D3.3 - Final S4G Components, Interfaces and Architecture Specification

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0.2	2019-08-13	UNINOVA	Version ready for partners inputs.
0.3	2019-08-19	LIBAL	Update and correct description related to GESSCon and LiBal System.
0.4	2019-08-20	EDYNA	Minor corrections.
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0.7	2019-08-30	UPB	UPB updates.
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0.10	2019-09-26	UNINOVA	Address reviewer comments.
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1.0	2019-10-04	UNINOVA	Final version, ready for submission to the EC.

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2019-09-11 (v0.9)	Orlando Tovar (LINKS)	Reviewed: • Minor corrections. • Comments and suggestions. • Some clarifications are needed.
2019-09-17 (v0.9)	Yini Xu (LiBal)	Approved: • General minor corrections. • Comments.
2019-10-04 (v0.13)	Orlando Tovar (LINKS)	Approved.

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Executive Summary

The deliverable D3.3 describes the Final S4G Components, Interfaces and Architecture Specification serving the objectives of the Storage4Grid (S4G) project. This document is meant to provide the final view and results of WP3 – "S4G Architecture", consolidating the work and developments during the entire project. WP3 ensured the alignment and compliance of S4G outcomes with European Union (EU) and international Smart Grid standards and pre-designed the S4G Storage Interfaces and Common Information Model (CIM).
Refer to the previous D3.1 – "Initial S4G Component Interfaces and Architecture Specification" [S4G-D3.1] and D3.2 – "Final S4G Component Interfaces and Architecture Specification" [S4G-D3.2] to keep track of the S4G architecture system evolution.

The main goal of this document is to present the final S4G common architectural and technical framework, in order to facilitate the work during the development, integration, operation, and exploitation of the project, as well as the communication among S4G stakeholders both within and outside the project.

This document presents multiple architectural views (based on the ISO/IEC/IEEE 42010:2011 standard[i]) to assist the understanding of the S4G system and key properties about its behaviour, composition and evolution. Functional view shows the generic functionalities provided by S4G components and prototypes both individually and as part of integrated configurations. Information view includes a description of main functional interfaces amongst components/prototypes within the S4G system. Communication view identifies the optimal channels and protocols and is presented making use of deployment diagrams. Deployment view presents a general deployment of the S4G on the three test sites (Bucharest, Bolzano, and Fur/Skive). Finally, Information security view shows what are the cybersecurity countermeasures adopted in the S4G system.

The specifications described in this document have been built collaboratively by the S4G consortium, drawing inputs and requirements from the high-level scenarios and use-cases documented in D2.2 – "Final Storage Scenarios and Use Cases" [S4G-D2.2] and requirements documented in D2.6 – "Updated Lessons Learned and Requirements Report" [S4G-D2.6] as well as from Description of Action (DoA) i.e. the contractual agreement signed by the consortium with the European Commission (EC).

Diagrams included in this document use standard formatting including Unified Modelling Language (UML) compliant formats, namely class, component, and deployment or sequence diagrams[ii]. Standards are described and adopted across all the different views, according to their relevant domain. Nevertheless, since the adoption, analysis and pre-design of standard protocols and data models is a key objective of S4G, a dedicated "cross-cutting" section has been defined to provide an overview of standards adopted and analysed across all the different S4G layers. A gap analysis on Low Voltage (LV) DC networks shows that there is still a barrier for introducing LV DC at 220-300 V, because manufacturers declare as nominal voltage for their appliances only the AC voltage level, even if their internal construction allows also DC supply in certain voltage levels. The project suggests that in the future, the appliances manufacturers should also declare the DC voltage levels when applicable (e.g., 220 or 300 V DC nominal voltage). Moreover, there are not power quality standards for DC networks, and this is another identified gap. Such measure will enable a simpler and smooth adoption of DC supply.

Section 8 addresses future oriented architectures sustained by large storage resources, particularly by introducing the concept of "microgrid-by-design" and of a new dynamic stability mechanism: electrostatic energy-based inertia, or simplified addressed as "electrostatic inertia", similar with the "mechanical inertia" of the traditional grids. This is a proof of concept demonstrated in simulations and compared as theory of operation with the classical mechanical inertia. The findings have been published in two peer-review journals and, as being a TRL2-3 (research to prove feasibility), it deserves future developments. As analysed, the "electrostatic inertia" can be a cornerstone finding to enable new microgrid functionalities and to address the inertia reduction danger in main grids with high Renewable Energy Sources (RES) penetration. The new

microgrid-by-design architecture is essentially enabled by large storage resources (Battery Energy Storage System (BESS) and supercapacitors) in inverter-based energy generators, especially in Solid State Transformers (SST) acting as microgrid formers.

1 Introduction

This deliverable document the design and architectural specifications for all the tangible outcomes of the S4G project, ensuring proper mapping towards EU and International Smart Grid standards. Its main goal is to define a common architectural and technical framework that facilitates communication during the development, integration, operation, and exploitation of the project.

The specifications described in this document have been built collaboratively by the S4G consortium, drawing inputs and requirements from the high-level scenarios and use-cases documented in D2.2 [S4G-D2.2] and requirements documented in D2.6 [S4G-D2.6] as well as from the project DoA.

1.1 Formalisms and formats adopted in this document

This document follows the general definitions and guidelines specified in the ISO/IEC/IEEE 42010:2011 standard[i], and it is therefore organized in multiple architectural views, each one associated to a dedicated section of this document.
The set of architectural views represented in this document has been chosen to match the Reference Architecture Elements defined by the Smart Grids Architecture Model (SGAM) framework, namely the functional, information, communication and component architectures[iii]. In general, all SGAM definitions for Interoperability layers, Domains and Zones were used in the S4G architecture whereas applicable. The Business Architecture of the S4G system has not been described in this document, as it is delegated to other documents, particularly D2.4 [S4G-D2.4].

Diagrams included in this document use standard formats including UML compliant formats, namely class, component, and deployment or sequence diagrams[ii]. According to the SGAM oriented organization, standards are described and adopted across all the different views, according to their relevant domains. Nevertheless, since the adoption, analysis and pre-design of standard protocols and data models is a key objective of S4G, a dedicated "cross-cutting" section has been defined to provide an overview of standards adopted and analysed across all the different S4G layers (section 7).

1.2 Reading guide

Architectural documentation structured in multiple views can be rather complex. In order to help readers in quickly finding their architectural concerns of interest in this document, Table 1 provides an overview of the key topics addressed.

Table 1. S4G system architecture reading guide.

Topic	Relevant Section
Generic functionalities provided by S4G components and prototypes individually or as part of integrated configurations	Section 2 - Functional View
Interfaces between components/prototypes and the information shared between them	Section 3 - Information Views
Communication protocols used between S4G components/prototypes	Section 4 - Communication View
General architecture of the S4G system deployed in the test sites	Section 5 - Deployment Views
What are the security countermeasures adopted in the S4G system	Section 6 - Information Security View
Standards adopted or analysed by the S4G project	Section 7 - Standards Overview

1.3 Deliverable scope

This deliverable documents the results generated by Work Package 3 – "S4G Architecture", and its task, namely:

- T3.1 - "Analysis of architectures, systems and standards".
- T3.2 - "Energy Storage System (ESS) Control Specification".
- T3.3 - "Decision Support Framework (DSF) Specification".
- T3.4 - "Pre-design of Storage Interfaces and Models".

This document is an update of D3.1 [S4G-D3.1] and D3.2 [S4G-D3.2]. No future update of this deliverable is expected.

1.4 Related documents

Table 2. List of related deliverables referenced in this document.

