H2020 OSMOSE PROJECT: Electrical Grid flexibility services from industrial loads through Demand Side Response (DSR)

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***Abstract*— In the future of Ancillary Services for the HV grid, Demand Side Response (DSR) will play an increasingly important role to ensure grid stability and promote Renewable Energy Sources integration in the electrical system. A particular use case of the Italian Demo of the H2020 project "Optimal System-Mix Of flexibility Solutions for European electricity" (OSMOSE) is to demonstrate multiple grid services provision based on DSR by seven industrial plants distributed in a HV grid area between Apulia and Basilicata. Sites have been managed by three Balance Service Providers (BSPs). On each industrial plant, project partners first have performed an energy audit and then they have installed all the electric and TLC equipment needed to test and manage the flexibilities identified. The main result of these activities was that the hardware required for DSR comes at a relatively small price compared to the magnitude of loads that could be controlled. Purpose of this work is to provide an analysis of possible benefits and limits of DSR for the grid as well as to direct a possible new future market strategy for these resources.**

Keywords—OSMOSE, Demand Side Response, Balancing Service Provider, Congestion Resolution, Automatic Voltage Control, automatic Frequency Restoration Reserve.

I. INTRODUCTION

The increasing pressure of climate change has led to a global effort to an energy transition from fossil fuels sources to renewable energy sources (RES) which, however, are characterized by an intermittent generation strictly connected to weather conditions. As well known, all international scenarios show a growing penetration of variable renewables, associated with a reduction in traditional forms of generation [1]. The conventional generation systems, based on thermal power plants, have full capacity to control and program the amount of power to be injected into the grid. On the contrary, the main feature of RES is the non-programmability of their generation profile, independently from the level of energy demand or necessities of the system. In addition, spread of renewables generates a new highly decentralized network which need a proper management system. This means major challenges for the electricity power system, with a significant impact on the Transmission System Operator's (TSO) activities. RES intermittencies cause on the electrical grid a reduction of adequacy margins, an increasing of over-generation periods and an increasing steepness of residual load evening ramp. Moreover, RES technical characteristics as of today, have an impact on system inertia and cause a reduction of resources providing frequency and voltage regulation.

For this reason, Demand Side Response (DSR) could have a crucial role to counteract the significant effect brought on the system by RES. DSR is defined as the capability of regulating the load of the energy profile in order to provide flexibility by reducing, shifting or increasing the electricity usage during peak or valley periods in response to time-based rates of some sort of financial incentive [2]. In other words, the goal is to shift part of the demand to the moments with overgeneration. According to the European Commission and the Smart Energy Europe [3], the theoretical potential for Demand Response is around 160 GW in 2030, 100 GW today and 20 GW already activated [4]. This potential is divided over the three main energy sectors: industrial, commercial, and residential.

Despite the high potential of demand response in the EU and despite the provisions in the current EU legislation, only a few countries have implemented an enabling framework to take advantage of it. Residential sector has the highest potential capacity but at the same time there is a logistical drawback concerning the extreme wide distribution and the involvement of a massive number of small loads.

Though industrial DSR has the smallest overall theoretical capacity, on the other hand it is the easiest flexibility to unlock. A lot of units are in fact directly connected on High Voltage (HV) grid and they represent large loads for the electrical system. For this reason, pilot projects and first initiatives of DSR are majorly involving the large industrial sites to test flexibility services.

A practical example is the Work Package 5 of The *Optimal System-Mix Of flexibility Solutions for European electricity* project (OSMOSE). The Italian demonstrator of the project, guided by Terna, has the goal to demonstrate multiple grid services based on industrial DSR, Renewable Energy Sources (RES) and Dynamic Thermal Rating [5]. OSMOSE is a H2020 EU founded project started in 2018 that aims for the development of flexibilities which can be used for a better integration of RES in the electrical system. The project is characterized by a global approach that aims to capture the synergies coming from the combination of different solutions

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in order to address not only technical benefits but also positive externalities for the society.

