Whitepaper on contributions of the **H2020 RESOLVD** project to standardization and regulation

ICT services and energy storage **for increasing renewable hosting capacity** of LV distribution grids.

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Acronyms and abbreviations

AMI	Advanced Metering Infrastructure
BMS	Battery Management System
BRP	Balance Responsible Party
BSS	Battery Storage System
CAPEX	Capital Expenditure
CDM	Canonical Data Model
CEC	Citizen Energy Communities
CEP	Clean Energy Package
CIM	Common Information Model
CPO	Charge point operators/owners
DAB	Dual Active Bridge
DER	Distributed Energy Resources
DG	Distributed Generation
DSO	Distribution System Operator
e-Directive	Directive EC 2019/944
EF	Energy Forecaster
EPRI	Electric Power Research Institute
EV	Electric Vehicle
e-Regulation	Regulation EC 2019/943
ESB	Enterprise Service Bus
ESS	Energy Storage System
EU	European Union
FCR	Frequency Containment Reserves
FDA	Fault Detection Application
GIS	Geographic Information System
GOS	Grid Operation Scheduler
HC	Hosting Capacity
ICT	Information and Communications Technology
IDPR	Intelligent Distribution Power Router
IEC	International Electrotechnical Commission
ILEM	Intelligent Local Energy Manager
IoT	Internet of Things
KPI	Key Performance Indicator
LV	Low Voltage
MDMS	Meter Data Management System
MV	Medium Voltage
NC	Network Code
OPEX	Operational Expenditure
PCS	Power Conversion System
PED	Power Electronic Device
PFS	Power Flow Simulator
PGM	Power Generating Module
PV	Photovoltaic
PMU	Phasor Measurement Units
PSA	Power Sharing Algorithm
QoS	Quality of Service
REC	Renewable Energy Communities
RES	Renewable Energy Sources
RfG NC	Requirements for Generators Network Code
RTU	Remote Terminal Unit
SaaS	Software as a Service
SCADA	Supervisory Control and Data Acquisition system
SGAM	Smart Grid Architecture Model
SOA	Service Oriented Architecture
TOTEX	Total Expenditure
TSO	Transmission System Operator
VPP	Virtual Power Plant
vRES	Variable Renewable Energy Sources
WAMS	Wide Area Monitoring System

Contents

1 Introduction

1_1 The context: the RESOLVD H2020 project

The RESOLVD project[1] is coordinated by the University of Girona and aims to contribute to setting the next generation of competitive technologies and services for smart grids addressed in the topic LCE-01-2016-2017 (Area: 4- Intelligent electricity distribution grid).

The objective is to improve the efficiency and the renewable energy hosting capacity of distribution networks, in the context of highly distributed renewable generation by introducing flexibility and control in the low voltage grid.

An innovative advanced power electronics device, with integrated storage management capabilities, will provide both switching and energy balancing capacities to operate the grid optimally. Continuous power flow control between storage and the grid will result in a flatter and reduced demand curve at the substation level with an associated loss reduction and improved voltage control and quality of supply.

The enhanced observability of RESOLVD provided through cost-effective Phasor Measurement Units (PMUs) and state-of-the-art short-term forecasting algorithms that predict demand and renewable generation will permit a reduction of uncertainty in grid operation and an increased efficiency. RESOLVD proposes hardware and software technologies to improve low voltage grid monitoring with wide-area monitoring capabilities and automatic fault detection and isolation.

This improved observability and monitoring system, combined with the capability of actuating on the grid, will benefit from robust scheduling methods to support self-healing and grid reconfiguration. RESOLVD will allow efficient grid operation and a maximised renewable hosting capacity. The integration of these technologies, allowing interoperability with legacy systems and third parties in a cyber-secure way, envisions new business models that will be analysed during the project.

1_2 Objectives

The main objective of this whitepaper is to collect the most important insights of the RESOLVD project. It summarizes the needs and expectations of the involved sectors to understand well the context of the project. Then, the RESOLVD technology solution is presented, both the software as well as the hardware solution. Subsequently, the analysis of the current regulation and the upcoming regulation initiatives are presented and analyzed. Finally, as a specific outcome of this report, recommendations to standardizing and regulatory bodies are provided.

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[1] https://resolvd.eu

2 Needs and expectations from involved sectors

2_1 Background

Distribution networks were initially designed to transport electricity unidirectionally, from generation (which can be scheduled with high predictability) through the transmission grid to "passive" customers. Introduction of distributed generation (DG) in the distribution network has led to a significant impact on the power flow and consequently, in the voltage (quality of supply) and current (congestion) conditions, which affects various parts of the utility/consumer equipment and protection devices. It should be noted that distributed generation can be both from traditional fossil fuel-based technologies or renewable generation technologies. This report focusses on the renewable generation technologies segment of DG. To cope with challenges arising from renewable DG, new solutions are being developed under the umbrella of smart grid technologies. DG, together with distributed energy resources like electric vehicles (EV) and various energy storage technologies have led to the emergence of new stakeholders (which can also be called new market actors) in the energy domain. Prosumers, aggregators, and charge point operators are few such new stakeholders. Energy transition has its challenges and is redefining the roles of different stakeholders. To address the challenges which come with the energy transition, the needs and expectations of various stakeholders have to be reassessed. This shall provide critical insights into what technologies would be required in the market in the near future.

This section provides insights into different stakeholders, which are impacted by the introduction of DG in low voltage (LV) networks. Relevant stakeholders are listed, and their needs are highlighted. Further stakeholders' narratives are provided, which forms reasoning behind their needs and throw light on what type of novel solutions they expect in the market. This is followed by a section that provides results of stakeholder interviews conducted so far in the RESOLVD project. The work presented here is based upon deliverable D6.1 – Stakeholders, actors and roles [1] (hereafter D6.1) and D6.2 – Stakeholders, actors, and roles, Final Version [2] (hereafter D6.1).

2_2 Stakeholders involved

An ad-hoc method was adopted to identify relevant stakeholders for the project outcomes. Respective technology developers in the project were asked to identify stakeholders that could be impacted by their technology. Based upon these exercises, pertinent stakeholders were identified, and an in-depth stakeholder analysis was performed to identify sources that could support the novel technologies in the market and elements which could hinder their market entry. The stakeholder analysis was performed based upon methodologies proposed in [3], [4]. For the scope of this report, stakeholders commercially affected by the introduction of DG in LV network are presented in Table 1, together with their market needs and expectations. Stakeholder's expectations from novel technologies are described using narratives to highlight solutions stakeholders are looking for. Both stakeholders need and expectations are collected using literature study and analysing business goals through respective web pages of stakeholders. The list presented here is a non-exhaustive, and the aim is to capture stakeholder's evolving expectations in changing the LV grid environment. Detailed stakeholder analysis, on which this work builds, can be found in [1], [2].

Table 1

Stakeholder needs and expectations

Needs	Narratives / expectations
Prosumers	
- Higher integration of self-generated electricity - Better information for making decisions on investments in renewables - Lower electricity price/ grid tariff	Prosumers are those entities that both produce and consume energy. Prosumer's objectives can be to maximize self-consumption, and/or minimize electricity-related costs, and/or capitalize on energy flexibility (hereafter just flexibility). To achieve these objectives, storage technologies and accurate forecasting tools are crucial. A prerequisite for being able to capitalize on flexibility at the LV grid level is that distribution system operators are able to forecast when and where flexibility is required.

Needs	Narratives / expectations
Distributions system operators (DSO)	
· High-resolution grid monitoring · Better grid management for improved reliability and power quality · Reducing losses · Delaying upgrade investments · Improved cybersecurity measures High-resolution grid monitoring · Better grid management for improved reliability and power quality · Reducing losses · Delaying upgrade investments · Improved cybersecurity measures	The growing presence of DG in the distribution networks is creating new challenges for network operators that were not present before. DSO want to cope up with such challenges without losing revenues and with minimal additional investments. They want to improve their profitability using digitization and avoid further investment in infrastructure upgrades. Moreover, they want to improve their profitability using digitization and avoid further investment in infrastructure upgrades. A detailed report on DSO challenges can be found in Deliverable D1.1 – Use cases definition [5]. Here key challenges faced by DSO are explained in brief. DG is making current flows highly variable in both magnitude and direction, resulting in a growing tendency of peaks in magnitude and duration that can exceed the thermal rating, and that can difficult the injection of those peaks of distributed energy resources (DER) generation. Such higher power flows also may increase distribution losses, and the transformer can experience saturation that leads to Joule losses. The presence of DG can make compliance with voltage regulation more complex. For example, injecting the power in the LV grid by DG increase the voltage level in the point of connection, which can lead to a surge, which is a violation of the voltage upper threshold. Similarly, the opposite situation of voltage drop can also occur due to the intermittent nature of DG. Intense voltage swells (surges) can result in the activation of the overvoltage protections, while voltage drops can provoke malfunction of devices. Voltage swings beyond normal operating ranges lead to supply interruptions and are related to the overall grid reliability. Insufficient power quality can be caused by failures and switching operations in the network (voltage dips and transients) and by network disturbances from loads and nonlinear devices (flickers, harmonics, and phase unbalances). Excess reactive power consumption is also included in this category. Uncontrolled islanding is one of the riskiest situations that can occur in the LV grid. This means that part of the network, despite being disconnected from the main grid (due to maintenance activity or protection elements actuation after a fault), keeps being powered by DG sources in an uncontrolled way. Non-technical losses (e.g., fraud) apart from being responsible for commercial losses also lead to measurement errors that can substantially affect the accuracy of predictions required for the optimal and efficient operation of the grid. Challenges associated with DG can be overcome by reinforcing the grid (as done traditionally); however, it is an expensive option. The alternative to this would be the smart management of the grid. This requires higher LV grid observability and tools to intelligently manage LV grids. Finally, increased information and communications technology (ICT) services, typical of a smart grid, with its extended interconnections, represent a large cyber-attack surface. A DSO needs measures to prevent such attacks, which could jeopardise the proper functioning of the LV grid.