ID	Title	Reference	Version	Date
D2.2	Final Storage Scenarios and Use Cases	[S4G-D2.2]	1.0	2018-07-31
D2.4	Final S4G Business Models	[S4G-D2.4]	1.0	2019-08-06
D2.6	Updated Lessons Learned and Requirements Report	[S4G-D2.6]	1.0	2018-06-07
D3.1	Initial S4G Component Interfaces and Architecture Specification	[S4G-D3.1]	1.0	2017-09-20
D3.2	Updated S4G Component Interfaces and Architecture Specification	[S4G-D3.2]	1.0	2018-08-31
D4.3	Final User-side ESS control system	[S4G-D4.3]	1.0	2019-06-13
D4.5	Final Grid-side ESS control system	[S4G-D4.5]	1.0	2019-09-25
D4.7	Final Cooperative EV charging station control algorithms	[S4G-D4.7]	1.0	2019-09-03
D4.10	Final USM extensions for Storage Systems	[S4G-D4.10]	1.0	2019-09-30
D4.11	Initial Energy Router	[S4G-D4.11]	1.0	2018-11-06
D4.12	Final Energy Router	[S4G-D4.12]	1.0	2019-09-12
D5.2	Final DSF Hybrid Simulation Engine	[S4G-D5.2]	1.0	2019-09-25
D5.5	Final DSF Connectors for external systems and services	[S4G-D5.5]	1.0	2019-09-25
D5.7	Final DSF Predictive Models	[S4G-D5.7]	1.0	2019-09-25
D6.3	Phase 3 Test Site Plans	[S4G-D6.3]	0.25	2019-08-30
D6.9	Final Interfaces for Professional and Residential users	[S4G-D6.9]	1.0	2019-09-25
D8.1	POPD Requirement No. 1	[S4G-D8.1]	1.0	2017-04-04

2 Functional View

This section presents the S4G high-level functional architecture to give an overview of its main components, including their main functionalities. It has been defined after collecting and categorizing the technologies and software components that the S4G project partners brought in with them. Moreover, its view has been refined considering S4G High-Level Use-Cases (HLUCs) and related stakeholders' requirements.

Section 2.1 shows how the S4G concept matches into the SGAM framework and recalls the three HLUCs and their deployment in the test sites (Bucharest, Bolzano, and Fur/Skive). Section 2.2 presents the S4G functional view following the SGAM guidelines.

2.1 S4G concept on SGAM framework

The M/490 framework defines the Smart Grid Reference Architecture[iii], which includes two main elements: (i) the Smart Grid conceptual model; and (ii) the SGAM framework. The conceptual model provides a high-level framework for the smart grid that defines seven high-level domains and shows the communication and electric energy flows connecting each domain. It is inspired by the National Institute of Standards and Technology (NIST) conceptual model[iv] and completes it by adding two new domains:

a) The Distributed Energy Resources (DER) domain.
b) The Flexibility concept, which groups consumption, production and storage together in a flexibility entity.

Both new domains are important in S4G project. Figure 1 summarizes the Smart Grid European conceptual model.

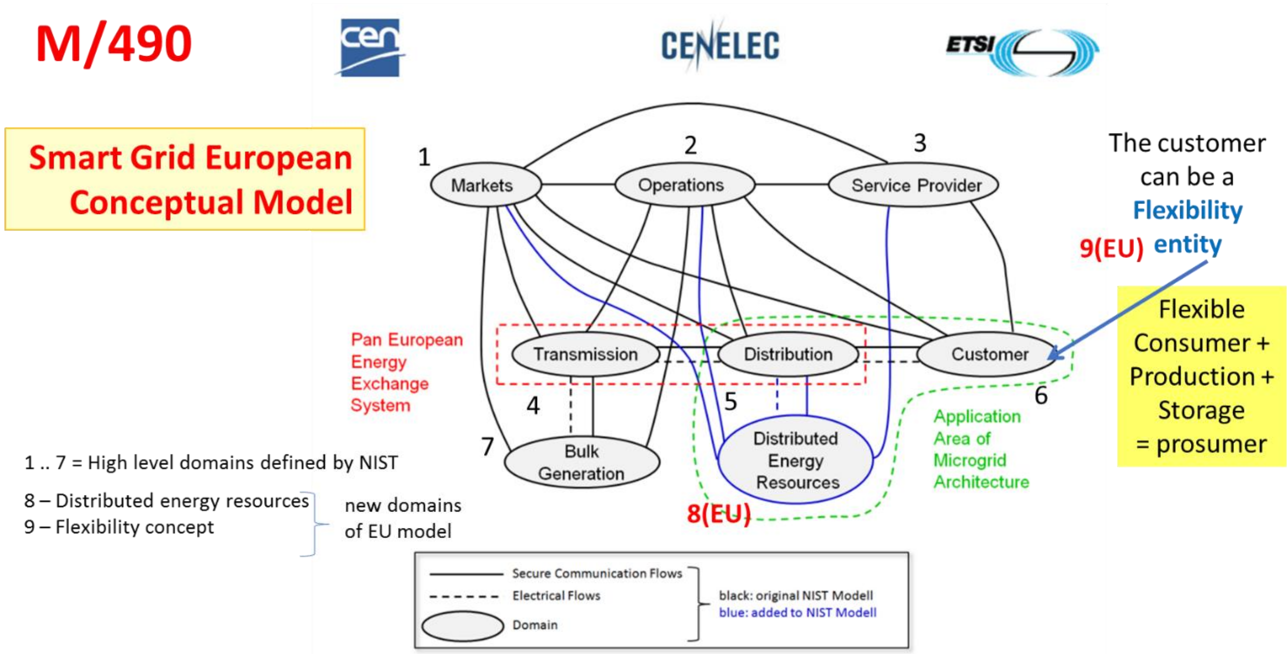

Figure 1. Smart grid European conceptual model (adapted from [iii]).

Figure 1 shows that the domains "Distribution", "DER" and "Customer" are becoming application areas of new electricity distribution and use architectures, thus being subject of new synergies and services. Initially, prosumers have been defined as dual entities (energy end-user and electricity generation unit) able to provide simultaneously generation and energy use, based on contractual/technical availability of these two functions. S4G extends the concept by including storage as a separate entity to be operated on the same premises/contractual basis of the energy customer. Theoretically, a storage unit is a prosumer which is using the same installation (storage and static converter) for providing the prosumer functionalities, however always asynchronously.

The SGAM is an important element of the Smart Grid Reference Architecture and has been developed to provide a framework for the smart grid architectures. It is an architectural approach, allowing for a representation of interoperability viewpoints in a technology neutral manner, both for the current implementation of the electrical grid and vision of future smart grids. SGAM uses a layered structure, supporting the requirement of interoperability, combining organizational, informational and technical aspects of the smart grid. Figure 2 presents the SGAM framework.

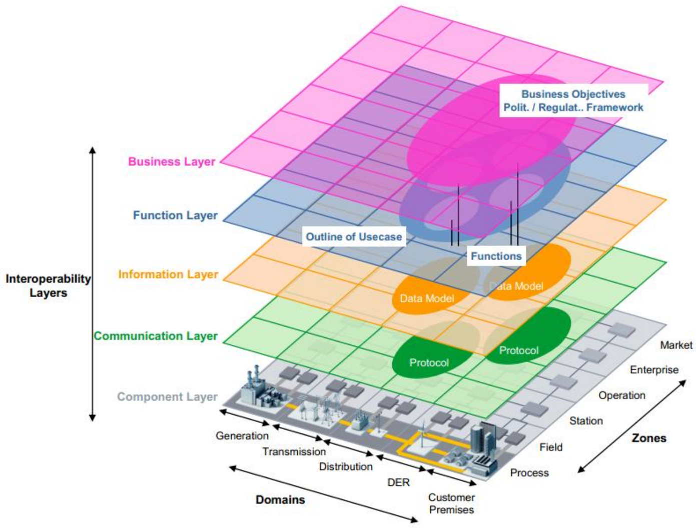

Figure 2. SGAM framework[iii].

Although a complete analysis of SGAM mapping is not in the scope of this project, in the following are presented preliminary versions of two of the five layers: the component layer and the function layer, the last one being very relevant to the S4G use-cases.
Figure 3 gives a view of the component layer. All S4G components have been introduced on this layer, as a structured set of components which are needed in different HLUCs.

