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Project acronym: RESOLVD

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D1.2 – Functional and operational requirements

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Primary Authors	Miha Smolnikar (CS), Ferran Torrent-Fontbona (UdG), Isidoros Kokos (ICOM), Luisa Candido (EYPESA), Francisco Diaz Gonzalez (UPC)
Contributors	CS, UdG, ICOM, EXPESA, UPC, JR
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Deliverable reviews

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Version 1.0	Reception Date	20.7.2018
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	Reviewers	CS consolidation of final version

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Acronyms and abbreviations

AMI	Advanced Metering Infrastructure
BMS	Battery Management System
CAN	Controller Area Network
CEF	Critical Event Forecaster
CEPA	Critical Event Prevention Application
CIM	Common Information Model
COX	Centre d'Operació de Xarxa (Network Operation Center)
CUPS	Codigu Universal de Punto de Suministro
DCU	Data Concentrator Unit
DMS	Distribution Management System
DPA	Data Pre-processing Application
DSO	Distribution System Operator
EF	Energy Forecaster
ESB	Enterprise Service Bus
FDA	Fault Detection Application
GIS	Geographic Information System
GM	Grid Meter
GNSS	Global Navigation Satellite System
GOS	Grid Operation Scheduler
GW	Gateway
HES	Head-End System
HLUC	High-Level Use Cases
HMI	Human Machine Interface
HTTP	Hypertext Transfer Protocol
HTTPS	HTTP Secure
HSR	High-availability Seamless Redundancy
HV	High Voltage
ICCP	Inter-Control Center Communications Protocol
IED	Intelligent Electric Device
ILEM	Intelligent Local Energy Manager
IP	Internet Protocol
IPMA	Island Power Management Application
IT	Information Technology
KPI	Key Performance Indicator
LV	Low Voltage
LTE	Long-Term Evolution
LRA	Losses Reduction Application
MDC	Meter Data Collector
MDMS	Metering Data Management System
MQTT	Message Queuing Telemetry Transport
MTBF	Mean Time Between Fixes
MTTR	Mean Time To Repair
MV	Medium Voltage
NTLFDA	Non-Technical-Loss-Fraud Detection Application
OT	Operational Technology
PCS	Power conversion system
PDC	Phasor Data Concentrator

PED	Power Electronic Device
PFS	Power Flow Simulator
PLC	Power Line Communication
PMU	Phasor Measurement Unit
PPS	Pulse Per Second
PQM	Power Quality Monitor
PRIME	PoweRline Intelligent Metering Evolution
PRP	Parallel Redundancy Protocol
PUC	Primary Use Case
QoS	Quality of Service
REST	Representational State Transfer
ROCOF	Rate Of Change Of Frequency
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition system
SHA	Self-Healing Application
SM	Smart meters
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
USB	Universal Serial Bus
UTC	Universal Time Coordinated
WAMS	Wide Area Monitoring System
WF	Weather Forecaster

Executive summary

This report builds on use cases defined in D1.1 and presents the results of the work carried out in Task 1.2 "Functional and operational requirements". For the identified systems, devices, services, and applications it provides the specifications of functional and operational requirements, which need to be met for the initiation of particular solution. The emphasis is on the components and functionalities developed by the project, while the legacy systems of DSO are presented with a focus on required adaptations and extensions.

The report is structured as follows. Section 2 provides an overview of use cases and the involved technical actors as well as provides methodology for actors' requirements capturing. Section 3 presents the legacy systems of DSO that are involved in the RESOLVD use cases and discusses their specific requirements. Those systems include Advanced Metering Infrastructure (AMI), Supervisory Control and Data Acquisition (SCADA) system, and Geographic Information System (GIS). Section 4 presents the requirements for the development of Power Electronic Device (PED), which is composed of Intelligent Local Energy Manager (ILEM), Battery Management System (BMS), Power Conversion System (PCS), and the batteries. Section 5 presents the requirements for grid observability, namely the Wide Area Monitoring System (WAMS), which is constituted of WAMS application server, Phasor and Power Quality Measurement devices (PMU and PQM), and Gateway (GW) device, responsible for the integration of field devices and local data aggregation. Section 6 presents the services and application composing the Distribution Management System (DMS). The support services of DMS are Data Pre-processing Application (DPA) and Weather Forecaster (WF). The supervision and analytics services of DMS are Power Flow Simulator (PFS), Energy Forecaster (EF), Critical Event Forecaster (CEF), Grid Operation Scheduler (GOS), and Fault Detection Application (FDA). The operation applications, which directly participate to grid control and provide primary user interfaces, of DSM are Critical Event Prevention Application (CEPA), Non-Technical-Loss-Fraud Detection Application (NTLFDA), Losses Reduction Application (LRA), Self-Healing Application (SHA), and Island Power Management Application (IPMA). Section 7 supplement the presentation of technical actors with the specification of requirements for assuring interoperability and data manipulation. In particular, a discussion on requirements of Enterprise Service Bus (ESB), Data Management System, and Data Analysis and Visualization Tool is provided. Section 8 concludes the report.

The report does not discuss (i) the integration and interoperability aspects of the individual components, nor (ii) the specific security requirements of particular use case or system as a whole. Those will be provided by the deliverables D1.3 and D1.4, respectively.

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1. Introduction

The RESOLVD project addresses the challenge of increasing the hosting capacity of Low Voltage (LV) grid. The approach is twofold. First, it aims to increase the infrastructure observability and consequently improve the assets utilization, and second, it introduces innovative power electronics device that increases the flexibility of critical grid segments. All this is supported by the development of analytics, optimization and decision support tools.

Part of the use case analysis that has been reported in D1.1, identified the involved technical actors (i.e. systems, devices and applications) and their interactions. This report structures those in associated clusters and discusses each one from the perspective of functional and operational requirements.

1.1. Scope of the document

This document presents a catalogue of legacy and project-developed technical actors. The intention is to provide detailed requirements specifications for the design and integration of those according to the objectives of the identified use cases. The legacy technical actors are presented mostly from the perspective of required adaptations for integration, while for the project-developed technical actors their individual components are identified and specified into the level of details know at the time of reporting.

The RESOLVD project has identified the following eight High Level Use Cases (HLUCs) in which different technical actors are interacting to pursue the objectives:

- *HLUC01: Prevention of congestion and over/under voltage issues through local storage utilization and grid reconfiguration.* It aims to forecast possible congestion and under/overvoltage situations and take the necessary actions to prevent or mitigate them. These actions include import and export of power from local storage systems and grid reconfiguration.
- *HLUC02: Voltage control through local reactive power injection.* It aims to control voltage by importing or exporting reactive power from local storage devices, using Power Electronic Devices (PEDs).
- *HLUC03: Improving power quality and reducing losses through power electronics*. It aims to control power quality. In particular, it comprises the compensation of reactive power, unbalanced currents and harmonics through actuation of PEDs.
- *HLUC04: Local storage utilization to reduce power losses*. It aims to forecast energy demand and supply, and modify the load profile of controllable units in order to minimise the energy losses of the system.
- *HLUC05: Self-healing after a fault*. It aims to detect, diagnose and locate faults in the grid and take the necessary actions for minimising the effects of the fault. It includes grid reconfiguration for isolating the fault.
- *HLUC06: Power management in intentional and controlled-island mode*. It aims to predict energy demand and supply in a grid island, and consequently, take the necessary actions to ensure power balance.
- *HLUC07: Detection and interruption of unintentional uncontrolled island-mode*. It aims to detect unintentional grid islands, e.g. due to a zero power flow between the main grid and the grid island, and take the necessary actions to interrupt the islanding.
- *HLUC08: Detection of non-technical losses (frauds)*: It aims to monitor individual and aggregated power consumption to detect fraud.

1.2. Contributions of partners

All consortium partners involved in the Task 1.2 contributed to the deliverable. The main specific contributions are summarized in Table 1.

Table 1: Partners' contributions to Deliverable D1.2

Partner	Contribution
UdG	Specification of DPA, WF, PFS, EF, FDA, NTLFDA, LRA, SHA
UPC	Specification of PED, ILEM, BMS, PCS, DMS, LRA
CS	Main editor and integrator of the document. Specification of WAMS; PMU, PQM, GW, PDC, FDA, SHA
JR	Security aspect and contribution to the specification of DMS
ICOM	Specification of ESB, Data Management System, Data Analysis and Visualization, CEF, GOS, SHA, LRA, IPMA
EYPESA	Specification of AMI, SCADA, GIS, DMS

1.3. Report structure

The report is structured as follows:

- Section 2 provides an overview of use cases and the involved technical actors as well as provides methodology for actors' requirements capturing.
- Section 3 presents the legacy systems of DSO that are involved in the RESOLVD use cases and discusses their specific requirements. Those systems include Advanced Metering Infrastructure (AMI), Supervisory Control and Data Acquisition (SCADA) system, and Geographic Information System (GIS).
- Section 4 presents the requirements for the development of Power Electronic Device (PED), which is composed of Intelligent Local Energy Manager (ILEM), Battery Management System (BMS), Power Conversion System (PCS), and the batteries.
- Section 5 presents the requirements for grid observability, namely the Wide Area Monitoring System (WAMS), which is constituted of WAMS application server, Phasor and Power Quality Measurement devices (PMU and PQM), and Gateway (GW) device, responsible for the integration of field devices and local data aggregation.
- Section 6 presents the services and application composing the Distribution Management System (DMS). The support services of DMS are Data Pre-processing Application (DPA) and Weather Forecaster (WF). The supervision and analytics services of DMS are Power Flow Simulator (PFS), Energy Forecaster (EF), Critical Event Forecaster (CEF), Grid Operation Scheduler (GOS), and Fault Detection Application (FDA). The operation applications, which directly participate to grid control and provide primary user interfaces, of DSM are Critical Event Prevention Application (CEPA), Non-Technical-Loss-Fraud Detection Application (NTLFDA), Losses Reduction Application (LRA), Self-Healing Application (SHA), and Island Power Management Application (IPMA).
- Section 7 supplement the presentation of technical actors with the specification of requirements for assuring interoperability and data manipulation. In particular, a discussion on requirements of Enterprise Service Bus (ESB), Data Management System, and Data Analysis and Visualization Tool is provided.
- Section 8 concludes the report.

2. Overview of technical actors

2.1. Identified systems, devices and applications

The use cases analysis provided in D1.1 identified 30 main technical actors that participate in the implementation of RESOLVD solutions. From the implementation point of view, those can be classified as systems (SYS), devices (DEV) and applications (APP), while from the development and integration point of view, they can be discriminated to legacy (LEG) and project (PRJ) developed ones. These actors have been grouped in the following main categories:

- Legacy systems of the DSO
  - Advanced Metering Infrastructure (AMI) [SYS, LEG]
    - Meter Data Management System (MDMS) [SYS, LEG]
    - Meter Data Collector (MDC) [SYS, LEG]
    - Data Concentrator Unit (DCU) [DEV, LEG]
    - Smart meter (SM) [DEV, LEG]
  - Supervisory Control and Data Acquisition (SCADA) System [SYS, LEG]
    - Remote Terminal Unit (RTU) [DEV, LEG]
    - Switchgear [DEV, LEG]
  - Geographical Information System (GIS) [SYS, LEG]
- Power Electronic Device (PED) [DEV, PRJ]
  - Intelligent Local Energy Manager (ILEM) [DEV, PRJ]
  - Battery Management System (BMS) [SYS, PRJ]
  - Power Conversion System (PCS) [DEV, PRJ]
- Wide Area Monitoring System (WAMS) [SYS, PRJ]
  - Phasor Measurement Unit (PMU) [DEV, PRJ]
  - Power Quality Monitoring Device (PQM) [DEV, PRJ]
  - Gateway (GW) [DEV, PRJ]
- Distribution Management System (DMS) [SYS, LEG]
  - Support services
    - Weather Forecaster [APPL, LEG]
    - Data pre-processing application [APPL, PRJ]
  - Supervision and analytics services
  - Critical Event Forecaster (CEF) [APPL, PRJ]
  - Non-Technical-Loss-Fraud Detection Application (NTLFDA) [APPL, PRJ]
  - Losses Reduction Application (LRA) [APPL, PRJ]
  - Self-healing Application (SHA) [APPL, PRJ]
  - Island Power Management Application (IPMA) [APPL, PRJ]
  - Operation applications
    - Power Flow Simulator (PFS) [APPL, LEG]
    - Energy Forecaster (EF) [APPL, PRJ]
    - Critical Event Prevention Application (CEPA) [APPL, PRJ]
    - Grid Operation Scheduler (GOS) [APPL, PRJ]
    - Fault Detection Application (FDA) [APPL, PRJ]

The system architecture as foreseen at the time of report is depicted in Figure 1. The final consolidated version will be reported in D1.3.

