LOLABAT

"LOng LAsting BATteries"

H2020-LC-BAT-8-2020: Next-generation batteries for stationary energy storage

Grant Agreement n°963576

D2.1: Requirements and specifications of NiZn batteries for stationary applications

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Abstract

Context and objectives of the deliverable

The deliverable D2.1 – Requirements and specifications of NiZn batteries for stationary applications – is one of LOLABAT's first deliverables and details the results of the assessment made over Rechargeable Nickel-Zinc Battery technology, the characterisation of the validation scenarios envisioned, and the end-use specification and general requirements to be considered, linked to the end-use applications defined within the project's scope.

D2.1 is the result of task 2.1, framed in the larger context of work package 2, focused on specification of requirements, norms and standards for the next generation of stationary batteries. From the different objectives targeted by work package 2, the specification of high-level technical and integration requirements for the next generation of stationary batteries is particularly relevant to the next phases of the project, mainly linked to the solution's technological improvement, characterisation, further development, conception and design.

Moreover, in D2.1, the end-use applications considered, the validation environments to set-up and the test scenarios proposed are described in detail. The supply, integration and testing procedures to implement that will serve to set-up the project's laboratorial demonstrations and performance assessments over the prototyped battery packs, in work package 6, will follow the general guidelines defined by D2.1.

Content of the deliverable

The report content is as follows:

- Introduction, where the projects technical scope is introduced, and the end-use applications considered are presented.
- Rechargeable Nickel-Zinc Batteries, a first review on technology's state-of-the-art.
- End-use applications characterisation, including the validations scenarios proposed and the laboratory set-ups considered for the following end-use applications:
    - Hybridisation of Hydro Power Plants
    - Smart Distribution Grid Management
    - Energy Balancing in Smart Buildings
    - Energy Storage for Remote Autonomous LV Supply Solutions – Industrial Application
    - Energy Storage Integration in Electro-Intensive Industry – Industrial Application
- High-level requirements, specifications and KPIs for RNZB, including the preliminary specification, the general and control-oriented requirements, and the performance indicators to be considered by each end-user when implementing the demonstration and performance assessment of the LOLABAT's prototypes.
- Summary of the report's conclusions

Attainment of the objectives and if applicable, explanation of deviations

All deliverable related and task related objectives were achieved, namely:

- The definition of the required set-ups to validate the technology within the relevant environments;
- The technical details, provided by LOLABAT's end-users, which will implement different use-cases addressing several stationary energy storage applications for NiZn batteries;
- The end-use specification for the battery pack prototypes to be developed;
- The main technical and integration requirements, that will feed the development phases envisioned within WP3 and WP4.
- Energy Storage Integration in Electro-Intensive Industry – Industrial Application.

Glossary

Abbreviation	Description
RES	Renewable Energy Source
EU	European Union
BESS	Battery Energy Storage System
DoD	Depth of Discharge
Li-ion	Lithium-ion
Zn	Zinc
ZnAir	Zinc-Air
NiZn	Nickel-Zinc
RNZB	Rechargeable Nickel-Zinc Battery
NiCd	Nickel-Cadmium
Cd	Cadmium
NiMH	Nickel Metal Hydride battery
EPES	Electrical Power and Energy System
PSP	Pumped Storage Plant
PV	Photovoltaic
TSO	Transmission System Operator
WP	Work Package
EOR	Extension of the Operating Range
PHIL	Power Hardware-in-the-Loop
EMS	Energy Management System
DER	Distributed Energy Resource
AI	Artificial Intelligence
ML	Machine Learning
DR	Demand Response
EV	Electric Vehicle
DSO	Distribution System Operator
AVR	Automatic Voltage Regulation
DG	Distributed Generation
SGO	Smart Grid Operator
BMS	Battery Management System
AC	Alternating Current
HIL	Hardware-in-the-Loop
CHP	Combined Heat and Power
IES	Innovative Energy System
HP	Heap Pump
mGT	micro Gas Turbine
TES	Thermal Energy Storage
DHN	District Heating Network
COP	Coefficient of Performance
SPM	Smart Polygeneration Microgrid

MPC	Model Predictive Control
LV	Low Voltage
MV	Medium Voltage
GHG	Greenhouse Gas
CAPEX	Capital Expenditures
OPEX	Operational Expenditures
IRR	Internal Rate of Return
NPV	Net Present Value
PBT	Payback Time
DC	Direct Current
KPI	Key Performance Indicator
BP	Battery Pack
IR	Industrial Relevant
POC	Point of Coupling
SoC	State of Charge
SoH	State of Health
TRL	Technical Readiness Level
p.u.	Per Unit

Deliverable content

1 Introduction

Electricity storage will play a crucial role in enabling the next phase of the energy transition. Along with boosting solar and wind power generation, it will allow the electrification of the economy in key segments of the energy market, namely in power intensive sectors. Moreover, in different end-use sectors, such as direct energy uses in industry, transport and residential and commercial buildings, the significant potential and the crucial importance of electricity storage to facilitate deep decarbonisation is evident. Storage based on rapidly improving batteries and other technologies will permit greater system flexibility – a key asset as the share of variable renewables increases. Total electricity storage capacity appears set to triple in energy terms by 2030, if countries proceed to double the share of renewables in the world's energy system [1].

LOLABAT is a research and innovation initiative that aims to develop a new promising battery chemistry – rechargeable Nickel-Zinc battery. The envisioned solution will have energy and power densities both the highest just after Lithium-ion battery, cost the lowest just after the Lead-acid battery, while profiting from abundant and available raw materials, non-toxic elements, high safety, low risk of thermal runaway, limited environmental impact and high recycling potential.

Some of LOLABAT's use case target relevant end-use applications at different system levels, also highlighted in reference [2], are such as:

- Generation level: arbitrage, capacity firming, curtailment reductions;
- Transmission level: frequency and voltage control, investment deferral, curtailment reduction, black starting;
- Distribution level: voltage control, capacity support, curtailment reduction;
- Customer level: peak shaving, time of use cost management, off-grid supply.

Electricity storage capacity can reduce constraints at network level and defer the need for major infrastructure investment. Behind-the-meter applications allow to manage electricity consumptions, reducing peak demand charges and increasing self-consumption. Along with high system flexibility, this calls for storage technologies with low energy costs and discharge rates, like pumped hydro systems, or new innovations to store electricity economically over longer periods, [1].

Research and development in the period to 2030 is therefore vital to ensure future solutions are available, have been demonstrated and are ready to scale up when needed. LOLABAT proposes a new version of the Nickel-Zinc battery for stationary energy storage applications, to be further developed via increasing its technology readiness level and preparing it for a future European industrialisation.

This document focuses the technology high-level requirements to address within the scope of LOLABAT, coming from the end-use applications considered, and the preliminary specifications of the battery pack prototypes to be developed and tested in the project.

2 Rechargeable Nickel-Zinc Batteries

Batteries are currently seen as important technological enablers for increasing the absorption of Renewable Energy Sources (RES) into the electric grid. However, improvement in their performance, cost competitiveness and sustainability should be achieved. For European Union (EU), a complete battery value chain and life cycle must be considered, from access to raw materials to innovative advanced materials, modelling, production, recycling, second life, life cycle and environmental assessments. Battery Energy Storage Systems (BESS) technologies are adapted to specific applications, with advantages and drawbacks; obviously, there is no single battery system optimal to all market segments. Lead-acid is a well proven battery technology since long time ago, and industrial lead-acid batteries are widely used for stationary and off-road traction applications (forklifts, airport trucks, etc.). However, Lead-acid battery suffers from lead's toxicity. Moreover, it has low gravimetric energy, poor performance at temperatures over 30°C and lower than -10°C and should not be kept discharged. An important drawback regarding the stationary energy storage applications is the poor cyclability and a limited practical Depth of Discharge (DoD) (less than 50%). The service life can be improved to 2000 cycles with additives such as carbon, but then the cost will increase significantly. Lithium-ion (Li-ion) technologies are presented as promising solutions for energy storage, thanks to their high cell energy density and cycle life. Li-ion technologies are successful in the field of portable electronic devices, because of their high energy density at cell level. However, they may not be a good choice for stationary energy storage applications. The industrial applications require batteries made of large capacity cells, in which the voltage and temperature should be individually and carefully controlled during charge and discharge. Risk of thermal runaway and consequent fire for large installations is high due an increasing ratio of core/surface. In case of fire and explosion, the flammable electrolyte, used in Li-ion technologies presents significant hazards. In addition, the growth of Li-ion production will not meet the demand for both stationary and e-mobility applications.

It is necessary to develop alternative technologies that are cost-competitive, highly performant for different grid applications as well as environmentally friendly and safe. Zinc (Zn), being a highly attractive anode material is used in several battery systems (zinc batteries) that have the potential to provide high attractiveness in terms of cost, safety, recycling (circular economy) and high specific energies. As a result of a revival of interest in zinc batteries, there are recent exploitations of Zn anode in rechargeable battery systems, with mainly 3 systems on the forefront: Zinc-Air (ZnAir), Zinc Manganese dioxide ($ZnMnO_2$) and Nickel-Zinc (NiZn). Among these three systems, NiZn in alkaline electrolyte with high conductivity is by far the most interesting technology. ZnAir is highly penalized by a low energy efficiency close to 50%, its low power and its sensitivity to CO2. ZnMnO2 shows a poor cycle life at high DoDs as a result of formation of inactive phases in MnO2 cathode. NiZn electrochemical system has been recognised since long time ago for its intrinsic qualities concerning its raw materials and safety; however, the short cycle life had prevented its major development and commercialisation until now. Sunergy has overcome this barrier, after 20 years of research and reworking of cell component formulas, composition and design. The new Rechargeable Nickel-Zinc Battery (RNZB) technology presented and developed in LOLABAT can be considered as a replacement for the well-known robust Nickel-Cadmium (NiCd) battery with extra advantages: no toxic material, more performant, more environmentally friendly, cleaner, safer and cheaper. NiCd as one of major BESS in the market, suffers from the ban on the highly toxic Cadmium (Cd). The results of LOLABAT project are likely to change the hierarchy among the main battery systems, namely lithium-ion, lead-acid, NiCd and Nickel Metal Hydride battery (NiMH), producing a remarkable impact in this area.

The new promising battery chemistry, RNZB is addressing properly the requirements of stationary energy storage solution with: high performance able to combine heavy use and deep cycling (2000 cycles at 1C rate and 100% DoD and 200000 cycles at 5% DoD), high energy efficiency (86-89%), high power (Pmax more than 1000 W/kg), high energy (50-90 Wh/kg, 80-200 Wh/l), low cost (due to cheap, abundant and highly recyclable raw materials, and due to no need for complex expensive auxiliary components such as sophisticated housing, cooling, and battery management systems because of low risk of thermal runaway; cell cost: 200-260 €/kWh), high stability and calendar life (can be kept discharged for several years and be used again) high sustainability (due to abundant and available raw materials with existing recycling methods from other industries), high safety (nontoxic raw materials, aqueous electrolyte, low risk of thermal runaway due to aqueous electrolyte and gas recombination solution), high recyclability (75% recycling efficiency existing for NiCd, a battery with the same cathode as NiZn). RNZB, having already a high performance, will be further improved during LOLABAT. The cycle life will be enhanced with an objective set at 4000 cycles at 100% DoD. The key concepts for achieving 4000 cycles are validated at Sunergy, based on the recent research work and results. The safety of battery cells has been already tested and more extensive tests will be performed. The initial costs estimated for the RNZB are already low and will be decreased further. They will be estimated for the whole system and will be optimised. RNZB battery offers a very good compromise in terms of performance, comparable to industrial lithium-ion batteries, cost (between lead-acid and nickel-cadmium), safety and environmental impacts. The objective set for LOLABAT is to assure a highly favourable performance and lifecycle, putting the whole energy storage cost on the path to fall below 0,05 €/kWh/cycle by 2030, as required by the work programme.

The specific applications for which the RNZB will be tested in LOLABAT are highlighted below, covering utility grid and industrial applications. The RNZB can be used at generation side as an example for hybridisation of a production system to provide more flexibility of operation and supply. Moreover, the RNZB is expected to be well suited to distribution grids challenges for a smooth and efficient integration of the RES, and to support new electrification uses like E-mobility integration, smart-grids operations like voltage and frequency response and congestion management in, e.g., micro-grids and weak distribution grids. Finally, RNZB has very good perspectives for being used beyond the meter in industrial applications.

General references: [3, 4, 5, 6, 7, 8, and 9]

3 End-use applications

This section introduces LOLABAT's end-use applications. The proposed application contexts, which within the scope of the project will define the set-ups to test RNZB for stationary energy storage application and assess its performance in different operational scenarios, will be framed by different end-users' laboratorial environments, so the viability and effectiveness of the innovative concepts added to RNZB technologies can be validated when applied to generation support services and bulk storage services, e.g., power plants' hybridisation, in services to support the Electrical Power and Energy System's (EPES) distribution infrastructure, e.g., smart distribution grids' management, and to customer energy management services, e.g., energy management in smart buildings, remote autonomous LV supply solutions and industrial application in electro-intensive industries.

3.1 Hybridisation of Hydro Power Plants

Electricity is vital to our modern life. However, the increasing concerns on sustainable development and the need to go towards a more carbon free energy mix have pushed many countries to revise their energy policies. As a result, a significant increase in RES, at an astonishing speed, is expected in the next decades. Because RES are highly intermittent, located far from the centre of consumption and require a power electronics interface for being connected to the grid, they will disrupt the traditional way to operate the power system. Therefore, the stability of the electrical grid and its existing dynamic will be inevitably impacted. To cope with these new issues, the need to strengthen the existing power system is more pronounced than ever. Therefore, flexible and controllable assets must be provided to grid operators to maintain system security and stability.

Pumped Storage Plants (PSPs) have more than a hundred years of maturity and are recognized as one of the most reliable assets for bulk storage application. By releasing water through a turbine or pumping water to an upper reservoir, electricity can be easily generated or stored. Usually, a classic PSP operate in daily cycle by decreasing the upper reservoir level during the day, when the load is high, and refilling at night when the energy price is low. However, this classical scheme is no longer valid with the high penetration of RES. For example, peaks of consumption happen at night, while peaks of production from RES such as Photovoltaics (PV) occur during the morning, in this sense it's difficult to guarantee the match between generation and demand. Therefore, production assets must adapt to the changes in the energy mix, and support particularly RES insertion. From a Transmission System Operator (TSO) standpoint, the PSP is seen as a unique asset for flexibility. In fact, they can provide/store large quantities of energy, with high power capabilities, and a high round trip efficiency. Therefore, over the last decade, research to enhance hydroelectric technologies have been very prolific. Most of the attention is generally focused on the following main topics:

- The provision of ancillary services.
- Maintenance schedule optimisation.
- Increase system performances by improving the operation range or the efficiency of the plant.

A key axis of the task 2.1 is to identify the potential end-use applications of the RNZB technology that will be further demonstrated in the Work Package (WP) 6. Regarding the areas of research mentioned above, the activity intended to be studied and demonstrated by SuperGrid Institute, within the task 6.2, is the "Extension of the Operating Range" (EOR) of a PSP to increase its availability and power range.

In fact, a typical conventional pump storage hydraulic power generally has an effective operating range in generator mode comprised between 50% and 100% of its nominal power, while pumping mode does not provide any adjustment ability. Those limitations in the operation of the hydraulic power plant in turbine mode is due to mechanical phenomena such as cavitation, discharge instability, and other unsteady phenomena that have damaging effect on the machine. Therefore, operation in these areas is restricted in time and forbidden for steady operation. However, it can be possible to go through these areas in transient conditions, but it is not recommended. The goal of the studied technology is to fill these dead bands (totally or partially), to significantly improve the operating range of the PSP. Harsh operation zones are still avoided, but a broader range of operation is achievable. This allows a better utilisation of the plant whether one or multiple turbines are considered. In return, the PSP operator can offer a greater power control range to the TSOs, and the economic attractiveness of the plant is increased.

In the next section, it is explained extensively how the upgrade of existing hydraulic power plant through the installation of the innovative RNZB's stationary storage technology can improve its flexibility and electric production.

3.1.1 Validation scenario: Extending Operating Range of a PSP

In this project, SuperGrid Institute will demonstrate the feasibility to extend the operating range of a PSP thanks to the help of RNZB batteries. It aims at evaluating the opportunities to extend services offered by an existing hydropower plant, designed to operate at fixed speed, upgraded with an energy storage system. This application is called EOR. It enables to improve the operating range of a PSP in both turbine and pump mode, even if units are usually restricted in turbine mode and must pump at rated power only. In the next paragraph, two distinctive scenarios, where the EOR principle can be adapted, are depicted:

- The EOR of a single hydraulic turbine.
- The EOR of a PSP with several hydraulic turbines.