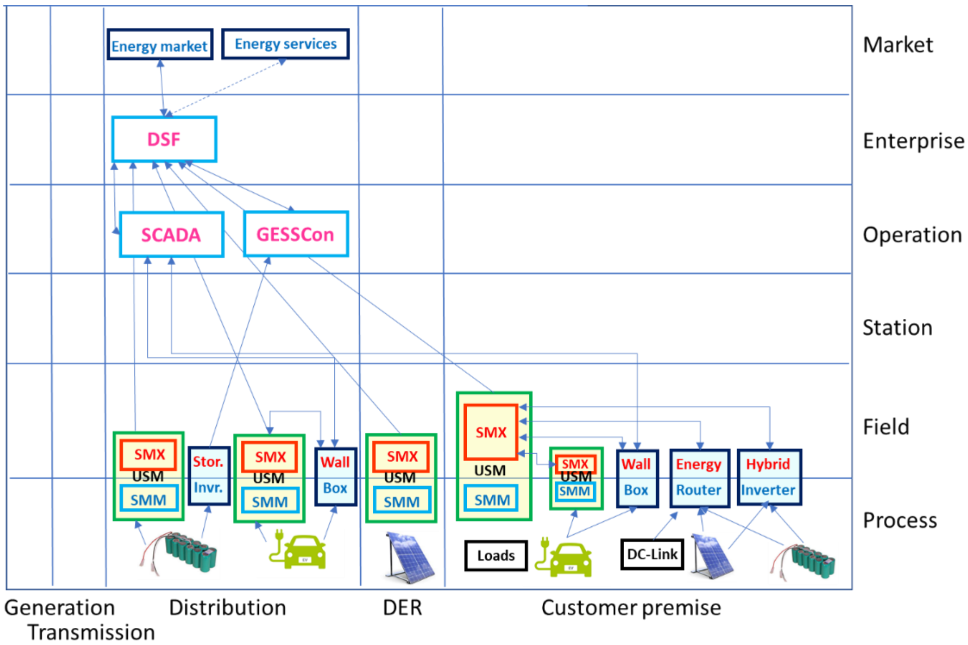

Figure 3. S4G SGAM Component layer.

It can be observed that three SGAM domains are addressed, namely the Distribution, DER and Customer premise. All zones except Station have been also addressed, with most of the components lying on Process, Field, and Operation zones. The grid-side Energy Storage System (ESS) has been considered as active in the Process zone, however it may be a case that it is placed on Station as well. The Market zone has been not a focus of this project, however it is present for possible connections. Moreover, many of the components have two segments, one in the process zone and one in the field zone. Usually in the field zone is the controlling part of the equipment, e.g. the Smart Meter eXtension (SMX), the microcontroller of the Hybrid Inverter (HI) or of the Energy Router (ER). For this reason, some components are placed on both zones. A complete description of the S4G components and their interconnections is given in the following sections.

The S4G technology is also addressing the flexibility, which is cornerstone of Universal Smart Energy Framework (USEF)[v]. In USEF, the definition of demand response is extended and includes control of local generation units, these two groups of application being coined as Active Demand and Supply (ADS). It is to be underlined that USEF assumes that:

> *"the new energy system must guarantee that flexibility will be sufficiently available and that peak loads can always be reduced whenever required to maintain network stability. This guarantee should be provided on both the long term and the short term. In current energy market processes to schedule the upcoming period, operators are inclined to ensure the distribution capacity required to support the market as far as possible in advance. This may conflict with the needs of energy suppliers, who prefer to keep flexibility available up to the last moment so they can adapt demand to unpredicted changes in energy production and consumption[v] "*

which is fully in line with the work and use-cases selected for demonstration in S4G.

2.1.1 Overview of functional aspects

The functional aspects are introduced in this deliverable through the function layer of SGAM, where a general function is associated to each HLUC. Detailed functional aspects are presented in section 2.2.

The SGAM Function layer represents the system design in terms of functionalities and services. The HLUCs described in D2.2 [S4G-D2.2] are mapped to SGAM considering the HLUCs logical actors. The HLUC is placed on the smart grid appropriate parts of the Domain and Zone areas. The following subsections show for each HLUC the simplified activity graph with generic interactions between the involved logical actors. More details regarding the information exchanged between the different S4G components/prototypes will be presented in the following sections.

2.1.1.1 HLUC-1: Bucharest (RO) – Advanced cooperative storage system scenario

The Bucharest HLUC is targeting an increased resilience of the prosumer using a new energy transfer architecture based on the ER, a DC bus on the prosumer premises, and neighbourhoods DC energy exchange. The new microgrid functionality intelligently exploits the operation of storage connected to the DC bus of the prosumer. This HLUC also addresses grid services specific to the prosumer operation such as avoiding curtailment due to high PV production, avoiding congestion in peak hours and black-start functionality.

Figure 4 presents this HLUC logical actors and their functionality. It can be observed that the logical actor "energy router" is in this case includes a similar functionality with the one of the hybrid inverter used in HLUC-3 (described in D2.2 [S4G-D2.2]), allowing the implementation of the DC bus and the DC link to neighbourhoods.

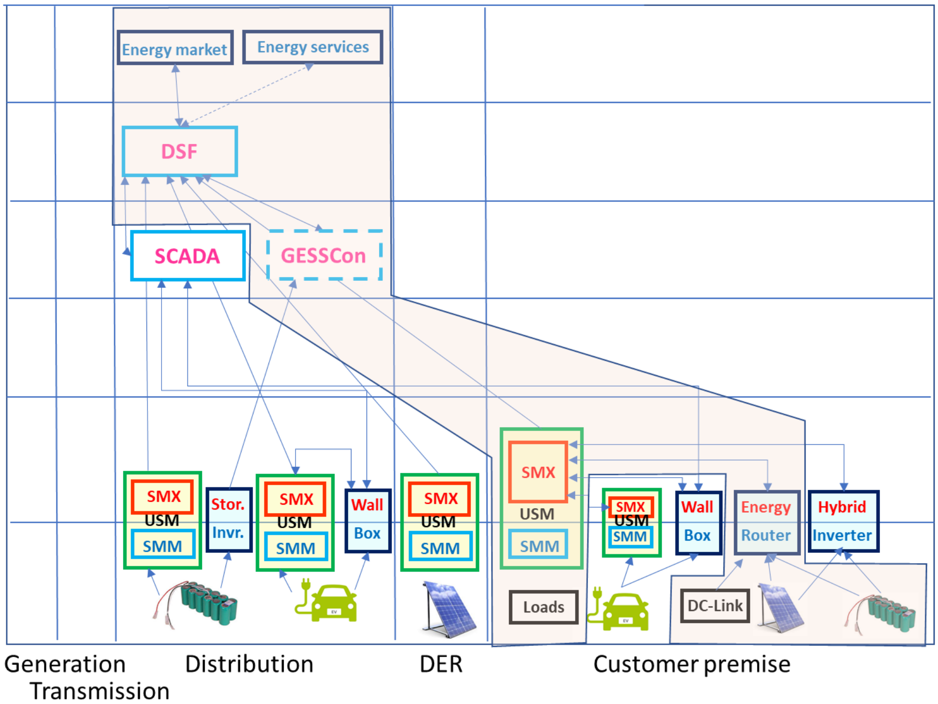

Figure 4. HLUC-1 Bucharest: S4G SGAM Function layer.

2.1.1.2 HLUC-2: Bolzano (IT) - Cooperative EV charging scenario

The Bolzano HLUC is targeting the maximization the Electric Vehicle (EV) charging in an existing grid through the optimisation and the use of storage resources on residential and commercial areas, as show in Figure 5.

