RESOLVD - RENEWABLE PENETRATION LEVERED BY EFFICIENT LOW VOLTAGE DISTRIBUTION GRIDS. SPECIFCATIONS AND USE CASE ANALYSIS

Joaquim Meléndez Frigola
Universitat de Girona – Spain
joaquim.melendez@udg.edu

Isidoros Kokos
Intracom Telecom – Greece
isik@intracom-telecom.com

Heidi Tuiskula
Smart Innovation Norway - Norway
Heidi.tuiskula@smartinnovationnorway.com

Andreas Sumper
Universitat Politècnica de Catalunya – Spain
andreas.sumper@upc.edu

Stefan Marksteiner
Joanneum Research – Austria
stefan.marksteiner@avl.com

Ramon Gallart
Estabanell Distribució - Spain
RGallart@estabanell.cat

Miha Smolnikar
Comsensus – Slovenia
miha.smolnikar@comsensus.eu

Ferran Torrent Fontbona
Universitat de Girona - Spain
ferran.torrent@udg.edu

ABSTRACT

The paper presents the RESOLVD (Renewable penetration levered by efficient low voltage distribution grids) project, which aims to improve the efficiency and the hosting capacity of distribution networks in a context of highly distributed renewable generation by introducing flexibility (storage management) and control in the low voltage (LV) grid. The analysis methodology - which follows the Smart Grid Architecture Model (SGAM) framework paradigm- is presented, along with the identified use cases and actors. The proposed initial architecture is also presented, as derived from the use case analysis process together with a cybersecurity analysis of integration and interoperability issues. The research is being motivated by business models and the expected impacts are summarized in the paper.

INTRODUCTION

RESOLVD (https://resolvd.eu/) is a H2020 research and innovation action (TRL5/6, 2017/2010) coordinated by Universitat de Girona and participated by the other six partners authoring this paper. The main objective of RESOLVD is to improve the efficiency and the hosting capacity of distribution networks, in a context of highly distributed renewable generation by introducing flexibility and control in the low voltage (LV) grid. An innovative advanced power electronics device (PED), with integrated storage management capabilities, will provide both switching and energy balancing capacities to operate low voltage smart-grids optimally. Enhanced observability of low voltage grids is proposed through cost-effective PMUs and state-of-the-art short-term forecasting algorithms that predict demand and local renewable generation. Enhanced observability and improved energy control, through power electronic, reduces the uncertainty in the low voltage grid operation and provides an increased efficiency in a scenario of high variability of demand and generation.
RESOLVD builds up an enhanced low voltage grid monitoring with (local) wide area monitoring (WAMs) capabilities to detect and forecast critical episodes (congestion, faults, voltage variations and quality of supply) and to schedule optimal grid configuration and energy management through heterogeneous storage elements. The interoperation of these technologies in a secure and safe framework will allow efficient grid operation and a maximised renewable hosting capacity.
RESOLVD technologies should interoperate with existing legacy systems (SCADA, AMI, MDMS, etc.) in secure and safe conditions. The project will be validated in a real grid owned by the Estabanell Distribució (project partner, DSO) that consists of two secondary substations with PV prosumers and equipped with an interconnection between the main feeders. Market potential of developed technologies is enhanced throughout the project time life by developing business models and collaborating with external stakeholders.

SPECIFICATIONS

The project aims to manage flexibility in the low voltage grid in a context of high penetration of distributed renewable generation. The following goals have been pointed:

- Maximise the use of actual infrastructures through active energy management and balancing at LV level.
- Reduce DSO planning uncertainty by means of demand and generation forecasting and application of robust optimisation methods for grid planning.
- Improve quality of supply (EN 50160 standard) by an improved daily operation of LV grid, facilitating flexibility management and maximal RES generation.
- Reduce losses through local use of energy (“zero km” paradigm)
- Increase RES hosting capacity in LV, facilitating evacuation of non-locally consumed generation
- Reduce energy not supplied from DER due to improved network
- Reduce demand peak at secondary substation.
- Deliver a secure-by-design Smart Grid (SG) architecture through threat modelling, stringent implementation and penetration testing.

RESOLVD aims to validate the achievement of these goals by deploying and validating a complete solution. Complete list of requirements in [7].