Needs	Narratives / expectations
Balancing Responsible Parties (BRP)	
▪ Minimise imbalances	BRP have a financial obligation to maintain generation/consumption as committed in the market [6]. BRP have contracts with the transmission system operator (TSO) for this obligation. In the occurrence of imbalances, fines are levied, or BRP take services from balance service providers at a cost. The introduction of intermittent DG increases imbalances and affects the profitability of BRP. Flexibility would help BRP to reduce their imbalances and thereby improve profits. Such energy flexibility can be facilitated through demand-side management and appropriate storage technology, which can respond to BRP needs within the required time period. Currently, BRP are not directly involved with DSO, however in the future with novel technologies, DSO would be able to facilitate flexibility services to BRP. Furthermore, better forecasting tools help in reducing imbalances by planning bids better in the market.
Aggregators	
▪ Capitalize on flexibility ▪ Better demand and generation forecasting ▪ New markets and market actors to provide products and services.	Aggregators are relatively new market players, who operate in the demand-side, to create new products and services by aggregating demand and generation [7]. Flexibility is one of the key products which is highly relevant for aggregators and would be necessary to efficiently integrate renewables and increase efficiency of the electric power system. As such, they are actively looking for markets and players where they can provide value by facilitating flexibility. Aggregators can offer flexibility, at different levels of the electric power system, by controlling demand, generation, and storage assets present in the grid through communication interfaces. The emergence of the Internet of Things (IoT) and the development of the smart appliances market together with maturity of smart metering infrastructures have provided aggregators with new opportunities to control devices that traditionally were difficult to manage. Storage and EV have become an important source of flexibility, which can either be owned by aggregators, or they can manage their customers' storage to provide value on top of it. For providing flexibility related services, forecasting tools play a critical role as they can significantly impact the risk associated with not meeting the commitments done in the market.

Needs	Narratives / expectations
Retailers	
▪ Better predictions for making low-risk trading decisions	Retailers aim to maximize their profits by buying energy at the wholesale market and selling it to customers with a profit margin [8]. If retailers make inaccurate demand predictions, they are likely to lose money. Forecasting tools thus are important for running a successful business for retailers. Advanced energy forecasting tools can equip retailers with better predictions of both generation and demand, thereby enabling them to trade more efficiently. With increasing DG share significance of accurate forecasting is rising as well. Aggregation, at an area (neighbourhood, substation, feeder, etc.) level, reduces forecasting uncertainty, and this makes real-time data availability and access a must. New technologies related to digitization and storage are emerging in the market, and retailers need to adapt their business by providing new, better, and more customer focussed energy services and products. In many ways, challenges to the business of retailers are like that of aggregators, and many new services for customers overlap. Currently, it is not clear how the business of retailers and aggregators will be differentiated in the future.
Distributed generation owners	
▪ Improved integration of local energy production to increase profitability	Such stakeholders want to maximize their profit by feeding as much electricity generated as possible to the grid [9]. Although DG covers both renewable energy technologies and traditional energy generation technologies, the focus here is on renewable-based DG. In the event where renewable energy production is higher than the demand, the DG has to be curtailed to maintain grid stability, and this results in commercial losses. In general, the higher the match between supply from DG and local demand, the higher the amount of electricity from DG, which can be absorbed by the grid. DG feed-in can be maximised by using storage technologies or if demand-side management is carried out.
Energy communities	
▪ Increased consumption from local energy resources ▪ Improved grid reliability ▪ Economic benefits from flexibility ▪ Possibly lower electricity price/grid tariff	Clean Energy for all Europeans Package (CEP) by the European Commission [10], [11]and in particular Article 194(2 defines two types of energy communities: Renewable energy communities (REC) and Citizen energy communities (CEC). The scope of these two types of energy communities is different, but their primary purpose is to provide environmental, economic or social benefits for its members or for the local areas where it operates, rather than financial profits. Energy communities may own DG and aim for having more decision-making power over their energy needs, be as self-dependent as possible, and reduce overall energy-related costs. Improved forecasting, improved storage utilization [12], [13], and access to flexibility have shown to be effective tools to achieve energy communities' goals. Furthermore, with advanced LV grid management tools community would be able to integrate more DG with minimal grid-related costs.

Needs	Narratives / expectations
Building operators, microgrid operators, and industries	
· Increased attractiveness through green profiling and innovative energy solutions · Possibility to trade energy flexibility assets · Better information for making decisions on investments in renewables · Efficient management of facilities - reduced electricity costs	Their overall objective is similar to that of energy communities. Storage, forecasting, and data analytics capabilities would be beneficial for them for scheduling of consumption, and generation (if it exists) and to maintain quality of supply. This would also minimize electricity bills. Furthermore, such players could capitalize by providing flexibility to DSO or other customers. A prerequisite for this is that DSO can forecast the need for flexibility and identify where it is required. Requirements of building technical codes on isolation, directives on self-consumption and renewable generation or the development of the smart readiness indicator draws a new framework for considering buildings (or their operators) a player.
Charge point operators / Charge point owners (CPO)	
· Lower peaks resulting in lower connection charges · Lower energy costs · Better management of flexibility available from EVs	CPO are relatively new market players who own and/or operate multiple EV charging points. Various ownership models currently exist in the market for such stakeholders. Operators may just provide charging infrastructure or be just be responsible for managing charging for infrastructure owners, or it can provide complete solution covering all value chains of EV charging (infrastructure, operation, and maintenance) [14], [15]as electro-mobility is, requires a global approach to ensure that all the involved actors obtain a benefit. Although electric vehicles (EVs. The main business objective of this stakeholder is to provide charging services to EV owners whenever required. To maximise profits and provide lucrative offers (like lower cost of charging) to EV owners, such stakeholders try to reduce the operating cost of charging. This can be done through smart charging to reduce peaks, to charge EVs when electricity prices are lower, and maximizing self-consumption (if they have local generation). Better forecasting and data analytic services would be beneficial for scheduling the charging of EVs and to avoid non-availability. As CPO operates large electrical loads, there exist new possibilities for charge point operators to capitalize on flexibility services.

Needs	Narratives / expectations
Suppliers (hardware, software, ICT infrastructures)	
· Capitalise on new technologies related to storage, and ICT infrastructures · Gain a competitive edge in the market with novel technologies in their portfolio	Self-explanatory.
Battery manufacturers/suppliers	
· Increase battery sales	Such a stakeholder's business ambition is to increase sales of batteries. As such, they will be interested in any technology which improves the value of battery solution to their end customers. This could be improved battery management, the possibility to reuse batteries, providing novel services from batteries (like flexibility) in the market.
Transmission system operators (TSO)	
· Better grid management / reliability · Receive balancing services at lower cost	TSO's main goal is to maintain the balance between supply and demand and assure the availability of supply. With the growth of DG penetration, TSO requires more flexibility to maintain the balance [9]. As such, they are investigating cooperation with DSO to procure flexibility as well as allowing new market players like aggregators, which can supply the needed flexibility.

The above table covers the stakeholders who are commercially affected by the energy transition. However, it should be noted that there are other stakeholders who have a presence in the energy domain but have no commercial interests. These stakeholders are the European Union (EU) Commission, national governments, municipalities, policymakers, regulatory bodies, and research institutions. As these are not commercially affected, these are not covered here.