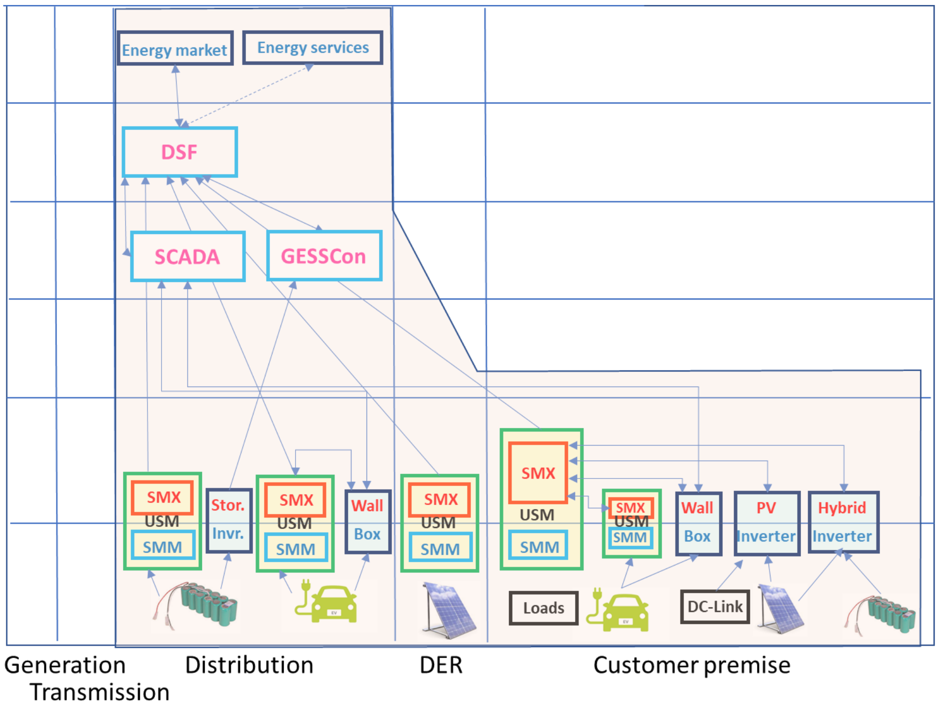

Figure 5. HLUC-2 Bolzano: S4G SGAM Function layer.

This HLUC is located in three domains, namely:

- **Distribution**: for commercial EV charging assisted by distribution-based storage (ESS).
- **DER**: considering the PV resource in the commercial area.
- **Customer premises**: considering a prosumer with Charging Point (CP), Photovoltaic (PV) production, and distinct storage resource.

2.1.1.3 HLUC-3: Fur/Skive (DK) - Storage coordination scenario

The Fur/Skive HLUC is targeting the maximization the PV integration in an existing or slightly enforced grid, through the optimisation of energy transfer and through the use of storage resources on residential and grid-side.

It can be observed in Figure 6 that this HLUC is targeting PV and storage at prosumer premises combined with grid-side ESS, used for optimizing the grid operation. EV charging and bulk PV at grid level are not involved.

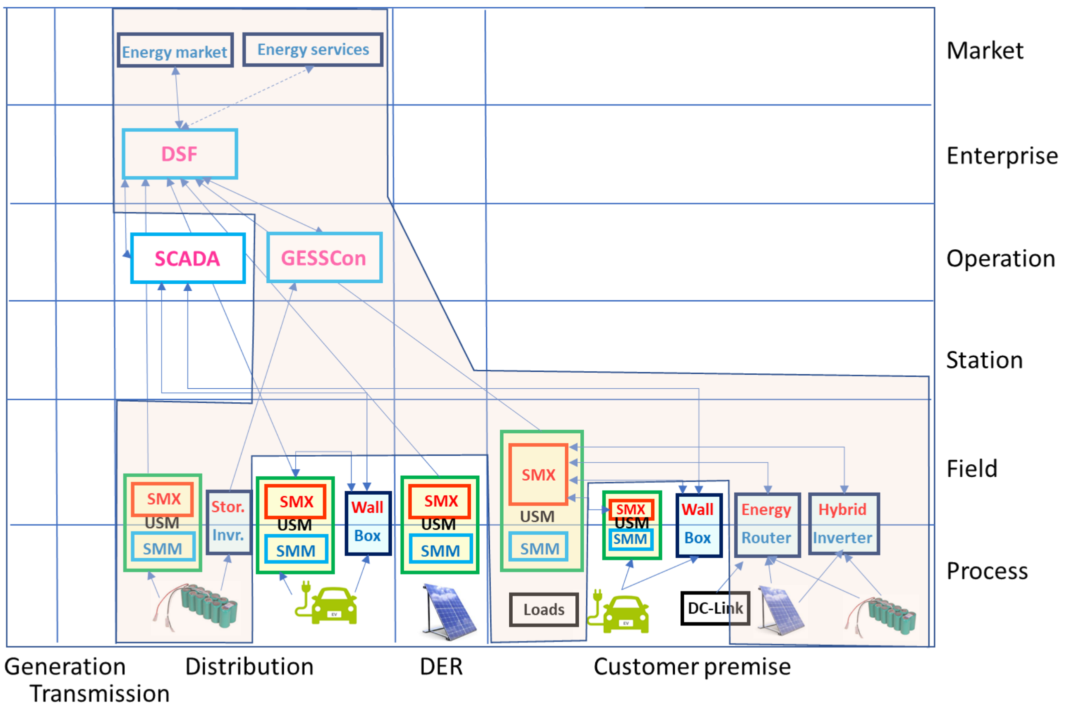

Figure 6. HLUC-3 Fur/Skive: S4G SGAM Function layer.

This HLUC is located in two domains, namely **Distribution** and **Customer premises**. A connection to the market logical actors is also generically considered.

2.2 S4G Functional View

The S4G functional view (Figure 7) is inspired on the SGAM view of Component, Functional, and Interoperability layers presented in section 2.1. The S4G functional view has been proposed in order to provide more detail and to consider Information and Communication Technologies (ICTs) aspects not included in SGAM views, which are important for the S4G project, e.g., the middleware level. Inspired from the zones of the SGAM framework, five layers were identified in S4G as described in the following subsections. The SGAM interoperability layers S4G mapping is also presented in this subsection.
Further details about the behaviour of each system's component and related subcomponents, including architectural elements that deliver the system's functionality are presented in section 2.3.

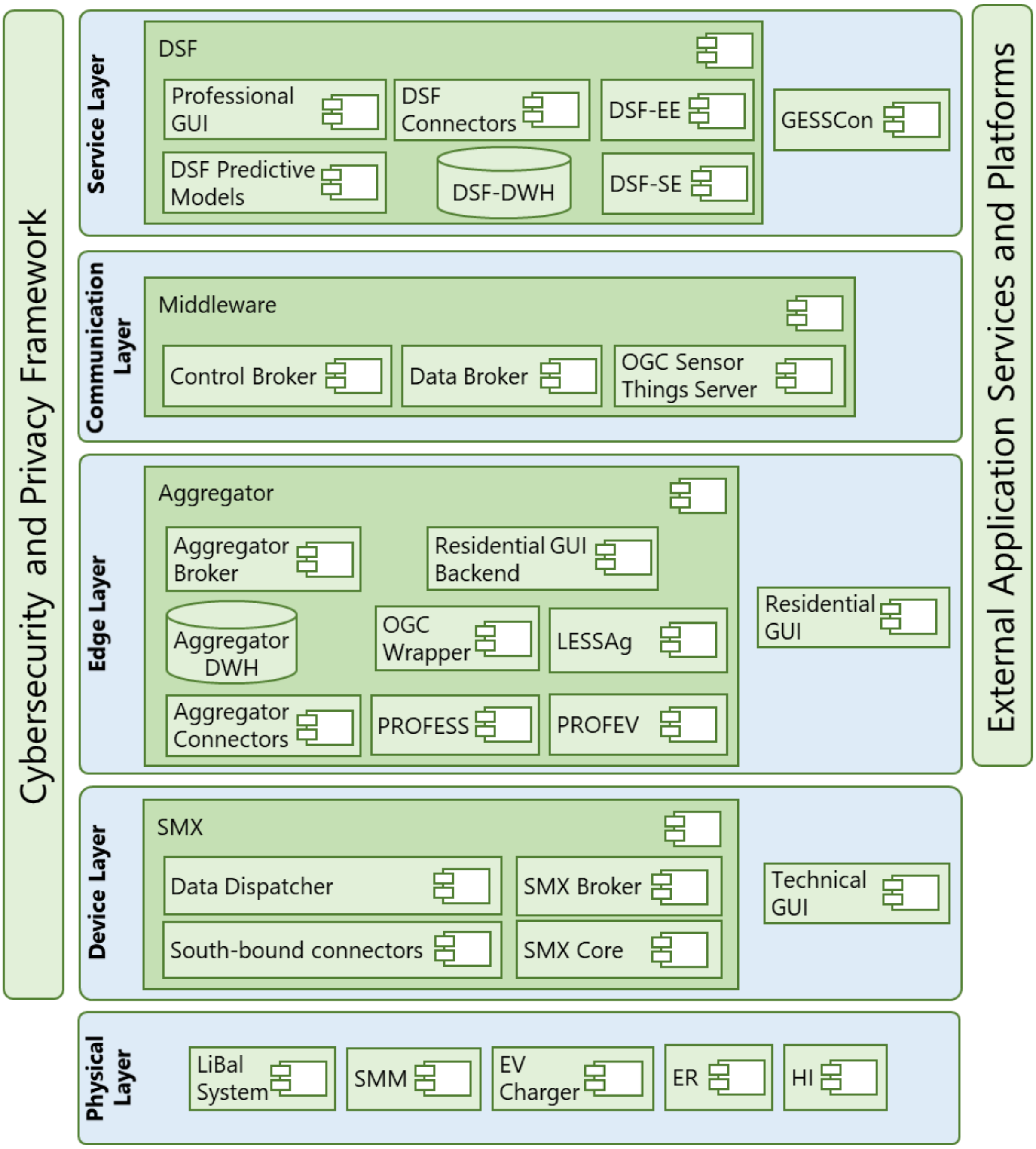

Figure 7. S4G functional architecture.