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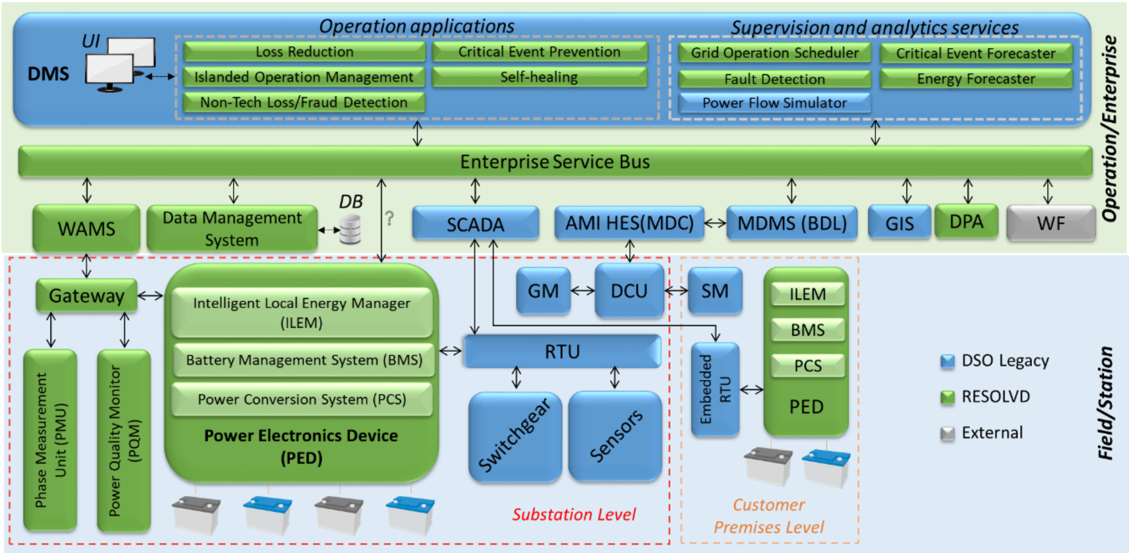

Figure 1 RESOLVD system architecture

2.2. Methodology for actors' requirements capturing

Requirements capturing is a vital step to ensure the success of a system under design. The requirements gathering has been to some extent performed along the process of use cases specification, while the results of requirements analysis is provided in this report.

In principle, the requirements can be divided into functional and non-functional ones. The functional requirements generally describe what the system has to do, which means defining processes, information, and interactions among system components and the environment. The non-functional requirements are characteristics that address operational and technical requirements, which means describing factors such as environment, business process, security, performance, scalability, etc.

Following the specification of use cases, the requirements of identified technical actors were captured from the perspective of required functionalities, foreseen interactions or required adaptations. Following the description of each technical actor scope and objectives, the requirements are provided in classes of:

- Functional requirements.
- Interface requirements.
- User interface requirements (where applicable).
- Operational requirements.

In complement to those, D1.3 will cover the aspects of interoperability, and D1.4 the security framework.

3. Involved legacy systems of the DSO

The solutions developed by the RESOLVD project make use of or interact with several legacy system of the DSO in order to assure appropriate grid system modelling, obtain access to historical data, and enable actual prototypes integration. In particular, (i) the Advanced Metering Infrastructure (AMI) systems is utilized to enable access to individual and aggregated historical data on grid nodes consumption, generation or load profile, (ii) the Geographic Information System (GIS) is used for grid modelling (topology, component parameters), and (iii) Supervisory Control And Data Acquisition (SCADA) system is exploited to represent current grid state and enable actuation.

The following sub-sections provide detailed requirements towards these systems from the RESOLVD project perspective.

3.1. Advanced Metering Infrastructure

The Advanced Metering Infrastructure (AMI) is a legacy system of DSO that is in charge of measuring and transmitting consumption and generation data from Smart Meters (SM) of the LV grid. As depicted in Figure 2, AMI is composed of several components responsible for measurement, transport and management of data.

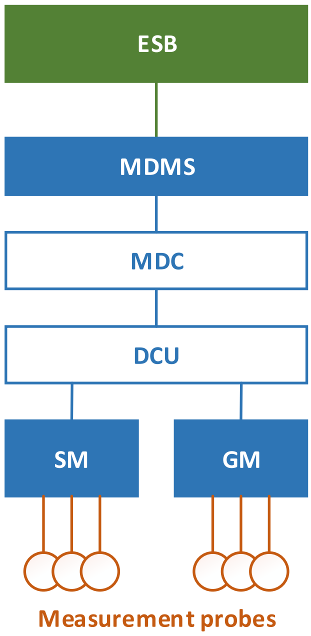

Figure 2 Components of the AMI system

SMs measure energy consumption/generation of an individual consumers and Grid Meters (GM) measure aggregated energy flow at the substation level. Data Concentrator Unit (DCU) is responsible of gathering measurement data from multiple devices and sending them to the MDC. In the case of RESOLVD pilot infrastructure, the communication between SM/GM and DCU is realized via the Power Line Communication (PLC) according to the PRIME Alliance standards [PRIME], but could otherwise also be realized through some mean of wireless communication. The Meter Data Collector (MDC) part of Head-End System (HES) takes care of collecting and validating all data at the operation centre of DSO, while Meter Data Management System (MDMS) is responsible for storing, analysing and further sharing of data.

General functional requirements

For the purposes of historic and real-time consumption/generation data exchange, the MDC and MDMS will need to interface the Distribution Management System (DMS) via Enterprise Service

Bus (ESB). Depending on the specifics of MDC and MDMS, an intermediate component towards ESB will be developed by the project.

Operational requirements

Reliability of SM data collection refers to the ability of detecting a communication fault and intervening with a retransmission request as well as the capability of every SM and DCU to internally store and recover data for a period of at least three months.

The performance of SM data collection reflects the employed strategies, which generally follows the regulative framework. As depicted in Figure 3, this typically means collecting SM data on a 15 min basis by means of pooling and making data available for further use after the period of X, which can vary between 15 min and 45 min. This means consumption/generation are made available within 30 min to 60 min after capturing.

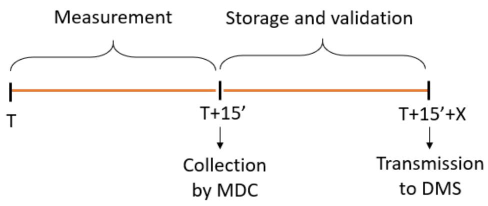

Figure 3 The process of SM data gathering

3.1.1.Meter Data Management System

The Meter Data Management System (MDMS) is a data base that includes data coming from SMs and GMs. It interfaces the MDC, which is in charge of actively collecting data, validating and storing them.

Functional requirements

The MDMS shall support to:

- Store data from the AMI, including the SM and GM.
- Communicate with the DMS to provide the AMI data.
- Communicate with MDC.

Interface requirements

The MDMS should support a communication interface to ESB.

Operation requirements

The MDMS must follow national regulations for secure transmission and privacy preserving handling of data, confidentiality, authentication, integrity, and protection against attacks through secure connections.

3.1.2.Smart Meter and Grid Meter

The Smart Meter (SM) and Grid Meter (GM) are devices installed at customer premises, location of distributed energy generation, or MV/LV substation.

Functional requirements

The SM and GM shall support to:

- Provide instantaneous measurements of voltage, current, phase and frequency.
- Calculate real and reactive energy imported (consumption) and exported (generation) .
- Send information to the DCU under request.

Interface Requirements

SM and GM to be used in the project are PRIME compliant. So basic interfaces are:

- P1 port, used to communicate with other service modules (wired interface with RJ12 connector).

P2 port, used to communicate with non-electrical meters (e.g. via Wireless M-BUS).
P3 port, used to communicate meter readings via PLC or cellular (LTE) wireless networks.

Operational requirements

SM rollouts must follow national regulations for secure transmission and privacy preserving handling of data. The SM capability to provide confidentiality, authentication, integrity, and protection against attacks through a secure connection must be provided out of the box.

3.2. Supervisory Control and Data Acquisition System

The Supervisory Control and Data Acquisition (SCADA) system is in charge of the overall monitoring and control of the distribution grid. It integrates assets monitoring via telecommunication network, local processing, storage and visualization of data, and remote triggering of actuators. A general architecture is depicted in Figure 4.

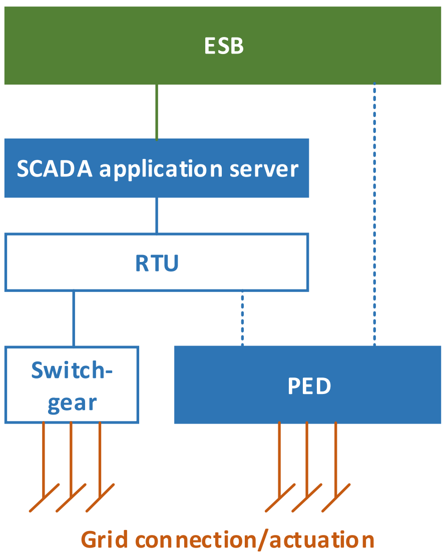

Figure 4 General SCADA architecture

The SCADA system collects data from HV/MV and MV/MV primary substations, and MV/LV secondary substations. For the implementation of RESOLVD pilot, the LV network topology under analysis will need to complement the associated MV network topology and get reflected in the SCADA interface.

The identified requirements provided in the following, relate to existing SCADA.

Functional requirements

The SCADA permits to monitor the operation and state of the MV/LV distribution grid and send commands as well. The project specific extensions shall support the:

- Reporting of the state of the switches (open / closed or in service / out of service).
- Display of lines or other components saturation in % according to the nominal level.
- Reporting of voltage, current, active and reactive power, and power factor and battery state provided by the PEDs.
- Reporting of status of the underlying communication infrastructure (active or deactivated).

- Triggering of command signals to PEDs and LV switchgears via RTUs.
- Communication with the DMS.

Interface requirements

SCADA will interface the DMS via ESB and the field devices via RTUs (including the PED). Specific requirements for those interfaces are part of PED and ESB specifications.

Operational requirements

Usual SCADA operational requirements in terms of availability, maintainability, reliability, performance, scalability, interoperability and security. No additional requirements are needed for the LV grid.

Some of these exigencies implies for example: For reliability purposes, a redundant copy of data and software is required. Additionally, permanent monitoring of the communication infrastructure to guaranty 24/7 availability.

For reliability purposes, the COX[1] can count on a redundant copy of data and software. Additionally, COX is permanently monitoring the communication infrastructure and can detect which parts might be inactive, unreliable or subject to a fault, thus it is possible to intervene in short time and mitigate the problem.

The system requires 24/7 availability. For this reason, all devices of COX feature uninterruptable power system and are hosted in an air-conditioned room with physical access control.

Data from the field assets are gathered through polling actions every 12 s at max. In case of a sudden alarming change in the measurements, the data are sent via push immediately from field to central control system.

3.2.1. Remote Terminal Unit

The Remote Terminal Unit (RTU) enables systems (e.g. SCADA) and field devices to exchange telemetry data and control messages.

Functional requirements

RTUs are connected to various components distributed in the grid (e.g. sensors of the substations, PEDs, switchgears etc.) through various communication technologies and protocols. Their role is to collect data measured by sensors and meters distributed on the field and forward this information to the SCADA.

Interface requirements:

RTUs interfaces, from one side, switchgears, sensors and PED. On the other side it is connected to the SCADA application server: in one direction it provides the SCADA with the collected field data, on the other direction it forwards control signals and schedules to the in-field devices.

Operational Requirements

Data from the field assets are gathered through polling actions every 12 s at max. In case of a sudden alarming change in the measurements, the data are sent via push immediately from field to central control system.

3.2.2. Switchgear

The switchgear is an actuator device that permits to switch lines and change grid configuration. The main function of switchgear is to protect and isolate electric equipment by interrupting short-circuit and overload phenomena. In RESOLVD, switchgears will also permit to reconfigure the network topology for different purposes: self-healing after a fault, power flow re-routing to avoid

[1] Centre d'Operació de Xarxa (Network Operation Center)

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critical events, or increasing the system efficiency. For this reason, switchgears will be deployed in the grid so as to enable ring or meshed configuration.

Functional requirements

The switchgear shall support to:

- Connect and disconnect lines to change the grid configuration for a given grid topology.
- Report its state to the SCADA via RTUs.

Interface requirements

Switchgears interfaces need to be compliant with those supported by the RTU and enable bidirectional communication. This means to:

- Receive via RTU the SCADA control signals commands to open or close the line.
- Send via RTU status information to SCADA (e.g. open/closed, active/inactive).

Operational requirements

Switchgear must be designed and dimensioned to withstand short-circuit events, high temperatures and other extreme conditions.