2_3 Stakeholders interviews

To further solidify findings from stakeholder analysis, face-to-face and telephonic interviews have been conducted with industry experts and members from the GEODE association. GEODE members comprise of European independent distribution companies of gas and electricity representing more than 1200 companies in 15 countries, both private & public owned. Together they serve a population of 100 million people in the EU and represent strong voices of medium and small DSO across Europe [16]. GEODE was targeted for interviews because DSO are prime beneficiaries of RESOLVD project. GEODE was targeted for interviews because DSO are prime beneficiaries of the RESOLVD project. Interviews aimed to understand the viewpoint from the influential stakeholders about issues addressed by RESOLVD and market perspectives on the project outcomes.

2_3_1 Interview questions

Interview questions were framed to collect viewpoints of industry experts on next-generation technologies (both hardware and software), which would be needed for efficient operations of future smart grid. The scope of these questions was limited to improving the hosting capacity of the distribution grid. The questions focus on three aspects: 1) current and future challenges of DSO under DG, 2) identification and validation of value propositions regarding advanced distribution management software tools, higher distribution grid visibility, novel power electronics for multiple storage management, and 3) how experts perceive the role of DSO in future smart grids.

2_3_2 Interviewee background

In total, 7 Interviews were conducted, which consisted of high-level industry experts from different stakeholder classes. Interviewees represented DSOs, regulatory bodies, and storage solution providers. Norway, Finland, Austria, and Germany were the geographic locations where these stakeholders are located. It should be noted that the experts, apart from representing respective companies, are also distinguished members of associations like GEODE.

2_3_3 Key outcomes of the interviews

- Everyone agreed that solutions to actively manage the LV grid are required, but when such solutions are needed depends upon DG penetration in a country as well as how much investments have already been done on grid upgrades. For example, in Finland, investments have already been made at the LV level concerning infrastructure and observability. So, the next investments are expected to happen at the medium voltage (MV) level. In general, a trend is being observed in increased costs associated with electricity distribution and transmission. Rural areas where grid connections are weaker, and larger surfaces for renewable energy sources (RES) installation are available, would require smart grid technologies first.

- Capital expenditure friendly regulation, as opposed to operational expenditure friendly one, is a major barrier for investment in smart technologies. To support innovations that enhance operational efficiency in the LV grid, regulations need to be adjusted accordingly.

- Flexibility services are effective in managing the grid; however, incentives are required, which shall allow stakeholders to capitalize on such services. Time variant tariff scheme is one such incentive but has not been implemented for end-users in most of the EU countries. Further standardisation on market mechanisms are required to facilitate the exchange of flexibility services between various market participants.

- Experts foresee that regulations will not allow DSO to own storage, and in general, there is consensus that DSO should procure storage services through a market mechanism. Also, it is expected that the battery solution will become a very lucrative option in the next 2-5 years. Need for advanced grid operation services like anti-islanding and self-healing will arise after 5 years. Phasor measurement units market demand is expected to arise in the long term (beyond 5 years) and will depend on economic feasibility rather than technical.

- Technical losses are not a major concern in any of the country interviewees come from. While non-technical losses are mentioned as a non-issue in all represented countries. In Finland, there are small non-technical losses, but it is expected to be solved through smart meters and data analytics. Data analytics solutions to identify non-technical losses are already available in the market.

- Reactive power management is a relevant issue faced by DSO across different countries, and interviewees agree that this can be solved through power electronics and battery technologies.

- When asked about business models for smart technologies, including storage, all the stakeholders had different views but agreed that regulation should play a vital role in deciding what business model will work.

- Regarding the future market role of DSO, the opinions were split between different interviewees. Everyone shared the view that the role of DSO will be similar as it is today, but it has to play a more active role in the future. Here again, regulations have to be clear on what are market boundaries for DSO business. Stakeholders agree that there is a need for flexibility market, which is local, but there is no clarity at the moment if DSO should become a local market facilitator for flexibility. Further, stakeholders believe that small DSO must merge because they will not have the capacity to actively supporting the new flexibility markets.

  - A general observation is that for investing in new technologies and changing business models, stakeholders are waiting for regulators to lead the way. Different stakeholders are testing new technologies at an experimental level to understand its importance and already have an opinion on what technologies might be successful. However, when it comes to business models, there are no strong opinions.

3 The RESOLVD solution

This section covers a general identification of the main elements which allow the hosting capacity increment and a summary that focuses on the solutions which are proposed in the RESOLVD project.

3_1 Use cases of the RESOLVD solutions

The RESOLVD analysed a set of use cases (Table 2) that can potentially improve the hosting capacity of low voltage grids.

Table 2

List of use cases of the RESOLVD project

Use case number	Use case Title	Contribution to the improvement of the DG hosting capacity
HLUC 01	Prevention of congestion and over/under voltage issues through local storage utilization and grid reconfiguration	The growing presence of DG in the distribution networks has the effect of making current flows highly variable in both magnitude and direction, resulting, in general, in a growing tendency of peaks in magnitude and duration that can exceed the thermal rating. These situations are also referred to as “congestion events.” Thanks to RESOLVD, it is possible to prevent these events, by the forecasting demand and generation, and consequently using the energy storage and the reconfiguration of the grid, to mitigate the congestions.

Use case number	Use case Title	Contribution to the improvement of the DG hosting capacity
HLUC 02	Voltage control through reactive power injection or consumption	The presence of DERs can make compliance with voltage regulation more complex. Injecting the power in the LV grid by DGs increase the voltage level in the point of connection. If, at this point, the grid voltage is already close to the upper limit of the allowed band, there will be a surge, which is a violation of the upper voltage threshold. On the other hand, if the voltage level in the grid is kept too low, to prevent surges, the opposite situation might arise: an important load connected to the grid can reduce the voltage at the connection point, provoking a voltage drop that is a violation of the lower voltage threshold of the allowed band. Traditionally, voltage regulation is not executed at the secondary substations (MV/LV transformer) level. Thanks to the power electronics device (PED) offered by the RESOLVD solution, it will be possible to correct the voltage level when a voltage surge or droop is detected and avoid in this way the supply interruptions caused by the automatic disconnection of the voltage protections.
HLUC 03	Improving power quality and reducing losses through power electronics	Apart from large voltage drops to near zero and congestion problems, grids suffer from smaller voltage deviations. The latter deviations are aspects of power quality. Power quality refers to the degree to which power characteristics align with the ideal sinusoidal voltage and current waveform, current and voltage unbalance. Insufficient power quality can be caused by failures and switching operations in the network (voltage dips and transients) and by network disturbances from loads and nonlinear devices (flickers, harmonics, and phase unbalances). Photovoltaic (PV) plants usually need to be coupled with inverters to provide AC; thus, they are major inducers of power quality issues in the grid where they inject power. The PED, developed in the RESOLVD project, is able to modify the waveform, according to the power quality level requested, thus confining the issues to the area where the DG is located.

Use case number	Use case Title	Contribution to the improvement of the DG hosting capacity
HLUC 04	Reduction of power losses through local storage utilization	The increasing penetration of renewable DG can be beneficial concerning the objectives of improving the energy sector's global efficiency and reducing greenhouse gas emissions. For example, the possibility to consume locally the energy generated by the DERs permits to avoid transport losses in the grid. The consequential reduction of back up generation leads to higher efficiency of the overall system. Nevertheless, given the fact that renewable DERs mainly consist of non-dispatchable energy, local load, and generation curves throughout the day (or the week) might not be instantaneously balanced. It is the case, for example, for the high PV generation episode during central hours of the day, which coincides with low demand in residential areas. The challenge is to differ the consumption of the energy being produced during these episodes by dimensioning and managing local storage installed in the LV grid.
HLUC 05	Self-healing after a fault	In the electrical systems, faults are common fact, and especially at LV level occur relatively frequently. Their origin can be associated with grid asset malfunction, physical intervention in infrastructure, or human misuse. The presence of DERs produces more events of over/under-voltage, thus activating the protections and causing a supply interruption. RESOLVD objective, in the presence of a fault, is to propose and execute possible reconfigurations of the network, to reconnect as many customers as possible, and reduce the duration of the interruption.
HLUC 06	Power management in intentional controlled island mode	The presence of DERs may lead, in the future, to a situation in which the grid can work in two modes: connected to the main grid or islanded from it. In the RESOLVD pilot, this second and less conventional situation will be tested. The power source, in this case, will be the battery system.
HLUC 07	Detection and interruption of unintentional uncontrolled islanding	Uncontrolled islanding happens when a part of the network, despite being disconnected from the main grid (due to maintenance activity or protection elements actuation after a fault), keeps being powered by DERs in an uncontrolled way. This phenomenon can occur in cases of overcurrent (anti-islanding) protection devices failure or when there is a balance between load and generation within the isolated grid. In this second situation, the network current never reaches the levels that would activate the overcurrent anti-islanding protection. As a consequence, parts of the equipment could be damaged, and the safety of people in contact with the grid lines (e.g., field operators) cannot be guaranteed.