2.2.1 Physical Layer

This layer includes all components involved in electrical processes.

2.2.2 Device Layer

This layer allows the effective communication and direct control of devices in the **Physical Layer** and communicates with the **Edge Layer** (presented hereafter), to receive specific control instructions or to send data of interest from/to the upper layers.

2.2.3 Edge Layer

This layer allows on-site data collection from various sources in the **Device Layer**, as well as to propagate remote messages from upper layers to specific S4G components in the **Device** and **Physical** layers.

2.2.4 Communication Layer

This layer enables communication and management data among distributed S4G applications. Moreover, it enables communication within Service Layer, Edge Layer and Device Layer. Besides, it enables communication with a Common Information Model (CIM) facilitating interaction or integration with new services.

2.2.5 Service Layer

This layer is where the intelligence of the platform is implemented, and specific processing modules are integrated to provide technical solutions compliant with the application requirements. It can be mapped in Operation and Enterprise zones. The services modules are combined together with knowledge-based components and decision support tools, whose aim is to assist human operators with storage analysis and planning, as well as to provide control actions to distributed ESS systems and EV CPs at user premises and at substation level.

2.2.6 Cybersecurity and Privacy Framework

This framework enables trust-based communication, policy management and technical support across all levels of the platform. More specifically, this framework ensures secure data flows and storage, protected information exchange and trusted federation mechanism to facilitate private information sharing.

2.2.7 External Application Services and Platforms

Provides data sources suitable to support analysis, planning, forecast, and optimization of storage systems behaviour.

2.2.8 S4G Interoperability layers SGAM mapping

Figure 8 shows the mapping between the S4G layers and the SGAM interoperability layers.

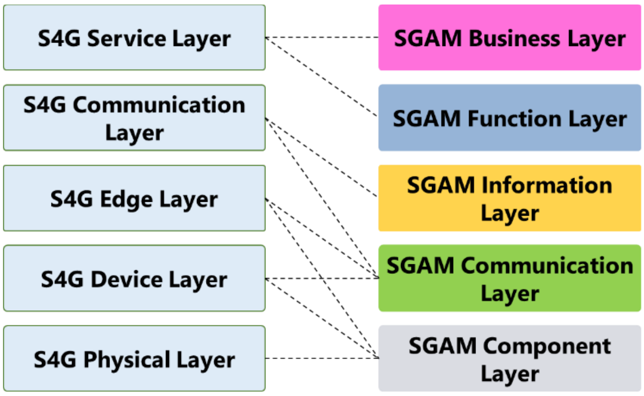

Figure 8. S4G mapping to SGAM Interoperability Layers.

2.3 S4G components and prototypes functionalities

This section provides a functional description of S4G components and prototypes according to its architecture layers.

2.3.1 Physical layer

2.3.1.1 LiBal System

The LiBal System is an ESS that includes lithium battery racks, Battery Management System (BMS), inverter and a site controller. The BMS is able to protect and monitor lithium battery. The inverter connects the ESS and local grid, enabling energy exchange. The site controller performs local power control of the ESS and enables communication between local units and the cloud. More information is available in D4.5 [S4G-D4.5].

2.3.1.2 SMM

The Smart Metrology Meter (SMM) is a certified smart meter suitable to be inter-connected to external systems and to measure energy consumption in a trusted/certified way. Its S4G communication interface is detailed in D4.10 [S4G-D4.10].

2.3.1.3 EV Charger

The Electric Vehicle (EV) Charger is an embedded device controlling a single point of energy delivery used for charging EVs. They can be connected to both public and private (residential) CPs. Its S4G communication interface is detailed in D4.10 [S4G-D4.10].

2.3.1.4 ER

The Energy Router (ER) is a power electronics device that manages the energy transfer from/to different sources (distribution grid, RES based distributed generators), loads and ESS. This component is fully detailed in D4.11 [S4G-D4.11] and D4.12 [S4G-D4.12], and its S4G communication interface is detailed in D4.10 [S4G-D4.10].

2.3.1.5 HI

The Hybrid Inverter (HI) is an inverter combining a battery inverter, PV inverter, controller and a system monitoring solution. The HI is able to supply household consumers with energy and to store surplus energy from a PV system in an ESS. In the S4G project it is used a Fronius Symo HI[vi]. Its S4G communication interface is detailed in D4.10 [S4G-D4.10].

2.3.2 Device layer

2.3.2.1 Technical GUI

The Technical Graphical User Interface (GUI) shows in real-time the SMX measurements by subscribing to Message Queuing Telemetry Transport (MQTT) topics. This component is fully detailed in D4.10 [S4G-D4.10].

2.3.2.2 SMX

The Smart Meter eXtension (SMX) is a modular software component running on a dedicated computer (namely the SMX hardware), which can host plug-in components providing added-value services (e.g., control, data storage), interoperability with specific local systems (e.g., controllable loads, storage systems, submeters) and remote devices (e.g., aggregator services, price signal services).
The SMX is often related to the SMM and they are put together because of their key role in handling S4G features which take place on the field. Such combination is called Unbundled Smart Meter (USM), and it is a next-generation smart meter suitable to offer unbundling services while keeping the level of trust and security required to support energy billing and certified measurements.
Physically, USM is composed by a SMM and an SMX hardware, hosting the SMX Core and SMX components. The USM concept will be used in this deliverable specially to represent the deployment views. Further details

about USM functionalities are presented in D4.10 [S4G-D4.10]. The SMX components are described in the following subsections.

2.3.2.2.1 South-bound connectors

Group of SMX connectors components providing bidirectional interoperability towards/from local devices on the field (e.g., EV chargers, HI, ER). Further details about these connectors are described in D4.10 [S4G-D4.10].

2.3.2.2.2 Data Dispatcher

The Data Dispatcher component is located at the device layer. It feeds data from the SMX to the Aggregator in charge of managing it exploiting the Aggregator Broker. The Data Dispatcher uploads local data batches periodically. The interval chosen is configurable and currently dimensioned concerning the sampling frequency of the SMXs. At the same time, it collects and can resend local data batches whenever sending failures occurred, e.g., due to network connection downtime. This component is also in charge of forwarding control messages coming from the Residential GUI and from the Service layer components towards the Physical layer using the Smart Meter eXtension (SMX) Broker.

2.3.2.2.3 SMX Broker

Smart Meter eXtension (SMX) Broker is a MQTT broker enabling communicating between the SMX components. Further details about SMX Broker are presented in D4.10 [S4G-D4.10].

2.3.2.2.4 SMX Core

The Smart Meter eXtension (SMX) Core implements a real-time database, preserving the communication with SMM and with all extensions running around SMX Core. It uses Role Base Access Control (RBAC) system to preserve security and privacy for the used data. Further details about SMX Core are presented in D4.10 [S4G-D4.10].

2.3.3 Edge layer

2.3.3.1 Residential GUI

The Residential Graphical User Interface (GUI) is a user-friendly Web-based application for prosumers to provide interaction with smart energy systems and EVs. It allows to check, in a secure way, the health level and data gathered from the local RES. It shows the EV information (e.g., plugged/unplugged, charging status, remaining charging time), ESS information (e.g., remaining charging time), real-time household production and consumption, and data analysis over various time frames. This component is fully described in D6.9 [S4G-D6.9].