Switchgear must permit manual operation in case of a fault.

Some operational constraints are envisioned derived from the limitation on their possible locations in the LV grid:

- Due to the limited space, the powering is realized through the LV line, without any battery back-up service.
- The process for restoring power after an interruption is initiated by the PED, located strategically within the network. From this point, it is possible to manage the grid operation. Switchgears that open and create islands of some branches remain open until the problem on the bus is solved. The affected segment is islanded, minimizing the disconnected zone and re-establishing the connection from the feeder of the secondary substation om one side or the other.

3.1. Geographic Information System

A Geographic Information System (GIS) is designed to capture, store, manipulate, analyze, manage, and present all types of geographical data. It is used to maintain the model of the grid and its assets.

Functional Requirements

The requirement of GIS for the RESOLVD project are to:

- Exchange data with DMS applications.
- Provide LV grid topology including line and feeder parameters.
- Send updated information to the DMS, each time a change is made in the infrastructure (e.g. substitution of a cable with another cable with different characteristics).

Interface Requirements

Communicates with DMS applications via ESB.

Operational Requirements

There are no additional requirements. Grid characteristics are "static data", they do not change unless the elements of the real infrastructure change. For this reason, it is sufficient to send them only in case of a change in the network infrastructure.

4. Power Electronic Device

The Power Electronic Device (PED) is a device in charge of locally managing energy at different levels. As depicted in Figure 5, it is composed of an Intelligent Local Energy Manager (ILEM), a Power Conversion System (PCS), a Battery Management System (BMS), and the batteries themselves.

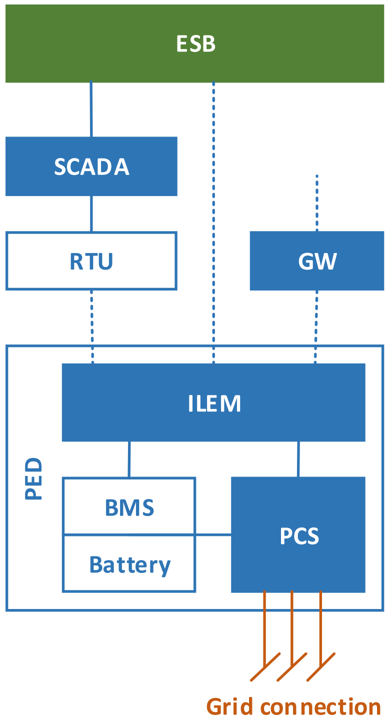

Figure 5 Design architecture of the PED device

The objective of the PED as a whole is to provide services to the distribution grid by performing different functions such as (i) compensating current harmonics, (ii) exchanging reactive power, (iii) supporting the voltage control, (iv) compensating unbalances among the three phases, and (v) ensuring the supply to the neighbourhoods in case of mains failure. The term PED is used when referring to the whole group of software and hardware components, while in the assessment of use cases a single component is brought into play where possible.

The PED and its subsystems will be designed, developed, integrated and deployed within the project. In the following, the specification of general functionalities and requirements are provided for the device as a whole and its subsystems. The provided information complements detail analysis of design concepts and assumptions provided in RESOLVD project deliverable D2.1[2].

Functional requirements

The PED must support interaction with other components that are of RESOLVD scope. In particular, it should be able:

- Measure voltage and currents from the grid.
- Measure voltage, current and state of the battery
- Calculate active, reactive power and power factor.
- Report the measurements and calculations to the SCADA via RTU.
- Calculate odd voltage harmonics components until the 13th, but not reporting to the SCADA.

[2] Public deliverables will be accessible at https://resolvd.eu/documents/

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- Receive battery schedules.
- Execute schedules to manage battery energy.
- Compensate harmonics.
- Interrupt unintentional islands.
- Balance phases.
- Control voltage by injecting reactive power.
- Provide a local user interface to configure and access parameters locally.

Measurements' requirements are reported in D3.1 which is devoted to specify the low voltage grid observability.

Interface requirements

For integration purposes, the PED (i.e. ILEM) must be equipped with the TCP/IP communication capability (Modbus other TCP/IP protocol in case more appropriate).

User interface requirements

The PED shall be equipped with a local user interface to configure and access parameters locally.

Operational requirements

Given the critical nature of operation, reliability is of key importance. All subsystems of PED should therefore be always available

The performance (sampling time) with exogenous actors is in the range of minutes. The PED is not aimed to be a metering device. The error in the root-mean-squared values derived from the current and voltage measurements of the PED at its connection point can be sensibly higher than the error provided by a proper metering device.

4.1. Intelligent Local Energy Manager

The Intelligent Local Energy Manager (ILEM) is an intelligent electronic device (IED) implementing the overall device control logic and in charge of PED subsystems interaction. It also acts as the front-end of PED for integration with other systems of the overall RESOLVD framework.

Its objective is to receive schedules, setpoints and other information from SCADA and act accordingly by setting the operation of PED subsystems. The status of device is regularly updated in SCADA and other observability components.

Functional requirements

Internally, the ILEM depends on the information provided by the PCS and BMS for properly distributing the power demands to different batteries included in the PED.

Externally, proper operation of ILEM depends on the information provided by SCADA and PMU/PQM (depending on the specific use case under considered).

The ILEM must be equipped with at least a TCP/IP port (i.e. Ethernet interface) and RTU (RS-485 serial interface) communication capability. In case more appropriate also other communication protocol can be chosen.

The ILEM must be equipped with a human machine interface (HMI) so as to facilitate the management and testing of the PED on the field.

Operational requirements

The ILEM should be always available while the PED is working. Reliability of this component is critical.

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The performance is critical, however the response time can be higher than for PCS given that setpoints and other information are provided in the range of minutes.

4.2. Battery Management System

The Battery Management System (BMS) is a subsystem of PED which is a system in charge of managing a battery, providing power and storage capacity according to the energy management requirements. It is a commercial device integrated into each battery module. Note, PED integrates different technology batteries, so, accommodates different BMSs according to the battery technology.

Its objective is to provide information to PCS for the protection of batteries in case of eventualities, as well as to inform the ILEM about the state of charge and availability.

Functional requirements

BMS works as an autonomous subsystem and provides information in an unidirectional manner. Therefore, it has no dependencies with other subsystems of PED.

The interface for data exchange varies, depending on the vendor of a commercial solution. Supporting a particular interface depends on the selection of battery technology, thus it does not comprise a particular design requirement.

Operational requirements

The BMS should be always available, since it should determine if the battery is able to work or not. The reliability is critical.

The performance criticality depends on the electrochemical technology being used. It is of high importance for high-tech batteries such as those based on lithium-ion technology and not so important for the lead-acid technology.

The BMS should be provided with communication ports such as CAN or Modbus RTU for proper integration into PED.

4.3. Power Conversion System

The Power Conversion System (PCS) is a device actually exchanging the electrical power between batteries and the main grid. It is equipped with all electrical protection devices and security measures for the proper operation of the PED as a whole on the field.

With the power electronics providing switching and energy management capacity, the objective of this device is to act on the grid according to the predefined scenario (dispatched by SCADA and locally managed by ILEM).

Functional requirements

For internal purposes (i.e. controlling the switching of the power transistors), PCS must have the capability to locally measure voltage and current exchanged at its connection point. From those, it calculates active and reactive power and provides it to ILEM.

PCS must allow receiving setpoints and commands from ILEM to charge/discharge batteries and provide other functionalities (such as compensate grid current harmonics, exchange reactive power, etc). Additionally, PCS must support receiving information from the BMS for triggering alarms in case of electrical eventualities. For such internal communication purposes CAN or MODBUS RTU interface must be supported to enable integration with ILEM and BMS.

The PCS must be provided with electrical interfaces to connect the battery terminals for power exchange.

Operational requirements

The PCS should be always available while the PED is working. Thus, the reliability of this subsystem is considered critical.

The performance is critical in terms of power losses minimisation and current harmonics compensation.

5. Wide Area Monitoring System

Traditionally, the Wide Area Monitoring System (WAMS) is referred to a collective infrastructure in charge of managing (i.e. measuring, aggregating and analysing) time-synchronized data (i.e. synchrophasors) coming from distributed sensor devices. It is composed of PMUs, PDCs (gateways), a dedicated ICT infrastructure, and application server facilities for acquisition, analysis, visualization, and archival of data. As such, WAMS complements other grid management systems by allowing dynamic conditions and stability monitoring.

In the context of continuous load growth, reduced operational margins, and dynamics introduced by distributed energy resources, the objectives of a WAMS is to protect power system from instabilities and collapses. In contrast to conventional protection devices, which provide local protection of individual equipment (e.g. transformer, generator, bus) the aim of WAMS is to support comprehensive protection covering the whole power system.

The architecture of WAMS is depicted in Figure 6. With respect to sensor devices, the RESOLVD project is additionally to PMUs considering also the PQM devices, while no actuation devices are foreseen to be directly triggered via WAMS.

The gateway (GW) is primarily responsible to act as a PDC and stream measurement data towards application server, however the RESOLVD project also considers this device to perform protocol conversion, facilitate wireless connectivity, and provide some computation power for the purposes of distributed and/or time critical applications.

Apart from collecting, analysing and storing field data, the WAMS application server is also responsible for managing the measurement devices (PMU and PQM) and interfacing with the DMS.

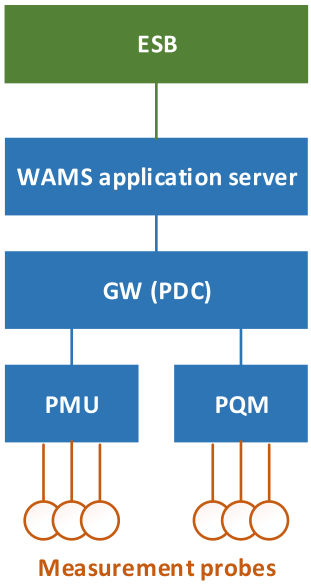

Figure 6 Architecture of WAMS system

The RESOLVD project aims to develop and integrate specific building blocks of WAMS architecture to fulfil the goals of detecting, diagnosing and locating faults and thereby support the self-healing mechanisms.

5.1. WAMS application server

Hereafter, the term WAMS is used to refer to the WAMS application server to be developed by the RESOLVD project. In the following, the specification of its functionalities and requirements are provided.

Functional requirements

The WAMS shall support the following overall functionalities:

- Communicate with PMU and PQM for data acquisition through the GW. In particular:
  - On-demand data acquisition based on request of connected application.
  - Alignment of data according to reference time tags (not the order of arriving).
  - Generation of output data streams compliant with the requirements of receiving service/application.
  - Data pre-processing.
  - Data quality and validity check (with respect to flags send along with the measurement data).
  - Data scaling (re-sampling).
  - Data format change.
- Perform basic data analysis. In particular:
  - Event detection according to user configurable predefined thresholds for detecting various disturbances or abnormal system conditions.
  - Real-time event detection functions, i.e. executed each time upon receiving a new data frame.
  - System frequency out of specified range.
  - The rate of change of the system frequency exceeding the specified threshold.
  - Bus voltage magnitude out of specified range.
  - Phase angle difference of two bus voltage phasors exceeding specified threshold.
  - The rate of change of the phase angle difference of two bus voltage phasor exceeding the specified threshold.
  - Any combination of the above.
  - Non-real-time event detection functions, i.e. executed on a user configurable period using any combination of stored (buffered) and online data.
- Provide permanent storage to the PMU and PQM data.
- Store temporal data from PMU and PQM, In particular, internal data storage capabilities of are:
  - Short-term (30 s) buffering of real-time data.
  - Event-driven permanent historian storage, recording all events detected by embedded data analysis function (see 'Data analysis requirements' above).
  - Raw data storage at the granularity of an individual event (5 s prior to the event and 10 s post the event) for user selectable field devices.
- Allow the management of PMU, PQM and GW devices (i.e. remote firmware upgrade, remote configuration, continuous operation monitoring and alarming).
- Communicate with the DMS via the ESB.

Interface requirements

- Dedicated TCP/IP connection to PMU/PQM/GW for device management purposes.
- Exchange of real-time data with other monitoring systems.
- Optionally, the exchange of data with other control system applications via the Inter-Control Center Communications Protocol (ICCP) [60870-6] or SCADA [60870-5].
- Support MQTT and HTTP message exchange protocols for integration with web services.
- At least two level access (user/service and administrator).
  - Interface requirements with the PMU and PQM:
  - Real-time data stream receiving with the support of IEEE C37.118.2 (synchrophasor) [C37.118.2].
  - TCP and UDP mode.
  - Unicast and multicast IP addressing with IPv4 and IPv6 support.

- Real-time data stream receiving according to IEC 61850-90-5 (synchrophasor) [IEC 61850-90-5].
- Modbus TCP/IP data stream exchange (power quality).