METHODOLOGY: USE CASES AND ACTORS

RESOLVD adopted the European conceptual Smart Grid Architecture Model (SGAM) framework ([1][2]), from specifications to design. Use cases derived from specifications have been mapped in the five interoperability SGAM layers: *business, functional, information, communication, components*. Actors and relationships derived from the use case analysis have been mapped in the SG zone-domain plane using the SGAM Toolbox ([3]). Identified use cases and actors, representing either legacy components or ones developed in the project, are presented in this section. A consolidated view of the SGAM Component and Information Layers derived from these UCs shows their interaction (The RESOLVD complete SGAM model will be available in [8]).

Use Case Analysis

Five business uses cases (BUC) focusing on resolving problems and challenges of the cost-effective operation of the LV grid have been defined (Table 1). Scope and boundaries of these BUCs, from the perspective of LV SG actors (DSO, aggregator, retailer, energy community, prosumer, DER/Storage owner) have been identified while leveraging existing as well as feasible future business models through novel utilisation of external Stakeholder Innovation Group (SIG) (See [10] as example). On the basis of the BUC analysis, eight conceptual (high level) use cases (HLUC) have been modelled to provide a decomposition in functions realized by logical actors-entities (List of actors in Table 2 and UCs in Table 1). Finally, a technical decomposition of the HLUCs, along with mapping of logical actors into physical components provided twenty primary use cases (PUC). Many logical actors involved in the PUCs, admit a one-to-one mapping with a single component; however, others were decomposed in different ones (e.g. PED decomposed in ILEM, PCS and BMS) or multiple actors deployed in a single one (e.g. DMS containing multiple applications). Details on such relationships are detailed in Table 2.

SGAM Analysis

The layout of RESOLVD components in the SGAM Component layer is presented in Figure 1. It depicts the location of the different components in the SG plane and their interrelations. The requirements on communications between components have been analysed from the basis of existing standards. Figure 2 (Information layer) depicts the mapping of different information models that will be investigated in the project, as resulted from the communication / interoperability analysis.

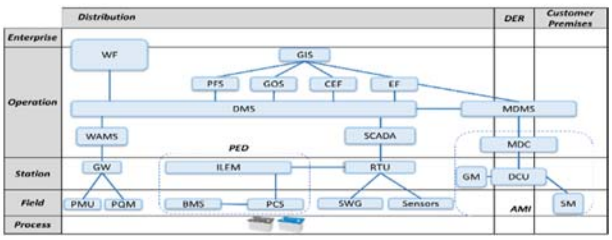

Figure 1 RESOVD SGAM Component Layer

Table 1 Use cases

BUCs
BUC01: Ensuring grid safety through real-time observability intelligent power electronics devices.
BUC02: Ensuring continuity of supply through dynamic network reconfiguration.
BUC03: Minimizing/delaying investment for network upgrade through smart grid-operation.
BUC04: Reducing technical losses through power electronics and local storage.
BUC05: Improving power quality through power electronics.
HLUCs
HLUC01: Prevention of congestion and over/under voltage issues through local storage utilization and grid reconfig.
HLUC02: Voltage control through reactive power injection or consumption.
HLUC03: Improving power quality and reducing losses through power electronics.
HLUC04: Reduction of power losses through local storage utilization.
HLUC05: Self-healing after a fault.
HLUC06: Power management in intentional controlled island mode.
HLUC07: Detection and interruption of unintentional uncontrolled islanding.
PUCs
PUC01-Demand and generation forecasting
PUC02-Power flow simulation
PUC03-Critical event forecasting
PUC04-Grid operation scheduling
PUC05-Grid operation schedule dispatch
PUC06-LV grid observability and monitoring
PUC07-Data pre-processing
PUC08-Collecting electric data (local & extern) by the PED
PUC09: Local reactive power management for voltage regulation
PUC10: Local active and reactive power management to correct power quality issues
PUC11: Fault detection and localization
PUC12: Detection of uncontrolled island-mode
PUC13: Interruption of uncontrolled island mode
PUC15: Individual consumption modelling
PUC16: Consumption monitoring
PUC17: Grid information data collection
PUC18: Analysis of present power measurements
PUC19: Assessment of suitable location for PED
PUC20: Orchestration applications