2.3.3.2 Aggregator

Set of components involved in data collection and control processes providing specific services with respect to the S4G requirements. It communicates directly with the SMXs belonging to the same physical area and with the services in Service Layer trough the Communication Layer. Further details about the Aggregator functionalities, associated to each subcomponent are described in the following subsections.

2.3.3.2.1 LESSAg

Software component used in the "Advanced Cooperative Storage Systems" scenario (HLUC-1) and is responsible for running site-wise ESS control algorithms enabling functionalities for advanced prosumers. It receives in quasi-real-time all available information from ER (ESS power, State of Charge (SoC), PV power generation, ER power to grid), power on PCC. Also, it needs to read the load predictions obtained as files from PROfiles SImiLarity Tool (PROSIT) as external profiles data generator. The most important aspect of this software is to match the information exchanged with the ER with the conditions of the Point of Common Coupling (PCC) in a certain period of time. LESSAg acts as the main Local Energy Management System (LEMS). It is an open source tool integrated as module in SMXcore, complying with General Public License (GPL) rules. This component is fully described in D4.3 [S4G-D4.3].

2.3.3.2.2 PROFEV

The Professional Realtime Optimization Framework for Electric Vehicles (PROFEV) is a framework that combines information from various energy sources and offers a flexible optimization setting environment for controlling EVs and ESS. The architecture includes modules for management and signal processing of sensor data (e.g., SMM, EV CPs), linking of predictive algorithms to deliver inputs to the optimization model, optimization modelling, linking of a solver, an optimization controller and a post-processer module for formatting the results or creating events. The framework offers an Application Programming Interface (API) that describes the insertion of new optimization models, allows the registration of data input and output and presents a set of commands to control the start of the framework. PROFEV is used in S4G for the optimal control of EVs. Therefore, PROFEV is able of running stochastic dynamic programming. This component is fully described in D4.7 [S4G-D4.7].

2.3.3.2.3 PROFESS

The Professional Realtime Optimization Framework for Energy Storage Systems (PROFESS) is a framework that combines data from various sources and offers a flexible optimization setting environment for controlling ESS. The architecture includes modules for management and signal processing of sensor data (e.g., SMM, ER, HI), linking of predictive algorithms to deliver inputs to the optimization model, optimization modelling, linking of a solver, an optimization controller and a post-processer module for formatting the results or creating events. The framework offers an API that describes the insertion of new optimization models, allows the registration of data input and output and presents a set of commands to control the start of the framework. PROFESS is used in S4G for the optimal control of ESS. This component is fully described in D4.3 [S4G-D4.3].

2.3.3.2.4 Aggregator DWH

The Aggregator Data Warehouse (DWH) is a time-series database containing data from the SMXs associated with the Aggregator. It is used by Residential GUI to show data in specific time slots as well as by PROFESS, PROFEV, and LESSAg to produce the related optimization settings. The Aggregator DWH is based on the same software of Decision Support Framework Data Warehouse (DSF-DWH) but contains only local data. Further details about Aggregator DWH are referred to DSF-DWH (section 2.3.5).

2.3.3.2.5 Aggregator Connectors

The aggregator connector are software components providing interoperability between specific third-party services and other S4G components through the DSF connectors (section 2.3.5).

2.3.3.2.6 Aggregator Broker

MQTT broker enabling communicating between the Aggregator components as well as with the associated SMX components.

2.3.3.2.7 *OGC Wrapper*

The Open Geospatial Consortium (OGC) Wrapper component is located at the edge layer. It feeds data from all the SMXs located on a single site to the Aggregator DWH and simultaneously forward these data towards the Service layer. It oversees discovery, registering and restoring of all the local site resources on the cloud OGC SensorThings server in order to maintain a shared centralized catalogue of resources and services. By maintaining this logical mapping between each SMX and the required cloud services, it propagates the messages, connecting the Device layer to the Service layer via MQTT exploiting the Aggregator Broker, the cloud Data Broker and cloud Control Broker. The resulting managed paths are:

- Sensors data from the Device layer (involving the SMXs managed by the current Aggregator) to the Service layer (targeting the DWH).
- Sensors data received from the Device layer to be aggregated for residential purposes.
- Control commands from the Service layer to the Aggregator targeting edge layer services.
- Control commands from the Aggregator to the Device layer (by targeting a specific SMX).

Each one of the previous paths will be linked, by generating a map of the MQTT topic used on the Device layer together with the ones used on the Service layer.
Due to differences in data formats exploited by the SMXs and the ones required by the time-series database (both on the cloud and on the aggregator), the OGC wrapper parse all the received sensor measurements and properly convert these to the INFLUX format[vii].

In order to manage temporary lack of Internet connectivity, the OGC wrapper store inside a local queue all the received measurements until the connection is back. After the successful restore of the connection, it flushes at a higher frequency (coherently configured respect the sampling time of each sensor multiplied to the number of sensors managed by the current aggregator) all the queued messages.
In order to improve the robustness of the developed solution, when the OGC wrapper boot-up, it needs to test its Virtual Private Network (VPN) connectivity to perform the required actions towards the OGC server to setup all the runtime structures with the proper mappings. In case of a temporary lack of connectivity during boot, it still needs to start and provide local services over the residential place by managing locally the sensors data flow. Whenever the Internet connection is restored, it will perform the discovery and eventually the registration operation towards the OGC server; then it reconfigures the mapping of the data and control flows id in compliancy with the CIM defined (based on the OGC SensorThings standard[viii]).

Concerning that the Residential GUI needs to show both real-time data and complex charts composed by historical data, about several measurements coming from the prosumer SMXs residing in the VPN, it is job of the OGC wrapper to perform some additional actions.
In particular, due to the absence of synchronization mechanisms of sensors clocks, it needs to align the real-time MQTT measurements exploiting the messages timestamps received, by performing a data fusion procedure. This procedure exploits a matrix where each column is related to a local sensor and the amount of row is defined as the maximum distance in time between the different data streams to permit aggregation. Whenever the OGC wrapper receives a new measurement, it evaluates where to put this data inside the matrix by analysing sensor id and the embedded timestamp. When a row of the matrix is filled, it can build up the aggregated message to be later exploited by the Residential GUI. Other logics allow to eventually shift and drop (only about the aggregation feature) some measurements if one sensor is temporarily not active or if it is recovering after a lack of network connectivity and consequently flushing old data too far in time to be aggregated, until the convergence of all the measurements to a value close enough to permit data fusion.

At the same time, this component can detect time drifting values between device layer components and the local system. To improve the overall stability, it can be configured to automatically send an email to all the IT involved technicians with some debug information's and the related warning.

2.3.3.2.8 Residential GUI Backend

The Residential Graphical User Interface (GUI) Backend is a server controlling main functionalities of the Residential GUI. It takes care of security related aspects, provides user authentication services, access to databases and allows the interaction with other S4G components. Further details are referred in D6.9 [S4G-D6.9].

2.3.4 Communication layer

2.3.4.1 Middleware

The middleware is one of the key elements of the S4G architecture as it integrates heterogeneous resources and systems. In this integration context, it provides modelling abstractions of services and resources enabling its search and discovery. The middleware components are described in the following subsections.

2.3.4.1.1 Control Broker

Scalable software component based on MQTT, handling dispatch of asynchronous data from S4G services components in charge in control functionalities (e.g., Grid Side Energy Storage System Controller (GESSCon)), in an event-oriented fashion (publish/subscribe communication pattern). It is deployed and maintained as a private cloud service or on the premises of the entity operating S4G-based services. Its access is restricted to only control components.

2.3.4.1.2 Data Broker

Scalable software component based on MQTT, handling dispatch of asynchronous raw data from S4G field components to the grid-side components, in an event-oriented fashion (publish/subscribe communication pattern). It is deployed and maintained as a private cloud service or on the premises of the entity operating S4G-based services.