3_2 The RESOLVD platform as a software solution

3_2_1 Overview

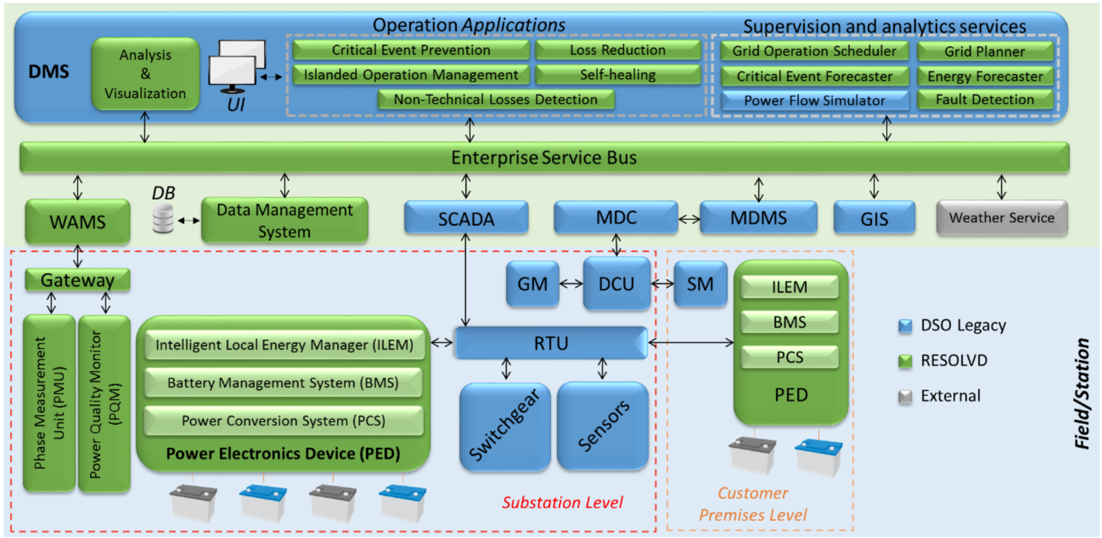
RESOLVD platform is a software solution that aims to integrate the advanced functionalities of active management and monitoring of the low voltage grid developed in the project. The platform is comprised of the following set of tools:

- Enterprise Service Bus (ESB), offering transparent integration with:
    - Legacy systems of the DSO (i.e., MDMS, SCADA, GIS),
    - Power Electronic Devices (PEDs),
    - External systems (i.e., Weather services),
    - Wide Area Monitoring System (WAMS);
- Data Management System, offering storage of data from heterogeneous data sources and different data types (e.g., grid model data, smart metering data, weather station data, load consumption/generation forecasts), offering validation and homogenization of data and guaranteeing accessibility with specific quality of service (QoS) characteristics;
- Supervision and Analytics Services, offering grid monitoring and optimal operation abilities, through advanced forecasting, grid event detection and optimization of grid asset dispatch, as a service;
- Operation Applications, providing the end-user interface for visualizing the status of the grid, the parameterization of the different business flows of the advanced grid functions, as well as for analysis of the impact of asset dispatch in the grid's operation (through key performance indicators (KPIs).

A high-level architecture of the solution is presented in Fig. 1, detailing the interaction of the above tools with their ecosystem.

Fig. 1

RESOLVD High-Level Architecture



3_2_2 Specifications

3_2_2_1 Design Principles

The architectural design is based on the principles of the SGAM (Smart Grid Architecture Model) and has implemented as Service Oriented Architecture (SOA) aimed to be provided as a Software as a Service (SaaS) solution with integration of services through an enterprise service bus SGAM design assures the interoperability at the different layers (component, information, communication, functional, business) through the adoption of the corresponding standards. Thus, the Common Information Model (CIM) [17] is the basis of the RESOLVD data model and supports the architectural design. Cybersecurity analysis has been performed at the very early stage of the design.

3_2_2_2 Integration

The design leverages IEC 61968-1 [18] as a guideline for the integration of legacy systems of the DSO. A middleware solution (ESB) was designed that integrates the systems at the control centre and facilitates information exchanges through the provision of standardised interfaces, service mediation, and orchestration, message transformation as well as other functionalities that allow seamless integration.

3_2_2_3 Data Management & Analysis

Different technologies offering storage and analysis of heterogeneous data, available at different rates and with different granularities were considered in the design of a central data repository (Data Management System), incorporating:

- A Triple store (e.g., Apache Jena [*https://jena.apache.org*]) for storing and querying CIM data in their native format,
- NoSQL solution (e.g., Apache Cassandra [http://cassandra.apache.org/]) for storing heterogeneous time series data,
- Data processing tools (e.g., Apache Spark [https://spark.apache.org]) for handling complex queries;

3_2_2_4 Forecasting

The RESOLVD platform integrates specific energy forecasting (Energy Forecaster - EF) services devoted to improving operation management. In particular, demand and generation forecasting services provide day-ahead forecasting with a resolution of one hour at the consumer connection point. Buses, where multiple consumers are connected, are aggregated as a single one. The output of these services is used to forecast possible critical events (critical event forecaster service in the platform, Fig. 1 in the grid, i.e., congestions and voltage variations affecting the quality of supply.

- *Demand forecasting service:* Data from smart meters, and managed through the advanced metering infrastructure (AMI) and meter data management system (MDMS) infrastructure, are leveraged using machine learning techniques (i.e., random forests algorithm due to its accuracy). Two different strategies are proposed depending on when the forecast starts and availability of weather forecast:

    - Day-ahead: Executed anytime to forecast the demand for the next day starting at 00:00 and requires data from the past days and next day weather forecasting.

  - Next-sample: A purely regressive method that allows forecasting the next 24 hours (sliding time window). Its use mainly focuses on providing the next sample (+1 hour), since the quality reduces over the prediction window.

- *Generation forecasting service:* Focused on PV production - following the requirements of the project's validation environment – leverages solar irradiance data and the reduction of the problem to the basic concepts of PV panel operation.

- *Critical event forecasting*: This service takes as inputs the results of the above energy forecasting services and via simulation of the power flows in the grid and analysis of the currents and voltages and their specified operation limits, detects possible congestions (critical line events) or over/sub-voltages (critical bus events). The module returns a list of the event specifying the time, magnitude, and the affected lines or buses in the grid.

3_2_2_5 Grid operation scheduling

RESOLVD incorporates an optimisation service (Grid Operation Scheduler – GOS) to support the optimal operation of low voltage smart grids with the presence of storage and renewable generation. The service offers as output the day-ahead scheduling of switchgear and the setpoints schedule of the battery (installed in the secondary substation) satisfying different optimisation objectives: avoiding congestions, minimising the reducing energy losses, and maximising the local consumption of renewable energy produced in the grid. In the project, the reconfiguration possibilities are being tested with two switchgears that allows the connection/disconnection of two feeders from respective secondary substations and a third switchgear that connects intermediate buses of those feeders, allowing different configurations including island operation with the batteries installed in the system.

3_2_2_6 Fault Detection

Fault Detection service is an extension of the wide-area monitoring system that exploits data generated by PMUs installed in the grid to detect sudden variations of phasors. Two strategies are implemented: one is a multivariate statistical monitoring system that gathers correlation among the monitored variables in the PMU network (multiple PMUs) to build statistical models during normal operating conditions and further exploiting those models to detect abnormal changes (in a statistical sense) in the data structure (e.g., faults, or sudden changes on load or generation). The second strategy follows event detection performed by PMUs and consists of pinpointing the location of the fault, which requires two-end measurements and the grid model.

3_2_2_7 User Interface

Operation applications aim to offer an intuitive and dynamic user interface for the operation for the realization of the following functionalities:

- Critical Event Prevention, for the prevention of critical events through the utilization of storage and switching actions,
- Island Power Management Application, in charge of power management of an uncontrolled islanding situation,
- Loss Reduction Application, aiming at reducing the grid losses through local storage utilization,
- Fault Detection Application, in charge of detecting, classifying and localizing a grid fault, based on real-time signal processing of field data.

3_2_2_8 Security

A centralized solution offering authentication, authorization and accounting functionalities, enabling the control of user access to network resources, as well as tracking of relevant activities was designed and implemented aiming to facilitate the integration of security mechanisms to mechanisms in the network of the different services developed or integrated. The identification of security requirements was based on a thread analysis, which identified several mitigation actions, e.g. segregating communications, using encryption or redundancies, use of specific cypher suites.