During the ongoing DSR experimentation phase the following ancillary services are being tested by single or aggregated industrial plants: Congestion resolution in coordination with an innovative energy management system developed in the project, Automatic Voltage Control regulation (AVC) and provision of automatic Frequency Restoration Reserve (aFRR)

II. Demo Site Location and Plants Engagement

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, there is a presence of grid instabilities in both 380 kV and 150 kV HV lines between Apulia and Basilicata regions (Fig. 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.

Since the area of the demonstrator is characterized by a presence of large industrial loads with a direct connection to the HV grid, the idea was to use these sites as new grid flexibility resources to increase the electrical system stability, providing both active and reactive power services.

Nineteen industrial customers have been identified and contacted for the participation to the OSMOSE project, seven of which agreed to participate in the demo activities as a third party. These sites belong to different areas of the industrial sector, as described in Table 1.

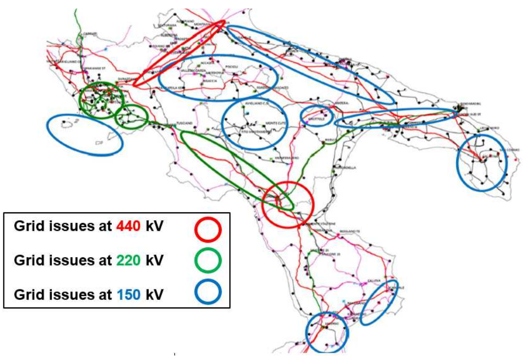

Fig. 1. Main areas in South Italy subjected to congestion on the HV grid

TABLE I. Industrial plants involved in Osmose Demo

Plant ID	*Plant name*	*Voltage [kV]*	*Region*
1	Powertrain industry	150	BASILICATA
2	Industrial Park	150	APULIA
3	Military Site	150	APULIA
4	Car manufacturer	150	APULIA
5	Foundry	220	BASILICATA
6	Steel factory	150	APULIA
7	Oil refinery	150	APULIA

The benefits coming from taking part to the project, were:

1. An energy audit of the site, performed by a Balance Service Provider (BSP), for plant's DSR availability assessment carried out completely on Osmose partner's expenses.

2. Free installation of 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.

To be noted is that the testing time is the one that the involved industrial consumers have agreed to participate, and it does not come with the support of finance measures for them.

III. Energy Flexibility Audit and Resource Characterization

All the plants engaged were initially not enabled for the provision of grid services. For this reason, three different BSP (Compendia, Edison and Enel X), participated as project partners.

The first step for the BSP, after the engagement phase of the plants, was to perform an Energy Flexibility Audit on each industrial site.

The study consists of a gradual analysis of the plants through a detailed characterisation of electrical loads, local electricity generation systems and back-up power supply systems in order to assess their potential electrical flexibility. Flexibility could be generated by increasing energy generation or conversely by reducing consumption from the grid. The flexibility audit was aimed to identify flexible power and to enhance it with dedicated projects. The following steps, were carried out during the audit:

- Identification of the various processes of a site that can be made flexible, their technical constraints and the methods for optimising these flexibility levers.

- Analysis of potential electrical flexibility and opportunities to achieve it.

- Estimation of the economic gain that can be obtained through optimum use of the different flexibility levers.

The execution of the Energy Flexibility Audits started from the analysis, for each factory, of all the production process. The purpose was to discover and define which components compiling the scope of the project, in terms of availability to be turn off, slow down, pick up and, in case of rotating machine, which are capable to respond at an underexciting or overexciting external request.

The next step was to identify the type of key flexibility resources and the information to be investigated during the site audit. The study of the different productive fields allowed to analyse a representative variety of plants, some peculiar to some sites, others common to all companies. Among the availabilities identified, in the first analysis, user plants and local electricity production plants.

Therefore, plants were divided into two macro-families: mainly resistive loads and loads from rotating machines. Instead, as far as it concerned production plants, generators were included in the assessment. From these analyses, three possible flexibility services were identified:

- Congestion Management**:** entails a variation of energy exchange with the grid related to a certain time period. Therefore, benefits can be provided by the resources involved in the project in different ways: increasing/decreasing loads consumption, increasing/decreasing generators production or load shifting.
- Automatic Voltage Control (AVC): industrial loads could increase or decrease their reactive power exchange with the grid, helping voltage regulation on the transmission grid. Based on the analysis carried out, this kind of service is better bearable because it should not include significant changes to the active power flows, that means theoretically no impact on the processes.
- Automatic Frequency Restoration Reserve (aFRR): this service is considered a continuous power exchange with the grid based on a signal received by the TSO, with the aim to restore the system emissions to the nominal frequency. Some of the analysed loads could be able to dedicate a certain amount of their nominal power for exchanging power with the grid with an effect which contributes to frequency services.