2.3.4.1.3 OGC SensorThings Server

The Open Geospatial Consortium (OGC) SensorThings Server implements the Sensing profile (part 1) of the OGC Sensor Things API[viii], based on Go-Sensor Things (GOST)[ix]. The OGC Sensor Things Server provides an open standard-based and geospatial-enabled framework to interconnect the devices, data, and applications over the Web with the registration of resources and services. This component has been introduced in order to achieve the technical objective 1 – "Design the S4G interfaces, namely a set of interfaces and a joint CIM suitable for monitoring and control of heterogeneous storage systems" described in the DoA, ensuring that the S4G components have a CIM for monitoring and control of heterogeneous storage systems.

2.3.5 Service layer

2.3.5.1 GESSCon

The Grid Side Energy Storage System Controller (GESSCon) is a cloud component that receives inputs from Data Broker (e.g., real-time ESS SoC), and DSF, e.g., 24-hours foresight on user's load profile, PV production, electricity price. The output data from GESSCon is a 24-hours scheduling of charge/discharge of the ESS systems. The output will be published to the Control Broker. PROFESS will subscribe to the respective topic, so it can execute the ESS control schedule with its own intelligence.

2.3.5.2 DSF

The Decision Support Framework (DSF) is one of the main outcomes of the S4G project (Figure 9 presents its concept). It is a tool for planning the best storage solution in terms of cost, lifetime, and efficiency in using renewable energy and self-consumption expansion. The aim is to evaluate and estimate the technical and business feasibility and sustainability of Medium Voltage (MV) and Low Voltage (LV) scenarios where storage solutions and EV charging solutions are installed.

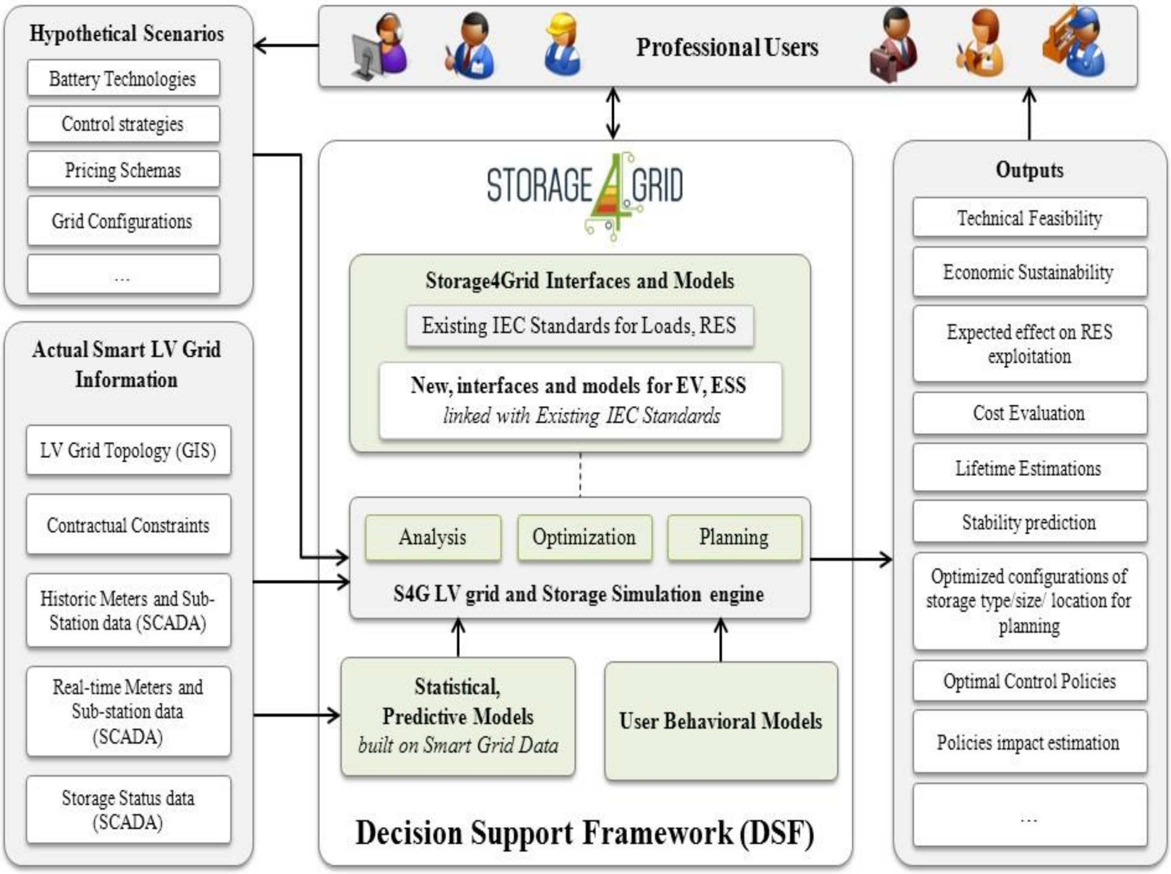

Figure 9. S4G decision support concept.

Figure 10 shows the phase 3 DSF functional architecture, implementing the concept of the DSF presented within the DoA. The final version of the DSF is defined as a loosely coupled collection of interoperable software components, integrating Distribution System Operator (DSO) system data and relevant data from third-party sources. The software can be combined in different configurations to perform analysis, planning, forecast and optimization tasks of distributed storage systems. Besides, the DSF allows performance evaluation of innovative cooperative strategies and predictive control algorithms.

Analysis, planning and optimization are supported by the simulation tool as well as by static, historic and real-time information from Supervisory Control and Data Acquisition (SCADA) and smart meters. The simulation tool supports analysis of feasibility and potential impacts at different scales of ESS (from substation-level to user-level systems) and EVs (from private to commercial fleets) on hypothetical scenarios.
In addition, the DSF provides to the users, means to evaluate the impact of controllable storage systems in terms of economic sustainability, expected effect on RES exploitation, control policies impact and lifetime estimation.