Figure 1 presents the dynamic strain of a hydraulic runner as a function of the output power (i.e. in a PSP the power output reflects the flow rate). As observed, it exhibits a non-convex shape which for sustainability reasons, induces a dead band in the acceptable continuous operation region (i.e. below the continuous operation threshold) [10, 11]. Therefore, the custom continuous operation range of a conventional hydraulic runner is generally set to the upper part of the acceptable continuous operation range which can approximately cover [50%, 100%] of its maximal power or less. The goal of the EOR method is to fill in this dead band and increase the operating range of the PSP. Thus, it leads to a higher flexibility of a PSP.

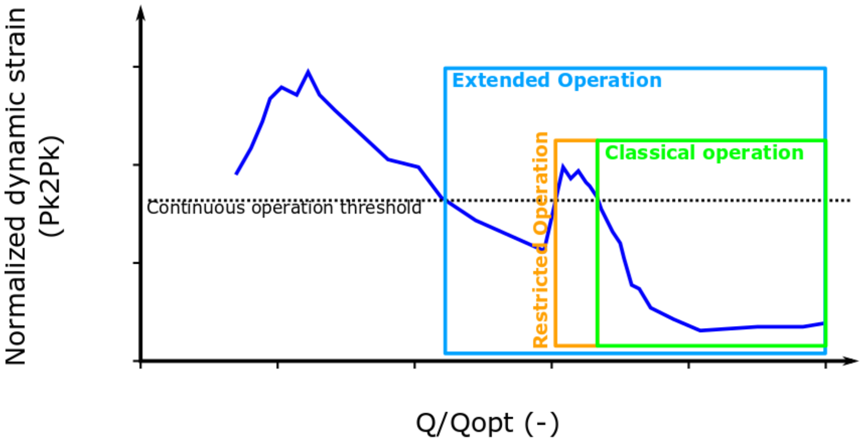

Figure 1: Dynamic strain limit the range of operation of a single hydraulic turbine.

Note that this concept can be further applied to the PSP with multiple powerhouses. This also means new innovative ways to optimise the operation of the plant can be demonstrated. Thus, the second scenario for demonstrating the EOR concept with the help of RNZB batteries would be to fill in the dead bands in the range of operation of a multi-group hydraulic power station.

Figure 2 illustrates the possible dead bands that can appear in the operation of PSP with 4 independent units. First, in Figure 2(a), the classical operation ranges of the plant is presented according to the state of the four units. Then, Figure 2(b) shows the possibility (in blue) to apply the EOR concept to propose new operating ranges. Before, note that in the operating ranges highlighted in green, no EOR concept is applied. It corresponds to a combination of units either in pump or turbine mode with generally a hydraulic short circuit configuration. This latter intends to facilitate the simultaneous operation of several units, and thus participates also to increase the operating range. This configuration is considered for the continuation of the study. As it can be observed in Figure 2, three kinds of opportunities can be denoted for EOR application:

- **EOR in turbine mode:** It consists in covering dead bands in turbine mode, when it is required to switch between N and N+1 active groups.

- **Full EOR:** It consists in covering all the full height of the dead band in pumping operation. Note that it would require a high-power capacity.
- **Partial EOR:** It covers partially pumping operations, and potentially allow a better technical and economic trade off since lower energy and power capacity are required.

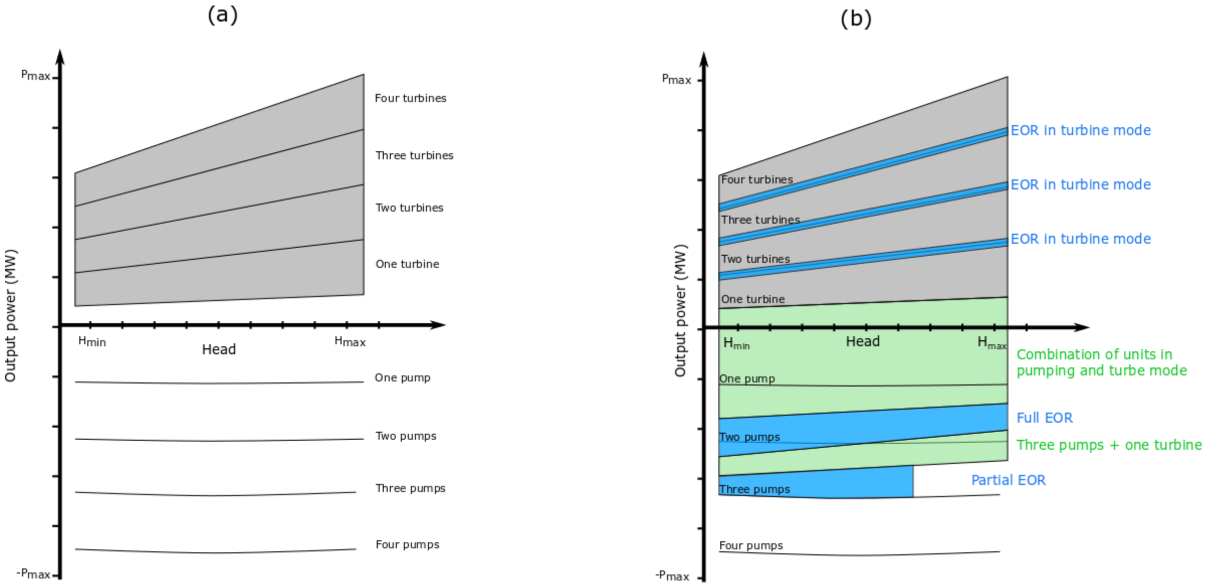

Figure 2: Range of operation of a multiple group pump storage plant with: (a) A conventional plant (b) The opportunities for the EOR concept with RNZB batteries to upgrade a conventional plant. Note that the head refers to the net pressure applied to the plant with respect to the filling of the upstream and downstream reservoirs.

Finally, Figure 3 describes the working principle of the EOR concept with RNZB stationary storage technology. It consists in dynamically switching the power output of the hydraulic turbine(s) (in blue) between two set points around a dead band (in red). This band corresponds to a harsh operation zone, which must be avoided. However, the goal is to be able to propose this operating point from TSO point of view. Therefore, the electrical production (in green) is smoothed out with batteries (in orange) to fulfil a given set point (black dashed line) inside the dead band.

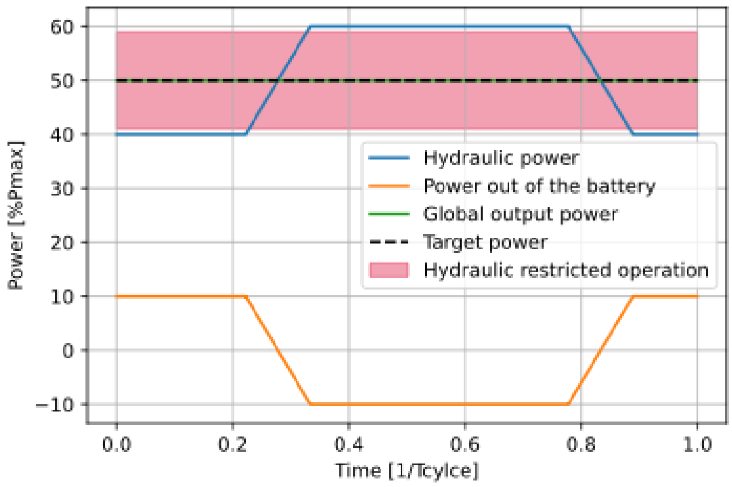

Figure 3: Working principle operation of the EOR concept applied to a single hydraulic turbine.

3.1.2 Laboratory set-up: SuperGrid Institute Power Hardware-in-the-Loop (PHIL) platform

Figure 4 shows the architecture of the platform for the demonstration of the SuperGrid Institute's technology.
A reduced scale model of the plant will be embedded in the demonstration, namely the pump turbine itself. This will remove the need for a plant numerical model as it will be a physical plant.
The control unit will have to embed the Energy Management System (EMS) & the control of the pump turbine together. And a physical emulator will be added on the hydraulic part to emulate the filling of the reservoirs feeding the pump turbine together with the behaviour of the hydraulic circuit (water hammer effects and such).
It is to be noted that the platform already exists in this configuration without the battery.

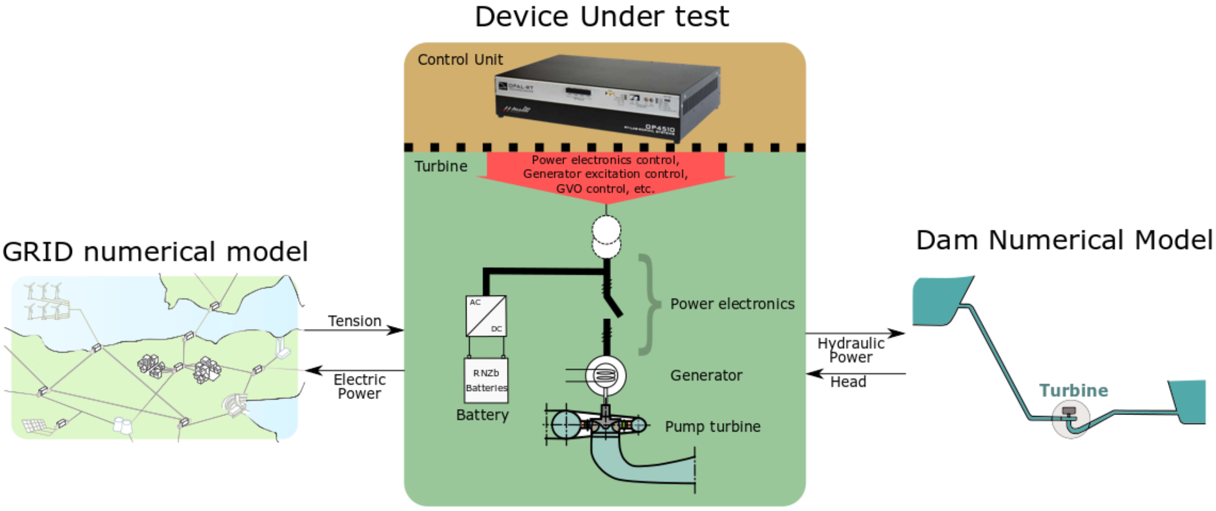

Figure 4: SupeGgrid institute PHIL platform architecture for the demonstration of the extension of the operating range of a PSP.

Figure 5: SuperGrid Institute's HydroPHIL pictures: Real Time, PHysics In the Loop, Hydraulic platform. Upper right is the main actuator of the PSP: namely the Guide vane ring. Lower right is the inside of the turbine, Runner, and Guide vanes.

3.2 Smart Distribution Grid Management

The incessant need of containing the global warming has forced countries to head the path towards the decarbonisation of their energy systems through the integration of green energy (e.g. solar, wind, etc) in lieu of high pollutant energy sources such as fossil fuels. Nevertheless, the decarbonisation process does not regard only the production of energy but also its transmission, distribution and use. Traditional electricity systems are demand-driven with almost no storage capabilities (only provided by hydro-power plants) and are based on a centralised approach: all the energy demanded by the customers is produced into big-sized energy power plants (e.g. nuclear and/or coal-fired power plants, etc) and through transmission and distribution lines is supplied into the customer premises. Renewables, if on one hand are the most promising mean for decarbonising the energy sector, on the other hand raise technical challenges that must be addressed to guarantee a secure, robust and reliable green electricity system. These challenges are mainly related to the intermittency and volatility of the RES technologies power output that might undermine the stability of the electric system. Moreover, the energy system of the future is also shaping the end-users' role, which are expected to become a more active part of the ecosystem, moving from being passive consumer to becoming more active prosumers and flexible consumers: entities that at the same time produce and consume energy, with a certain degree of flexibility, thus participating in energy trading in both directions, i.e., offering and selling electricity to the market when self-production exceeds self-consumption, or buying electricity when the self-production is not enough to fulfil their own demand.

On the core of the energy transition underway, which implies the abovementioned system's decarbonisation but also its digitalisation and decentralisation, is the technical infrastructure supporting a vast EPES and integrating a large amount of assets, the so-called smart grid. A smart grid is a complex system that embraces: green and conventional energy power plants, transmission and distribution networks, storage systems, smart meters and Internet of Things technologies (that allow to monitor the behaviour and operation of the system at the scope of detecting react and pro-act to changes in usage and multiple issues, called self-healing capability), prosumers/flexible consumers and other Distributed Energy Resources (DER), such as electric vehicles.

As previously stated, and since not all that glitters are gold, even the decarbonisation process (that as for today is mainly aiming at greening the energy and mobility sector) has its own bottlenecks: several technical challenges must be addressed to ensure the quality of supply and the reliability of the system. Main concerns are linked to the intermittency of the RES which basically can be coped in two ways: i) by making use of Artificial Intelligence (AI) and Machine Learning (ML) algorithms to predict with high precision and granularity both demand and generation at the scope of minimising their mismatch; ii) by rendering the system as flexible as possible by means of storage systems and flexible services (such as Demand Response (DR), Power-to-x, etc). For what concerns e-mobility, it is well recognised that a heavy integration of Electric Vehicle (EV) would hugely impact on the electricity grid which would need to be upgraded to deal and allow the integration of a such high load. However, once these technical barriers are overcome EVs can also act as a storage system and thus increase the flexibility of the system, to mitigate the challenges associated with RES and to provide the grid with ancillary services, such as voltage regulation, frequency regulation, spinning reserve, etc.

Smart grids play an important role in building up a low-carbon future by allowing for renewable energy hosting, improving energy accessibility, bringing resilience to the main grid (thanks to their "self-healing" capability) and optimizing energy costs.

The benefits of a smart grid include improved efficiency and reliability of the electricity supply, integration of more renewable energy into existing network, supporting the development of electric vehicles at scale, new solutions for customers to optimize their electricity consumption and reduction of carbon emissions.

In the following sections the envisioned services for the LOLABAT technology, aiming at coping some of the issues that smart-grids operator face, are explained.

3.2.1 Validation scenario: E-mobility integration using BESS for load levelling at the charging stations connection points

The increase of EVs and consequently of the number of support infrastructures they require, namely charging points, led to some drawbacks on e-mobility urban integration, mostly related to grid congestion issues. The sudden increase on electricity demand in certain urban and suburban areas where EVs use is spreading quickly can negatively impact the electricity supply quality due to frequency and voltage instabilities caused by high currents requested when charging infrastructures' electricity demand reaches daily peaks. With the evolution of EVs batteries and charging technologies, targeting quicker charging times, the problem becomes more serious and the power demand from this consumption segment cannot be neglected anymore.

High power demand can contribute to increase power losses and voltage drops across the supplying distribution network, and system operators are starting to look for alternative ways to strengthen their networks and make them flexible enough to deal with these technical challenges, without burdening their network's reinforcement capital and operation expenditures. Distributed BESS present themselves as a key asset and a plausible solution to assist system operators dealing with this stress over their networks. By integrating BESS in the distribution grid areas where EV charging infrastructures are constraining grid's technical operation, it will be possible to mitigate some of these negative effects. BESS will be able to provide grid services such as peak load shaving and load levelling, which results in load variance minimisation and ultimately a cost reduction from the customer perspective.

Considering the abovementioned context, LOLABAT's tech capacity to provide balancing services at the EV chargers connection point will be assessed. For the envisioned validation is expected that the BESS can act as a sort of power buffer, smooth the load curve of the charging infrastructure and manage the power demanded from the grid to mitigate the negative impacts both in terms of power fluctuation and peak demand. The two features of the BESS to be monitored are: the fast response (meaning the ramp rate) and the energy capacity. An example of the foreseen contribution from the BESS is depicted in Figure 6.

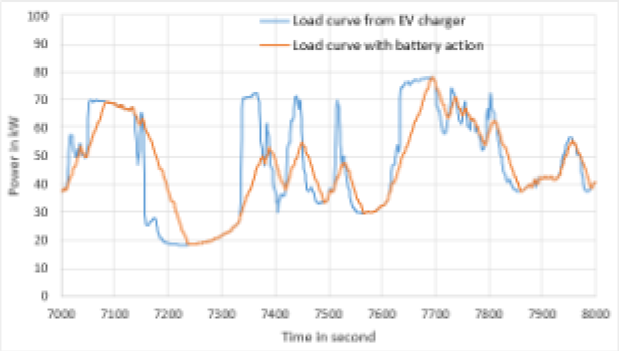

Figure 6: EV charging point load curve evolution due to battery action.