User interface requirements

The WAMS should comprehend a basic user interface to:

- Visualize measurement data from individual field devices (synchrophasors, frequency, power quality).
- Report field devices status and uptime.
- Display events log.
- Provide interface for field devices configuration and diagnosis.
- Display alarms of detected events.

Operational requirements

The following key performance indicators of WAMS define its operational requirements:

- The application shall be able to receive real-time data streams at highest sampling rate from at least 10 devices.
- The permanent storage shall support for a minimum of 30 days history recording.
- Upon receiving, data pre-processing and repacking should be executed with 100 ms for a maximum number of data streams.

5.2. Phasor Measurement Unit

The Phasor Measurement Unit (PMU) is a device that measures the electrical waves on an electricity grid. Using a reference timing source (typically provided via Global Navigation Satellite System, GNSS), it enables time-synchronized measurements of voltage, current, frequency and phase signal properties (i.e. synchrophasors) on multiple remote measurement points of a distributed system. It requires fast and reliable communication links to feed the data through PDC (gateway) to the WAMS applications.

The main objective of PMU is to enable improved monitoring and dynamic control of the power grid via WAMS. Presently, PMUs are being widely used in the TSO segment of the grid, while a number of ongoing developments and trials (including those of the RESOLVD project) are associated to DSO use cases. Some of these include topology detection, islanding detection, fault localization, state estimation, etc.

A PMU device will be developed during the project. In the following, the specification of minimum functionalities and requirements are provided as identified to support measurement and transmission of quantities defined by the use cases.

Functional requirements

The PMU shall be completely integrated, ready for deployment at the substation, and compliant with standards for the communication with PDC. It shall conform the following technical requirements:

- Measure electrical parameters of the power system in frequency band of 45-55 Hz.
- Support measurements of at least 4 voltage channels, 6 current channels, 6 digital inputs and 6 digital outputs.
- Support measurements of voltage and current synchrophasors (magnitude and angle in polar form) at a refresh rate of 25 Hz, 50 Hz and 100 Hz.
- Support measurements of frequency and rate of change of frequency (ROCOF).
- Timestamp measurements according to Universal Time Coordinated (UTC) at the resolution of at least 1 μs.

- The PMU shall respect the accuracy of measurement in static and dynamic conditions as defined in IEEE C37.118.1 standard [C37.118.1].
- Support data transmission over Ethernet, facilitating copper or optical physical port interface.
- Support operation via redundant connectivity infrastructure, employing HSR or PRP protocols.
- Support DC and AC auxiliary power supply in the range between 24 V and 230 V.

Interface requirements

The physical and communication protocol related interface requirements include:

- The primary communication between PMU and PDC shall be realized over Ethernet (10/100/1000 Base Tx).
- The Ethernet interface shall support redundant operation model according to HSR and PRP specifications.
- For synchrophasors data streaming the TCP and UDP transport protocols shall be supported.
- For management and maintenance purposes, PMU shall comprehend additional Ethernet interface, exposing Web-based user configuration interface.

Reference timing requirements

PMU shall support the following three principles for synchronization:

- GNSS time receiver shall support internal clock synchronization to UTC source as well as include delays compensation to achieve at least 1 μs time accuracy.
- PTP local area network protocol for clock synchronization according to the IEEE 1588 [1588].
- 1PPS (Pulse Per Second) analog electrical signal that has a width of less than 1 s and a sharply rising or abruptly falling edge that accurately repeats once per second.
- The time synchronization module shall allow for a hierarchical combination of different timing sources and continuously observe the clock synchronization lock. In case of clock synchronization invalidity, an alarm should be triggered and communicated to the PDC.
- The internal time base shall have minimum stability of 1 ppm.

Hardware realization and enclosure requirements

Requirements specific to physical realization of the device are as follows:

- The Ingress Protection (IP) of the enclosure shall confirm the IP31 degree (i.e. protection from tools greater than 2.5 mm and protected from condensation).
- All hardware components cooling shall be implemented as passive (i.e. without any ventilators).

Operational requirements

The key performance indicators of PMU are as follows:

- The PMU shall feature a self-monitoring and diagnostic capability to identify validity of data (with respect to internal estimation algorithms) and capability of communication interfaces. In case of any abnormality an alarm should be triggered and communicated to PDC and WAMS.
- The design of PMU algorithms and procedures shall ensure that the impact of frequency fluctuation between 45 Hz and 55 Hz as well as the presence of harmonic signal components is within the permissible limits of standards [C37.118.1].

- The PMU shall be capable of operating in an ambient temperature range from -10°C to +55°C and relative humidity from -10% to +90%.

5.3. Power Quality Monitor

The Power Quality Monitor (PQM) is a device enabling precise power quality monitoring (e.g. harmonics, RMS, active/reactive power). The measures fall in two basic categories, i.e. disturbances (parameter peak or RMS value exceeding a specified threshold during a transient event) and steady state variations (presented with statistical significance of parameter variation over time).

The main objective of PQM is to complement the PMU measurements and thereby allow for wide area determination of power quality and identification of disturbances like harmonics, flicker, sags and swells.

A PQM device will be developed during the project. In the following, the specification of minimum functionalities and requirements are provided as identified to support measurement and transmission of quantities defined by the use cases.

Functional requirements

The PQM shall be completely integrated, ready for deployment at the substation, and compliant with standards. It shall conform the following technical requirements:

- Measure the following electrical parameters of the power system:
  - 3-phase voltage.
  - 3-phase current.
  - Frequency.
  - Real, reactive and apparent power.
  - Power factor (cosinus phi).
  - Harmonics (up to 50^{th} component).
- Support basic digital inputs capturing and digital outputs control.
- Timestamp measurements according to Universal Time Coordinated (UTC).
- Support data transmission over Ethernet, short-range wireless and cellular connectivity interfaces.
- Support DC and AC auxiliary power supply in the range between 24 V and 230 V.

Interface requirements

The physical and communication protocol related interface requirements include:

- Z-Wave or Wireless M-BUS short range wireless radio interface.
- LTE cellular radio interface (Cat. 3, Cat. M1, Cat. NB).
- Ethernet interface (wired).
- CoAP and MQTT message exchange protocols.
- For management and maintenance purposes, PQM shall feature Web-based user configuration interface.

Hardware realization and enclosure requirements

Requirements specific to physical realization of the device are as follows:

- The Ingress Protection (IP) of the enclosure shall confirm the IP31 degree (i.e. protection from tools greater than 2.5 mm and protected from condensation).
- All hardware components cooling shall be implemented as passive (i.e. without any ventilators).

Operational requirements

The PQM shall be capable of operating in an ambient temperature range from -10°C to +55°C and relative humidity from -10% to +90%.

5.4. Gateway

The Gateway (GW) is a device enabling interconnection of various systems and devices through its physical interfaces in order to aggregate and adapt different data streams for interoperability with host applications. The adaptation can refer to translation of communication protocols, change of communication medium (i.e. wireless and wired), time alignment and synchronization of multiple data streams, adjustment of sampling/refresh rate, etc.

The objective of GW in RESOLVD is twofold. First, to enable interconnection of various field devices/system and communicate to the application server via Internet. This involves the support of (i) different physical interfaces such as serial, short range wireless, Ethernet, etc. to interconnect collocated devices, (ii) device specific data exchange protocols, and (iii) wireless or wired Internet connectivity and server-sided message exchange protocols. Second, the GW should as well support remote management and maintenance of connected devices and provide certain level of computation capacity to host time-critical parts of applications that need to be executed on the field. The latter is predominantly related to the aggregation and basic manipulation of syncrophasor measurements.

The GW device and its embedded services will be developed during the project. In the following, the specification of identified functionalities and requirements are provided, reflecting mostly the requirements of PMU, PQM and PED devices.

Functional requirements

The GW shall be completely integrated, ready for field deployment and compliant with requirements of interconnected devices (PMU, PQM and PED). It shall conform the following technical requirements:

- Support the interconnection of four devices via RS-485 serial, Ethernet or short-range wireless (e.g. Wireless M-Bus) interfaces.
- Support device specific message exchange protocols, such as Modbus for PED device and IEEE C37.118.1/2 for PMU.
- Support HTTP protocol for remote management and maintenance.
- Support basic local data processing, such as adaptation of sampling rate and short-term data buffering.
- Support wired (Ethernet) and wireless (cellular) Internet connectivity.
- Provide online monitoring of devices and connectivity status.
- Provide at least two level access control (administrator and user).
- Support DC and AC auxiliary power supply in the range between 24 V and 230 V.

Interface requirements

The physical and communication protocol related interface requirements include:

- RS-485 serial interface.
- Universal Serial Bus (USB) interface with host capability.
- Ethernet interface.
- Short-range wireless (e.g. Wireless M-Bus, Z-Wave, ZigBee).
- Cellular connectivity interface based on Long Term Evolution (LTE), e.g. Cat-3, Cat-M1, Cat-NB, depending on the application requirements.
- Wi-Fi interface (optionally).

Hardware realization and enclosure requirements

Requirements specific to physical realization of the device are as follows:

- The Ingress Protection (IP) of the enclosure shall confirm the IP31 degree (i.e. protection from tools greater than 2.5 mm and protected from condensation).
- All hardware components cooling shall be implemented as passive (i.e. without any ventilators).

Operational requirements

The key performance indicators of PMU are as follows:

- Simultaneous hosting of at least three field devices.
- The GW shall be capable of operating in an ambient temperature range from -10°C to +55°C and relative humidity from -10% to +90%.

In the following, specific requirements for field devices (i.e. PED and PQM) interconnection and PMU data aggregation are provided.

5.4.1.Field devices integration

The GW as a device allowing for integration and interoperability of locally interconnected devices and Internet access point towards server-sided applications, shall fulfil the following specific requirements.

Protocol requirements

- Hosting of various field devices.
- Modbus RTU (over serial line).
- Modbus TCP/IP (over Ethernet).
- M-Bus (optionally, device specific implementation).
- Server-side application connectivity.
- Support of HTTP and MQTT message exchange protocols.
- Support for IPv4 and IPv6 networks.

Hosted application requirements

- Support local (of field) execution of basic application that consist of pre-defined logical blocks and their interconnection using flow-based programming principles.
- Support management of field devices (monitoring, configuration, events logging).

5.4.2.Phasor data concentrator

The PDC is a component between multiple PMUs and a centralized WAMS application server. It has the following specific requirements.

Main functional requirements

- Handling of PMU real-time data streams, including receiving, validating, time-aligning, repacking and forwarding.
- Conditions monitoring and exchange of PMU configuration information.
- Buffering and temporal data storage.
- Interfacing to other PDCs and applications.

Support functional requirements

- Reference clock distribution for devices synchronization.
- Abnormal conditions detection, logging and alarming.

- Simple data validation according to prescribed attributes.

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6. Distribution Management System

DMS is a system utilized by the DSO, which provides the functionalities of advanced monitoring and control from a centralized location, i.e. the control center. As depicted in Figure 7, it is in principle interconnected with all other information technology (IT) and operational technology (OT) systems of grid supervision and management, and usually facilitates the orchestration of activities and participants (actors) involved in a particular use case. Its operation can be automatic or subordinated to human control.

To enable integration and assure interoperability, ESB is employed to provide the "glue" functionality among the heterogeneous systems. The specific requirements of it are discussed in Section 7.1, while the application to specific use cases is provided in deliverable D1.3[1].

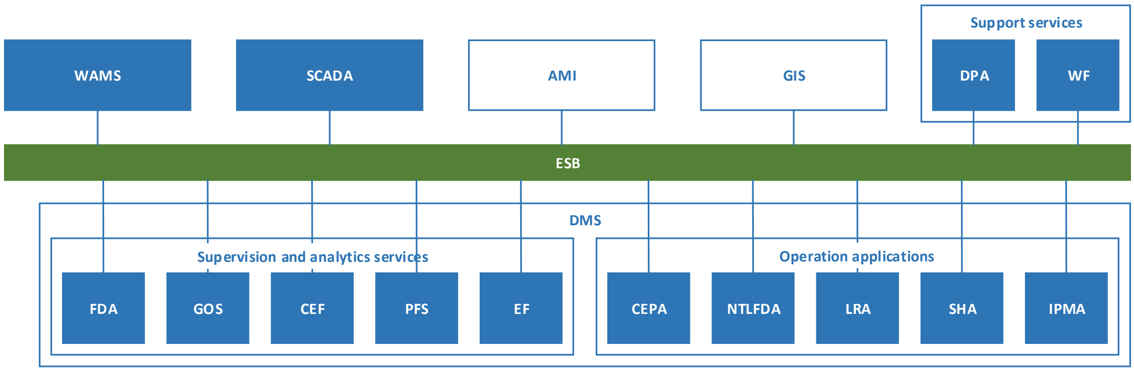

Figure 7 A suite of DMS applications and interconnection with others systems via ESB

DMS is a legacy system of DSO. During the project, specific services and applications will be developed to provide new advanced functionalities. In the following, the specification of functionalities and requirements are provided as identified in general or arising from specific applications.