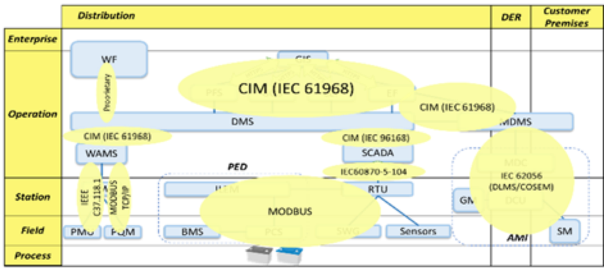

Figure 2 RESOLVD SGAM Information Layer

Table 2 Logical Actors (systems, devices, applications and human) in the RESOLVD architecture

Actor	Type	Name: Description (status in the project: legacy/development)
AMI	System	**Advanced Metering Infrastructure** that collects consumption and generation data from SMs of LV grid prosumers. The infrastructure is composed by the following devices and systems: MDC, DCU, SM and GM. (Legacy)
BMS	System	**Battery Management System**, in charge of managing different battery technologies providing power and storage capacity, according to the energy management requirements. It forms part of the PED (Developed).
CEF	Application	**Critical Event Forecaster** is the application in charge of predicting possible congestion or over-under voltage events in the succeeding forecasting time-horizon (H-time).(Developed)
CEPA	Application	**Critical Event Prevention Application** in charge of the orchestration of data management and executive actions, for the prevention of critical events through the utilization of storage and switching actions.(Developed)
DCU	Device	**Data Concentrator Units** are responsible of gathering measurement data from multiple metering devices installed at the substation or at the customer premises level, and sending them to the MDC. It is part of the AMI. (Legacy)
DPA	Application	**Data Pre-processing Application**, permits to clean, correct, complete and validate data once aggregated from various sources. (Developed)
DMS	System	**Distribution Management System** supports advanced monitoring and control of the distribution grid from the DSO control centre. In most of the use cases it participates as a main orchestrator actor.
EF	Application	**Energy Forecaster** is an application in charge of predicting demand and generation values in the succeeding time-horizon (H-time), in specific points of the grid, using prosumers and weather forecast data. (Developed)
FDA	Application	**Fault Detection Application** is in charge of detecting, classifying and localizing a grid fault, based on real-time signal processing of field data. (Developed)
GW	Device	**Gateway**s are devices enabling the interconnection of various systems and devices. It can provide functions such as data aggregation, protocol conversion and coordination of end devices. (Developed)
GIS	System	**Geographic Information System** is designed to capture, store, manipulate, analyse, manage, and present all types of geographical data. It maintains the model of the grid and its assets.(Legacy)
GOS	Application	**Grid Operation Scheduler application** provides separate schedules for each actuator of the grid, satisfying a predefined objective function that depends on the specific scenario. (Developed)
GP	Human Actor	**Grid Planner** is a human actor/analyst that designs the optimal location and size of the power electronics devices to be installed in the LV grid. The GP interacts with the PTF by requiring relevant data.
ILEM	Device	**Intelligent. Local Energy Manager** is an electronic device (IED) in charge of communication and implementing the control logic of a PED. It is part of PED. (Developed)
IPMA	Application	**Island Power Management Application** is in charge of orchestrating the data management and executive actions, for the power management of a controlled island. (Developed)
LRA	Application	**Loss Reduction Application** orchestrates data management and executive actions, for the reduction of losses through local storage utilization. It works autonomously or controlled by a human operator. (Developed)
MDC	System	**Meter Data Collector** is responsible of the collecting and managing measurement data at the operation centre of the DSO, by interfacing data concentrating units (DCUs). It is part of the AMI and forwards data to MDMS. (Legacy)
MDMS	System	**Meter Data Management System** validates, stores, processes and analyses large quantities of Smart Meter data.
PMU	Device	**Phasor Measurement Unit**s provide time-synchronized measurements of voltage, current, frequency and phase (i.e. synchro-phasors) in a distributed system. Feeds data to phasor data concentrators and the WAMS. (Developed)
PTF	Human Actor(s)	**Planning Task Force** is a team, from DSO and technology providers/installers, that collaborate with the common objective of identifying the most suitable technology size and location based on technical-economic criteria
PCS	Device	**Power Conversion System** is device capable of acting on the grid providing switching and energy management capacity, through power electronics. It forms part of the PED. (Developed)
PED	Device	**Power Electronic Device** is device composed of an ILEM, a Power Conversion System (PCS) a BMS and the batteries themselves; that is in charge of locally managing energy at different levels. (Developed)
PFS	Application	**Power Flow Simulator**, the application that simulates power flows in the grid, predicting the voltage and current values of each bus for the following H-time.
PQA	Device	**Power Quality Analyser** permits to measure, store and analyse grid data. It allows the recording of a continuous set of power data and can be installed permanently or during temporal campaigns.
PQM	Device	**Power Quality Monitoring** is an instrument enabling precise power quality monitoring (e.g. harmonics, RMS, active/reactive power) data (transient disturbances and steady state variations). (Developed)
RTU	Device	**Remote Terminal Unit** is a communications enabled Intelligent Electric Device (IED) that interfaces the DMS or Supervisory Control and Data Acquisition (SCADA) system and field devices. (Legacy)
SHA	Application	**Self-healing Application** implements the orchestration mechanism of data management and executive actions, for self-healing after a fault. It can work autonomously or controlled by a human operator. (Developed)
SM (GM)	Device	**Smart Meters (Grid Meter)** are metering devices installed at the customer (substation with DCU) premises or DER location that measures power profiles and energy consumption. It is part of the AMI. (Legacy)
SCADA	System	**Supervisory Control and Data Acquisition system** is in charge of the overall monitoring and control of the distribution grid, integrating remote control systems and data storage functionalities. (Legacy)
SWG	Device	**Switchgears** are the actuators of the LV grid that permit to switch lines and change grid configuration. To be installed.
WF	Application	**Weather Forecaster is a** service offering forecasting weather conditions services. (Developed)
WAMS	System	**Wide Area Monitoring System** is in charge of managing (collecting, concentrating, transmitting and monitoring) and exploiting PMU data. It is composed of PMUs, gateways and dedicated ICT infrastructure (Developed)