3_3 The PED as a hardware solution

3_3_1 Introduction

The Power Electronics Device is equipped with local energy storage to provide flexibility to low voltage grids. As an energy storage system, it can enhance the operation and power quality of low voltage grids by, for instance, contributing to the security of supply for costumers in case of grid eventualities; exchanging active and reactive power flows with the network following economic and / or technical criteria; and compensating current harmonics through cables affecting customers. Furthermore, an energy storage solution in the distribution grids can also enhance the hosting of renewables, reduce the impact of electric vehicles, manage the grid assets congestion, and be an energy back-up for utilities and communities.

The PED has its particular special features, and one is the hybridization of energy storage. This refers to the inclusion of different types of batteries to take advantage of the main performances of each one depending on the service to provide. The main idea is to achieve a cost reduction of the whole energy storage solution, fulfilling the divergent power and energy requirements in a single solution, as long as it guarantees the batteries' life maximization and their optimal operation.

The PED is composed of two main subsystems, which are framed into a power plane and a management plane. The components included within the power plane are those exchanging power with the external network the PED is connected to. So, in this regard, there are the Power Conversion System (PCS) and batteries. The power plane of the PCS is modular to integrate different batteries of diverse characteristics. In detail, the PCS architecture for modular and hybrid energy storage consists of front-end inverter modules together with parallel dual active bridge modules. This power architecture offers excellent reliability, efficiency, compactness and behaviour under grid faults. Besides, it offers excellent flexibility while integrating different batteries of different characteristics.

The frond-end inverter module is featured by its high modularity, reliability, efficiency and compactness for the reason that they include advanced silicon carbide transistors technology. Besides, the inverters modules are capable of providing advanced services such as reactive power, harmonics and unbalances compensation as well as grid forming after a blackout situation. The dual active bridge module (so the dc-dc converter integrating each of the batteries into the PED) is also characterized by its high modularity and efficiency. They also include silicon carbide transistors technology and galvanic isolation through a high-frequency transformer for compactness maximization.

Within the management plane mentioned above, there are algorithms for managing the internal operation of the PED, as well as the external communication and interfaces and the PED services. The management plane is composed of a front-end application which is called Intelligent Local Energy Manager (ILEM). The ILEM controls the power exchange with the network. It can also decide whether or not following exogenous setpoints in case of eventualities. In this sense, the ILEM has the responsibility of managing a group of heterogeneous batteries optimally according to the operator's setpoints. The solving of such management optimization is solved by the Power Sharing Algorithm (PSA) through a mathematical optimization using diverse and representative time series data on the grid power flows to distribute the scheduled power demand received among the battery types embedded, maximizing the batteries performance and minimizing their degradation. Finally, the PED through the ILEM is operated locally via a web application and/or remotely via Modbus TCP/IP, as a four-quadrant controllable storage system.

3_3_2 PED specifications

The PED is a Power Electronic Device connected (depicted in Figure 2) in parallel and non-intrusive way with the low voltage grid. It is able to provide power quality improvement (active current balancing, reactive and harmonic compensations) and also to dispatch active and reactive power thank to its 4-quadrant operation.

It is featured to its capacity of integrating a Hybrid Energy Storage Solution at different voltage levels with galvanic isolation thanks to its Dual Active Bridges (DABs).

Moreover, the PED integrates an ILEM, who is responsible for managing the Hybrid Energy Storage Solution according to the operator's setpoints.

The whole solution can be operated locally (via a web application) and remotely (via Modbus TCP/IP) when it is managed on a manual way (as a four-quadrant controllable storage system) or a scheduled basis performing the Power Sharing Algorithm.

To conclude, the Power Sharing Algorithm is responsible for distributing the scheduled power demand received among the battery types embedded in, considering different aspects including the performance and degradation of each type.

Fig. 2

PED cabinet without the front door

In particular, the proposed PED for RESOLVD pilot was defined according to the grid consumption and generation of the pilot. The main requirements are listed below:

- AC output power up to 75 kVA for low voltage distribution networks (400 V and 50 Hz)
- 1 DC input power up to 20 kW for a storage system from 315 V to 385 V (in particular a lithium battery detailed below)
- 1 DC input power up to 20 kW for a storage system from 200 V to 270 V (in particular lead-acid battery detailed below)
- Power quality functions: three-phase current balancing and harmonic compensation
- Grid supporting functions: active and reactive power dispatching and reactive power compensation.
- Grid forming (i.e. island mode) and the capability to grid reconnection without blackout.

The electrical specifications of the PED are summarized in Table 3:

Table 3

Electrical specification of PED

Electrical specs		
Inverter stage topology	4-wires 3-phase bridge split capacitor	
AC rated power	75 kVA	
Rated AC voltage (phase to neutral)	400 V (230 V compatible)	
AC Voltage range	85% - 110% (according to EN 50438)	
AC Frequency	50 Hz (60 Hz compatible)	
AC Rated current	108.6 A	
DC/DC stage topology	DAB (galvanic isolation)	DAB (galvanic isolation)
DC rated power	20 kW	20 kW
Rated DC voltage	345 V	240 V
DC voltage range (at rated power)	315 V – 385 V	200 V- 270 V
DC rated current	63.5 A	100 A

In addition, the PED has to communicate with Supervisory Control and Data Acquisition system (SCADA) and battery's battery management system (BMS); the communications and protocols are summarized in Table 4.

Table 4

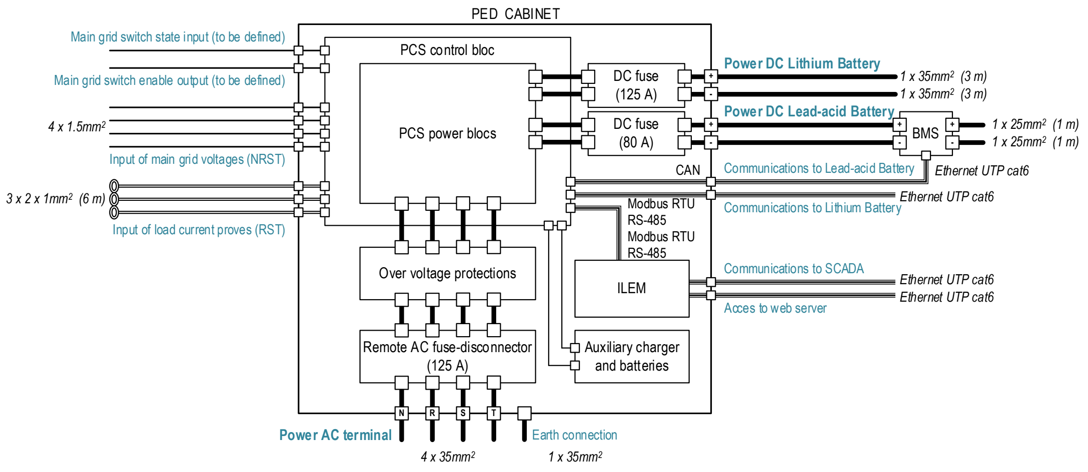
Communications specifications of PED

Communications specs	
Supported protocols	CAN bus, Modbus Remote Terminal Unit (RTU) and Modbus TCP/IP
BMS interaction	CAN bus and Modbus RTU
PED interaction	Locally through web application R (Web application interface attached in the Annex) Remotely through Modbus TCP/IP (Modbus map attached in the Annex)

Finally, Figure 3 details the electrical and communications interactions with the cabinet.

Figure3

PED external connections



To conclude, the PED section, the rest of the mechanical and dimensions specifications are introduced in Table 5 and shown in Figures 4 and 5.

Table 5

Mechanical specifications of the PED

Other specs	
Working temperature	-10 °C – 40 °C
Cooling	Forced-Air
IP and IK protection	IP54 and IK10
Weight AC part	~ 180 kg
Weight DC part	~ 200 kg
Dimensions	1900 mm height x 800 mm width x 400 mm depth

3.3.3 Storage system specifications

The storage system is constituted by two batteries; both are integrated by the PED. The first battery is a lithium battery pack (shown in Figure 4), it is provided by FENECON, and its capacity is about 30 kWh. The rest of the specifications are detailed in Table 6. The second battery is a lead-acid battery provided (shown in Figure 5) by Ultracell, and its capacity is about 18 kWh. The rest of the specifications are included in Table 7.