Functional requirements

DMS acts as a central actor that needs to interface to a number of different software and hardware components of the overall system. Its orchestrating capabilities permit to trigger the actions necessary for the fulfilment of use case objectives, while it relies on the ESB to interface among the system components.

In RESOLVD, DMS is constituted of a number applications that can be classified as (i) supervision and analytics services and (ii) operation applications. All of those may as well require particular support services and interact with other legacy or project developed systems via ESB. While the project's aim is to automate a large part of support, supervision and analytics services, the execution of operational action on the field will require the authorization of a human operator from the DSO.

The functions and associated requirements of particular services and applications are discussed in the following subsections.

Operational requirements

The operation of DMS is considered critical and therefore needs to operate in an environment supporting 24/7 uptime. This means providing uninterruptible power supply and locating the servers in appropriate air-conditioned servers/computer room. The internet connection or any other physical/virtual telecommunication channel needs to be available 24/7 as well.

For reliability purposes, the software needs to be copied and executed on demand in another physical location.

Performance wise, the DMS requirements are quite demanding, as (i) services need to be executed in parallel and may require the response time in the range of ms, and (ii) orchestrating among other applications should not introduce degradation of target key performance indicators. The various applications composing the DMS have individual performance requirements, depending on the need of the specific tool.

6.1. Support services

The support services are purposely developed applications that allow data manipulation and interaction with 3rd party services.

6.1.1. Data Pre-processing application

The Data Pre-processing Application (DPA) is an application to be developed in the project that provides functionalities to clean, correct, complete, and validate data.

Functional Requirements

The DPA should support to:

- Identify and correctly label missing values, outliers and wrong values (data completeness).
- Provide a unified time reference for all the data.
- Resample and aggregate data from different sources.
- Communicate with WAMS, MDMS and Data Management system.

Interface Requirements

The DPA should via interact with other systems and applications via ESB.

6.1.2. Weather Forecaster

The Weather Forecaster (WF) is an external service, usually provided by weather agencies, that provides data related to both weather forecast and historic weather data.

Functional requirements

- Shall provide weather forecast (at least temperature and irradiance) with specific resolution (minimum 1 hour), period and location under request.
- Shall be able to provide historical weather data (temperature, irradiance) with specific resolution (minimum 1 hour), period and location under request.

6.2. Supervision and analytics services

The supervision and analytics services are project developed applications aimed at the support of operation applications. They are executed on demand and in principle do not interact with grid control systems.

6.2.1. Power Flow Simulator

The Power Flow Simulator (PFS) is a service that performs a power flow analysis given the power generation and demand, the configuration of the grid, and the current topology.

The PFS is a project developed application. In the following, the specification of functionalities and requirements are provided as identified in general or arising specifically from the project-defined use cases.

Functional requirements

The PFS shall be able to:

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- Retrieve grid topology from GIS.
- Return the power flow analysis (bus voltages and lines loading or power flow) given the power generation and demand at each bus, and the grid configuration.
- Store the power flow simulations.

Interface requirements

The PFS has to interface with MDMS, GIS and SCADA systems and has the following interface requirements:

- Access smart meter data from MDMS via HTTP/HTTPS REST services.
- Request grid topology from GIS via HTTP/HTTPS REST services.
- Request grid configuration from SCADA via HTTP/HTTPS REST services.

The PFS should return simulated bus voltages and lines power flow via HTTP/HTTPS REST services to the requesting application.

The PFS shall provide an open interface to an external authorization, authentication and accounting system

Operational requirements

The principal operational requirements of PFS include:

- The application should have a high degree of availability. The scheduled downtime should not last more than one full day and not more than two days accumulatively over the one-month period. Unscheduled downtime should not exceed 7 days per month.
- Mean Time To Repair (MTTR) due to hardware malfunctions shall not exceed 96 consecutive hours. Software maintainability should follow standard practices (e.g. versioning).
- The start-up time and full availability of the application's functionality must be within 10 min. The average response time for receiving non-technical losses detection should not exceed 10 min.
- The overall performance of the system must be able to grow with more powerful hardware and complexity of the considered system.
- The application shall protect the data and services from unauthorized access. It shall also provide authentication and secure transaction. Accounting must support the monitoring of any unauthenticated accesses attempt. The application shall be placed behind a firewall to minimize risks of external attacks.

6.2.2. Energy Forecaster

The Energy Forecaster (EF) is a service that performs energy generation and demand forecast using data from SMs, GMs and WF.

The EF is a project developed application. In the following, the specification of functionalities and requirements are provided as identified in general or arising specifically from the use cases.

Functional requirements

The EF shall be able to:

- Retrieve grid topology from GIS.
- Return energy forecast (power demand and/or generation at specific busses) with the estimated uncertainty for a given time period, given data of the power generation and demand of each customer in the grid for the last week, the grid configuration (forecasting phase) and other contextual data (weather, calendar, etc.) in the same period and in the forecasted period.

- Aggregate energy data from SM at the specified grid busses, when needed.
- Train energy forecast models (power demand and generation forecast models) given historical data of power demand and generation of each customer (training phase).
- Store forecast models for specified grid busses representing different aggregations of prosumers.
- Allow user to provide the periodicity of the training phase.
- Automatically trigger the process of the training phase.
- Access smart meters' data stored in the MDMS.
- Store energy forecasts.

Interface requirements

The EF has the following interface requirements:

- Accessibility:
    - Provide time period to be forecasted, SM data (active and reactive power) during the previous week to forecast, weather forecast and during the previous week, grid configuration, relevant buses.
    - Return energy forecast (power consumption and demand at specific busses).
- Interaction with GIS:
    - Request topology of the grid.
    - Provide grid ID.
- Interaction with MDMS:
    - Request SM data (power generation and consumption)
    - Providing: Location, Time Period.
- Support REST services over HTTP or HTTPS.
- Provide an open interface to an external authorization, authentication and accounting system.

Operational requirements

The principal operational requirements of EF include:

- The application should have a high percentage of availability. The scheduled downtime should not last more than one full day and not more than two days accumulatively over the one-month period. Unscheduled downtime should not exceed 7 days per month.
- Mean Time to Repair (MTTR) due to hardware malfunctions shall not exceed 96 consecutive hours. Software maintainability should follow standard practices (e.g. versioning).
- The start-up time and full availability of the application's functionality must be within 10 min. The average response time for receiving non-technical losses detection should not exceed 10 min.
- The overall performance of the system must be able to grow with more powerful hardware and complexity of the considered system.
- The application shall protect the data and services from unauthorized access. It shall also provide authentication and secure transaction. Accounting must support the monitoring of any unauthenticated accesses attempt. The application shall be placed behind a firewall to minimize risks of external attacks.

6.2.3. Critical Event Forecaster

The Critical Event Forecaster (CEF) is a service that performs critical event forecast using data from SMs, which are managed by the MDMS and power flow simulation results obtained from the EF. The CEF is a project developed application. In the following, the specification of functionalities and requirements are provided as identified in general or arising specifically from the use cases.

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Functional requirements

The CEF shall be able to:

- Retrieve grid topology from GIS.
- Return critical event forecast (with the type and severity[3]), given the power flow simulation results obtained with energy forecast, and given the voltage measurement by each SM in the last 24h of available data, and given the grid configuration (forecasting phase).
- Train critical event forecast models given historical voltage measurements by each SM (training phase).
- The user shall be able to provide the periodicity of the training phase.
- Automatically trigger the process of the training phase.
- Access smart meters and grid meters' data stored in the MDMS.
- Store critical event forecasts.

Interface requirements

The CEF has the following interface requirements:

- Accessibility:
  - Provide power flow simulation results and smart meter data (voltages), grid configuration, time period.
  - Return critical event forecast with the type and severity[3]).
- Interaction with GIS
  - Request topology of the grid.
  - Provide grid ID.
- Interaction with MDMS:
  - Request SM data (power generation and consumption).
  - Provide location and time period.
- Support REST services over HTTP or HTTPS.
- Provide an open interface to an external authorization, authentication and accounting system.

Operational requirements

The principal operational requirements of CEF include:

- The application should have a high percentage of availability. The scheduled downtime should not last more than one full day and not more than two days accumulatively over the one-month period. Unscheduled downtime should not exceed 7 days per month.
- Mean Time to Repair (MTTR) due to hardware malfunctions shall not exceed 96 consecutive hours. Software maintainability should follow standard practices (e.g. versioning).
- The start-up time and full availability of the application's functionality must be within 10 min. The average response time for receiving non-technical losses detection should not exceed 10 min.
- The overall performance of the system must be able to grow with more powerful hardware and complexity of the considered system.
- The application shall protect the data and services from unauthorized access. It shall also provide authentication and secure transaction. Accounting must support the monitoring of any unauthenticated accesses attempt. The application shall be placed behind a firewall to minimize risks of external attacks.

[3] Severity is an indicator that considers both, the magnitude and duration of a critical event (over/under-voltage and congestion).

6.2.4. Grid Operation Scheduler

The Grid Operation Scheduler (GOS) is a service that calculates a grid operation schedule (PED and switchgears schedules) that optimises a given criterion. The GOS is a project developed application. In the following, the specification of functionalities and requirements are provided as identified in general or arising specifically from the use cases.

Functional requirements

The GOS shall be able to:

- Retrieve grid topology from GIS.
- Return a grid operation schedule (individual schedule for each grid actuator) given energy forecast, current grid configuration, current state of grid actuators and the objective function to optimize, and in case of self-healing it also requires the location (line) of the detected faults.
- Allow user to select an optimization objective among minimizing losses, minimizing/preventing critical events, balancing power (island operation), self-healing.
- Store grid operation schedules calculated.

Interface requirements

The GOS has the following interface requirements:

- Accessibility:
    - Provide energy forecast (at relevant buses), grid configuration, grid actuators state, optimization objective, detected faults (only for self-healing).
    - Return grid operation schedule (individual schedules for each grid actuator (PED and switchgear).
- Interaction with GIS
    - Request topology of the grid.
    - Provide grid ID.
- Support REST services over HTTP or HTTPS.
- Provide an open interface to an external authorization, authentication and accounting system.

Operational requirements

The principal operational requirements of GOS include:

- The application should have a high percentage of availability. The scheduled downtime should not last more than one full day and not more than two days accumulatively over the one-month period. Unscheduled downtime should not exceed 7 days per month.
- Mean Time to Repair (MTTR) due to hardware malfunctions shall not exceed 96 consecutive hours. Software maintainability should follow standard practices (e.g. versioning).
- The start-up time and full availability of the application's functionality must be within 10 min. The average response time for receiving non-technical losses detection should not exceed 10 min.
- The overall performance of the system must be able to grow with more powerful hardware and complexity of the considered system.
- The application shall protect the data and services from unauthorized access. It shall also provide authentication and secure transaction. Accounting must support the monitoring of any unauthenticated accesses attempt. The application shall be placed behind a firewall to minimize risks of external attacks.

6.2.5. Fault Detection Application

The Fault Detection Application (FDA) is an application that automatically detects, diagnoses and locates faults (e.g. short circuits, line imbalances) or other critical events (e.g. unintentional islanding) in the grid using PMU data. Once events are detected, it notifies the DMS. The FDA also automatically detects critical events using SM/GM data stored in the MDMS. The detection of critical events is used to analyse the performance of the critical event prevention application. The FDA is a project developed application. In the following, the specification of functionalities and requirements are provided as identified in general or arising specifically from the use cases.

Functional requirements

The FDA shall be able to:

- Retrieve grid topology from GIS.
- Retrieve PMU data from WAMS.
- Detect, diagnose and locate faults using PMU data.
- Send an alert to the DMS when a fault is located with a description of the fault and its location.
- Build a statistical model of PMU data without faults to further use it to detect faults.

Interface requirements

The FDA has the following interface requirements:

- Interaction with WAMS:
  - Request PMU data (with subscription service).
- Interaction with GIS:
  - Request topology of the grid.
- Support REST services over HTTP or HTTPS.
- Provide an open interface to an external authorization, authentication and accounting system.