The BESS connected to the same network of the EV charger, based on a proper control scheme, should be able to limit the maximum ramp rate at the common coupling point –10%, as indicated from the Distribution System Operator (DSO) for weak grids, is a typical and acceptable value of the rated power/minute for this kind of application. Maximum peak consumption management.

The BESS, when supporting grid supplying to the charging infrastructure, will ensure that grid's maximum power capacity is not reached. This means that when the plugged EVs cluster is requesting more power than the maximum grid capacity, this surplus – difference between the demand and the rated power of that part of the network – is provided by the BESS. This requirement is more an economical target, since whenever the customer exceeds the contractual maximum power, a fee must be paid, but also a technical one, since the use of the battery might avoid grid upgrades.

Figure 7 is a graphic representation of the targeted application scenario described and should be used as reference for the scenario lab testing set-up to prepare.

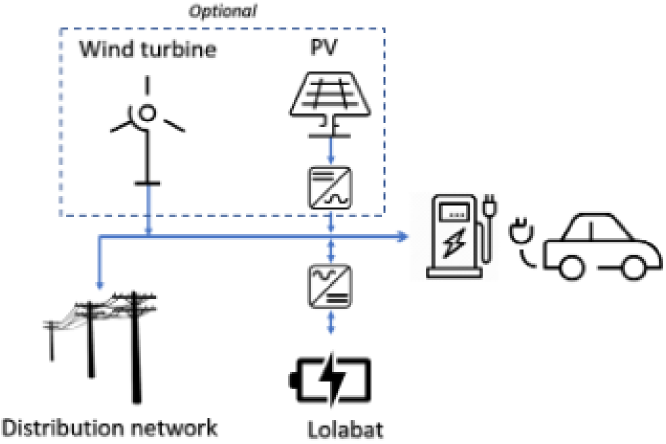

Figure 7: Conceptual scheme of the EV charging application.

3.2.2 Validation scenario: Voltage response using BESS in smart distribution networks with high DG penetration

Voltage regulation is a grid service aiming at keeping the voltage level in each node of the grid within the desirable limits. The regulation is made up of three services: primary, secondary and tertiary regulation. Within this scenario only the first two will be assessed. In both cases, the regulation is made by injecting either inductive or capacitive reactive power – Q – into the grid. The two services differ mainly for the timeframe implied: primary regulation takes over fast and short-lasting variations, while the secondary one copes with the medium-lasting voltage variations.
The *primary regulation*, also called Automatic Voltage Regulation (AVR), is a mandatory service that all the grid-connected generation units must provide. An example of possible control strategy to be implemented for the provisioning of the AVR performed by the BESS is depicted in Figure 8. The set of BESS and inverter is equipped with a controller, the AVR, that retrieves the voltage deviation from the nominal level defining the set point for the reactive power either inductive or capacitive to be injected or absorbed.
The *secondary regulation*, also known as reactive power compensation, is activated by the network operator– DSO – which send a reference for the reactive power to be injected into or absorbed from the grid. Usually this set point is computed by monitoring the voltage level in a sensitive node of the grid (called "pilot node").

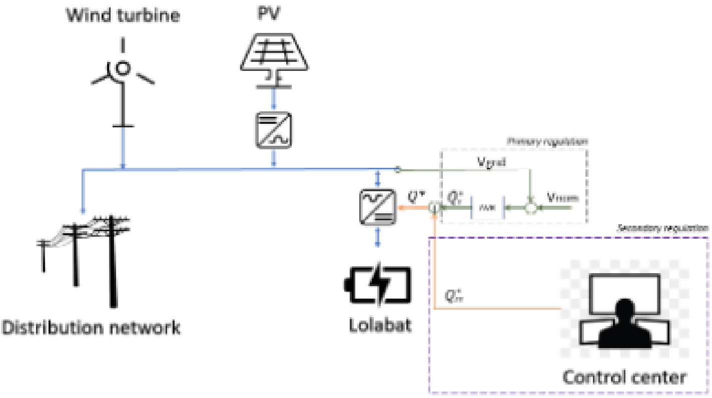

Figure 8: AVR performed by the LOLABAT technology.

It is worth to mention that the amount of Q that can be supplied by the BESS depends on its operating conditions, namely active power injected/absorbed and the minimum allowable power factor, and thus a capability curve must be defined for the BESS. Figure 9 shows a typical BESS capability curve which defines, for a given operating condition, mainly the current active power at the output of the BESS, the maximum reactive power that the BESS can make available for the provisioning of the secondary regulation.

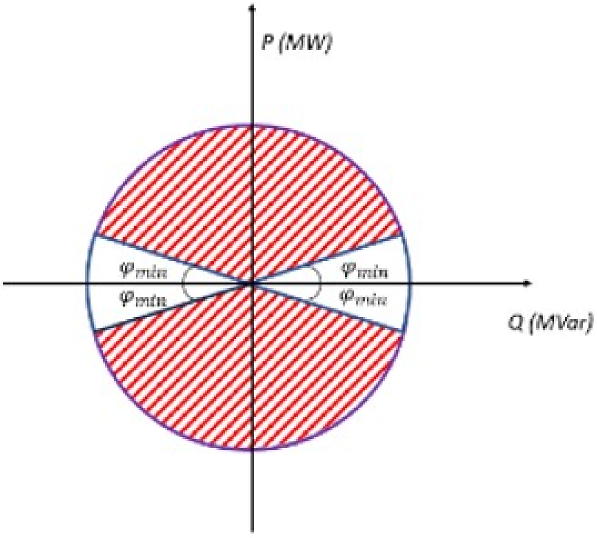

Figure 9: Capability curve of the BESS.

The restriction is imposed by a thermal limit which is set by the rated power – the circle with radius equal to the rated power – and the minimum power factor of the group BESS-inverter – the area in white. If there are no restrictions about the minimum power factor the capability curve of the BESS coincides with the full circle.

3.2.3 Validation scenario: Congestion management using BESS in smart distribution networks with high DG penetration

Congestion events are attributable to grid constraints and occur due to the impossibility of the transmission line to deliver electricity without exceeding thermal limits designed to ensure reliability. These limits are reached in periods of generation or load peaks. In the first case, the most common mechanism adopted to limit this event, is the energy curtailment which entails the reduction or restriction of a generation unit's output. In the second case flexibility services which intervene on the demand side, such as demand response or in extreme cases load shedding, allow to cope congestion events.

DSOs face a significant increase of congestion events in specific zones characterised by a high penetration of Distributed Generation (DG). Currently, networks' reconfiguration and generation curtailment are applicable to manage congestions and ensure system's stability. However, these might not be the most economically viable mechanisms to reduce the networks' overloads. In fact, by installing distributed BESS, DSOs can cope with congestion problems caused by decentralised renewable generation in a more profitable way. In one hand, BESS might be charged during periods of peak generation whenever this exceeds both demand and system constraints, allowing to reduce the number of curtailments an RES plant will be subjected to. On the other hand, BESS might provide the surplus power to the customer when the grid is overloaded and cannot deliver. It is worth to mention that both scenarios are only feasible whenever the BESS is within a certain proximity to the DG unit and/or loads, i.e., same node or branch.

DSO and Smart Grid Operator (SGO) might take advantage of battery energy storage assets to limit the number of congestion events while at the same time they fulfil demand requests without curtailing RES. To do that, the DSO must set the reference power – either injected or absorbed – by the BESS and use the battery flexibility to solve grid congestion constraints and ensure the balance between generation and consumption.

Figure 10 shows a conceptual scheme of the congestion management process using a BESS. By forecasting local generation and demand, and knowing the topology of the grid, the DSO, by means of load-flow analysis together with an optimal BESS scheduling whose objective is to avoid/limit congestion events, will be able to define the best charge/discharge schedule for the BESS.

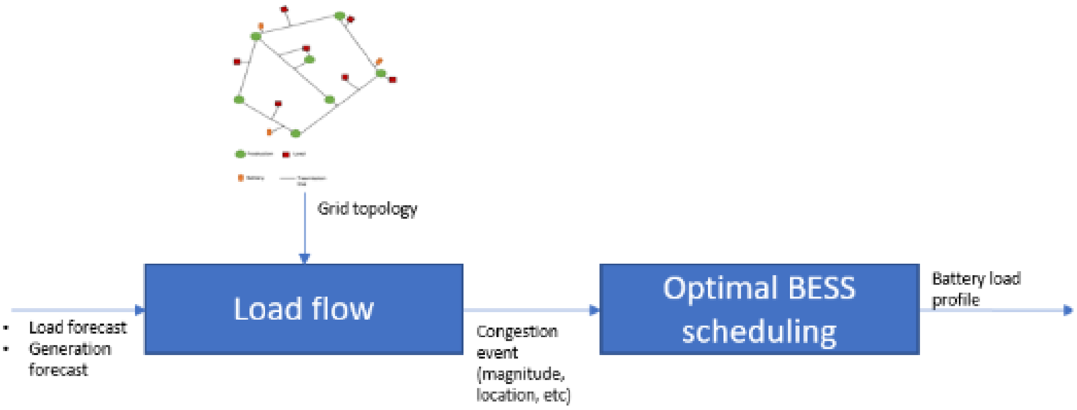

Figure 10: Conceptual scheme for the congestion management mechanism.

3.2.4 Laboratory set-up: EDP Labelec Smart Grid Lab

In this section, the test rig which will be implemented and used by EDP to validate the LOLABAT prototype under the different scenarios described in sections 3.2.1 and 3.2.2, is presented.

The demonstration campaign for the use case related to EV chargers' integration will be articulated over two phases hereafter referred as pre-validation and validation phase. In the pre-validation phase, the capability of the prototype to sustain the main grid while supplying a real EV charger will be tested, in terms of peak reduction and load levelling. The operating condition of the validation scenario instead, will entail the integration of several EV chargers to evaluate the prototype's performances in a scaled-up system. The deep integration of several EV chargers will be emulated via a grid-simulator device acting as programmable load.

Figure 11 shows the lab set-up envisioned to rehearse the LOLABAT in the pre-validation phase, which foresees:

- The LOLABAT prototype equipped with its own Battery Management System (BMS).
- The inverter to connect the BESS prototype to the main grid and the EV charger.
- An EV-charger.
- The main grid, which pooled with the BESS will supply the EV charger.
- A local controller, which by measuring the EV charger request can define the set-point for the charging/discharging power of the LOLABAT battery that would allow to keep the ramp rate and the peak power at the grid connection point always between its limits.

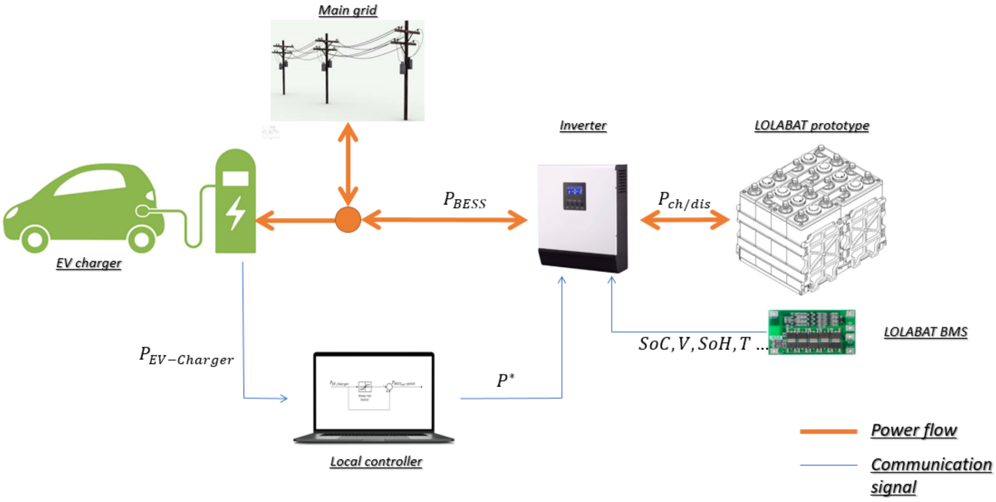

Figure 11: Test rig for the pre-validation phase of scenario 1: EV chargers' integration.

Figure 12 shows, the lab set-up planned to demonstrate the capability of the LOLABAT in the validation scenario. The test bench is made up of:

- The LOLABAT battery equipped with its own BMS.
- The required power electronic interface equipment, i.e., the inverter which interfaces the BESS prototype with the emulated EV charger.
- A controllable Alternating Current (AC) load, which plays the role of the EV charger. Different demand profiles will be emulated to rehearse the prototype under several operating conditions. The different profiles can be programmed either through the dashboard of the device or via an external device (a laptop or an external waveform generator both to be connected to the simulator).
- A local controller, which by measuring the EV charger request can define the set-point for the charging/discharging power of the LOLABAT battery that would allow to keep the ramp rate at the grid connection point always between its limits.

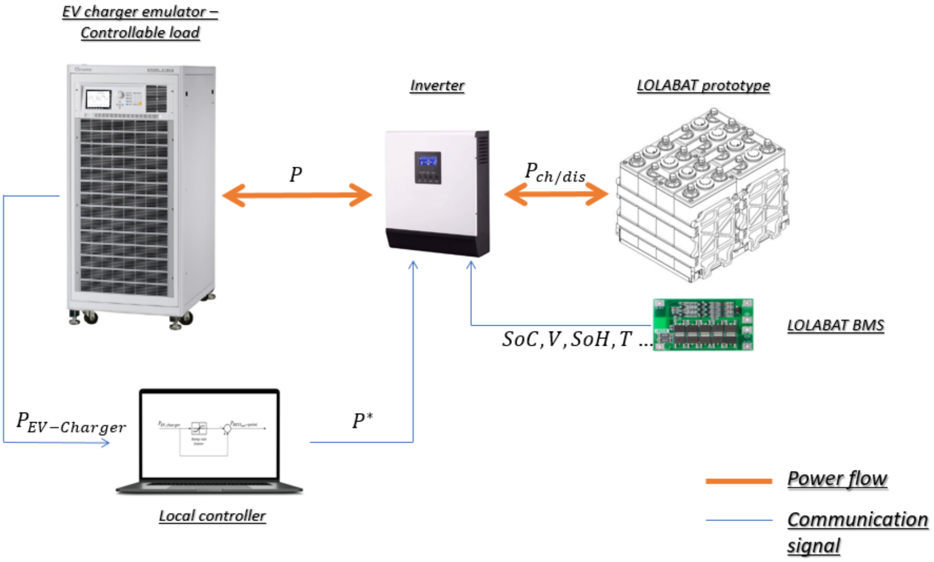

Figure 12: Test rig for the validation phase of scenario 1: EV chargers' integration.

A similar set-up will be adopted for the validation of the second scenario: voltage response (Figure 13). In this case, through a Hardware-in-the-Loop (HIL) simulation, the test rig will simulate the behaviour of a grid where voltage fluctuations are taking place in different nodes of the network. The controllable load, in this case, would reproduce the pilot-node where the inductive or capacitive reactive power is injected/absorbed by the LOLABAT prototype to sustain the voltage and keep it within the limits, it would hence act as an inductive or capacitive load depending on the operating condition. The local controller on one hand will measure the actual reactive power provided by the prototype and by carrying out a load flow analysis for a grid configuration will be able to predict the voltage profiles in the grid-nodes, while on the other hand it will define the new set point for the reactive power needed from the BESS.