Table 6

Lithium battery pack specifications

Lithium battery specs	
Manufacturer	FENECON
Model	C PLUS 25
Nominal capacity and voltage	87 Ah (C/3)
Rated voltage	348 V nominal voltage for the whole pack, 3.2 V per cell.
Maximum discharge current	90 A (1C)
Discharge temperature	-15 °C to 50 °C (25 °C recommended)
Charge temperature	0 °C to 40 °C (25 °C recommended)
Efficiency (round trip)	94.7%

Table 7

Lead-acid battery pack specifications

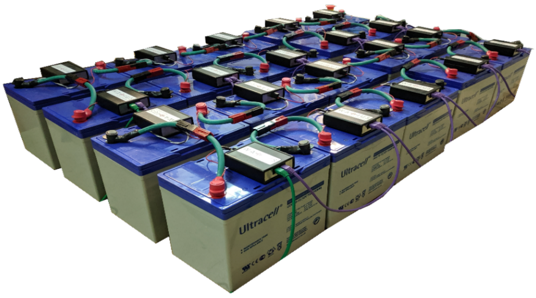
Lead-acid battery specs	
Manufacturer	Ultracell
Model	UCG75-12
Nominal capacity	75 Ah (C/10)
Rated voltage	240 V for the whole pack, 12 V per battery.
Maximum discharge current	900 A
Discharge temperature	-15 °C to 50 °C (25 °C recommended)
Charge temperature	0 °C to 40 °C (25 °C recommended)
Efficiency (round trip)	91.6%[2]

Figure 4

Lithium battery pack

Figure 5

Lead-acid battery pack



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[2] This efficiency has been derived from the information in the datasheet It was not directly included in there.

4 Regulation framework

4_1 The Clean Energy Package

In 2009, the Third Energy Package added to the creation of an internal market the scope of environmental sustainability to align the energy sector with the EU objectives of decarbonization by 2050. The Directive 2009/72/EC [19], in the *Art.3* states: "*Member States shall ensure* [...] *electricity undertakings are operated in accordance with the principles of this Directive with a view to achieving a competitive, secure and environmentally sustainable market in electricity [...].*"

Afterwards, in November 2016 The Clean Energy Package was published as a "recast" of the Third Energy Package, containing a set of regulations and directives to continue the energy transition started back in 2009.

Among the CEP regulations and directives, the ones that refer to the electric sector are the e-Directive (EC 2019/944; [11]) and the e-Regulation (EC 2019/943; [10]***and in particular Article 194(2***), their subject matter and scope are centred in "*setting the basis for an efficient achievement of the objectives of the Energy Union and in particular the climate and energy framework for 2030* (e-Regulation), via the *creation of common rules for all the assets connected to the power system, with a view to creating truly integrated, competitive, consumer-centred, flexible, fair and transparent electricity markets in the Union*" (e-Directive). Besides, they also aim to create models for system operators to cooperate and set fair rules for cross-border exchanges.

The e-Directive and e-Regulation are mainly focused on the creation of markets to promote the energy transition. In terms of market design, there is a group of markets, flexibility markets, that can be crucial to promote the widespread of new agents and technologies in the energy sector [20]. A subgroup of these flexibility markets, the balancing markets, have been promoted on the European roadmap since the start of the deregulation strategy and the Third Energy Package promoted such path via slowly opening the participation on the market to new agents. In the e-Directive**,** the role of aggregators and Energy Storage Systems (ESS), among others, is enhanced being considered frequently as important agents and technologies to regulate for. Also, *the* e-Regulation says, pointing to the same direction, "*safe and sustainable generation, energy storage and demand response shall participate on equal footing in the market* [...]" (Art. 3 (j)).

On flexibility, the e-Regulation starts to focus on smaller loads via the aggregator actor, while at the same time promotes the long-term investments that will still be important for the development of the market (e-Regulation**:** *Art. 3 (e, g)).* This change of scope can also be seen in the e-Directive *Art.8 (2 (k))* where a requirement before authorising the construction of new capacity is to take into account alternatives such as demand response and energy storage.

The e-Directive provision (39) says: *Market participants engaged in the aggregation are likely to play an important role as intermediaries between customer groups and the market*. Thus, the right of all customers to be free to purchase aggregation services is clearly defined on e-Directive: *Art. 13 (1) & Art.15 (2 a)*, the same happens with fair participation of aggregators in the balancing markets (e-Regulation**:** Art. 3 (j)), and demand response through aggregation is promoted together with a defined framework which clearly states that aggregators have the right to enter electricity markets without the consent of other market participants.

Article 32 (2) of the e-Directive starts to define flexibility markets for congestion management, an incipient market for distribution-level ancillary products that shall be ruled by DSO and where MV and LV aggregation and ESSs can play an important role.

ESS-wise, the CEP addresses some of the concerns attributed by stakeholders and researchers to previous directives. One important advance is the official definition of Energy Storage from a technology-neutral approach (e-Directive: *Art. 2 (59)*); furthermore, DSO network planning shall include the use of energy storage (among others) to use as an alternative to system expansion. This is said in e-Directive *Art. 32 (3)* and points towards the need for ESS and other technologies to provide stability to the distribution system. However, the *Electricity Balancing guidelines* [21]Having regard to the Treaty on the Functioning of the European Union, Having regard to Regulation (EC (EC 2017/2195) do not give indications for the creation of standardized Frequency Containment Reserve (FCR) products, the ones in balancing markets where ESS can stand out the most due to their technical capacities.

Article 36 of the e-Regulation states that "*Distribution system operators shall not own, develop, manage or operate energy storage facilities*" to provide services that can be obtained via existing electricity markets. Such a statement follows the willingness of the EU to unbundle the electricity market, and therefore provide a level playing field for all participants, which should lead to a fairer electricity system. As already seen, these statements may lose entity when observing the reality of flexibility market regulations: other than the FCR indeterminacy commented before, non-frequency ancillary services shall also be an important market for ESS. However, it was not until the CEP that the first step towards a defined and harmonized market for these products was set as an objective. And until the mandatory outcomes of the CEP are applied in National laws, a significant amount of time will still pass.

From an active consumer point of view, e-Directive *Art. 15 (5)* addresses one important problem related to ESS due to their double nature of generator and load. It states on point (b) that member states shall ensure active customers owning ESS that would not be subject to any double taxation. Furthermore, point (d) allows the same storage facility owned by an active customer to provide several services simultaneously, if technically feasible. This kind of statements, for instance (d), are important for the spread of ESS and new technologies in general, because they remove uncertainty and allow them to take advantage of their full potential.

However, while new directives and some regulations point towards a higher integration and need of ESS on the power grid, the actual *Generation* [22]Having regard to the Treaty on the Functioning of the European Union, Having regard to Regulation (EC (EC 2016/631) and *Demand Connection* [23]Having regard to the Treaty on the Functioning of the European Union, Having regard to Regulation (EC (EC 2016/1388) Grid Codes, which determines the technical requisites for generators and loads to connect to the grid, clearly state on *Art. 3 (2):* "*This Regulation shall not apply to (d) storage devices except for pump-storage power-generating modules* […]". Which may lead ESS in limbo for some cases, creating uncertainty for investors.

Finally, besides some possible criticism, it is remarkable that the creation of Network Codes for energy storage and aggregation is pointed as a future outcome of the e-Regulation in *Art. 59 1(e).* These new network codes could suppose an important drive for energy storage and aggregation, as already have been the Electricity Balancing guidelines for balancing markets throughout Europe, partially due to their obligatory nature and partially thanks to the clear definition of how to proceed, which eases the path for those member states that are not so enterprising.

4_2 Regulation on Energy Storage Systems and Aggregation

The introduction of battery storage systems (BSS) either as physical facilities or as aggregated virtual power plants (VPP) can have a large impact on how DSO approach grid extension and stability. Within the increasing penetration of DG, these are the main concerns in terms of reliability but also in terms of costs due to the big investments needed to prepare the grid for the new DG paradigm using the old fit-and-forget approach. However, the not-so-new liberalization of electricity markets in Europe opened a new horizon of possibilities for grid management via the trading of energy products where BSS can play a prominent role. These ancillary services markets can help DSOs to increase the reliability and hosting capacity (HC) of the grid without the need for new investments.

The European Union has identified the development of Network Codes and Guidelines as a crucial element to enhance the creation of the internal energy market [24]DC NC and HVDC NC, which inherently will give a drive to new market agents such as BSS. In [24]DC NC and HVDC NC Network Codes are classified into three main groups:

- **Connection codes:** They set the requirements for the connection of different users and technologies. The ones proposed on the Third energy package aim at:

  - The secure integration of decentralized resources and demand response.
  - Harmonize the playing field of grid users across member states.
  - Increase competition among equipment providers by harmonizing the requirement they need to comply within different markets.

- **Operation codes:** Composed by the System Operation Guidelines and the Emergency and restoration Network Codes, they set the minimum requirements for TSO and DSO concerning operational security and set rules and responsibilities for the coordination system operators at a national level and across the Internal Electricity market.

- **Market codes:** Their main objective is the creation of an ambitious new European internal energy market to reflect and enhance the changing technical features of electricity production systems [25], via:

  - The standardization of market products to create a stronger internal market, where all products can be traded across member states if needed.
  - Regulate at TSO level how cross-zonal capacity allocation and congestion management are determined at long and short-term (Forward and Spot markets), which consequently will affect the offer on balancing markets.