Operational requirements

The principal operational requirements of FDA include:

- The application should have a high percentage of availability. The scheduled downtime should not last more than one full day and not more than two days accumulatively over the one-month period. Unscheduled downtime should not exceed 7 days per month.
- Mean Time to Repair (MTTR) due to hardware malfunctions shall not exceed 96 consecutive hours. Software maintainability should follow standard practices (e.g. versioning).
- The start-up time and full availability of the application's functionality must be within 10 min. The average response time for receiving non-technical losses detection should not exceed 10 min.
- The overall performance of the system must be able to grow with more powerful hardware and complexity of the considered system.
- The application shall protect the data and services from unauthorized access. It shall also provide authentication and secure transaction. Accounting must support the monitoring of any unauthenticated accesses attempt. The application shall be placed behind a firewall to minimize risks of external attacks.

6.3. Operation applications

The operation applications of the DMS aim to interact with the grid control systems (i.e. SCADA, PED) in order to fulfil the objectives of a particular use case of the RESOLVD project.

6.3.1. Critical Event Prevention Application

The Critical Event Prevention Application (CEPA) is an application implementing the orchestration mechanism of data management and executive actions, for the prevention of critical events through the utilization of local storage and switching actions. The CEPA is a project developed application. In the following, the specification of functionalities and requirements are provided as identified in general or arising specifically from the use cases.

Functional requirements

The CEPA shall provide the following functionalities:

- Follow a business process by accessing data from different sources (e.g. MDMS, Weather Forecaster) and triggering external processes (e.g. EF, CEF) while handling any information provision, in order to detect and prevent critical events.
    - The business process shall operate in a periodic manner as provided by the user.
- Access grid configuration data.
- Access weather forecast data.
- Access smart metering data (energy and voltage).
- Request and retrieve an energy forecast.
- Request and retrieve a power flow simulation.
- Request and retrieve a prediction of critical events.
- Detect if a prediction response contains any critical events.
- Request and retrieve corrective grid operation schedule(s).
- Support a process for avoiding critical events which can operate in a manual or automated manner, as demanded by the user.
- Upon detecting a critical event and receiving the suggested schedule(s):
    - In the manual operation, the input of the user shall be requested in order to continue the workflow (process for avoiding critical events), by selecting a schedule. The user shall be able to skip the action of prevention.
    - In the autonomous operation, the application shall automatically continue the workflow (process for avoiding critical events), by automatically selecting a schedule.
- For avoiding critical events, the application shall be able to provide to the SCADA the suggested grid operation schedule.
- Request from WAMS if any critical events were detected at a specific location and time for correlation with the critical events forecast, marking them with relevant status occurred/avoided.
- Store the details of the business process flow, the steps of the process, and reference to the data accessed from the different sources.
- Provide a UI for presenting the critical events (forecasted or historic) as well as offer the ability to export the data in textual format (e.g. csv, xls, json).

Interface requirements

The CEPA has the following interface requirements:

- Interaction with SCADA:
    - Interface 1:
        - Request grid configuration data.
        - Provide location, time.
    - Interface 2:
        - Request grid operation schedule dispatch command.
        - Provide grid operation schedule.
- Interaction with MDMS:
    - Request SM data (energy and voltage at maximum sampling of 15 min).

    - Provide supply point (CUPS[4]), time period, and data type (energy / voltage).
- Interaction with Weather Forecaster:
    - Request weather forecast data.
    - Provide location, time period.
- Interaction with EF:
    - Request generation and demand forecast data.
    - Provide SM data (consumption and generation), weather forecast, and grid configuration data.
- Interaction with PFS:
    - Request power flow simulation.
    - Provide grid configuration data and generation and demand forecast data.

Communicate with CEF:

    - Request critical events.
    - Provide grid configuration data, SM data (voltage), power flow simulation data.
- Communicate with GOS:
    - Request grid operation schedule calculation command.
    - Provide generation and demand forecast data, power flow simulation data, and grid configuration data.
- Communicate with WAMS:
    - Request critical events.
    - Provide location, time, type.
- Support REST services over HTTP or HTTPS.
- Provide an open interface to an external authorization, authentication and accounting system.

User interface requirements

User Settings

The user shall be able to set the following attributes in the application:

- Manual / automatic mode of critical event prevention.
- Periodicity of execution of business workflow.
- Alarms settings for critical events (e.g. severity, type).
- Economic KPIs: PFS contributes to the financial results considering the capital and operational expenditures of the selected generation structure on the basis of the specific composition and interaction of different generation resources. In consequence, financial Key Performance Indicators (KPIs), like Levelized Cost of Electricity (LCoE), Return of Investment (RoI) or Net Present Value (NPV), can be derived for the evaluated scenarios.
- Power Losses cost: Associated to losses in components due to active and reactive power. Active power loss consists in AC side components, such as AC transformers, AC distribution lines, and so on. Reactive power side components.
- Risk Costs: These can be estimated from derived equivalent costs to consumers for damages caused by power events (e.g. interruptions), which mainly depends on the probability and duration of the events (interruptions) and the typology of consumers.

Analysis of critical events history

The application shall provide the capability to analyze historical critical events based on their attributes (date/time, location, type, approved/denied, occurred/avoided, voltage level), whilst also correlate other information of each step of the workflow (e.g. scheduled solution implemented) and provide the ability to add/edit notes.

[4] CUPS is the supply code Codigu Universal de Punto de Suministro.

More specifically is shall support the following features:

- Show the list of critical events (forecasted / verified events).
- Support filtering of information (critical events) based on severity, location, date/time, type and voltage level.
- Support ordering of information (critical events) based on severity, frequency of occurrence (number of events per time unit computed in the period of time under analysis) or probability of occurrence, total load shedding during the event (an initial failure can trigger others), and time and duration of the occurrence.

Probability of occurrence of these events.

- Present a map view with tagged locations of the critical events with the ability to zoom in/out a specific location, support for location filter.
- Present and give access to information in each step of the workflow for correlation. Workflows model flow of information within the organisation and the operations carried out on that information. Workflows are associated to predefined network models and changes of these models produce transitions in the workflow. Workflow correlation agents are responsible for integrating information from the network state and behaviour of operators that intervene. Some of these transitions are used to model actions or to communicate with a separate action agent. In this way the correlation and action agents work together to provide a quick response that rectifies problems as soon as they arise. Thus, the workflow should show the time evolution in each step of the workflow, in the determined point of the grid, of the following information for further correlation:
    - Consumption trends.
    - Power flow simulation results.
    - Detection of critical event.
    - Grid operation schedules suggested.
    - Approval/denial of the schedule suggestion by the operator.
- Add/edit a general description and notes for each critical event.

<u>Analysis of critical events forecast</u>

The application shall provide the capability to analyze forecasted critical events based on their following attributes: date/time, location, type whilst also correlate other information of each step of the workflow (e.g. scheduled solution implemented) providing the ability to add general description and notes.

More specifically it shall support the following features:

- Show forecasted critical events as a list.
- Present a map view with tagged locations of critical events.
- Support filtering of information (critical events) based on severity, location, date/time, type.
- Support ordering of information (critical events) based on severity and time proximity.
- In manual mode, a notification shall present the operator of the forecasted critical event, together with the suggested grid operation schedule(s).
- Present information of each step of the workflow:
    - Consumption trends.
    - Power flow simulation results.
    - Detection of critical event.
    - Grid operation schedules suggested.
    - Approval/denial of the schedule suggestion by the operator.

<u>Statistical Analysis</u>

The application shall provide statistics on:

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- Frequency of critical events in a certain area (multiple locations) and/or of a certain type and/or severity. Severity usually refers to the consequences of the event. Usual practice rates failure effect severity on a scale of one to 10 where one is lowest severity and 10 is highest. Table 2 shows proposed severity ratings and their meaning.
- Grid operation schedules implemented based on attributes such as approved/denied
- Utilization of the battery to solve critical event e.g. total energy provided/consumed

Table 2: Severity rating

Rating	Meaning
1	No effect..
2	Very Minor: Values close to its operational limits.
3	Minor: Parameters affecting the electrical service or quality of wave less than 60 s.
4-6	Moderate: Parameters affecting the electrical service or quality of wave less than 180 s.
7-8	Moderate: Parameters affecting the electrical service or quality of wave more than 180 s.
9-10	Very high: It is require workers action.

Statistics and graphs should be presented in an easy-to-interpret format.

Operational requirements

The principal operational requirements of CEPA are reported in Table 3.

Table 3 CEPA Operational Requirements

Requirement Type	Description	Pilot threshold	Final product threshold
Availability	High availability of the application shall be achieved.	>95%	99%
	Scheduled continuous downtime should not exceed a specific threshold.	2 days	2 consecutive hours
	A maximum occurrence of scheduled downtime shall not be surpassed.	7 days per month	12 hours per month
	Unscheduled downtime should not exceed a certain threshold	7 days per month	30 minutes per month
Maintainability	Mean Time to Repair (MTTR) due to hardware malfunctions shall not exceed a certain threshold.	-	2 consecutive hours
	Software maintainability should follow standard practices (versioning etc.)	NA	NA
Reliability	The application shall not suffer loss of service more than a specific threshold.	5 times per month	5 times per year
	The mean time between fixes (MTBF) shall exceed a minimum threshold.	7 days	2 hours
Performance	The start-up time and full availability of the application's functionality must be no longer than a specified threshold.	30 min	10 min
	The average response time for receiving external information (e.g. SCADA, WAMS, AMI), shall not exceed a certain threshold.	15 min	20 s

Scalability	The overall performance of the system must be able to grow with more powerful hardware.	NA	NA
Security	The application shall protect the data and services from unauthorized access.	NA	NA
	It shall provide authentication and secure transaction.	NA	NA
	Accounting shall be supported for monitoring any attempt to unauthenticated accesses.	NA	NA
	Shall be placed behind a firewall to minimize risk from external attacks.	NA	NA

6.3.2. Non-Technical Loss and Fraud Detection Application

The Non-Technical Loss and Fraud Detection Application (NTLFDA) is an application implementing data analysis that permits the detection of non-technical losses (fraud detection) by utilizing SM and GM data accessible via MDMS. It can be based on different strategies. The NTLFDA is a project developed application. In the following, the specification of functionalities and requirements are provided as identified in general or arising specifically from the use cases.

Functional requirements

The application shall provide the following functionalities:

- Follow a business process for accessing data from MDMS and launching alerts for detected frauds.
- Detect non-technical losses (frauds) based on MDMS data.
- Provide the ability to the user to start or stop the process.
- Operate in a manual or automated manner, as demanded by the user.
    - In case of the automated operation, automatically run the process for non-technical losses detection.
- Support user configuration of:
    - Time period and locations in the manual operation mode.
    - Time period, locations and periodicity in the automated operation mode.
- Access grid topology.
- Access SM and GM data.
- Present the detection of non-technical losses to the user.
- Store the details of the process of non-technical losses (fraud) detection (data analysed and non-technical losses detections).
- Provide a UI for presenting the detected possible frauds as well as offer the ability to export the data in textual format (e.g. csv, xls, json).

Interface requirements

The NTLFDA has the following interface requirements:

- Interaction with MDMS:
    - Request SM and GM (at concentrator) data.
    - Provide supply point (CUPS), time period, and data type (energy / voltage).
- Interaction with GIS:
    - Request topology of the grid.
- Support REST services over HTTP or HTTPS.
- Provide an open interface to an external authorization, authentication and accounting system.

User interface requirements

User Settings

The user shall be able to set the following attributes in the application:

- Manual / automatic mode.
- Periodicity of execution of business workflow.
- Time period and locations of analysis.

Analysis of critical events history

The application shall provide the capability to analyse detected possible frauds.

More specifically is shall support the following features:

- Show the list of frauds.
- Support filtering of information based on location, date/time, type and voltage level.
- Support ordering of information based on location, date/time, type and voltage level.
- Present a map view with tagged locations of frauds with the ability to zoom in/out a specific location, support for location filter.

Operational requirements

The principal operational requirements of NTLFDA are reported in Table 4.

Table 4 NTLFDA operational requirements

Requirement Type	Description	Pilot threshold[5]	Final product threshold
Availability	High availability of the application shall be achieved.	-	99%
	Scheduled continuous downtime should not exceed a specific threshold.	-	2 consecutive hours
	A maximum occurrence of scheduled downtime shall not be surpassed.	-	12 hours per month
	Unscheduled downtime should not exceed a certain threshold	-	30 minutes per month
Maintainability	Mean Time to Repair (MTTR) due to hardware malfunctions shall not exceed a certain threshold.	-	2 consecutive hours
Reliability	The application shall not suffer loss of service more than a specific threshold.	-	5 times per year
	The mean time between fixes (MTBF) shall exceed a minimum threshold.	-	2 hours
Performance	The start-up time and full availability of the application's functionality must be no longer than a specified threshold.	-	10 minutes
	The average response time for receiving external information (e.g. smart meter data), shall not exceed a certain threshold.	-	20 seconds

6.3.3. Losses Reduction Application

The Losses Reduction Application (LRA) is an application implementing the orchestration mechanism of data management and executive actions, for the reduction of losses through local storage utilization. It can work autonomously or controlled by a human operator. The LRA is a

[5] Not to be verified during the pilot of the project

project developed application. In the following, the specification of functionalities and requirements are provided as identified in general or arising specifically from the use cases.