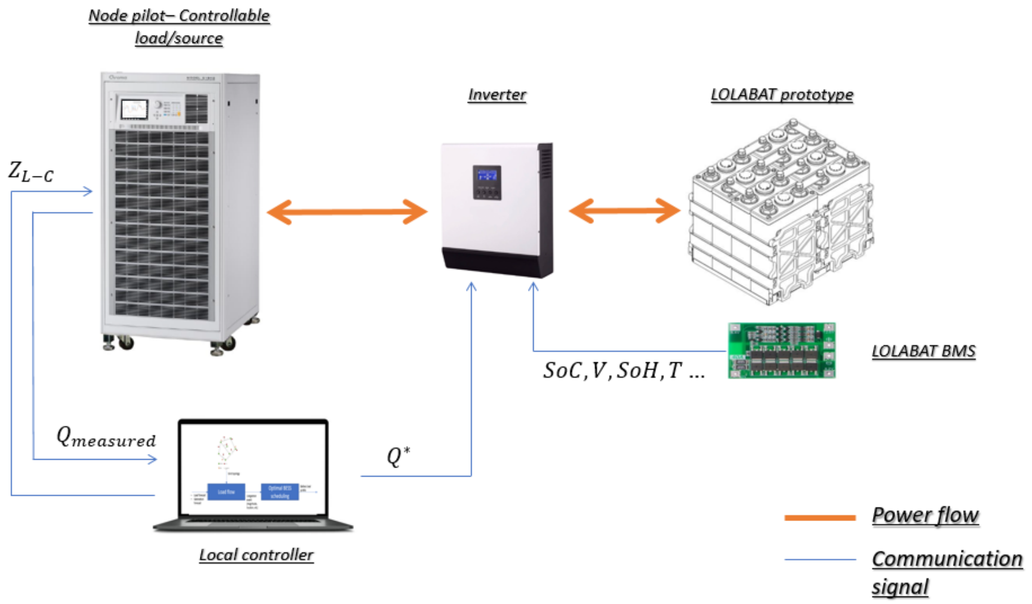

Figure 13: Test rig for the validation of scenario 2: Voltage response.

Finally, the same set-up used to validate the previous scenarios and in particular scenario 1, will be used to perform the management of congestion events representative of the third application (Figure 14). In this case, the controllable source will emulate the behaviour of a PV system (or any other power plant), where peaks in the generation are foreseen. When these peaks exceed the maximum allowable power (set by the distribution feeder) the LOLABAT prototype will intervene to store the exceeding power ensuring the compliance with the grid constraints.

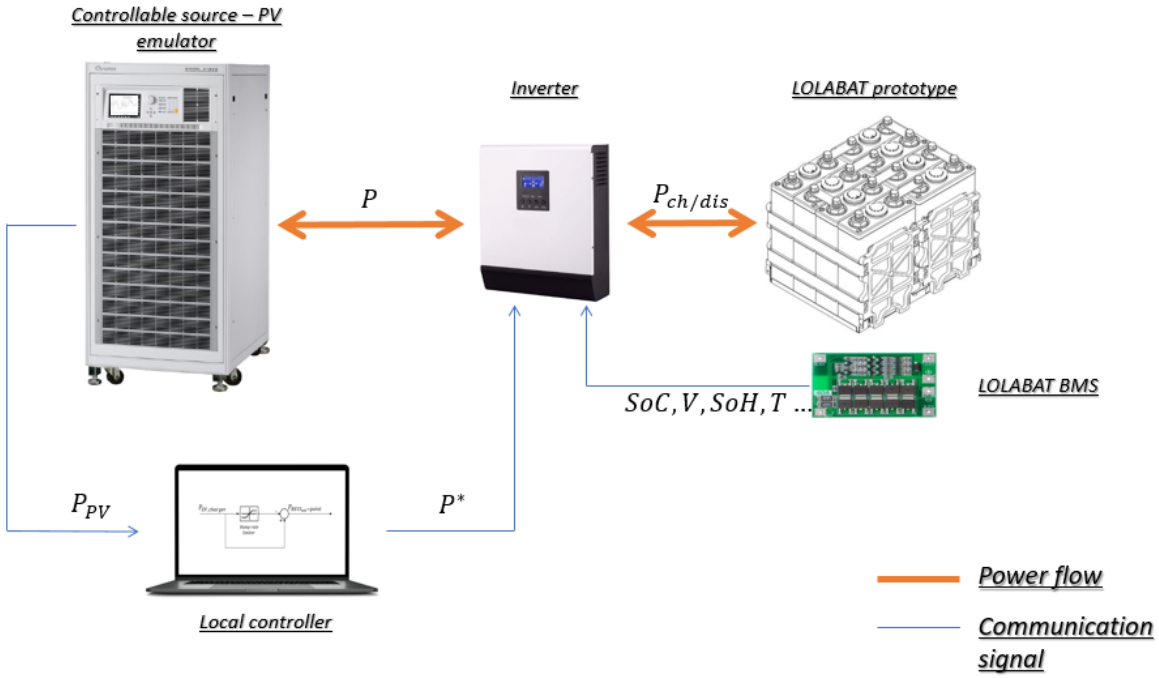

Figure 14: Test rig for the validation of scenario 3: Congestion management.

3.3 Energy Balancing in Smart Buildings

The concern on climate change and on the growing power demand are leading to an increasing penetration of RES in the energy mix. However, RES are unpredictable sources of electricity, as dependent on natural sources, such as wind or sun. BESS can increase the flexibility of renewables power plants by storing energy during peaks of energy production and release it later to satisfy peaks of demand. In addition, BESS can improve the quality and reliability of the energy provided to the grid. In the current energy scenario, DER installed within microgrids are also gaining interest due to their potential to reduce transmission and distribution losses and to increase energy efficiency. This is because the energy production is close to the end user and it involves efficient energy conversion systems such as Combined Heat and Power (CHP) and RES coupled with BESS. Currently, residential and tertiary buildings are responsible for around 40% of the EU energy consumption [12]. At the same time, one of the goals that Europe set by 2050 is to reach buildings energy neutrality. Therefore, additional effort should focus on the integration of efficient and sustainable energy systems together with smart management systems in the residential sector.

The application studied by UniGenova focuses on the daily balancing of energy within tertiary buildings, where the aim is to provide electrical and thermal energy to a user, ensuring high efficiencies and low environmental impact. The demo site is in the Innovative Energy Systems (IES) Laboratory of the Savona's Campus of University of Genova. The IES site includes different energy systems such as facade solar panels, a Heat Pump (HP), a micro Gas Turbine (mGT) and Thermal Energy Storage (TES) systems. Regarding the thermal energy management, the system shows good flexibility due to the presence of TES systems which are used to collect the thermal energy produced by the HP and mGT and release it at a more convenient time for heating purposes. With respect to the electric energy management, now the electricity demand can only be satisfied by the mGT or by the grid. The addition of an electric storage system could be beneficial for the overall system since it would improve the local self-consumption, reduce the amount of energy to be exchanged with the grid and increase energy savings [13]. A 10 kWh battery pack will be installed in the IES plant to evaluate the benefits of this technology when operating in synergy with the other components of the plant. The performance of the battery will be evaluated in two different scenarios: IES plant operating in parallel with the grid and IES operating in island mode.

The IES plant, shown in Figure 15, includes the following components:

- A micro gas turbine (a CHP unit), which provides in nominal conditions 100 kWel and 160 kWth.
- A heat pump, which requires 10 kWel and can provide 46 kWth (when the low heat source is at temperature of 35/40°C).
- 34 façade solar panels.
- Two water thermal energy storage systems, both of 5 m^3 of capacity, one for the storage of the heat produced by mGT and HP, and the other one for the storage of the heat produced by the solar panels.

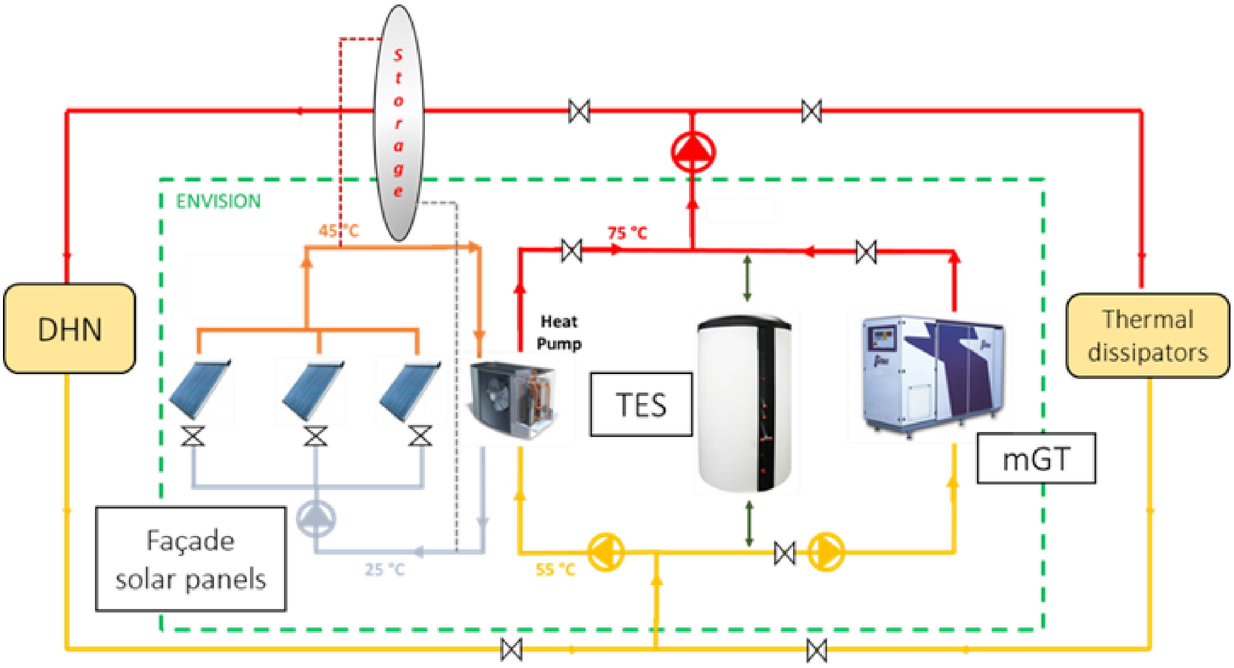

Figure 15: Original IES demo site layout.

The working principle of the plant is the following. The mGT can be used to supply electrical energy to the HP and to satisfy the electrical demand. Both the mGT and HP can be used to provide heat at a temperature of around 75/80°C to a District Heating Network (DHN), which distributes hot water to the users. The TES in between the mGT and HP is used to provide more flexibility in the management of electrical and thermal demand. The facade solar panels are used to exploit the building surfaces to provide heat to the HP to improve its Coefficient of Performance (COP) and consequently increase the heat produced. The intermediate TES is used to stabilise the temperature of the heat provided to the HP evaporator.
For completeness, the mGT and HP electrical data are provided in Table 1.

Table 1: mGT and HP electric data.

Micro gas turbine electrical data	
Frequency output	50 Hz
Max apparent power	120 kVA
Rated current	173 A
Nominal voltage output	400/230 V AC, 3 phases
Start-up voltage	400 V AC, 50 Hz
Start-up power	max 15 kW

Heat pump electrical data	
Total power input	10 kW
Nominal current	16 A
Power supply	400 / 3+N / 50
Current for the heat pump start up	118 A
Maximum current absorbed by the heat pump	21 A

For testing purposes, it is also possible to emulate different thermal loads connecting the system to controlled thermal dissipators, avoiding the connection with the actual DHN.
The IES plant presented above will be tested in two different scenarios: grid connected mode and island mode.

3.3.1 Validation scenario: On-Grid application

In the first scenario, the IES plant will be connected to the local Smart Polygeneration Microgrid (SPM) of the Savona's Campus. The SPM includes several commercial CHP units, traditional prime movers and renewable generators. The EMS manages the import of electrical energy, thermal energy or fuel to the system, or the export to the external network or to another system (see Figure 16). A Model Predictive Control (MPC) system, already developed by UniGenova, will be integrated with the battery managing system. Battery loads will be optimised with day ahead schedule following the needs of the campus and in accordance with solar panel production forecasts.

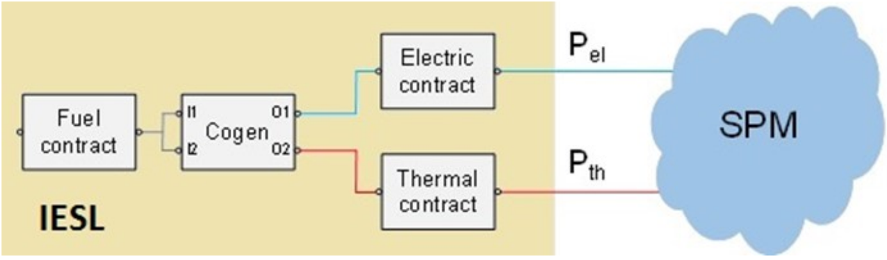

Figure 16: Electric and thermal import contract units.

The installation of BESS into a micro-grid would allow to:

- Reduce import and export with the main grid by maximising the local production, especially from renewable sources.
- Improve power quality.
- Increase the profits of the plant.

The services that the battery pack can provide in this configuration are the following:

- Peak shaving and load levelling, which means energy-shifting for short or intermediate time scales (seconds to minutes).
- Improvement of the power quality by absorbing disturbances that may occur during the normal functioning of the plant. This includes frequency and voltage support.

For the charging of the battery, it is possible to use either the mGT or the energy imported from the smart grid. In the first case, it can be beneficial to charge the battery when there is an overproduction of electrical energy produced by the mGT. The mGT could be forced to produce more than needed in cases where the thermal demand is high, but the electrical demand is low, or when the electrical demand is lower than the power produced by the mGT when working at the minimum environmental load. It is also possible to charge the battery with the energy produced by the smart grid. This is an advantage when the energy selling prices are low, for example when there are peaks of energy produced by the renewable sources of the SPM.
For the dis*charging of the battery*, it is possible to use the stored energy to power the HP or sell the energy to the SPM. This can be an advantage when the mGT is not operating (usually during the night).

3.3.2 Validation scenario: Island mode

An island operative configuration of the IES plant will also be tested. The goals to be achieved in this configuration are:

- To serve the user without purchasing energy from an electricity distribution network.
- To maintain the frequency and voltage of the islanded grid within their limits. This means that the inverters of the mGT and battery must regulate the active and reactive power to ensure grid stability and good power quality.

The electrical and thermal loads will be emulated in such a way that the maximum peak power required is less that the installed power. Depending on the load condition, it will be possible to use the mGT to power the HP, provide energy to the user and/or charge the battery. The battery will be used to power the HP and/or provide energy to the user. The EMS will be set to reduce the operating costs of the plant, which in this case are only represented by the cost of the fuel supplied to the mGT. This means that the BESS will be charged when the mGT operates with higher efficiencies and it will be discharged when it is more efficient to reduce the mGT load and provide energy through the battery.

As it can be seen from the electrical specifications of mGT and HP of Table 1, the start-up power required for both mGT and HP are higher than the battery pack capability. Therefore, the islanded test will start after having completed the start-up with electricity provided by the grid.

3.3.3 Laboratory set-up: Innovative Energy Systems Laboratory of the Savona's Campus of University of Genova

The UniGenova test rig components were already described in the introduction of Section 3.3. For completeness, the components of the plant are also summarised below:

- The LOLABAT prototype equipped with its own BMS;
- The inverter to connect the BESS prototype to the micro gas turbine, the heat pump and the grid;
- The components of the IES laboratory demo site: one micro gas turbine, one thermal energy storage system and one heat pump, 34 solar panels and the other TES;
- A control system that is used to operate the different components of the plant based on the energy demand, operating costs and plant state. The control scheme that will be implemented is an MPC, which through a mathematical model is able to predict the future status of the system. An optimization algorithm is applied to find the best control action, aiming at minimizing the operating cost. At each time step, the MPC performs an optimization over a predicted horizon which results in a sequence of set-points representative of the current and future time steps. Only the set-point of the current time step (first element of the output) is delivered to the system. A market function is also included in the control system to optimise both economics and energetic aspects

The schemes for the first and second validation scenarios are displayed respectively in Figure 17 and Figure 18. For simplicity, the TES and solar panels connected to the HP are not shown, since they are only connected thermally.