There is a natural order of creation of Network Codes, starting with Connection codes to assure all the new assets connected to the grid won't affect its secure and reliable operation, to market codes that rely on these assets already connected to the grid. However, the truth is that the Connection Codes that emerge from the Third Energy Package (Requirements for Generators 2016/631/EC and Demand Connection 2016/1388) explicitly do not apply to BSS. For this reason, only a few countries, usually with high penetration of DER and variable RESs (vRES) onto their grids and therefore suffering from their consequences if not managed properly, have developed such important rules to remove uncertainty for investors and clarify how BSS should connect to the grid.

Some of them (the ones available) are:

- **Denmark:** With already high penetration of DER by 2007 [26], among other things, decided to create a specific section of their Requirements for GeneratorsNetwork Code (RfG NC) for BSS.
- **Germany:** Due to their will to stop all the Nuclear Power plants by 2020 made a strong turn on its generation profile which caused reliability problems to local feeders where vRES power plants were connected. It is remarked on [27] the importance of the creation of Network Codes to make a safer grid. Gradually the role of BSS has also been defined in the following network codes:

- **VDE-AR-N4100:** Technical Connection Rules for Low Voltage Grids.

- **VDE-AR-N4105:** Power Generation Plants on Low Voltage Grids.
  - **Italy:** Nowadays Italy is together with Germany and Denmark one of those few countries with specific network codes for low voltage connection of BSS. The Italian connection codes are:

- **CEI 0-21:** Connection on low voltage grids of DER and BSS.

- **CEI 0-16**: Connection on medium voltage grids of DER and BSS.

If Connection Codes for BSSs are the first step to enhance their widespread, another key regulation are Market codes, from which the economic viability of BSSs investments may depend. It has to be taken into account that both, grid extension avoidance and grid stability based on BSSs, strongly rely on European regulations to enhance the creation of markets [28] to provide those products since no DSO is allowed to own, develop, manage or operate energy storage facilities (as shown in the previous section). Note that at this date only balancing products have a European regulatory framework, while non-frequency ancillary products are not yet standardized by the EU. This is a hindrance for ESS on those countries reluctant to create markets.

From the ancillary services market perspective, BSS can interact with the grid needs in two bonded ways, investment deferral (long-term vision) and stability and efficiency (short-term vision). The following list, based on [29] and [30], shows the most important services that BSS can provide to the grid:

- **Black start capability:** Due to their technical characteristics, BSS can provide black start capabilities to generators in case of need. This is a key service for grid stability in case of emergency, and the use of BSS can avoid large investments in providing generators with such capacity. [31] evaluates the potential of BSS to provide black start services to a gas turbine. A closer look at the real implementation of this service is the report [32] where the UK TSO analyses the capabilities of BSSs to provide black start services to the grid.

- **Island operation capability**: It refers to the ability of some DER or BSS to operate local parts of the grid as an independent system during, for instance, distribution station failures or other distribution/transmission system issues. This kind of capabilities cannot be mandatory to all the new assets connected at the distribution level but instead is an interesting opportunity to economically-reward those that can. [33] contemplates islanding operation capacity as a service that could be provided by BSS, in fact, it alludes to the example of EKZ Battery storage [34] which is capable of island energy supply.

- **Balancing products:** They are the only ones that nowadays have a strong European regulatory framework (EC 2017/2195), which defines three types of products, Frequency Containment Reserves, Frequency Restoration Reserves and Restoration Reserves. From all of them, FCR is where BSS can outstand as market players due to their technical capabilities.

- **Synthetic Inertia:** Up until now, part of the grid frequency stability was provided naturally by large synchronous power generating modules (PGMs). The new grid scheme will be composed by spread generators, usually asynchronous, that won't naturally provide such stability based on rotating inertia. For this reason, a new product will emerge that all DER but also BSS can provide via power electronic interfaces. [35] studies and simulates the capability of BSS to provide synthetic inertia, and concludes the importance of fast reaction power sources like BSS to provide stability to the forthcoming grid.

- **Steady-state voltage control:** This kind of products is thought to keep the voltage nominal value inside the required margins. Nowadays this is done managing large PGMs, but with the introduction of generation assets at the distribution side of the grid, voltage control at feeder level will become more and more important. An example of a BSS used to provide voltage control services at MV level is the Dutch DSO Alliander N.V that installed a BSS (as a VPP) distributed along with the feeders near the Amsterdam Arena Stadium to address the voltage issues on the MV network that surrounds it. The case-study and its outcomes are presented in [36].

- **Reactive current injection:** This service is aimed to feed the short-circuit during a fault to ensure that the protection system acts fast. There are some specific network codes (NCs) for BSS that already contemplates this capacity not as a service but as a requirement. For instance, the Danish *Technical regulation 3.3.1 for battery plants* [37], in the section 3.3.1 requires for BSS with power ratings over 1.5 MW to be "*able to deliver additional reactive current during the fault sequence*."

- **Power quality support:** This category includes a vast variety of services such as reactive power compensation, balancing three-phase load unbalances, cancellation of harmonics coming from non-linear loads, etc. Power quality support is based on the capabilities given to BSS by the power electronics interface they need to be connected to the grid. [38], simulates and analyses the effects on the power quality of the grid when an Intelligent Distribution Power Router (IDPR; similar to a Power Electronic Device) provides services to it backed up by a BSS. In the *Conclusions* section, the paper states when talking about the contribution of the IDPR device: "*These services greatly contribute to ensuring power quality and security of supply to customers; to enhance the integration of renewables, and to expand the useful life of grid infrastructures.*"

Energy storage regulation is still incipient in most member states, if there is any part of the power system where energy storage is, directly or indirectly, already integrated these are balancing energy markets, thanks to the mandate to establish such markets via EC 2017/2195 guideline. On the other hand, non-frequency related ancillary services markets, where BSSs can play a key role, only exist as research-projects across Europe, partially due to the lack of European guidelines for such markets.

Regarding balancing markets, in most cases, there is not a clear statement indicating that BSS can participate. Usually, the fulfilment of the prerequisites is enough, which in some cases, especially in terms of bid sizes can be a hindrance, also in the case of VPP if aggregation is not allowed on the market, this can be a barrier.

From a non-grid-supportive point of view, BSS can provide other services, some of them listed in [39]including those heavily hydrocarbon-based as fuel for transportation. Some of these renewable sources have an uncontrollable output and managing the variability is challenging. The current upward trend in renewables participation will demand even more flexibility from the energy systems. Among several options for increasing flexibility, energy storage (ES: energy arbitrage (Time shifting), uninterrupted power supply (for residential, commercial or industrial use), variable renewables integration, energy management, demand management, etc.

The following list shows some examples of proper member states regulations, product definitions and projects that may set the scope for the forthcoming regulations on BSS:

- **Connection codes:** Denmark [37], Germany [40] and Italy [41]

- **Balancing products:** Thanks to the publication of the Electricity Balancing Guidelines, this may be the section in which, nowadays, ESSs are more enhanced. BSSs have unique technical capacities that will only be maximized with the creation of specific products. One product that should set the path is Enhanced Frequency Response, designed by National Grid ESO (UK TSO) aiming at the extremely fast response-capacity of ESSs [42]. These services can be provided from LV and MV grids, but concern (nowadays) at TSO level.

- **Local flexibility markets:** The e-Regulation stated in Art.59 [10]and in particular Article 194(2, the need for a market aimed at the provision of non-frequency products. This kind of products will undergo expansion when the local need for their provision arises due to the high penetration of DG. BSS facilities can find an important remuneration source from local flexibility products provision. First steps are being made in the form of projects, such as:
  - Piclo-Flex [43]: Is a local-market trading platform for ancillary services provided by all kinds of assets. All the UK DSOs participate in this platform submitting offers for flexibility of either frequency or non-frequency related products.

- **Other initiatives using BSS**:
  - Aggregation of end-users: CrowdNet project, the Dutch TSO Tennet together with the retailer Eneco is currently providing balancing products via the creation of a VPP aggregating end-users storage systems [44].
  - Congestion management: Ringo project, the French TSO RTE has a project named RINGO [45] aimed to use BSSs as virtual power lines. The German TSOs and DSOs are planning to develop a similar project called GridBooster.
  - Private investment: Schwerin Battery Park [46] is a private battery park located in the Schwerin district of Lankow, with an actual energy capacity of 15 MWh it has been used as FCR provider, but nowadays has also capabilities to provide products such as black start mode, full islanding mode and renewables integration in grid restoration scenarios.
  - Balancing and congestion management: EKZ Battery storage [34], is a project developed by EKZ, the main swiss DSO, that has just finished installing their largest BSS with an energy capacity of 7,5 MWh. It will be used mainly to provide FCR but also to help the grid with large penetration of RES.