Functional requirements

The application shall provide the following functionalities:

- Follow a business process flow for assessing and mitigating grid losses by accessing data from different sources (e.g. MDMS, Weather Forecaster) and triggering external processes (e.g. EF, PFS) while handling any information provision.
    - The business process shall operate in a periodic manner as defined by a human operator.
- Provide the ability to the user to start or stop the process.
- Access grid configuration data.
- Access smart metering data.
- Request and retrieve an energy forecast.
- Request and retrieve a power flow simulation.
- Present the expected power losses reduction as a % of the current value.
- Request and retrieve corrective grid operation schedule(s).
- Support a process for reducing grid losses, which can operate in a manual or automated manner, as demanded by the user.
- Upon receiving the suggested schedule(s):
    - In the manual operation, the input of the user shall be requested in order to continue the workflow (process for reducing grid losses), by selecting a schedule. The user shall be able to skip the action of reduction.
    - In the autonomous operation, the application shall automatically continue the workflow (process for reducing grid losses), by automatically selecting a schedule.
- For reducing grid losses, the application shall be able to provide to the SCADA the suggested grid operation schedule.
- Store the details of the business process flow, the steps of the process, and reference to the data accessed from the different sources.
- Provide a UI for presenting the history of requests for grid losses reduction as well as offer the ability to export the data in textual format (e.g. csv, xls, json).

Interface requirements

The LRA has the following interface requirements:

- Interaction with SCADA:
    - Interface 1:
        - Request grid configuration data (also PED state or battery level).
        - Provide location, time.
    - Interface 2:
        - Request grid operation schedule dispatch command.
        - Provide grid operation schedule.
- Interaction with MDMS:
    - Request SM and GM (at concentrator) data.
    - Provide supply point (CUPS), time period, and data type (energy / voltage).
- Interaction with EF:
    - Request generation and demand forecast data.
    - Provide SM data, weather forecast, grid configuration data.
- Interaction with PFS:
    - Request power flow simulation.
    - Provide grid configuration data and generation and demand forecast data.

- Interaction with GOS:
  - Request grid operation schedule calculation command
  - Provide generation and demand forecast data, power flow simulation data, and grid configuration data.
- Support REST services over HTTP or HTTPS.
- Provide an open interface to an external authorization, authentication and accounting system.

User interface requirements

User Settings

The user shall be able to set the following attributes in the application:

- Manual / Automatic mode of LRA.
- Periodicity of execution of business workflow.
- Notification settings: the application can notify the user about the potential future loss. The user will be able to decide when he/she wants to be notified by setting the maximum acceptable loss, that is an expressed in %. When this threshold is overcome, the system notifies the user and proposes an alternative schedule.

Analysis of grid losses

The application shall provide the following specific grid losses analyses:

- Show the list of power losses reductions achieved.
- For each power loss reduction action the list of grid operation schedules shall be able to be presented.
- Support filtering of information related to power losses reductions based on location, date/time and voltage level.
- Support ordering of information related to power losses reductions based on location, date/time, type and voltage level.
- Present a map view with tagged locations of the power losses reductions with the ability to zoom in/out a specific location, support for location filter.
- Add/edit a general description and notes for each request.

Statistical Analysis

The application shall provide statistics on:

- Aggregated grid losses reduction in a certain area (multiple locations).
- Grid operation schedules implemented based on attributes such as approved/denied.
- Utilization of the battery to reduce power losses e.g. total energy provided/consumed.

Statistics and graphs should be presented in an easy-to-interpret format.

Operational requirements

The principal operational requirements of LRA are reported in Table 5.

Table 5 LRA operational requirements

Requirement Type	Description	Pilot threshold	Final product threshold
Availability	High availability of the application shall be achieved.	>95%	99%

	Scheduled continuous downtime should not exceed a specific threshold.	2 days	2 consecutive hours
	A maximum occurrence of scheduled downtime shall not be surpassed.	7 days per month	12 hours per month
	Unscheduled downtime should not exceed a certain threshold	7 days per month	30 minutes per month
Maintainability	Mean Time to Repair (MTTR) due to hardware malfunctions shall not exceed a certain threshold.	-	2 consecutive hours
	Software maintainability should follow standard practices (versioning etc.)	NA	NA
Reliability	The application shall not suffer loss of service more than a specific threshold.	5 times per month	5 times per year
	The mean time between fixes (MTBF) shall exceed a minimum threshold.	7 days	2 hours
Performance	The start-up time and full availability of the application's functionality must be no longer than a specified threshold.	30 minutes	10 minutes
	The average response time for receiving external information (e.g. smart meter data), shall not exceed a certain threshold.	15 minute	20 seconds
Scalability	The overall performance of the system must be able to grow with more powerful hardware.	NA	NA
Security	The application shall protect the data and services from unauthorized access.	NA	NA
	It shall provide authentication and secure transaction.	NA	NA
	Accounting shall be supported for monitoring any attempt to unauthenticated accesses.	NA	NA
	Shall be placed behind a firewall to minimize risk from external attacks.	NA	NA

6.3.4. Self-Healing Application

The Self-Healing Application (SHA) is an application implementing the orchestration mechanism of data management and executive actions, for self-healing after a fault. It can work autonomously or under control of a human operator.

The SHA is a project developed application. In the following, the specification of functionalities and requirements are provided as identified in general or arising specifically from the use cases.

Functional requirements

The application shall provide the following functionalities:

- Follow a business process flow for managing a grid fault situation by accessing data from different sources (e.g. WAMS, MDMS, Weather Forecaster) and triggering external processes (e.g. EF, PFS) while handling any information provision.
- Provide the ability to the user to start or stop the application.
- Operate in a manual or automated manner, as demanded by the user.
    - In automated mode, triggered immediately when faults are detected/reported by WAMS or FDA.
- Access grid configuration data.
- Access smart metering data.

- Request and retrieve an energy forecast.
- Request and retrieve a power flow simulation.
- Request and retrieve corrective grid operation schedule(s).
- Upon receiving the suggested schedule:
    - In the manual operation, the input of the user shall be requested in order to continue the workflow (process for self-healing).
    - In the autonomous operation, the application shall automatically continue the workflow (process for self-healing).
- For healing faults, the application shall be able to provide the suggested grid operation schedule to the SCADA.
- Present grid faults and grid operations scheduled in response.
- Store the details of the business process flow, the steps of the process, and reference to the data accessed from the different sources.
- Provide a UI for presenting the history of requests for self-healing as well as offer the ability to export the data in textual format (e.g. csv, xls, json).

Interface requirements

The SHA has the following interface requirements:

- Interaction with SCADA:
    - Interface 1:
        - Request grid configuration data.
        - Provide location, time.
    - Interface 2:
        - Request grid operation schedule dispatch command.
        - Provide grid operation schedule.
- Interaction with MDMS:
    - Request SM and GM (at concentrator) data.
    - Provide supply point (CUPS), time period, and data type (energy / voltage).
- Interaction with EF:
    - Request generation and demand forecast data.
    - Provide SM data, weather forecast, grid configuration data
- Interaction with PFS:
    - Request power flow simulation
    - Provide grid configuration data and generation and demand forecast data.
- Interaction with GOS:
    - Request grid operation schedule calculation command.
    - Provide generation and demand forecast data, power flow simulation data, and grid configuration data.
- Support REST services over HTTP or HTTPS.
- Provide an open interface to an external authorization, authentication and accounting system.

User interface requirements

<u>User Settings</u>

The user shall be able to set the following attributes in the application:

- Manual / Automatic mode of self-healing applications.

<u>Analysis of fault history</u>

The application shall provide the capability to analyze historical faults based on their attributes (date/time, location, type, approved/denied, occurred/avoided, voltage level), whilst also correlate other information of each step of the workflow (e.g. scheduled solution implemented) and provide the ability to add/edit a general description and notes.

More specifically is shall support the following features:

- Show the list of faults.
- Support filtering of information (faults) based on location, date/time, type and voltage level.
- Support ordering of information (faults) based on frequency of occurrence and time.
- Present a map view with tagged locations of the faults with the ability to zoom in/out a specific location, support for location filter.
- Present information of each step of the workflow for correlation:
  - Consumption trends.
  - Power flow simulation results.
  - Suggested grid operation schedules.
  - Approval/denial of the schedule suggestion by the operator.
- Present information of the status of each step of the workflow and provide access to relevant data.
- Add/edit a general description and notes for each fault

Statistical Analysis

The application shall provide statistics on:

- Frequency of faults in a certain area (multiple locations) and/or of a certain type.
- Grid operation schedules implemented based on attributes of approved/denied, occurred/avoided.
- Utilization of the battery to reduce power losses e.g. total energy provided/consumed, maximum power provided/consumed.

Statistics and graphs should be presented in an easy-to-interpret format.

Operational requirements

The principal operational requirements of CEPA are reported in Table 6.

Table 6 SHA operational requirements

Requirement Type	Description	Pilot threshold	Final product threshold
Availability	High availability of the application shall be achieved.	>95%	99%
	Scheduled continuous downtime should not exceed a specific threshold.	2 days	2 consecutive hours
	A maximum occurrence of scheduled downtime shall not be surpassed.	7 days per month	12 hours per month
	Unscheduled downtime should not exceed a certain threshold	7 days per month	30 minutes per month
Maintainability	Mean Time to Repair (MTTR) due to hardware malfunctions shall not exceed a certain threshold.	-	2 consecutive hours
	Software maintainability should follow standard practices (versioning etc.)	NA	NA
Reliability	The application shall not suffer loss of service more than a specific threshold.	5 times per month	5 times per year

	The mean time between fixes (MTBF) shall exceed a minimum threshold.	7 days	2 hours
Performance	The start-up time and full availability of the application's functionality must be no longer than a specified threshold.	30 minutes	10 minutes
	The average response time for receiving external information (e.g. smart meter data), shall not exceed a certain threshold.	15 minutes	20 seconds
Scalability	The overall performance of the system must be able to grow with more powerful hardware.	NA	NA
Security	The application shall protect the data and services from unauthorized access.	NA	NA
	It shall provide authentication and secure transaction.	NA	NA
	Accounting shall be supported for monitoring any attempt to unauthenticated accesses.	NA	NA
	Shall be placed behind a firewall to minimize risk from external attacks.	NA	NA

6.3.5. Island Power Management Application

The Island Power Management Application (IPMA) is an application implementing the orchestration mechanism of data management and executive actions for the power management of a controlled island. It can work autonomously or under control of a human operator. The IPMA is a project developed application. In the following, the specification of functionalities and requirements are provided as identified in general or arising specifically from the use cases.

Functional requirements

The application shall provide the following functionalities:

- Follow a business process flow for managing a grid island situation by accessing data from different sources (e.g. MDMS, Weather Forecaster) and triggering external processes (e.g. EF, PFS) while handling any information provision.
- Provide the ability to the user to start or stop the Island Power Management process.
- Operate in a manual or automated manner, as demanded by the user.
- The operator shall be able to define a specific region of the grid that the process will analyse.
- Access grid configuration data.
- Access smart metering data.
- Request and retrieve an energy forecast.
- Request and retrieve a power flow simulation.
- Present a view of the islanded grid area including information on grid configuration, PED schedules, as well power quality metrics (i.e. frequency and voltage).
- Request and retrieve suggested grid operation schedule(s).
- Upon receiving the suggested schedule:
    - In the manual operation, the input of the user shall be requested in order to continue the workflow (process for managing an islanding situation).
    - In the autonomous operation, the application shall automatically continue the workflow (process for managing an islanding situation).
- For managing an islanding situation, the application shall be able to provide the suggested grid operation schedule to the SCADA.
- Store the details of the business process flow, the steps of the process, and reference to the data accessed from the different sources.

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- Provide a UI for presenting the history of requests of island power management situations, as well as offer the ability to export the data in textual format (e.g. csv, xls, json).

Interface requirements

The IPMA has the following interface requirements:

- Interaction with SCADA:
    - Interface 1:
        - Request grid configuration data.
        - Provide location, time.
    - Interface 2:
        - Request grid operation schedule dispatch command.
        - Provide grid operation schedule.
- Interaction with MDMS:
    - Request SM data (energy or voltage).
    - Provide location, time period, and data type (energy / voltage)
- Interaction with EF:
    - Request generation and demand forecast data.
    - Provide SM data, weather forecast, and grid configuration data.
- Interaction with PFS:
    - Request power flow simulation.
    - Provide grid configuration data and generation and demand forecast data.
- Interaction with GOS:
    - Request grid operation schedule calculation command.
    - Provide generation and demand forecast data, power flow simulation data, and grid configuration data.
- Support REST services over HTTP or HTTPS.
- Provide an open interface to an external authorization, authentication and accounting system.