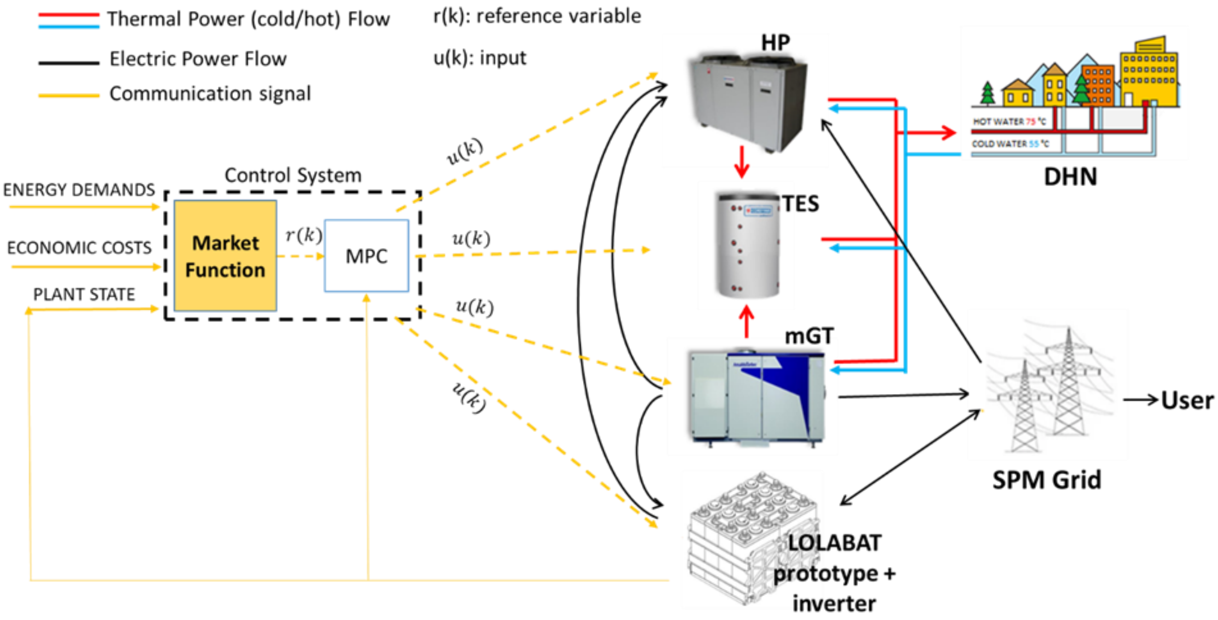

Figure 17: Test rig for the on-Grid application.

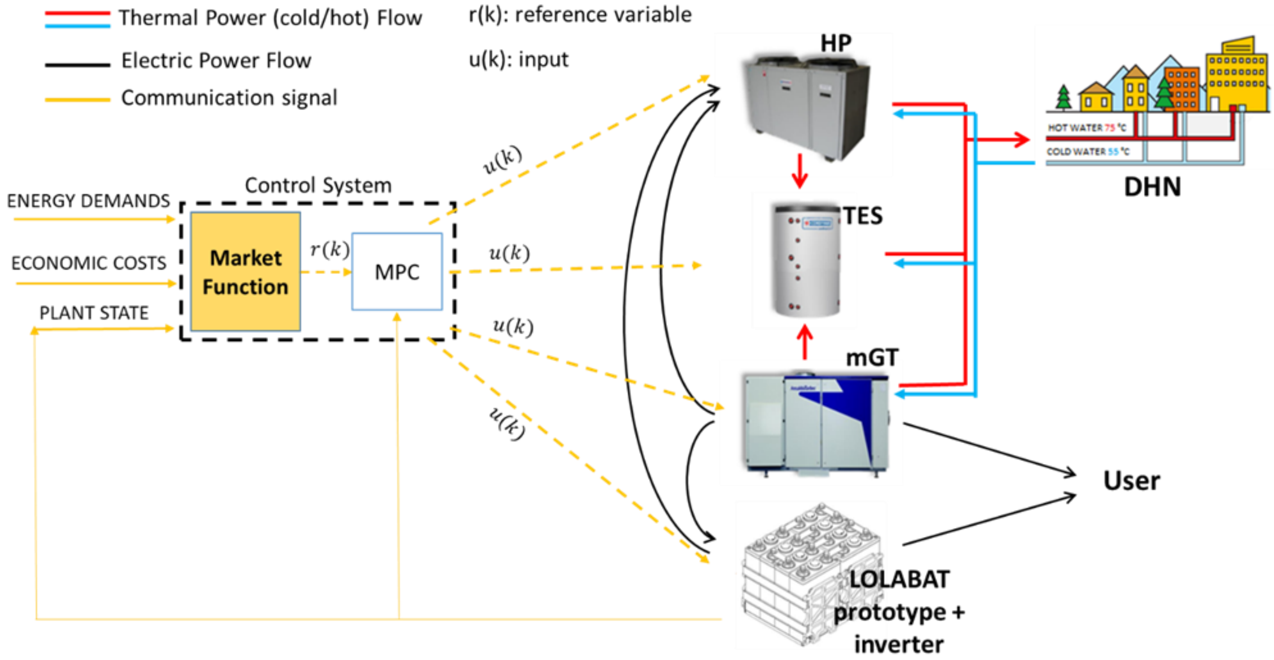

Figure 18: Test rig for the island mode scenario.

3.4 Energy Storage for Remote Autonomous LV Supply Solutions – Industrial Application

There are many industrial applications where there is a need of energy storage for remote autonomous low voltage supply systems such as remote measurement systems like seismic stations and off- grid pipeline stations characterised by very low background noise. In such remote sites, depending on the application, an independent low voltage power system is required to provide an uninterrupted power supply ensuring that the system functions continuously, sending the required monitoring data to the base stations.

One such application is elaborated within this end-sue application: *Seismic stations* are generally installed in remote places, characterised by very low background noise. In such remote site, the seismic devices powered by electricity can be exposed to damage caused by electric surges, often produced by lightning. Voltage and current surges cause most of the damage to seismic equipment around the world, producing station failures that can compromise the functionality of a seismic monitoring system. Surge protections are probably the most used tools in preventing station failure even if they are not always effective. Fortunately, a direct hit by lightning causing equipment unrecoverable damage, despite the best protections, only rarely happens. Most lightning-related damages are caused by induction surges in cables, even when the source is at some distance from the station. Over decades, the main cause of instrumentation failure has been the lightning fall near seismic stations, compromising the proper functioning of the seismic monitoring system. Voltage and current surges could also come from the main power supply. In this case, the only solution is to completely isolate the seismic station from main power supply or to use alternative power sources using, for example, photovoltaic panels. There are however situations where this strategy is not applicable (environmental restrictions, low daily sunlight, etc..). Another alternative power supply tested over years is based on the use of fuel cells, but the system has been discarded because of its weakness in cold environment and the need for frequent and expensive manual refuelling.

In LOLABAT, we present an innovative solution, that may become a benchmark for these types of applications, represented by Tesla turbines/bladeless turbines combined with pressurized fluid storages. Tesla turbine consists of an array of parallel thin disks very close to each other, separated by spacers and assembled on a shaft, forming a rotor. Such a rotor is fitted in a cylindrical housing with its ends closed by plates properly fitted with bearings to hold the rotor shaft. Fluid enters tangentially into the turbine from stator. The momentum of the moving fluid is transferred to disks because of viscosity and adhesion. The friction force generated by the fluid transfers this momentum. The manufacturing activity of Tesla turbine is strictly related to SIT proprietary technology, world patent pending: a specific adjustment on the turbine. Such original variation allows the Tesla turbine to be used in specific environments, reaching good performances and high flexibility within a large range of fluids (also biphasic fluids).

These turbines are extremely versatile and adaptable, mainly thanks to their blade-less characteristics. This last point enables to use the turbine with any kind of fluid to guarantee an electric power production. Tesla turbines coupled with compressed air storages would guarantee a stable energy supply with defined duty cycles considering any environmental condition. The turbine is characterized by significantly low vibrations and few precautions can eliminate them. To use this innovative turbine inside the above-mentioned applications, it is required an efficient and durable energy storage device. The energy storage device needs to be maintenance free, long lasting, and able to provide continuous low voltage power supply to devices. Hence, The Tesla turbine integrated with an energy storage device – RNZB – to provide a constant supply to low-power design devices in the applications mentioned above, shall improve the whole system's performance. RNZB is a highly efficient low-cost energy storage device as compared to other storage systems that store zero-emission energy to provide the constant supply of power to fulfil the power demand in remote areas.

3.4.1 Validation scenarios: Compressed air tank volume and battery pack module

The scheme of the validation scenario for energy storage for remote application Low Voltage (LV) system consists of following components as shown in Figure 19:

- Compressed air tank/supply.
- Tesla/bladeless expander (130 W).
- RNZB (LOLABAT) (2,5 kWh – 2 modules of 1,25 KWh in series).
- Data acquisition systems.

The working principle of the system is as follows: Compressed air at desired pressure flow to inlet port of the Tesla expander through pressure regulating valves and sensors. The high-pressure energy is converted into kinetic energy inside the stator of the turbine. The high velocity fluid drives the rotor of expander, creating torque and hence power at the shaft. The turbine is connected to the generator and inverter which supplies the power to the battery pack RNZB. The continuous low voltage power is then supplied to desired application.

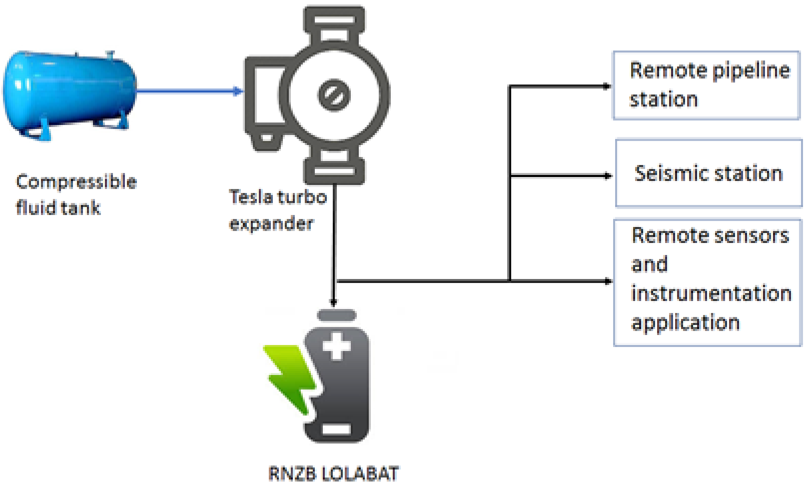

Figure 19: Conceptual scheme bladeless Tesla Turbo expander for the remote autonomous areas.

Some scenarios are identified, depending upon the usage requirement, for an advantageous intermittent utilization of Tesla turbine to feed a battery pack suited for the remote application. In the most promising scenario, the Tesla turbine is coupled with a pressurized air tank of about 0,9 m^3 (10 bar) to generate the power of 130 W. The considered battery pack for energy storage is composed by 2 modules (1,25 kWh each) of 25V RNZB batteries at 100Ah.

Scenario 1: Compressed air tank volume

- In this scenario, the system will be operated at different air tank volume or different inlet pressure of compressed air at expander inlet. This will change the power output of the tesla expander. Hence in this scenario, the working conditions of the system to see the impact on the overall system i.e. power produced, working time and total station lifetime.

Scenario 2: battery pack module

- In this scenario, a different battery pack module will be tested individually (1,25 kWh) at the design expander power to evaluate the working time and total station lifetime. This scenario would be helpful in certain applications where doubling of station endurance is required.

3.4.2 Laboratory set-up: Innovative Energy Systems Laboratory of the Savona's Campus of University of Genova

The scheme of laboratory set up of energy storage for remote application LV system consists of following components as shown in Figure 20:

- Compressed air tank/supply.
- Tesla/bladeless expander (130 W).
- RNZB (LOLABAT) (2,5 kWh – 2 modules of 1,25 KWh in series).
- Data acquisition systems.

The working principle of the system is as follows: Compressed air at desired pressure flow to inlet port of the Tesla expander through pressure regulating valves and sensors. The high-pressure energy is converted into kinetic energy inside stator of the turbine. The high velocity fluid drives the rotor of expander, creating torque and hence power at the shaft. The turbine is connected to the generator and inverter which supplies the power to the battery pack – RNZB. The continuous low voltage power is then supplied to the desired application. The data is recorded using data acquisition system and successively analysed.

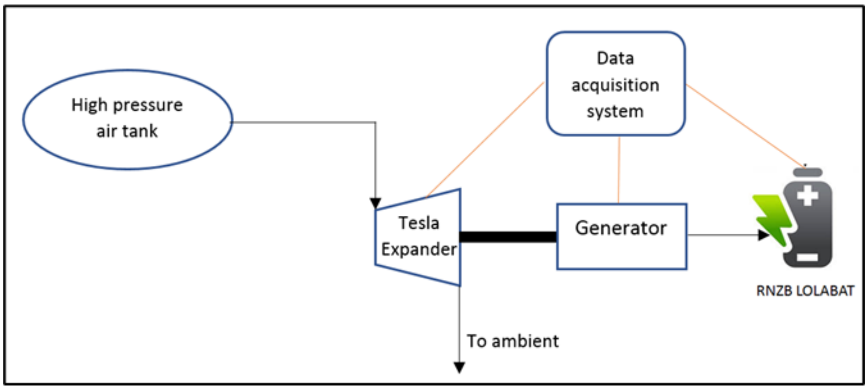

Figure 20: Experimental set up: energy storage for remote application LV system.

General references: [14 and 15]

3.5 Energy Storage Integration in Electro-Intensive Industry – Industrial Application

This end-use application regards a manufacturing plant of copper and copper alloy products, owned by KME and based in Italy, in Fornaci di Barga (LU).
The production process in the plant is depicted in Figure 21.

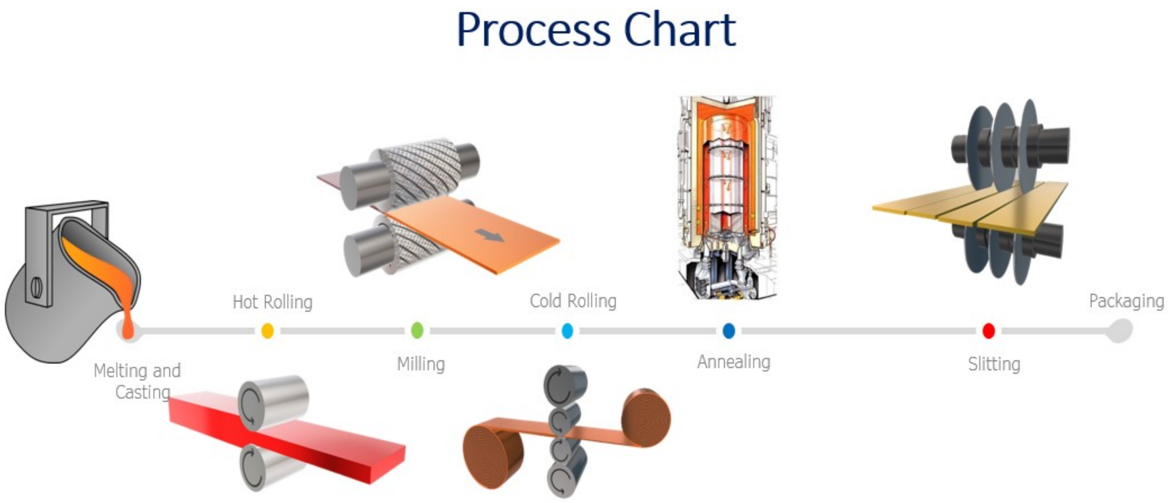

Figure 21: Scheme of the production process in KME's plant.

A mix of raw material is loaded on melting furnaces according to technical and economic aspects as well as material availability, always assuring the best quality of the product.
The first step of the process (slabs or high tick pre-rolled coil) is carried out through Electrical Melting Furnaces to Vertical Cast.
Slab produced in the Foundry is heated in a special furnace before being first hot rolled. After further rolling passes it will give a high thickness coil with an oxidised surface.
The oxidised surface of the high-thickness coil is scalped through a milling line which uses tools to remove the oxide from the two faces of the material.
The cold rolling operation reduces after several passes the thickness to the one requested by the following phases or by the final product.
Between the rolling operations an annealing phase is requested due to metallurgical reasons. Moreover, a chemical cleaning treatment is necessary to remove the oxide. A special equipment is used to assure the full respect of environmental parameters
This operation gives the geometrical shape requested by the final customer, usually strips.
The plant is energy intensive consumer and its annual consumption is around 67 GWh.
The main consumer (nearly 30% of the total consumption) is the foundry department where the copper is melted.
The load profile of the plant is not flat, and it has several peaks (especially during the day) and valleys (in the nights and weekends).
In the following pictures are highlighted the consumption profiles of:

- A typical week of the full plant, the foundry dept (that cover nearly 30% of the total consumption) and of the main rolling machines (that cover nearly 10% of the total consumption).