All sites, except the military base, could provide Congestion resolution service, for a total maximum theoretical regulating capacity of 48.9 MW (13.9 MW loads, 35 MW generators). In the project context, this service will be tested in coordination with an innovative Energy Management System, so called Z-EMS. Two sites could test AVC, by the provision or the absorption of reactive power, for a maximum theoretical capacity of 30 MVAr (7 MVAr loads, 23 Mvar generators). All sites were theoretical able to provide aFRR, by automatic active power regulation, for a maximum capacity of 50,9 MW (11.9 MW loads, 39 MW generators). Table 2 summarizes the results of the Energy Audit performed by the BSP for each item of the plants.

Once all the loads have been defined, these were selected by the BSPs and ABB in order to differentiate the available resources, thus increasing their representativeness also considering the infrastructural costs necessary to connect the users. After that, ABB verified the technical feasibility of connections. For some reasons such as the availability of connectivity in the field rather than changes to the structures of the plants or the temporary unavailability of the sites initially involved as well as the available budget, the connected plants have resulted in a total availability lower than initially assumed for the three services considered. In addition, other successive deepening revealed that most of the items had to be rejected due to:

- Mechanical stress in rotating machine in case of sudden switch on /switch off.
- Absence of inverters which allows a soft regulation of the loads in order to follow a given external set point.
- High lack of production and related economic losses, not restored by the demo project.
- High cost to be sustain for the creation of infrastructures needed for the connection of the loads to the BSP Platform.

Some of the above-mentioned critical issues are strictly related at the features and restrictions of the demo project and may be solved when the ancillary services offer can be restored in markets.

In conclusion, the final useful demo capacity of the resources will be assessed directly during the tests phase, and it will depend also on the operating energy conditions and on plant production processes.

TABLE II. FLEXIBILITY ANALYSIS RESULTS

Plant ID	*Device*	*Load [kW]*	*Load [Mvar]*	*Service*
1	Chiller	400		Congestion, aFRR
2	Compressors	400		Congestion, aFRR
	Generator 1-2-3-4	1000-4000	2	Congestion, aFRR, AVC
	Generator 5-6-7	3000-8000	4	Congestion, aFRR, AVC
	Generator 9-10	4000-16000	8	Congestion, aFRR, AVC
3	Stop/Modulation charging	6000		Congestion, aFRR
	Rephase System		7	AVC
4	Cogenerator	4000		Congestion (up)
		7000		Congestion (down)
		11000		aFRR
			9	AVC (up)
			2	AVC (down)
	Air Treatment	200		Congestion (down)
		200		aFRR
	Compressor	200		Congestion (down)
		200		aFRR
	Chiller	1100		Congestion (up)
		1900		Congestion (down)
5	Blast Machine 1	95		Congestion, aFRR
	Blast Machine 2	90		Congestion, aFRR
	Decoring Plant	73		Congestion, aFRR
	Sand Regeneration plant	65		Congestion, aFRR
	Sand Regeneration plant conveyors	45		Congestion, aFRR
	Water Boiler	20		Congestion, aFRR
	Compressor	150		Congestion, aFRR
6	Furnace	600		Congestion, aFRR
	Electric Arc Furnace	800		Congestion, aFRR
7	K2207	600		Congestion, aFRR
	Tank Circulation Pump	700		Congestion, aFRR
	Pumps	280		Congestion, aFRR
	Heating system	1000		Congestion, aFRR
	Fans	250		Congestion, aFRR

IV. Upgrade of the Industrial Sites

To achieve the provision of the flexibility services identified, on each site ABB installed a hardware solution to enable the services provision from single and aggregated loads and to connect the field devices to the BSP's platform. The hardware is characterized by a cabinet containing the devices necessary to interface the plant with a remote system and it is identified as a "Local Control Unit" (LCU).