4_3 DSOs Remuneration

Regardless the final path chosen by each member state, one thing has to be accounted, the role of the DSO in the new paradigm shall go a step further and change from a passive management approach, based mainly on years-in-advance network planning plus solving incidences occurring to the infrastructure via network investments, to an active role whit constant intervention on the grid.

This change also implies a variation on the DSOs business model and thus sets out if the actual national remuneration model of DSOs fits the new paradigm where, although investments on grid expansion and reinforcement will still be needed, the main aim of the DSO will be the second-by-second management of the feeders to keep the system operating within its margins.

In terms of financial revenues, until today the business model of DSOs has been based on Capital Expenditure (CAPEX) remuneration, where DSOs are paid a certain amount for each asset needed to update the grid. Now, the Operational Expenditure model (OPEX) is arising as a possible best fitting alternative for the new paradigm, where DSOs remuneration comes from the service provided to the grid and not purely from the purchase of assets.

The Energy Research Centre of the Netherlands, in the document [47] from 2007, studied how DG penetration can affect revenues of DSOs business models. At that moment, and still, now, CAPEX was the widespread remuneration method for DSOs and TSOs. Conversely, the document concluded that, while the penetration is low or mediocre, the appropriate remuneration model may be OPEX due to the predominant regulation of the grid over gird expansion investments. However, if the DG penetration is higher, the appropriate model is not so clear, and thus concluded that further studies would be needed while suggesting a *hybrid model*.

In [48], from 2014, a deeper look at the effects of DG penetration on DSOs business models concluded that the tasks assigned to DSOs need to be examined to properly assess the possible change of remuneration model. The possible effects of DG penetration on the remuneration methods found were:

- Decrease OPEX costs when compared to the classic approach.
- Uncertainty about the effects on CAPEX costs, on the one hand in the long run using DER for grid operation can decrease these costs. However, on the significant short-term expenditures for investment into Smart Grid infrastructure will be needed.

The authors concluded that new regulations would need to focus on incentivising active system management to cushion the initial costs of DG penetration, such as new investment, grid losses,… This leads to a *hybrid model* where OPEX and CAPEX remuneration models are both applied, also known as Total Expenditure (TOTEX). But before that, it is important to:

a) Redefine actual OPEX and CAPEX structures, including new assets and categories.
b) Incentivise the optimal choice between grid investment and active management.

Last but not least document [49] starts by remarking the weight of the distribution network on the forthcoming years based on the expected, by the International Energy Agency, €600 billion investment in a 20 year period, of which 80% will be allocated on the development of the distribution network. Other than that, it introduces the notion of CAPEX remuneration cost-based (as normal) and OPEX remuneration incentive-based, which should remunerate DSOs according to KPIs related to operational efficiency, system sustainability, etc. This remuneration change of scheme should affect the way that distribution costs are allocated among end-users; in other words, it can stimulate the DSO to define innovative grid tariffs to direct the consumption or production of grid-users in a system-efficient way [50]where Distributed Energy Resources (DERs. Finally, it also highlights the crucial role of R&D, demanding new member states regulations where demonstration expenses are not treated like other costs owing to their expected benefit for the grid.

5 Insights from the RESOLVD project for standardization and regulation bodies

5_1 Common Information Model

The Common Information Model [51] is considered as one of the core standards for the transition to smart grids. It is an open standard for representing power system components originally developed by the Electric Power Research Institute (EPRI) in North America and now a series of standards under the auspices of the International Electrotechnical Commission (IEC). The model was initially developed for the transmission grid but later expanded in the description of the distribution grid as well as for describing energy markets related interactions.

Based on the CIM family of standards, a Canonical Data Model (CDM) was designed for the information flowing from/to the RESOLVD Platform - in the context of the control centre. More specifically, the following standards were considered during the data modelling process:

- IEC61968 series [17], which deals with information exchanges in electrical distribution systems and was developed by IEC Technical Committee 57,
- CGMES [52] (v2.4.15), which was developed by ENTSO-E as a European profile[3] of CIM, whilst it was adopted by the IEC as IEC CGMES Technical Specifications (IEC TS 61970-600-1:2017 and IEC TS 61970-600-2:20).

To address the specificities of the project, custom schemas were created as subsets of the above profiles or new data schemas were created from existing CIM classes, and in some occasions by extending existing classes of the standard data model. The modelling of the information involved the following information objects:

- Measurements: Inspired by IEC 61968-9 [53] profile;
- Forecasts: The above measurement model with some extensions was used to handle energy and critical event forecasting provided by EF;
- Grid Model: Created based on CGMES “Equipment” (EQ) profile with some modification to model the PED. Data from the Geographic Information System (GIS) were converted to this data model;
- Grid Configuration/Status: Utilizes the CGMES “Steady State Hypothesis” (SSH), “Topology” (TP) and “State Variables” (SV) profiles for modelling the status of the grid and the PED assets, tackling as well the communications with the Power Flow Simulator (PFS);

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[3] A profile is a subset model of the full CIM model which can act as a self-contained model and focuses on a specific application domain

- Grid Schedule: Initiates from the "Wires" package and models the schedules of the Switchgear and the PED, also utilizing classes from "Core" and "LoadModel" packages. It mostly focuses on communication with the SCADA and the GOS;
- Faults: Based on the "Faults" package as well as "Core" can "Common", a schema was identified for modelling the faults occurring in the grid, identified by the fault detection application (FDA).

CIM provided a useful guideline towards designing an interoperable solution, even though there was a significant overhead in the initial phases of the design - given the model covers a vast domain, is fractioned in many packages and there are hundreds of classes and several relationships among them. Nevertheless, the model provides great flexibility for designing domain-related information. For instance, there were several ways to model the PED in the grid model. On the other hand, this may create confusion; hence, proper guidance is required on applying the standards in the modelling phase. Following this experience with this standard series, what was also identified, was an absence of modelling of energy forecast information object, which is trivial in applications designed in the context of smart grids.

5_2 Regulation

As part of the Clean Energy Package, both e-Regulation and e-Directive were approved in 2019, providing the framework for the transition towards cleaner and more sustainable energy. The member states are now called to implement and transpose into national laws this framework and to provide so the energy industry a stable legal environment. From the energy industry perspective, they are also forced to adapt themselves to this new regulation framework, which can bring challenges as well as opportunities. Novel markets and business models will be based on these new rules, so for sake of fostering those new opportunities, a timely implementation, as well as a harmonized and long-term legal stability, is requested.

Art. 32 on Incentives for the use of flexibility in distribution networks of the e-Directive is establishing that *"[…] the regulatory framework shall ensure that distribution system operators are able to procure such services from providers of distributed generation, demand response or energy storage […]"* and that "*Distribution system operators shall procure such services in accordance with transparent, non-discriminatory and market-based procedures […]"* with the only exception if *"[…]such services is not economically efficient or that such procurement would lead to severe market distortions or to higher congestion."* However, such market-based procedures are not further defined. No clarification on centralized or peer-to-peer approach, size, nor timeframes are given. Here market design will be fundamental to establish rules where investment in flexibility assets operating on such markets need a stable framework to invest. Some markets are more developed, like the balancing markets, defined by Electricity Balancing Guidelines [21]Having regard to the Treaty on the Functioning of the European Union, Having regard to Regulation (EC with a clear framework to be developed throughout Europe, while others, like congestion markets the network codes are pushing towards local markets, are enhanced by the e-Regulation (Art.59) but still without definition.

Network codes are foreseen in e-Regulation (Art.59), as mentioned before. These codes need to be developed and adopted to national law. It is interesting to see the conclusion of GC0096 [54] on Energy Storage (UK - Grid Code modification report) highlighting that the most important change to include energy storage in network codes is the proper definition of its capabilities and configurations, more technical requirements. It states that "*So far as the Grid Code is concerned, most of the changes are reflected through the Glossary and Definitions. With the rest of the code remaining more or less unchanged other than in respect of specific items relating to storage. The key point here is that by amending the definitions such that Electricity Storage is now incorporated into the definition of a Power Generating Module and Generating Unit means that the obligation on Generators will also include storage. […]*" and also, it is highlighted that "*In the majority of cases, it is expected that Storage would meet the same requirements as Generation and HVDC technologies.*" (Section: Assigning appropriate technical requirements - p. 27). Therefore, from this perspective, the changes on the network codes regarding including storage or other services would not suppose a major intervention. The main issue lies in how novel assets like storage may participate in market-based procedures.

Traditionally, DSOs are making their investment decisions based on the investment for novel assets following national regulation that are using schemes to remunerate the CAPEX of those investments. With the establishment of market-based procedures to use flexibility in distribution networks, it is needed to explore new hybrid approaches, also taking into account the OPEX. If the remuneration models are not changed accordingly, DSOs will have low incentive to use local flexibility and so changes that local markets for grid services will attract third party investments are low.

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