User interface requirements

<u>User Settings</u>

The user shall be able to set the following attributes in the application:

- Manual / Automatic mode of island power management application

<u>Analysis of islanding situations</u>

The application shall provide the capability to analyze historical islanding situations based on their attributes (date/time, location, type, voltage level), whilst also correlate other information of each step of the workflow (e.g. scheduled solution implemented) and provide the ability to add/edit a general description and notes.

More specifically it shall support the following features:

- Show the list of islanding situations tackled.
- Support filtering of information (situations) based on location, date/time, type and voltage level.
- Support ordering of information (situations) based on frequency of occurrence and time.
- Present a map view with tagged locations of such situations with the ability to zoom in/out a specific location, support for location filter.
- Present information of each step of the workflow for correlation:
    - Consumption trends.

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- Power flow simulation results.
- Grid operation schedules suggested.
- Approval/denial of the schedule suggestion by the operator.

- Present information of the status of each step of the workflow and provide access to relevant data
- Add/edit a general description and notes for each islanding situations

Statistical Analysis

The application shall provide statistics on:

- Frequency of islanding management situations in a certain area (multiple locations).
- Utilization of the battery to reduce power losses e.g. total energy provided, maximum power provided.

Statistics and graphs should be presented in an easy-to-interpret format.

Operational requirements

The principal operational requirements of IPMA are reported in Table 7.

Table 7 IPMA operational requirements

Requirement Type	Description	Pilot threshold	Final product threshold
Availability	High availability of the application shall be achieved.	>90%	99%
	Scheduled continuous downtime should not exceed a specific threshold.	2 days	2 consecutive hours
	A maximum occurrence of scheduled downtime shall not be surpassed.	7 days per month	12 hours per month
	Unscheduled downtime should not exceed a certain threshold	7 days per month	30 minutes per month
Maintainability	Mean Time to Repair (MTTR) due to hardware malfunctions shall not exceed a certain threshold.	-	2 consecutive hours
	Software maintainability should follow standard practices (versioning etc.)	NA	NA
Reliability	The application shall not suffer loss of service more than a specific threshold.	5 times per month	5 times per year
	The mean time between fixes (MTBF) shall exceed a minimum threshold.	7 days	2 hours
Performance	The start-up time and full availability of the application's functionality must be no longer than a specified threshold.	10 minutes	10 minutes
	The average response time for receiving external information (e.g. smart meter data), shall not exceed a certain threshold.	1 minute	20 seconds
Scalability	The overall performance of the system must be able to grow with more powerful hardware.	NA	NA
Security	The application shall protect the data and services from unauthorized access.	NA	NA
	It shall provide authentication and secure transaction.	NA	NA

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	Accounting shall be supported for monitoring any attempt to unauthenticated accesses.	NA	NA
	Shall be placed behind a firewall to minimize risk from external attacks.	NA	NA

7. Interoperability and data manipulation requirements

7.1. Enterprise Service Bus

The Enterprise Service Bus (ESB) is a middleware that provides messaging transformation and content-based routing capabilities as well as other features that allow seamless integration among enterprise applications. The core concept of the ESB architectural pattern is that different applications are integrated by communicating via a bus instead of communicating directly with each other. Among of the benefits of this service-based abstraction layer are the loose coupling of applications, the single point of communication, minimal integration coding, scalability, facilitation of standard interfaces & protocols, as well as the advanced monitoring capabilities and proper quality of services.

Functional requirements

The ESB shall provide the following functionalities:

Support message intelligent routing to multiple destinations based on different conditions/policies e.g. addressability, static/deterministic, content-based, rules-based, policy-based.
Support data transformation for multiple data formats.
Support both synchronous and asynchronous communications.
Support complex event processing, including pattern detection of specific combinations of events (events patterns), filtering of events, aggregation and transformation, as well as event relationship analysis.
Support service orchestration, coordinating multiple implementation services to be exposed as a single-aggregated service.
Support business process automation, offering ability to model and automate complex business processes.
Offer the ability of configuration (i.e. deployment, service registration, database setup).
Offer the ability to monitor its operation (e.g. message flows, faults, usage patterns), through auditing and logging capabilities.

Interface requirements

The ESB shall be able to exchange information with the following systems and applications:

SCADA, for accessing grid configuration and providing grid operation schedule data.
MDMS, for accessing SM and GM data.
Weather Forecaster, for accessing weather forecast and historic data.
GIS, for accessing grid topology.
DMS supervision and analytics services (EF, CEF, PFS, GOS, FDA), for facilitating the communications.
DMS operation applications (i.e. CEPA, SHA, LRA, IPMA), for facilitating the communications.
WAMS, for accessing PMU data.
PED, for accessing PED status and providing grid operation schedules.
Data Management System, for:
    - Storing data from legacy systems and DMS's applications and services.
    - Providing access to stored data to DMS's applications and services.

- An external authorization, authentication and accounting system.

User interface requirements

The ESB shall offer user interface that:

Allows for configuration of the deployment, database setup as well as for service registration.
Supports monitoring its performance through KPIs.

Operational requirements

The principal operational requirements of ESB include:

- A high percentage of availability (higher than 90%) should be supported. System's scheduled downtime should last no more have more than 5 consecutive hours and no more than 5 days in total per month. Unscheduled downtime should not exceed 3 days per month.
- Mean Time to Repair (MTTR) due to hardware malfunctions shall not exceed 72 consecutive hours. Software maintainability should follow standard practices (e.g. versioning control, automated testing, continuous integration).
- During the operational period of the pilot shall not suffer loss of service more than 5 times/month; the Mean Time Between Fixes (MTBF) during the pilot shall be 5 days at minimum.
- The start-up time and full availability of the ESB's functionality must be no longer than 5 minutes.
- The overall performance of the system must be able to grow with more powerful hardware. Multiple instances of the system shall be able to cooperate for increasing performance.
- Support data models of the CIM, IEC 61850 and IEC 60870 standards series.
- Protection from unauthorized access, authentication and secure transaction as well as accounting shall be supported.

7.3. Data Management System

The Data Management System will allow the transparent integration of heterogeneous data types (from smart metering data to models of distribution grid, load consumption / generation forecasts etc.), offering validation and homogenization of data and guaranteeing accessibility with specific QoS characteristics. This element will act as a centralized storage of data from legacy systems and results of computation algorithms, allowing the decoupling of the legacy systems from the operation of the advanced functionalities that will be integrated in the DMS.

Functional requirements

The Data Management System shall provide the following functionalities:

Support data storage capabilities for diverge data from different external data sources:

- Grid configuration data from SCADA.
- Grid topology data from GIS.
- Grid operation schedule from GOS.
- Demand and generation forecasts from EF.
- Smart metering data from MDMS.
- Weather data (forecast and history) from weather forecaster.
- Power flow simulation data from PFS.
- Critical events data from CEF.
- Grid fault data from FDA.
- Grid power losses data from LRA.
- Status of PED.

Support storage of business workflow data from DMS's operation applications (i.e. CEPA, SHA, LRA, IPMA).
Support storage of KPIs calculated for DMS operation applications.
Provide accessibility to the stored data through the ESB.
Provide data manipulation capabilities of the stored data through the ESB.

Interface requirements

The Data Management System shall provide interfaces to:

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ESB for data storage, access and manipulation.
Data analysis and visualization tool for data storage, access and manipulation.
External authorization, authentication and accounting system.

Operational requirements

The principal operational requirements of Data Management System include:

- The system should have a high percentage of availability (higher than 90%). System's scheduled downtime should last no more have more than 5 consecutive hours and no more than 5 days in total per month. Unscheduled downtime should not exceed 3 days per month.
- Mean Time to Repair (MTTR) due to hardware malfunctions shall not exceed 72 consecutive hours.
- During the operational period of the pilot shall not suffer loss of service more than 5 times/month; the Mean Time Between Fixes (MTBF) during the pilot shall be 5 days at minimum.
- The start-up time and full availability of the application's functionality must be no longer than 5 minutes.
- The overall performance (transactions handled) of the system must be able to grow with more powerful hardware. The capacity of the database must be able to grow in order to match increased needs of storage.

Shall support the integration of different DB types (both relational and non-relational). Shall support the integration of multiple DB technologies (e.g. MySQL, Oracle).
Data backups from the DMS related applications and services, as well as PED related information shall be kept.

- Protection from unauthorized access, authentication and secure transaction as well as accounting shall be supported.

7.3. Data Analysis and Visualization Tool

The Data Analysis and Visualization Tool will, one hand, host intelligent algorithms for metrics (KPIs) calculation that can be utilized for monitoring, optimization and profiling, whilst providing the computations as a service to other applications. On the other hand, it will present the results of the computations – possibly correlated with other stored data – either as an autonomous visualization or as an embeddable artefact to be integrated in other applications.

Functional requirements

The Data Analysis and Visualization Tool shall provide the following functionalities:

Calculate evaluation metrics on a regular basis.
Calculate evaluation metrics upon request.
Visualizations of information through user interfaces.
Offer visualizations as an embeddable artefact to be integrated in other applications.
User notification that a request is being processed, upon requesting a visualization.
Allow for visualizations parameterization (i.e. time period, data sets displayed).

Interface requirements

The Data Analysis and Visualization Tool shall provide interfaces for:

Communication with the Data Management System to access stored data as well as for store calculated metrics.
Accessing the list of KPI.
Triggering a calculation of a specific KPI.
Accessing the list of visualizations.
Presenting a visualization.

Accessing a visualization that can be embedded in another application.
External authorization, authentication and accounting system.

User interface requirements

Two different roles shall be supported, the role of the administrator and that of the operator:

The administrator shall be able to define the metrics to be calculated.
The administrator shall be able to define the periodicity of calculation.
The administrator shall be able to define the visualizations, selecting type of graphs, time period and metrics or raw data to be presented.
Both, the administrator and operator, shall be able to parameterize the visualizations.

A visualization might be composed by a single of multiple graphs (dashboard).

The following views define further requirement on user interfaces:

KPI Definition

Shall provide an interface for defining KPIs.
Shall provide an interface for setting a periodicity of KPI calculation.

Visualization Definition

Shall provide an interface for defining and storing graphs of stored data (raw data or KPIs) or metrics calculated on the fly.
Shall be able to store a graph with a chosen static (specific) time period of the data to be visualized or a dynamic one (e.g. last week).
Shall provide an interface for defining dashboards of different graphs.

Visualization

The user shall be able to select a visualization from the list of available ones.
The user shall be able to select/modify the time period of visualization.
The user shall be able to zoom in/out a graph of the visualization.
The user shall be able to select specific data sets to be presented in the visualization.

Operational requirements

The principal operational requirements of Data Analysis and Visualization Tool include:

- A high percentage of availability (higher than 90%) should be supported. System's scheduled downtime should last no more have more than 5 consecutive hours and no more than 5 days in total per month. Unscheduled downtime should not exceed 3 days per month
- Mean Time to Repair (MTTR) due to hardware malfunctions shall not exceed 72 consecutive hours. Software maintainability should follow standard practices (e.g. versioning control, automated testing, continuous integration)
- During the operational period of the pilot shall not suffer loss of service more than 5 times/month; the Mean Time Between Fixes (MTBF) during the pilot shall be 5 days at minimum.
- The start-up time and full availability of all functionalities must be no longer than 5 minutes;
- The overall performance of the system must be able to grow with more powerful hardware. Multiple instances of the system shall be able to cooperate for increasing performance.
- Protection from unauthorized access, authentication and secure transaction as well as accounting shall be supported.

8. Conclusion

The RESOLVD project has the objective of improving efficiency and the hosting capacity of distribution networks in a context of highly distributed renewable generation. For this it is developing an innovative power electronics devices enabling flexibility on the grid edge, an advanced grid observability and forecasting solution, and a number of services and applications enabling coordinated, resilient and efficient operation of the grid.

This report presented the technical and operational requirements of the identified technical actors that are involved in the particularly considered use cases (defined in D1.1). The aim of the specifications is to serve as a baseline for individual devices, systems, services and applications development and as identifier of foreseen interactions. In this respect, the report discusses both, the involved legacy systems of DSO, and the project developed solutions. The requirements for project developed components are structured in three main section:

- Power Electronic Devices, which is being developed in WP2,
- Wide Area Monitoring System, which is being developed in WP3, and
- Distribution Management System services and applications, which are being developed in WP3 and WP4.

Additionally, the principal requirements for interoperability and data manipulation are discussed from the perspective of solutions being developed in WP4. Further analysis on interoperability and integration of technical actors according to the use cases will be provided in D1.3, while the holistic by-design security aspect will be covered in D1.4.

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