INTEGRATION: ARCHITECTURE AND CYBESECURITY

Architecture design has been developed according to the ISO/IEC/IEEE 42010:2011 ([4]), which establishes a methodology for the architecture description of software systems. The different actors and interoperability layers from SGAM analysis were used to design the architecture presented in Figure 3.

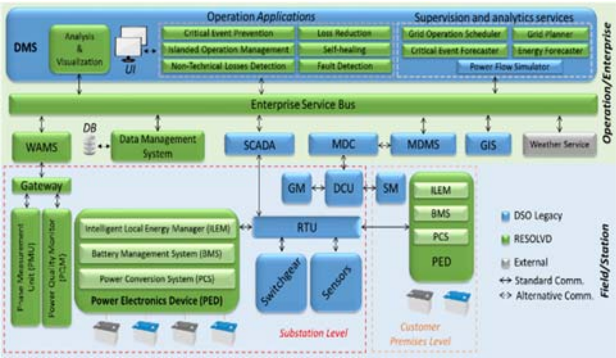

Figure 3 RESOLVD Architecture: Component view

Special attention has put in the integration analysis; that has been performed at three levels: physical (interconnection of devices and communication networks), application (interoperability, data access and computing) and business (coordination of functions according to business goals). In RESOLVD the last two levels are off special importance due to the heterogeneity of data sources, number of services and applications and business goals. Towards this, the design was complemented with additional components:

1) Enterprise Service Bus (ESB): Considering the speed of change in requirements, as well the reliability and security aspects, the concept of a Service Oriented Architecture (SOA) is supported by a flexible integration middleware (the ESB).
2) Data Management System: An important aspect of integration is the accessibility to data for the needs of analysis and visualization, in presence of high volumes and velocity of data generated by the numerous field devices and other sources. The Data Management System will allow the transparent integration of heterogeneous data technologies & vendors, various data types (from start 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.
3) The Data Analysis and Visualization System: Aims at hosting intelligent algorithms, providing the computations as a service to other applications, whilst presenting the stored data or results of the computations as an embeddable artefact to other applications.

