio 2, which is described in paragraph 1.3.2.1, are:

- Active power regulation: a relevant module of the first level SCADA could enable the total active power regulation of the entire wind farm, by operating on one of two limits:
  - the safety limit, corresponding to the maximum power value that cannot be exceeded
  - the setpoint limit, corresponding to the power value that the system should follow

  In case of an external wind farm set-point received from a central control room (i.e. in case of grid curtailments) or directly from the grid operator, the system could automatically allow the dynamic limitation of each WTG power output to totally comply with the external set-point at wind farm level through a closed loop: in fact, the system will verify that the measured power output will satisfy the wind farm set-point at the grid connection point
- Reactive power regulation: the first Level SCADA system manages the information collected from the wind turbines and the electrical substation, in accordance with regulation set points established by the operator or by the control room (SCADA 2 System). In the wind turbine, the PLC controls all the variables involved in the generation of reactive power, preventing these variables from exceeding the limits established for each wind turbine model (according to the relevant P, Q capability curve). The PLC protects the machine so that it and all its components can operate in a safety way according to the designed criteria. Therefore, the wind turbine reduces the reactive power to zero when the set point requested conflicts with the design limits, which would cause it to be outside the operating range of the turbine causing potential damage to the main components. The Siemens-Gamesa power plant controller can receive selected set point for the reactive power regulation through:

- a cosphi set point
- a reactive power output set point (limiting to the WTG P,Q capability curve)
- an external reference voltage, exploiting the ability to produce reactive power and to contribute to the voltage regulation under specific operating conditions and telecommunication apparatus performances

Siemens-Gamesa 2.5 MW WTGs are capable of generating and consuming reactive power, following the set-points commanded by the reactive power/voltage regulation tool installed in SCADA system. They are capable of generating and consuming reactive power up to 822 kVAr (equivalent to a power factor of 0.95 at rated MW output). This reactive power represents the 33% of the rated active power of the WTG.

3 Conclusion

Deliverable 5.1 provides a detailed description of the following aspects of WP5 demonstrator:

- The HV grid portion in which all three use cases will be tested. grid issues were characterized in order to understand how relevant the tests results will be
- Flexibility resources that will be used for the testing of flexibility services provision:
  - RES power plants: two wind power plants, one of which with an integrated BESS, will be used for the testing of Synthetic Inertia and AVC provisions
  - Industrial customers that will provide congestion management, aFRR and AVC services
- Market regulatory context: the requirements for the participation to the Italian ancillary service market have been illustrated
- Market evolution: an overview of the Resolution 300/2017/R/eel has been presented in order to identify the synergies between WP5 and the evolution of the Italian market
- Technical specifications of flexibility services: a definition of the selected flexibility services provision has been introduced, taking into account the Grid Code framework
- Economic analysis: for each selected service, qualitative and quantitative studies have been performed, in order to estimate their value
- Hardware and software components: the aggregator platform architecture and main functionalities, as well as the hardware solution for the control of loads and the control logics of RES power plants have been illustrated

The information collected in this document will be used as the starting point for the "*general technical specifications of the demo implementation"* (Deliverable 5.2), in which the DS and RES technical specifications will be extended and integrated also with the DTR devices, EMS and forecasting models specifications, so to provide all the needed indications for the physical implementation of the demonstrator.

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