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

Each of the seven industrial site was equipped with a LCU, that is able to exchange data, in terms of acquiring input and send output commands or set points, using both traditional wired Input/ Output (IO) and communication protocols operating on adequate communication channels. The main component installed inside the LCU is a Remote Terminal Unit (RTU) of ABB [6]. The data can be managed by logics performed on the Programmable Local Controller (PLC).

In terms of data acquisitions, the LCU can 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 in case of necessity it can be coupled with other modules to extend the capacity of data acquiring. The module of Digital acquisition is able to process different types of signals or a combination of them. Moreover, the cabinet contains an Intelligent Electronic Device (IED), ethernet connectivity devices and a power source.

Figure 2 highlights the main internal components of the ABB's RTU. The HCI (Host Communication Interface) shows connectivity with an upper level of controllers (RTU acts as controlled role), typically local EMS, using advanced protocol for electrical application through WAN networks.

The SCI (Substation Communication Interface) shows 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, Weather Station or Sensors.

PDP icon in the figure shows the possibility to acquire hardwired Process Data, where status, measures can be connected and 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.

During the experimentation campaign the described general LCU system has a twofold purpose. Firstly, it connects data to the BSP platform and receives the commands from it. Secondly, it reflects the Input/ Output list (I/O list) together with the BSP's commands or directly on the devices, for automatic regulations, or to a Human-Machine Interface (HMI) located on site or remotely. Through the HMI plant operators can monitor the loads and act on them when an activation or deactivation order arrives. The communication protocol between the Local Controller and the BSP platform is IEC 60870-5-104 [7], while on the field side the developed protocols were Modbus RTU or TCP, as there is a widespread penetration of these two protocols in industrial applications.

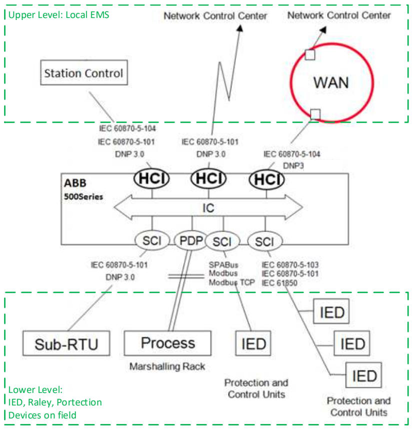

Fig. 2. Phisical Layer Architecture

One of the general key findings of the on-site implementation activities was that there are several constraints to respect, such as risk related to cybersecurity and/or unauthorized access, as well as radio interference with other equipments presented in the factories. Also, the activities proved to be more demanding that it seemed, due to the heavy need of retrofit of the sites (lack of connectivity infrastructures and automation devices in old plants).

A. *Costs of Upgrade*

Table 3 summarize the final flexibility services to be tested and the total costs related to the adequacy for each of the 7 industrial plants involved in the project.

To provide congestion resolution service it is not required a fully automated system since it belongs to the so-called slow regulation services. On the contrary, for automatic services, as AVC and aFRR, it is mandatory, for the correct execution of commands, a full automation of the entire architecture. Therefore, upgrade costs have depended on the type of service to be tested. Other main factors that affected the costs were: technological state of the plants, distance from the cabinet to the devices and number of sources that have been connected to the LCU. More in details:

- Oil refinery and Powertrain industry already had a structured IT automated network. This allowed a rapidly and efficient deployments of the sites.
- Military site had an IT infrastructure well engineered and already available equipment for controls were used. Costs are mainly related to the typology of service.
- Foundry had an IT infrastructure completely absent, and the equipment were in a large area. In addition, almost all devices were not able to communicate with a useful IT protocol.
- Industrial Park had the highest upgrade cost. This site supported IT infrastructure but unfortunately some devices did not allow the remote connection and IT useful protocols today available.
- Car manufacturer and Steel factory costs are mainly influenced by the positioning of the LCU in the plants.