As presented in Figure 3, the set of artefacts being integrated in RESOLVD falls in two categories: legacy/integrated (blue), developed (green) during the project and external (grey). The first basically includes the DSO legacy systems, such as: SCADA, GIS, MDMS, MDC (AMI HES), DCU, GM, SM, RTU, PFS, Switchgear, Sensors (substation level) and actual DMS. A Weather Service component is identified as an external service, whereas, the developed artefacts can be separated in three clusters:

1) Advanced tools and applications for the DSOs
   - DMS Operation Applications:
     - Critical Event Prevention (CEPA)
     - Non-Technical Loss and Fraud Detection
     - Losses Reduction (LRA)
     - Self-Healing (SHA)
     - Power management in intentional and controlled-island mode (IPMA)
     - Supervision and Analytics services
     - Energy Forecaster (EF)
     - Critical Event Forecaster (CEF)
     - Grid Operation Scheduler (GOS)
     - Fault Detection Application (FDA)
     - Grid Planner (GP)
   - The Enterprise Service Bus (ESB)
   - The Data Management, Analysis and Visualization tools
2) Power Electronic Device (PED)
   - Intelligent Local Energy Manager(ILEM)
   - Battery Management System (BMS)
   - Power Conversion System (PCS)
3) WAMS Infrastructure
   - WAMS
   - PMU/PQM devices
   - Gateway (GW)

From the perspective of the physical/communication integration, the adoption of standard solutions that can guarantee interoperability, is a requirement. In the context of SGs several standards (e.g. CIM standards series, IEC 61850) have been developed to support this integration. However, not all the standards are either interoperable among each other nor completely secure when combined in the same architecture. Thus, potential threats ([5], [6]) have been studied for the involved protocols. Table 2 summarises this analysis w.r.t the considered threats. Analogous analysis has been performed for devices; although, space limitation does not permit to reproduce it here. Identified threats have been converted into a list of security requirements. Identified threats have been converted into a list of security requirements (see Table 2 for the protocol requirements) that includes, for example the necessity of segregating communications, using encryption or redundancies (detailed requirements analysis in [9]). These requirements, if implemented correctly, should assure a secure system for the low voltage distribution intelligence developed within the project. The implementation details (specific algorithms, cipher modes the protocol/device provides or the usage of a security service at a different level, e.g. a VPN service) will be specified in later project stages.

Table 3 Overview of the protocol modelling for the threat model

Requirement	IEEE C37.118	IEC 61850-8-1	PRIME1	Modbus RTU	Modbus TCP/IP	IEC 60870-5-104	IEC 61968-100	STG-DC
Communications Segregation	X			X	X	X		X
Enforce IEC 61850-90-5 Security	X							
Use PRIME Prole 2			X					
Enforce Modbus TCP/IP Security with encryption					X			
Use IEC 62351 with cryptographic protection						X		
ESB HTTPS Protection							X	
SOAP Security								X

Note: multiple requirements in protocols (columns) are mutual alternatives (one of each has to be fulfilled)

OUTCOME: BENEFITS AND VALIDATION SCENARIO

RESOLVD aims to demonstrate how actual infrastructures can increase the hosting capacity (installed at consumer premises) by providing an active and local energy management and balancing. This requires the installation of enough storage to avoid congestions; and, at the same time, to assure that produced energy is consumed locally. A novel power electronics device will manage this energy according to schedules provided by the platform when critical events (congestions, voltage variations, islanding, etc.) are forecasted at the same time that can provide balancing and compensation services autonomously.

RESOLVD will be validated in a LV grid, owned by the DSO Estabanell Distribució, that consists of two secondary substations (250kVA and 630kVA), located in L'Esquirol (Catalunya), with presence of PV generation and an operable interconnection point between two feeders (to be installed during the project). One of the substations will be equipped with 44.7 kWh of energy storage (14kWh lead acid pack and a 30.7kWh lithium ion pack) dimensioned to supply energy during 4 hours to customers in both substations when isolated from the main grid and without PV generation. A Power electronics device with three 25kVA front end inverters will manage energy locally providing at the same time power quality services (balancing, reactive compensation, harmonic filtering, etc.). PMU will be installed also in the grid aiming to detect sudden variations on generation and/or demand and for fault detection purposes. Information generated by these devices, together with Smart metering data constitute the data substrate that will be managed in the RESOLVD platform to support the grid operation based on previously described architecture.

Business models analysis and exploitation possibilities are continuously supporting technological development in order to maximise the impact of RESOLVD on the distribution grids' operation and contribute towards sustainable energy landscape.

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