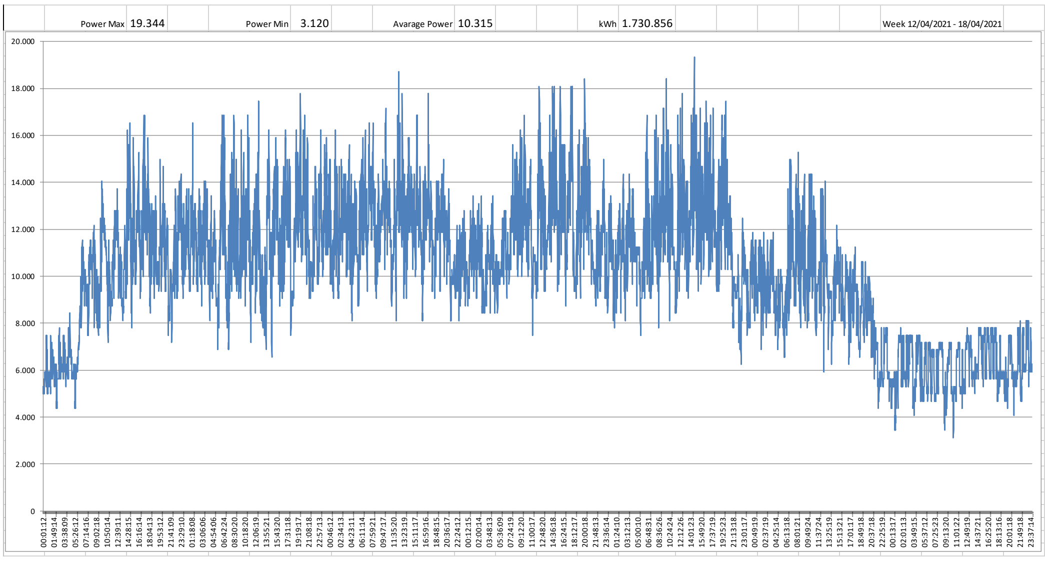

Figure 22: Load Profile of a typical week of the full plant – minute consumptions.

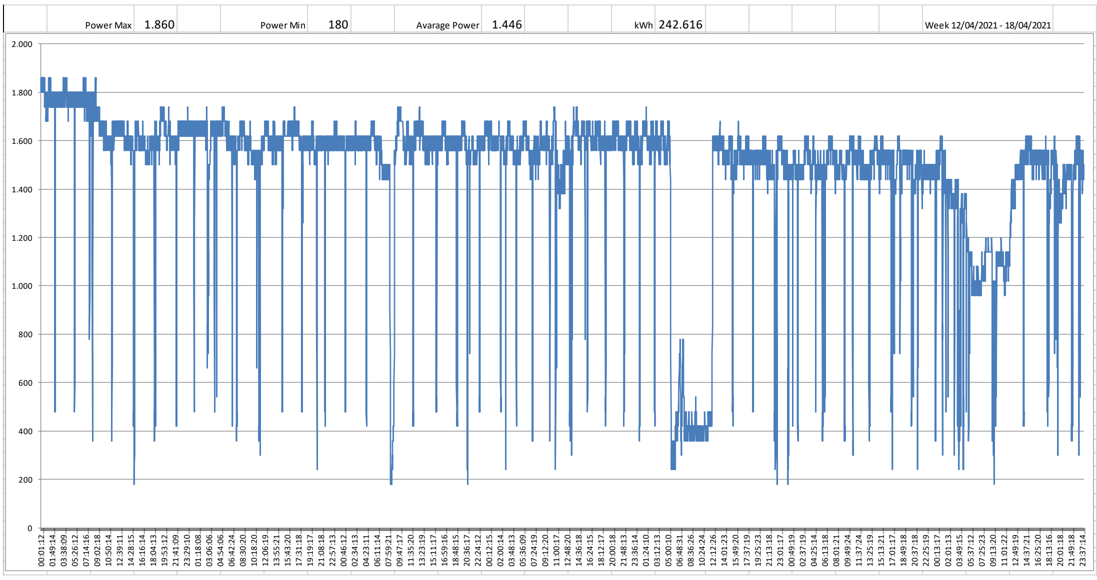

Figure 23: Load Profile of a typical week of Foundry – minute consumptions.

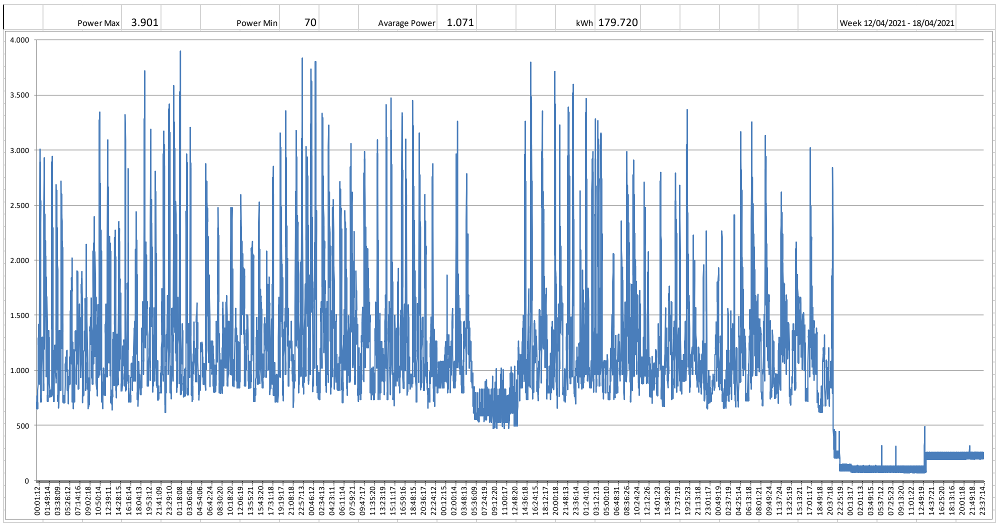

Figure 24: Load Profile of a typical week of the main rolling machine – minute consumptions.

- A typical working day of the full plant, the foundry dept (that cover nearly 30% of the total consumption) and of the main rolling machines (that cover nearly 10% of the total consumption).

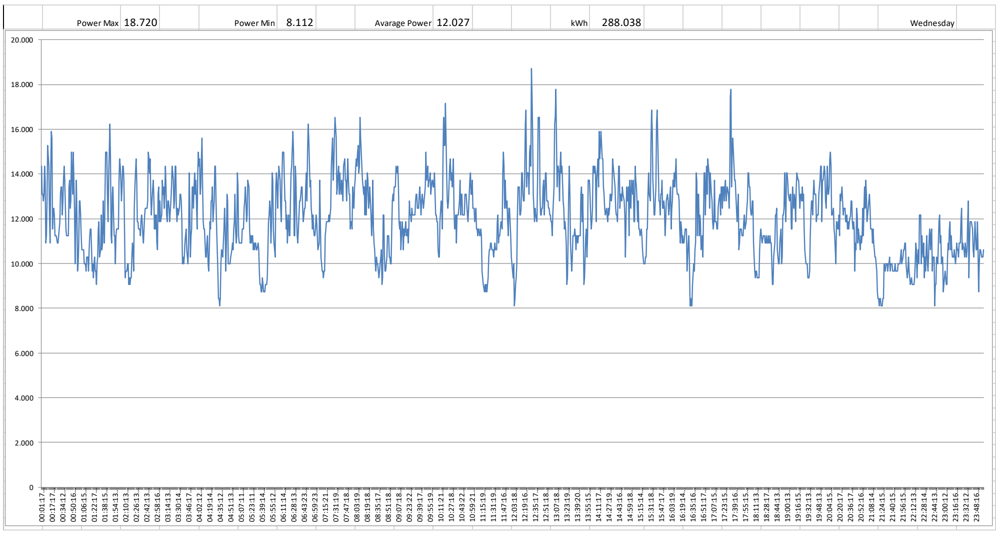

Figure 25: Load Profile of a typical working day of the full plant – minute consumptions.

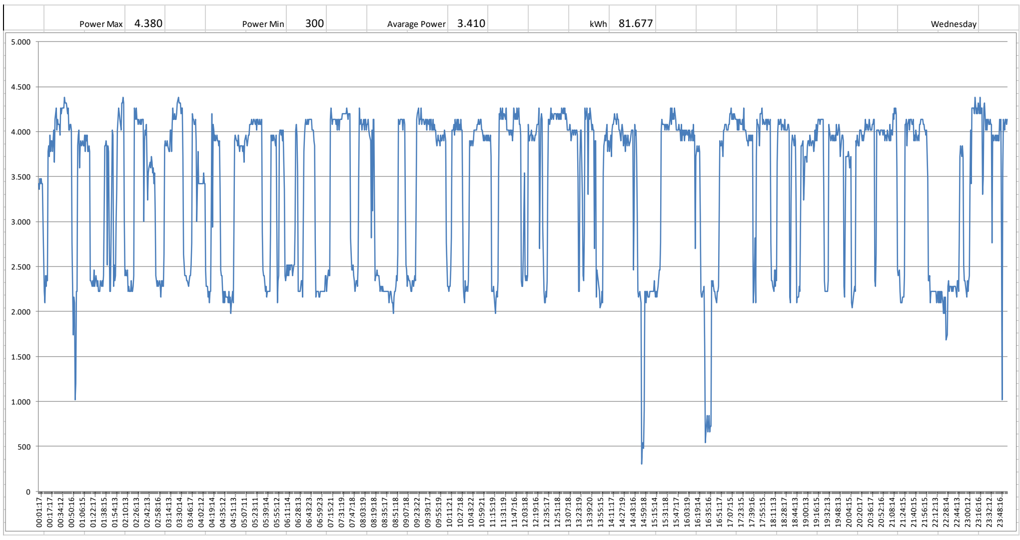

Figure 26: Load Profile of a typical working day of Foundry – minute consumptions.

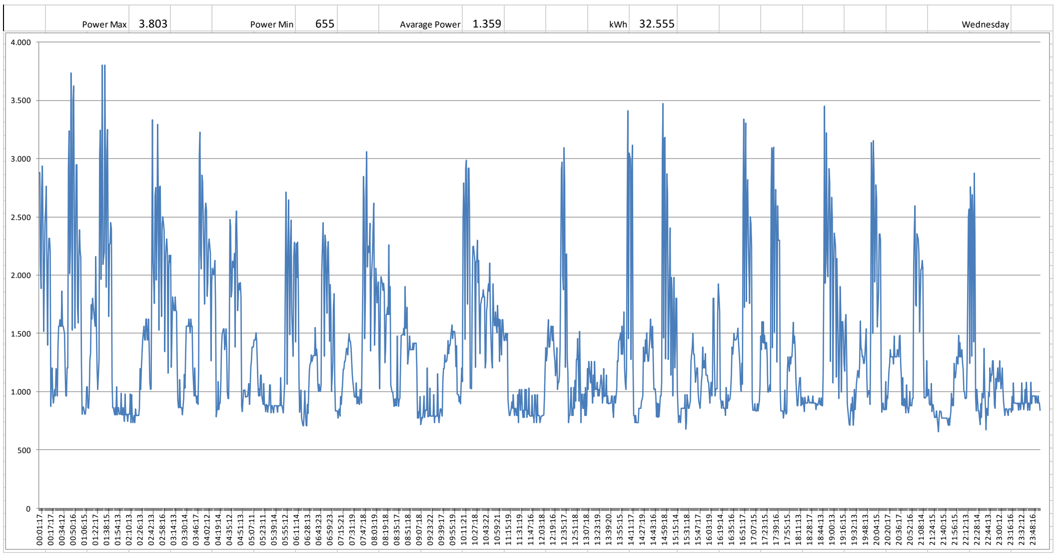

Figure 27: Load Profile of a typical working day of the main rolling machine – minute consumptions.

- A typical weekend day of the full plant, the foundry dept (that covers nearly 50% of the total consumption) and of the main rolling machines (that cover nearly 2.5% of the total consumption).

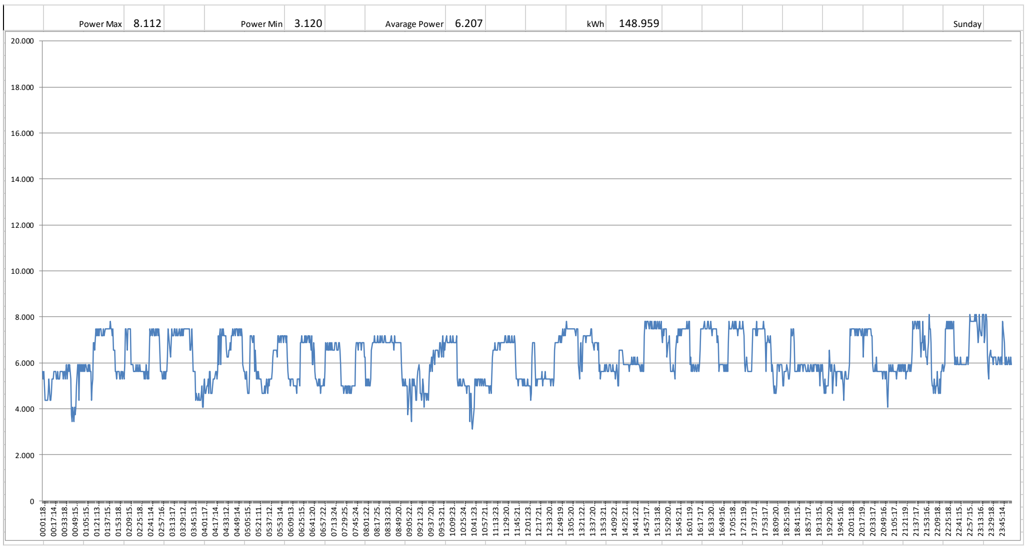

Figure 28: Load Profile of a typical weekend day of the full plant – minute consumptions.

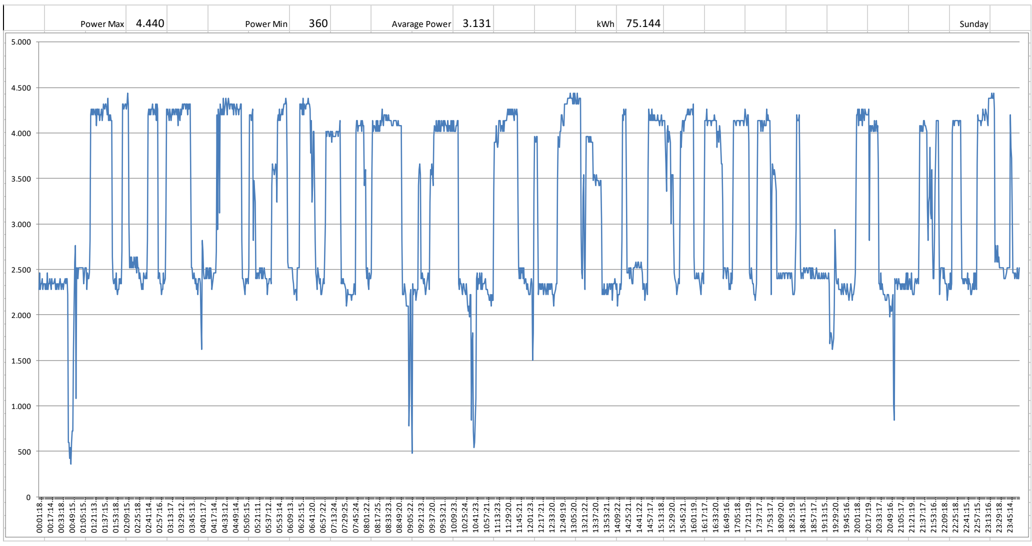

Figure 29: Load Profile of a typical weekend day of Foundry – minute consumptions.

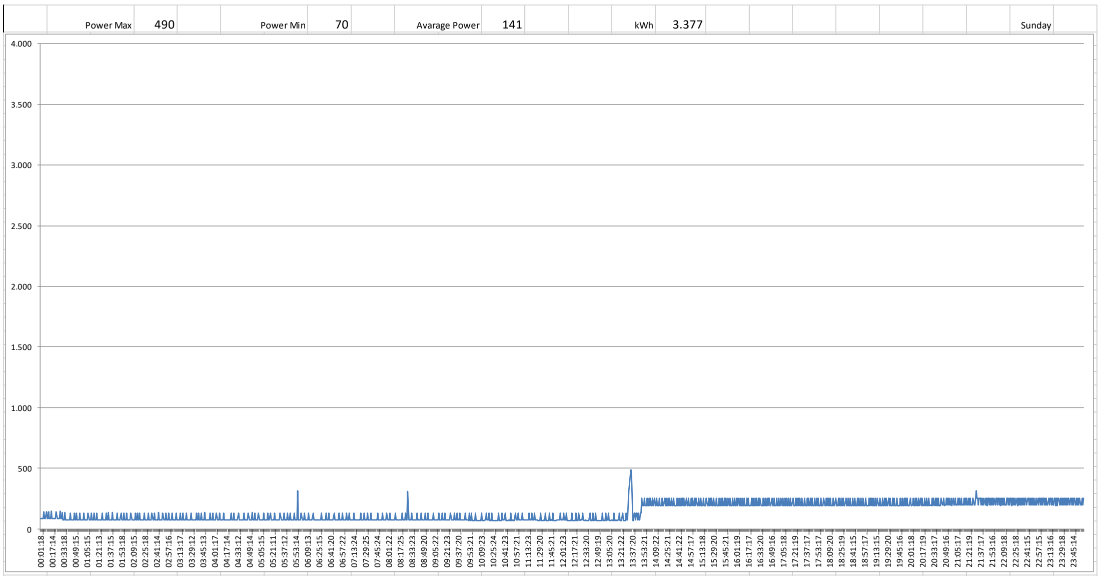

Figure 30: Load Profile of a typical weekend day of the main rolling machine – minute consumptions.