TABLE III. COSTS OF INDUSTRIAL SITES UPGRADE

Plant ID	***Plant name***	***Flexibility Services***	***Total Cost [k€]***
1	Powertrain industry	Congestion resolution aFRR	9.8
2	Industrial Park	Congestion resolution AVC	99.7
3	Military Site	AVC	30.6
4	Car manufacturer	Congestion resolution	49.0
5	Foundry	Congestion resolution	70.0
6	Steel factory	Congestion resolution	23.3
7	Oil refinery	Congestion resolution	4.5
-	LCU Construction (all plants)	-	37.5

The main output coming from the sites upgrade activities was that the installation of the required devices for demand response comes at a relatively small price compared to the magnitude of the load that could be controlled and, thus, easily reachable.

V. BSP PLATFORM

According to the Italian Ancillary services market [8] Terna allowed the aggregation of loads and generators properly managed by a BSP in a so-called Virtual Power Plant (VPP). The role of a BSP is to work as an interface between the industrial plants and TSO's requests, in order to make plants' electrical flexibility useful to provide significant grid flexibility services.

The aggregation platform receives the dispatching orders directly from Terna, elaborate the best way to satisfy the order and sends the signals to the field devices. In parallel to this, the field devices upload into the aggregation platform all the information needed for their optimal management, such as availability of flexibility. The main requirement for the platform is provide a reliable service so to compete with traditional plants. To do so the BSP has to provide the dispatching service as if it was a single unit. This is achieved by the development of a proper algorithm in which the flexibility embedded in dispersed resources is bundled to emulate a traditional plant (Figure 3). Each BSP who participated to the project, has developed a platform to receive the dispatching orders, smartly understands how to move the underlying resources and sends signals to the field devices which enable communication between single resources. 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 platforms have the following features:

- Measures and alarms acquisition from RTUs, measurements aggregation and real-time communication with Terna systems.
- Dispatch reduction/increase signals for loads and/or production.
- Field devices diagnostic and performance analytics.
- TSO's dispatching order reception and optimal management strategies.

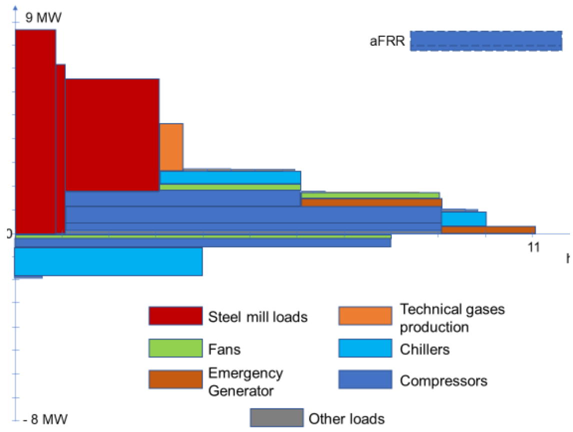

Fig. 3. Example of Resource aggregation strategy

- Data storage and reporting (remuneration, financial settlement, penalties, billing and invoicing)
- Analytics, fault prediction and consumption / production forecasting tools.

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

For the communication between the platform and field devices, requirements for communication protocols are softer, provided that the BSP is able to send the required measures to the TSO with the desired accuracy. For the communication with the TSO, Terna typically adopts as a standard communication system, protocol IEC-870-5-104. Nevertheless, in the project context, this protocol was developed only for Automatic Voltage Control service. Differently for congestion resolution, since it will be tested in coordination with Z-EMS algorithm, it has been decided with all the technical parties involved, that the communication system is going to be based on a Managed File Transfer (MFT) software provided by Terna. Lastly, aFRR service will be tested only locally from BSP platform to the industrial site involved, since this experimentation will be a technological characterization of the resources.

VI. SITE MANAGEMENT STRATEGIES

Depending on the TSO's request, each BSP has the capacity to choose which plants to select to satisfy it. A possible discriminant is represented by the maximization of the profit between the price proposed in an aggregate offer for the aggregate to Terna and the single costs agreed between the BSP and the plants. As regards the choice of the loads inside the plants, for congestion resolution service those that can be activated automatically would be preferable to those that must be performed manually. This strategy was developed to abstain from incurring in possible penalties envisaged by a future market in case of errors in the response to the command, one possible situation in case of executed manually loads.

A. *Congestion Resolution*

Congestion happens when the transmission capacity of a line is not able to transport the electrical power needed. To cope with these situations, generation and/or demand is adjusted by the TSO [9], thanks to the procurement of resources participating in the ancillary service market. As stated, in the project congestion resolution will be tested in coordination with the Z-EMS algorithm. Z-EMS solves an optimal power flow in all the South Italy 150 and 132 kV grid, aiming at detecting future congestions, with 3 hours ahead time horizon and solving/mitigate them using DSR and DTR. To do that, BSP will present day ahead a set of callable aggregated upward and downward offers to the Z-EMS. Bids will be formulated considering the forecast of the aggregated electrical state of the plants (electrical node) and their technical constraints thanks to the data acquired by the LCU transmitted to the BSP Gateway. The flexibilities offered will be contained in a file that each BSP will provide to Z-EMS before each test day and represent some of its input data. Offers pre-selected by the algorithm can be accepted by Terna. For those selected by Terna, regulation orders will be sent to their BSP Gateway. However, once the offer has been accepted, the actual resolution phase is passed in which the various parties implement what has been planned up to now. At the end of the process, the BSP will decide how to respect the aggregated command received, dividing it among the resources at its disposal, communicating via the LCU.

B. *Automatic Voltage Control*

The nodes voltages of the national power system are essentially determined by the reactive power transits on the lines. It is possible to regulate the voltage in the nodes of the network setting the production (or absorption) of reactive power [10]. The AVC is typically enforced at two levels:

- Primary regulation: the terminals voltage is regulated to a present voltage value Vrif (local regulation)
- Secondary regulation: the TSO send a reactive power Qrif set point to the BSP, that will then command the flexibility resources according to predefined regulation logics (centralized regulation).

During the experimentation phase, AVC will be tested locally and with the sending either V or Q setpoints directly from Terna control application to the BSP Gateway via IEC-870-5-104. In those tests are involved generators and rephase systems, both with control devices of the excitation system. The control system can receive a power factor cos φ reference from the outside, hence it works with two separate functions:

- The reactive power available will be calculated as a function of the active power supplied, considering the constraint that the power factor (cos φ) cannot be less than a minimum reference value which is related of the technical specifications of the items. The value of the reactive power available will then be sent constantly to Terna which decide the reactive fee to be requested from the plant.
- In the secondary regulation, the reference power factor value to which the plant must be brought would be sent to the regulator according to the Reactive Power set point sent by Terna.

C. *Automatic Frequency Restoration Reserve*

To maintain the system frequency at its nominal value, there are a designated set of control actions acted by the TSO, known as frequency control measures [9]. This part of the experimentation is focused in assessing the technical capabilities of some industrial loads to follow a rapidly (up to 4 seconds) changing power setpoint. Unfortunately, most of the loads identified in the flexibility analysis turned out to be unusable for experimentation purpose. This was mainly due because they are devoted to critical processes, and it has been deemed too costly and risky for the third parties to modify their control system. Therefore, the remaining testable resources are the chillers of Heating Ventilation and Air Conditioning (HVAC) systems. Power absorption of HVAC is basically a function of the difference between the environment temperature and a set point comfort temperature imposed. The goal of this experimental campaign will be to find a power-temperature correlation to create a real time power reserve band based on the boundary conditions and without creating a discomfort temperature on the sites.

VII. Conclusions

The first key takeaway coming from the project experience is that there is a very high potential of flexibility from industrial DSR with a quite cost-effective for the upgrade of the plants. Nevertheless, Energy audit proved also that almost all the industrial processes are naturally optimized to maximize the industrial production and minimize the economic losses. If no sufficient remuneration will be provided for the flexibility services, the useful modular electric power could be only a very small percentage of the total achievable power. Project test phase will provide to demonstrate the technical performances of each resource, their aggregation strategy, through the developed BSP platform, and the economic losses related to the variation of energy programs. The final aims of this experimentation will be to use the acquired know-how to evaluate the benefits for the grid and the economic revenues for the industrial plants in order to enabling new flexibility resources in the Ancillary Service Market.

VIII. Acknowledgments

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