As shown in the pictures above, the introduction of a BESS should be useful for optimizing consumption profile and energy costs.

Therefore, the main important advantage that this application could bring is from the economical point of view through the peak shaving concept.

The BESS size is important to define where is more convenient to install it: a BESS with small capacity could be installed as support to a single machine; a BESS with high capacity could be installed at higher plant level. The strategy behind the BESS application is better described in the next section.

3.5.1 Validation scenario: BESS application for peak shaving in electro-intensive industries

According to the energy efficiency Directive 2012/27 / EU, the promotion of best energy practices in the industrial sectors should represent a priority as it is responsible for almost 37% of the EU's total electricity consumption and causes peak demands for the electrical grids [16]. It is necessary to identify and apply strategies for the industries energy supply optimization. **Electric storage systems** represent one of the main allies for these strategies to be implemented. There are many applications for electric storage systems in manufacturing industries. Applications for maintaining production in case of a blackout are already established and economical, but applications for optimizing energy supply are becoming increasingly interesting for manufacturing companies. **Peak shaving** is one application for optimizing energy supply, which has the potential to reduce the grid charge of industrial consumers [17].

Electricity demand and loads have a variable trend, creating peaks during the day. Continuous growth in peak, due to the increase of the end users and the concentration of the activities in specific time slots, raise the possibility of power failure and increase the cost of supply. In these moments the purchase of electricity from the grid reaches higher values due to the high demand.

With the peak shaving strategy, it is possible to reduce the consumption in a certain period, avoiding requiring energy from the grid when it is already overloaded. This is either possible by temporarily scaling down the production, activating an on-site power generation system, or relying on batteries.

By installing batteries, it is possible to apply the peak shaving concept as follow:

- Charge the battery whenever electricity rates are at their lowest (during off-peak hours).
- Discharge the battery to avoid paying peak prices during the most expensive times of the day.

The benefits deriving from peak shaving are not only related to the end-user who can save on the electricity bills, but also to the Grid Operator, who does not have to manage congested networks and can maintain a reduced per unit electricity generation cost.

Carbon emission reduction is a significant consequence of peak shaving. To compensate for peak demand, power plants consume a greater quantity of fuel, increasing carbon emissions. By eliminating peaks, the variety of loads is reduced and the consequent extra energy production from power plants decreases [18].

Peak shaving is achieved through the charging of BESS when demand is low (off-peak period) and discharging when demand is high, as shown in Figure 31 [19].

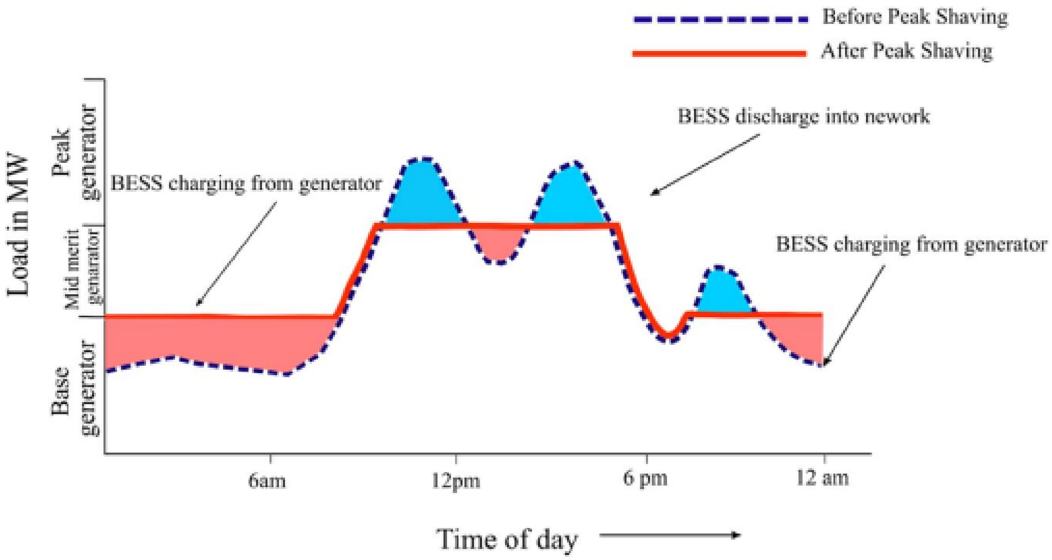

Figure 31: Peak Shaving Strategy.

Peak shaving can be regulated directly through an EMS using algorithms that forecast the electricity consumptions during the day thanks to the historical data and the real time pricing set by the utility provider. Based on this information it allows to regulate the charging and discharging phases.

The KME plant peak profile is between 4 MW and 16 MW (average in 15 minutes) and must face shortage (especially during the day) and overcapacity (especially during the night and weekends). A storage with dimension of >2.7 MW and >10 MWh (to cover all the plant) or a lower one (to be defined for covering one or more loads) could help to manage the electricity consumption. Both scenarios will be further investigated for the KME plant.

The distribution network is at 10.5 kV and a storage with a capacity of more than10 MWh could be connected to the main electric cabinet while a lower capacity storage could be connected to the department electric cabinet at the distribution voltage of 400 V.

3.5.2 Feasibility study

To evaluate the potential of the future integration of LOLABAT battery in KME manufacturing process, a feasibility study will be realized. The purpose of this analysis is to study the possible benefits deriving from the installation of the battery within the KME plant such as enhanced security and continuity of supply, industrial energy efficiency, emission savings and cost reduction. Any possible limitation and criticality will also be sought. The idea is to take a picture of the baseline electricity consumption within the plant, comparing it with suitable local and international benchmarks and with the reduction target foreseen for KME and to identify potential battery strategy applications for improvement of energy efficiency level by carrying out a techno-economic feasibility study and by defining an energy efficiency action plan.
The procedure is briefly described below:

1. *Data Collection*
   Collection of the plant layout, real monitoring data, consumption profiles and distribution of consumptions within the plant, related costs, characteristics and use of the equipment using electricity, general features of the plant, processes and facilities.

2. *Evaluation of the energy performance of the plant*
   Analysis to evaluate the energy performance of the plant and benchmarking with reference values, elaborating detailed proposals for improvement of energy efficiency level through the battery installation.

3. *Identification of additional equipment needed for the installation*
   In case of integration of a large-scale battery, a new Medium Voltage (MV) connection has already been considered. For a small-scale battery installation, no additional equipment has been foreseen for the moment, but further analysis will be conducted during this phase.

4. *Analysis of the installation and connection to the grid requirements and regulatory framework*
   BESS installation requires the adaptation to standards and protocols that will be analysed in detail for the KME application, based on the outputs produced within T2.2 (Assessment of norms and standards for NiZn) and T2.3 (Assessment of the compliancy/integrability of NiZn batteries for stationary applications) of the project and the national framework.

5. *Characterization and sizing of the battery*
   Sizing is essential for assuring the correct operation. Installation of BESS at a random size or non-optimum size can increase cost, system losses, and lead to larger BESS capacity. If the sizing of BESS can balance the capital cost of storage system and electricity bill savings, the maximum financial benefit will be achieved from peak shaving. The method consists of three steps: the load profile analysis, the determination of the power and capacity of BESS. The optimal size of BESS is determined based on the economic valuation [20].

6. *Preliminary design and proposed solutions*
   Different installation scenarios (locations within the plant, battery sizes…) and the most suitable possibilities will be presented. The possibility of installing renewable generation systems within the KME

plant coupled to the BESS will also be analysed and simulated in the SuperGrid laboratory to evaluate the optimization of the energy consumption and costs reduction.

7. *Energy and environmental benefits evaluation*
   Examination of the influence of the proposed solutions (phase 6) on changes in current energy consumption, Greenhouse Gas (GHG) emissions, air pollutant emissions compared to the previous analysed *business-as-usual case* (phase 2), quantifying benefits and highlighting the potential drawbacks. The analysis will allow to understand if the previously defined targets are achievable through the proposed solutions. The analysis will perform the comparison with traditional energy storage systems (Lead Acid, Lithium batteries…).

8. *Estimation of investment needs*
   Estimation of the possible Capital Expenditures (CAPEX) related to the installation and implementation of the solutions.

9. *Cost-benefit analysis*
   Estimation, based on the results obtained from the SuperGrid simulations, of the related variation of Operational Expenditures (OPEX) and consequent evaluation of the investment under a financial perspective through the most common financial indicators (Internal Rate of Return (IRR), Net Present Value (NPV), Payback Time (PBT), etc.). The economic analysis will perform also a comparison with the traditional energy storage systems (Lead Acid, Lithium batteries…).

3.5.3 Laboratory set-up: SuperGrid Institute PHIL Platform

Figure 32 shows the platform architecture for the demonstration of the end use application under issue (Energy storage integration in electro intensive industry). It is composed of two distinct elements:

- The hardware under test, which is the LOLABAT prototype envisioned for this demonstration, (developed in WP4) and the associated EMS.
- An emulator, namely the 'GRID & Plant numerical model' that will provide at any time the boundary condition adapted to the industrial case study.

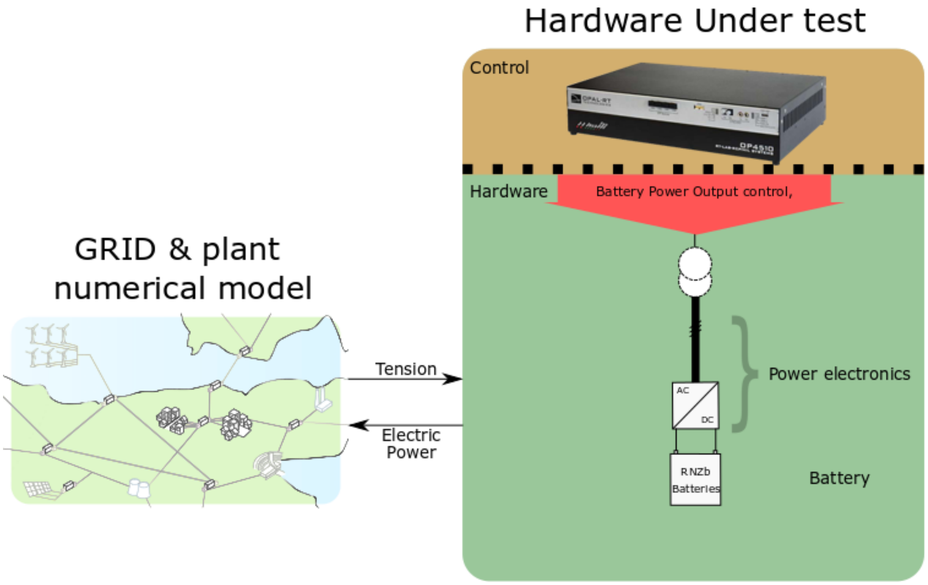

Figure 32: SuperGrid Institute PHIL Platform architecture for KME & RINA-C demonstration: Energy storage integration in electro intensive industry.

The emulator is made of a numerical model for the grid (including solicitations), a numerical model for the electro intensive plant, and a 4 quadrants Tension source that provides the voltage at the delivery point for our hardware under test, in this case a 3-phase 400V voltage bus is presumed but in the case of different needs of KME & RINA-C and further investigation, a Direct Current (DC) link may also be feasible.

Figure 33 shows the implementation of the grid & plant emulator.

The hardware under test is made of the LOLABAT battery packs prototype delivered by the WP4, a suitable converter for the dispatch of the output power, and the implementation of a dedicated EMS.

The control unit in which the EMS will be programmed is an OPAL OP4510 real time controller with a Matlab/Simulink interface that enables acquisition and control sampling period down to 50ùs (In its actual configuration).

Different simulations will be performed through this architecture. The results will represent the inputs for the energy and environmental benefit evaluation and the cost-benefit analysis that will be performed by RINA-C for the KME plant.

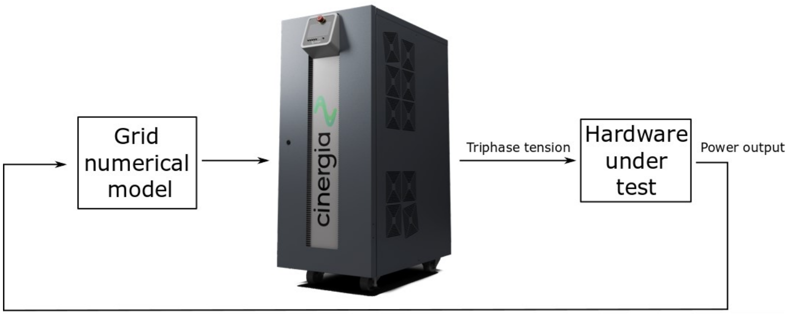

Figure 33: The Grid emulation includes a numerical model that processes the power out of the Hardware under test and provides using a 4 quadrants tension source an adequate boundary condition to the HUT.

4 High-level requirements, specifications and KPIs for RNZB

This section summarises LOLABAT's high-level requirements, considering the end-use applications introduced, as well as the Key Performance Indicators (KPIs) linked to the validation scenarios envisioned within each end-use application, and that will be assessed latter during the battery packs' lab testing phase. Moreover, the preliminary specifications of the test RNZB packs that will be tested for stationary energy storage applications will also be highlighted.

4.1 High-level requirements for RNZB and LOLABAT end-use applications KPIs

Considering the end-use applications presented, and that should be addressed by LOLABAT's technology validation framework, to be implemented in WP6, the high-level requirements are summarised in the following tables.

4.1.1 Hybridisation of Hydro Power Plants

The sizing, made here, focuses on a hypothetical PSP made of 4 groups of 130 MW for a total nominal power of 520 MW.

For the first scenario envisioned, a 20% dead band of the maximum active power of a single group (20%*130 MW = 26 MW) is considered for the operation of this latter as shown in Figure 1. It is targeted to have a range of operation of [25, 100] % of the nominal power of the station in comparison with the conventional range of [55, 100] %.

For the second scenario envisioned, the sizing case is made for the partial EOR. The goal is to cover the dead band in pumping operation un to 80 MW. Note that, it would potentially lead to no more than 150 MW additional continuous range of operation (cf. Figure 2).

In those cases, the initial sizing of the battery is made as follows:

- The power corresponds to the height of the dead band in MW, with margins including losses due to battery ageing.
- The energy is proportional to the inverse of the number of cycles that can be achieved every hour (cf. Figure 3 that represents an overview of one cycle). 2 cycles per hour are considered with an efficiency of 90% in charging and discharging mode of the battery.

Table 2: End-use specification.

Requirements	BP	IR
	Value/Range	**Value/Range**
Maximum 30-sec Discharge Pulse Current	Not relevant	Not relevant
Rated Power	5 kW	S1: 30 MW S2: 90 MW
Maximum Depth of Discharge	80 %	80 %
Rated Capacity	0,765 kWh	S1: 4,5 MWh S2: 13,8 MWh
Expected life cycles	TBD	TBD

Table 3: General requirements.

Requirements	Short description	Scenario	Value/Range	Type[i]
Ramp Rate	It is the average rate of active power variation per unit of time, from the instant when the active power is higher than 10% of the set-point and the time at which the power at the POC gets higher than 90%	S1 & S2	20 [%battery rated power/second]	T-O
Discharge/Charge duration	It's the duration of a single charging/discharging cycle. It's important because during this time the operating limits (e.g. SoC, SoH, etc) of the BESS must be always fulfilled	S1 & S2	From 1s to 450s	T-O

[i] The type of requirement could be: technical (T), performance-related (P), safety (S), integration requirement (I). Moreover, would be worthy to specify to which component it is referred: battery (B), inverter (I), overall system (O), controller (C), etc. Feel free to add others.

The next table presents the communication and control inputs that the BMS must track and transmit to the higher layers of the control structure of the facility. Those data are necessary for all the scenarios mentioned above.

Data are split into several groups according to their usefulness:

- **Converter:** It corresponds to the data that are necessary for the control of the converter that interfaces the battery pack to the test rig.
- **EMS:** It stands for the data that are needed by the EMS to control and optimize the power flow during the demonstration, planned to prove the capability of the LOLABAT technology and to facilitate the hybridization of a hydraulic power plant.
- **Monitoring:** The data only requires to be aware of the state of a system and observe any change which may occur over time.

- **Alarm:** Provides an alert that needs an urgent attention.
- **Process:** Indicates the activity that is in progress.

As observed, prioritisation rule is used to determine which data take priority over other data for this demonstration. Furthermore, several data types are indicated. They correspond to the ways the data will be stored to ensure a good match with the test platform. Note that, here, the term "Data", in the table below, means a typing information and it is not necessary a signal.

Finally, the level of accuracy of the data are provided. It is worthy to mention that this is defined in relation to the metric system indicated in the name column.

Note that Table 4, describes an extensive number of variables that do not necessarily describe the final implementation of the BMS. An arbitration may occur when the BMS is developed enough, and the EMS specification is done.

Table 4: Communication and control requirements.

Name	Description	Needs	Priority	Type	Precision
BESS output voltage [V]	It's the output voltage of the battery pack at its terminal.	Converter	Mandatory	Analog	< 1/100
BESS output current [A]	It's the output current of the battery pack.	Converter	Mandatory	Analog	< 1/1000
Module voltage [V]	It's the output voltage of each module of the battery pack.	Monitoring	Optional	Analog	< 1/100
Module current [A]	It's the output current of each module	Monitoring	Optional	Analog	< 1/1000
Average pack temperature [°C]	It's the average temperature of the battery pack	Monitoring	Optional	Analog	< 1/10
Maximum module temperature [°C]	It's the temperature value of the module with the highest temperature	Monitoring	Optional	Analog	< 1/10
Minimum module temperature [°C]	It's the temperature value of the module with the minimum temperature	Monitoring	Optional	Analog	< 1/10
Temperature alarm	It corresponds to an abnormal rise in temperature, with two thresholds (TBD), for a module monitored in the battery pack.	Alarm	Mandatory	Boolean	/
State of Charge (SoC) [%]	It's the overall SoC of the battery pack	EMS	Mandatory	Analog	<1/100
Minimum (SoC) [%]	It's the minimum value the overall SoC can reach.	EMS	Mandatory	Data	<1/100
SoC alarm	It corresponds to an alarm that indicates the minimum (or maximum) SoC limit is reached by one module of the battery pack	EMS	Optional	Boolean	/
State of Health (SoH) [%]	It's the overall SoH of the battery pack	EMS	Optional	Analog	<1/100
Minimum SoH [%]	It's the minimum value the overall SoH can reach.	EMS	Optional	Data	<1/100

SoH alarm	It corresponds to an alarm that indicates the minimum SoH limit is reached by one module of the battery pack	EMS	Mandatory	Boolean	/
Maximum available charging power [W]	It's the maximum charging power that the battery pack can accommodate	EMS	Mandatory	Analog	<1/1000
Maximum available discharging power [W]	It's the maximum discharging power that the battery pack can accommodate	EMS	Mandatory	Analog	<1/1000
Maximum power ramp rate [W/s]	It's the maximum ramp rate allowed by the battery pack	EMS	Optional	Analog or Data	<1/1000
Maximum charging current [A]	It's the maximum charging current that the battery pack can accommodate	EMS	Mandatory if the maximum charging power is not available	Analog	<1/1000
Maximum discharging current [A]	It's the maximum discharging current that the battery pack can accommodate	EMS	Mandatory if the maximum charging power is not available	Analog	<1/1000
Balancing alarm	Signal the need for the balancing, prevent from unnoticed or expected failure during the process or in case of a faulty BMS	Alarm	Mandatory	Boolean	/
BMS state	It indicates if the BMS is turn on or off, in fault, or the balancing process is in progress.	Process	Mandatory	N bits	/

Table 5: End-use application linked KPIs.

KPIs	Short description	Scenario	Value/Range
Time response[1]	It's the time that passes from the reception of the set-point (either settled by the users or triggered by an external event) and the achievement of that power level at the Hybrid PSP output.	S1 & S2	Milliseconds to seconds
Efficiency	It's the efficiency of the Hybrid PSP with respect to the Power set point	S1 & S2	%
Damaging on the hydraulic turbine	It's an image of the supplementary damage due to crossing of restricted operation zones and additional start-up & shutdowns for the realization of the EOR	S1 & S2	p.u.
Continuous operation range extension	It's the novel operating range that are allowed for the plant	S1 & S2	% of initial range

4.1.2 Smart Distribution Grid Management

Table 6: End-use specification

Requirements	BP	IR
	Value/Range	Value/Range
Maximum 30-sec Discharge Pulse Current	Not relevant	Not relevant
Rated Power	10 kW	100 kW – 300 kW
Maximum Depth of Discharge	80 %	80 %

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[1] https://rules.dnvgl.com/docs/pdf/dnvgl/rp/2017-09/dnvgl-rp-0043.pdf

Rated Capacity	10 kWh	100 kWh – 300 kWh
Expected life cycles	7000 – 10000	7000 – 10000

Table 7: General requirements

Requirements	Short description	Scenario	Value/Range	Type[i]
Ramp Rate	It is the average rate of active power variation per unit of time, from the instant when the active power is higher than 10% of the set-point and the time at which the power at the POC gets higher than 90%	S1	10 [%rated power/minutes]	T-O[2]
		S2	Not relevant	
		S3	Not relevant	
Discharge/Charge duration	It's the duration of a single charging/discharging cycle. It's important because during this time the operating limits (e.g. SoC, SoH, etc) of the BESS must be always fulfilled	S1	From 1 ms to 100s	P-B
		S2	From 1 minute to 1 hour[3]	P-B
		S3	1 hour – 8 hours[4]	P-B

[i] *The type of requirement could be: technical (T), performance-related (P), safety (S), integration requirement (I). Moreover, would be worth to specify to which component it is referred: battery (B), inverter (I), overall system (O), controller (C), etc. Feel free to add others.*

Table 8: Requirements on EMS information exchanged

EMS information exchanged				
Requirement	**Description**	**Scenario**	**ID**	**Type**
SoC [%]	It's the SoC of the whole BESS	All	Batt_soc	Int32
BESS output voltage [V]	It's the output voltage of the BESS at its terminals	All	Batt_Volt	Int32
Cell voltage	It's the voltage level of each cell	All	Cell_Voltage	Array: n dimension (n is the number of cell)
Maximum available charging Power (W or kW)	It's the maximum charging power that the BESS can accommodate	S1, S3	Batt_Pmax_charge	Int32
Maximum available discharging Power (W or kW)	It's the maximum discharging power that the BESS can accommodate	S1, S3	Batt_Pmax_discharge	Int32

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[2] In this case the Overall system comprises also the EV charger. The requirements thus refer to the ramp rate in the grid-connection point.

[3] https://rules.dnvgl.com/docs/pdf/dnvgl/rp/2017-09/dnvgl-rp-0043.pdf

[4] Cannot be generalised easily. Another option would to consider the timeframe of the intraday market: 15 minutes.

Maximum under excited reactive power (VAr or kVAr)	It's the maximum inductive reactive power that the set BESS/inverter can accommodate	S2	System_Qmax_inductive	Int32
SoH [%]	It's the SoH of the BESS	All	Batt_soh	Int32
Average cell temperature [ºC]	It's the average temperature of the BESS	All	Batt_AvgTemp	Int32
Maximum cell temperature [ºC]	It's the maximum temperature of the cells	All	Cell_MaxTemp	Int32
Minimum cell temperature [ºC]	It's the minimum temperature of the cells	All	Cell_MinTemp	Int32

Table 9: End-use application linked KPIs

KPIs	Short description	Scenario	Value/Range
Time response[5]	It's the time that passes from the reception of the set-point (either settled by the users or triggered by an external event) and the achievement of that power level at the ESS output.	S1	Milliseconds to seconds
		S2	Seconds
		S3	Milliseconds
Round-trip efficiency	It's the efficiency of the BESS including the consumption of the auxiliary system.	All	80-90 %
Reduction of RES curtailment[6]	It represents the number of RES curtailments avoided thanks to the use of the BESS	S4	≥5 %
Reduction of congestion event[7]	It represents the number of congestion events avoided thanks to the use of the BESS	S4	≥5 %
Ramp-rate EV charger connection point	It's the ramp rate of the power at the connection point between the EV charger and the grid	S1	10 [% rated_power/min]

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[5] https://rules.dnvgl.com/docs/pdf/dnvgl/rp/2017-09/dnvgl-rp-0043.pdf

[6] A typical duty cycle must be defined (e.g. daily, weekly or monthly profile for a smart grid with high penetration of RES). The number of curtailments with and without the BESS will be compared.

[7] A typical duty cycle must be defined (e.g. daily, weekly or monthly profile for a smart grid with high possible overloads). The number of overloads with and without the BESS will be compared.

4.1.3 Energy Balancing in Smart Buildings

Table 10: End-use specification

Requirements	BP	IR
	Value/Range	Value/Range
Maximum 30-sec Discharge Pulse Current	Not relevant	Not relevant
Rated Power	10 kW	100 kW
Maximum Depth of Discharge	80 %	80 %
Rated Capacity	10 kWh	350 kWh
Expected life cycles	7000 – 10000	7000 – 10000

Table 11: General requirements

Requirements	Short description	Scenario	Value/Range	Type[i]
Ramp Rate	It is the average rate of active power variation per unit of time, from the instant when the active power is higher than 10% of the set-point and the time at which the power at the POC gets higher than 90%	S1 / S2	10 [% rated power/minutes]	T-O
Discharge/Charge duration	It's the duration of a single charging/discharging cycle. It's important because during this time the operating limits (e.g. SoC, SoH, etc) of the BESS must be always fulfilled	S1 / S2	Minutes to 1 hour	P-B

[i] *The type of requirement could be: technical (T), performance-related (P), safety (S), integration requirement (I). Moreover, would be worth to specify to which component it is referred: battery (B), inverter (I), overall system (O), controller (C), etc. Feel free to add others.*

Table 12: End-use application linked KPIs.

KPIs	Short description	Scenario	Value/Range
Time response[8]	It's the time that passes from the reception of the set-point (either settled by the users or triggered by an external event) and the achievement of that power level at the ESS output.	S1/S2	Milliseconds to seconds
Round-trip efficiency	It's the efficiency of the BESS including the consumption of the auxiliary system.	S1/S2	80-90 %

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[8] https://rules.dnvgl.com/docs/pdf/dnvgl/rp/2017-09/dnvgl-rp-0043.pdf

Reduction of RES curtailment[9]	It represents the number of RES curtailments avoided thanks to the use of the BESS	S1/S2	≥5 %
Fuel savings[10]	It represents the number of RES curtailments avoided thanks to the use of the BESS	S1/S2	≥5 %
Cost saving[11]	It represents the number of congestion events avoided thanks to the use of the BESS	S1/S2	≥5 %
Working time in island mode	It is the time the plant can operate in island mode without affecting the users supply capacity or quality	S2	Hours - days

4.1.4 Energy Storage for Remote Autonomous LV Supply Solutions – Industrial Application

Table 13: End-use specification.

Requirements	**BP**	**IR**
	Value/Range	**Value/Range**
Maximum 30-sec Discharge Pulse Current	Not relevant	Not relevant
Rated Power	130 kW	130 kW
Maximum Depth of Discharge	80 %	80 %
Rated Capacity	2,5 kWh	1 kWh – 5 kWh
Expected life cycles	4000	4000

Table 14: General requirements.

Requirements	**Short description**	**Scenario**	**Value/Range**	**Type**[i]
Charging voltage	It is the voltage at which turbine generator charges the battery.	S1/S2	Standard voltage	T-O

[i] *The type of requirement could be: technical (T), performance-related (P), safety (S), integration requirement (I). Moreover, would be worth to specify to which component it is referred: battery (B), inverter (I), overall system (O), controller (C), etc. Feel free to add others.*

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[9] A typical duty cycle must be defined (e.g. daily, weekly or monthly profile for the smart grid). The number of curtailments with and without the BESS will be compared.

[10] A typical duty cycle must be defined (e.g. daily, weekly or monthly profile for the smart grid). The fuel consumption with and without the BESS will be compared.

[11] A typical duty cycle must be defined (e.g. daily, weekly or monthly profile for the smart grid). The operating cost with and without the BESS will be compared.

Table 15: End-use application linked KPIs.

KPIs	Short description	Scenario	Value/Range
Output Power	Output power of the turbine for given tank volume of air to charge the battery.	S1/S2	0,13 – 2,5 kW

4.1.5 Energy Storage Integration in Electro-Intensive Industry – Industrial Application

Table 16: End-use specification.

Requirements	BP	IR
	Value/Range	**Value/Range**
Maximum 30-sec Discharge Pulse Current	Not relevant	Not relevant
Rated Power	130 kW	130 kW
Maximum Depth of Discharge	100 %	100 %
Rated Capacity	2,5 kWh	1 kWh – 5 kWh
Expected life cycles	4000	4000

Table 17: General requirements.

Requirements	Short description	Scenario	Value/Range	Type[i]
Output Power	Output power has to be immediately available when requested at the maximum value.	S1	2700 [kW]	T-P-O

[i] The type of requirement could be: technical (T), performance-related (P), safety (S), integration requirement (I). Moreover, would be worth to specify to which component it is referred: battery (B), inverter (I), overall system (O), controller (C), etc. Feel free to add others.

Table 18: End-use application linked KPIs.

KPIs	Short description	Scenario	Value/Range
Time response	It's the time that passes from the reception of the set-point (either settled by the users or triggered by an external event) and the achievement of that power level at the ESS output.	S1/S2	60 seconds

4.2 General specification of LOLABAT's battery pack prototypes

Regarding the preliminary specification of the battery pack prototypes to be considered within the scope of LOLABAT, the main technical characteristics are highlighted next.

Table 19: Summary of the specifications of LOLABAT's battery pack prototypes.

End-use application	Hybridisation of Hydro Power Plants	Smart Distribution Grid Management	Energy Balancing in Smart Buildings	Energy Storage for Remote Autonomous LV Supply Solutions – Industrial Application	Energy Storage Integration in Electro-Intensive Industry – Industrial Application
End-user	SuperGrid Institute	EDP Labelec	UniGenova	UniGenova + SIT	KME + RINA-C + SuperGrid Institute
Nominal capacity (Ah)	100	100	100	100	100
Nominal voltage (V)	100	100	100	25	100
Energy (kWh)	10	10	10	2,5	10
Power (kW)	10	10	10	0,13	10
Configuration	8 modules in series (64S) 8 cells in series per module	8 modules in series (64S) 8 cells in series per module	8 modules in series (64S) 8 cells in series per module	2 modules in series (16S) 8 cells in series per module	8 modules in series (64S) 8 cells in series per module
Dimensions per module (mm)	231,5 x 240 x 292	231,5 x 240 x 292	231,5 x 240 x 292	231,5 x 240 x 292	231,5 x 240 x 292
Volume of the battery pack (m^3)	0,130	0,130	0,130	0,032	0,130
Weight of the battery pack (kg)	200	200	200	50	200

5 Conclusion

This report includes all the initial inputs, in terms of end-use specifications, high-level requirements and validation characterisations, to feed the next phases of the project, focused on the solution's improvement, prototype's full characterisation, concept and design, and eventually the demonstration implementation and performance assessment.

This report is based on several alignment discussions within the project's consortium, namely between the end-users and the solution providers, with the objective of providing specifications as much detailed and unified as possible. However, achieving a consolidated definition of specifications is not straightforward, due to the variety of end-use applications. It should be highlighted that the specifications proposed for LOLABAT prototypes could be not enough mature concerning the industrial applications on a larger scale. Nevertheless, the demonstrations that will be realised in WP6 through the battery packs of up to 10 kWh, allow to better define the upscaling requirements from TRL 5 towards an industrial scale. Increase in the precision of the validation scope, by defining more detailed testing procedures also considering the simulation-based validations, targeting the scaling-up of the prototype assessment, e.g., emulating an industrial relevant testing scenario, can be considered as a first action for the performance demonstration and lab testing phase. Following this initial characterisation of the end-use applications envisioned, detailed test plans, including compliance (with the specifications) and performance (according to the testing scenarios) tests, should be considered within the scope of WP6.

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Appendixes