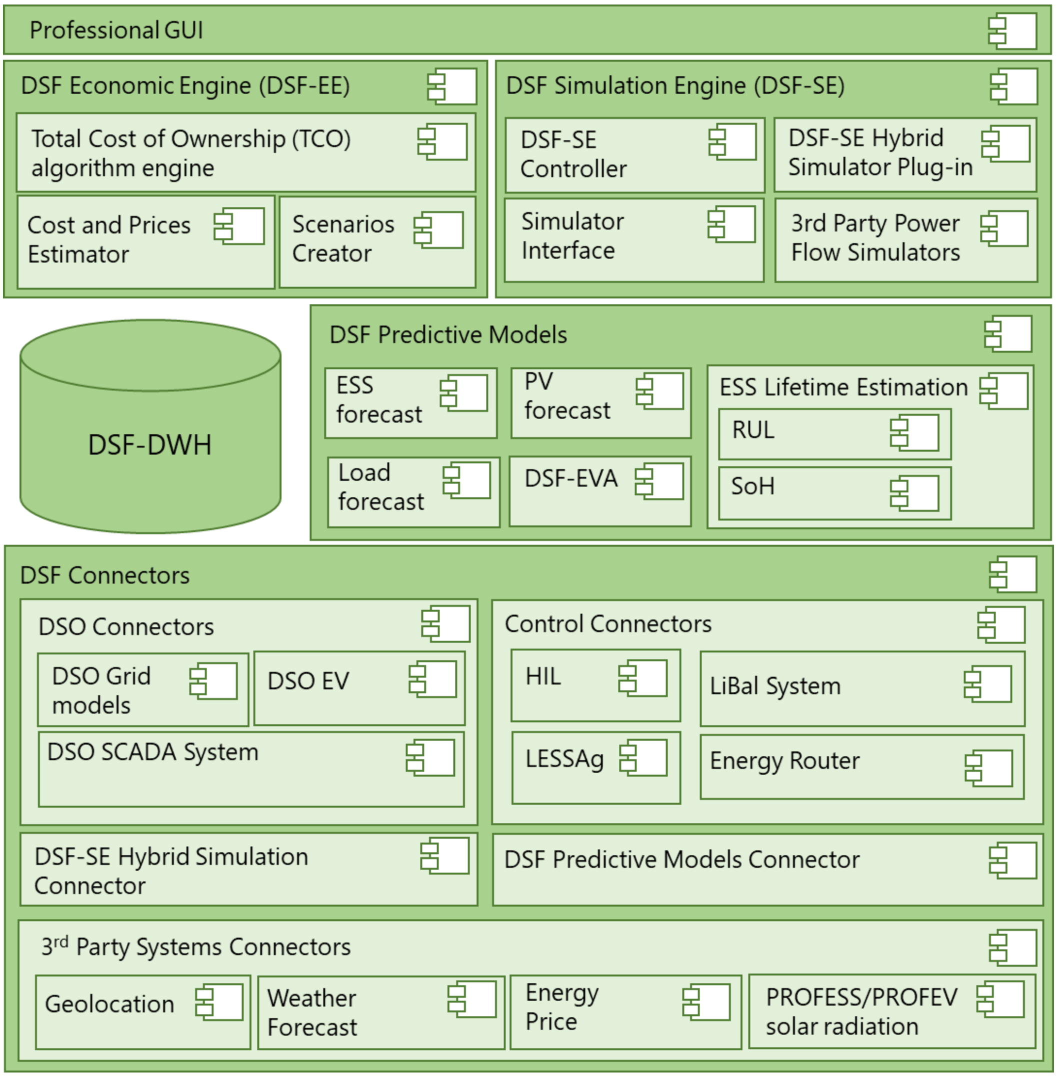

Figure 10. DSF functional architecture.

The DSF inputs are:

- **Statistical Predictive Models**: These are the DSF Predictive Models developed within task T5.4 – "DSF Statistical Predictive Models and Lifetime Estimation" to properly mimic the behaviour of ESS and other entities, described in D5.7 [S4G-D5.7].
- **User Behavioural Models**: Represented by load profiles which defines how the user consumes energy.
- **Actual Smart LV Grid Information**:
    - **LV Grid Topology**: Representation of DSO's grid topology. It is enabled by the DSF connectors, described in D5.5 [S4G-D5.5].
    - **Contractual Constraints**: Provided by DSO and the S4G External Stakeholder Group (ESG). There were considered to draw the requirements. Further details are described in D2.4 [S4G-D2.4].
- **Historic Meters and Substation data (SCADA)**: Collected from EDYNA's SCADA system available through the DSF connectors.
- **Real-time Meters**: Measurements from SMXs at residential and commercial places.
- **Storage Status Data (SCADA)**: Collected from the Control Connectors, described in D5.5 [S4G-D5.5].
- **Hypothetical Scenarios**: These are the scenarios analysed by the Professional Users. Furthermore, in order to analyse the economic feasibility, the implementation focused on the scenarios described in D2.4 [S4G-D2.4], and D5.2 [S4G-D5.2], namely:
    - **SCENARIO 0**: grid strengthening without any storage system.

- **SCENARIO 1**: grid strengthening with different degree of household storage penetration (HLUC-3-PUC-3 [S4G-D2.2]).
- **SCENARIO 2**: storage systems deployed by DSOs at substation level (HLUC-3-PUC-2 [S4G-D2.2]).
- **SCENARIO 3**: SCENARIO 1 combined with SCENARIO 2 (HLUC-3-PUC-4 [S4G-D2.2]).

The DSF outputs are:

- **Technical Feasibility**: The technical feasibility of a hypothetical scenario is determined by the professional user based on the Decision Support Framework Simulation Engine (DSF-SE) Key Performance Indicators (KPIs), e.g., voltage level, current, losses. In case the hypothetical scenario is not technically feasible, the Professional GUI will show the output values which surpass the given threshold in red. Further details are described in D5.2 [S4G-D5.2] and D6.9 [S4G-D6.9].
- **Expected effect on RES exploitation**: The simulation results of a given hypothetical scenario (featuring PV installation) without energy storage systems are compared with the results of the same scenario with ESS. The penetration level of PV/ESS is gradually increased to allow a comparison of results. Based on this analysis, a statement about the expected effect on RES exploitation is performed by Professional Users.
- **Optimized configuration of storage type/size/location for planning**: The Professional User is able to draw conclusions over the optimal size and location of the storage based on the DSF-SE KPIs.
- **Stability Prediction**: It gives the effect of the usage of energy storage on grid stability, e.g. for a certain scenario, what is the voltage level with and without storage. It can be analysed through the DSF-SE KPIs.
- **Optimal control policies**: They are defined as maximise self-consumption, self-production, and minimize bill for jointly controlling the charging process and the storage, to benefit prosumers and minimize impact on the grid. These are considered within the DSF-SE simulation. Further details about the optimal control policies are described in D4.3 [S4G-D4.3].
- **Battery Lifetime estimation**: The lifetime estimation is set according to the ESS operational mode. It is considered by the Decision Support Framework Economic Engine (DSF-EE) to provide the techno-economic analysis. Further details are described in D5.2 [S4G-D5.2].
- **Economic Sustainability**: Evaluation of Total Cost of Ownership (TCO) with a comparison between a baseline scenario (grid strengthening without any storage systems but with different level of PV and/or EV penetration) and a scenario with storage system at substation level. The sustainability term means to consider a long run investment evaluation from DSO point of view. This feature is provided by the DSF-EE and described within D5.2 [S4G-D5.2].
- **Cost Evaluation**: In the TCO analysis, the DSF-EE will provide a delta difference between the two TCOs.
- **Policies impact estimation:** Qualitative evaluation of the effects of the economic model for different stakeholders. The techno-economic model is based on hypothesis that define a set of possible scenarios with related impact on different actors (e.g., DSO, prosumers, aggregators, producers of batteries).

The DSF components are briefly described in the following subsections.

2.3.5.2.1 Professional GUI

The Professional GUI is a dedicated S4G GUI for professional users (e.g., DSOs) to simulate the impact of storage systems in a selected grid radial over a certain timeframe. The professional GUI originates from the HLUC-3-

PUC-1 described in D2.2 [S4G-D2.2] and is further described in D6.9 [S4G-D6.9]. It enables professional end-users to interact with the functionalities of the DSF components for storage analysis and planning.

2.3.5.2.2 DSF-SE

The Decision Support Framework Simulation Engine (DSF-SE) is software component acting as a service, which is able to execute power flow simulations of a grid featuring heterogeneous ESS, loads (including EVs) and renewables-based electricity generation. The DSF-SE presents an API for its interaction and integration with other components (for instance to perform optimizations). In S4G the DSF-SE works together with the Professional GUI for demonstrating HLUC3-PUC-1. Furthermore, it implements a hybrid simulation plug-in to perform early evaluation of newly designed interfaces for storage systems. The DSF-SE is described in D5.2 [S4G-D5.2].

2.3.5.2.3 DSF-EE

The Decision Support Framework Economic Engine (DSF-EE) is a tool providing economic insights to the DSF-SE technical outcomes based on scenarios with distributed storage systems at substation and prosumer level. The DSF-EE is described in D5.2 [S4G-D5.2].

2.3.5.2.4 DSF Predictive Models

These models are meant to empower S4G DSF and GESSCon with reliable forecast and estimations to optimize the ESS and RES exploitation. These are developed within Task 5.4 and documented in D5.7 [S4G-D5.7]. The DSF is supported by load, PV production and ESS status forecast, while GESSCon is supported by RUL and SoH algorithms. The DSF Connectors enable the DSF Predictive Models to other S4G components.

2.3.5.2.5 DSF Connectors

Set of interoperable software components providing related DSO data, control interfaces for hardware in the loop simulation, as well as integrating with 3rd party data sources and exposing the *DSF Predictive Models*. The DSF connectors are grouped together on a single central server. It is typically deployed and maintained on the premises of the entity operating S4G-based services. The DSF connectors are described in D5.5 [S4G-D5.5].

2.3.5.2.6 DSF-DWH

The Decision Support Framework Data Warehouse (DSF-DWH) is the central system used to store data from all test-sites in the S4G. Its structure is depicted in Figure 11. The development of a Data Warehouse is not within the core objectives of the project. Nevertheless, this is a key component supporting the S4G test site, as well as a key test-bench where all data and information model developed by S4G must be reflected.
In order to match the project requirements, the DWH is implemented using existing open-source solutions for industrial-scale real-time data processing and storage, namely the TICK suite[x].

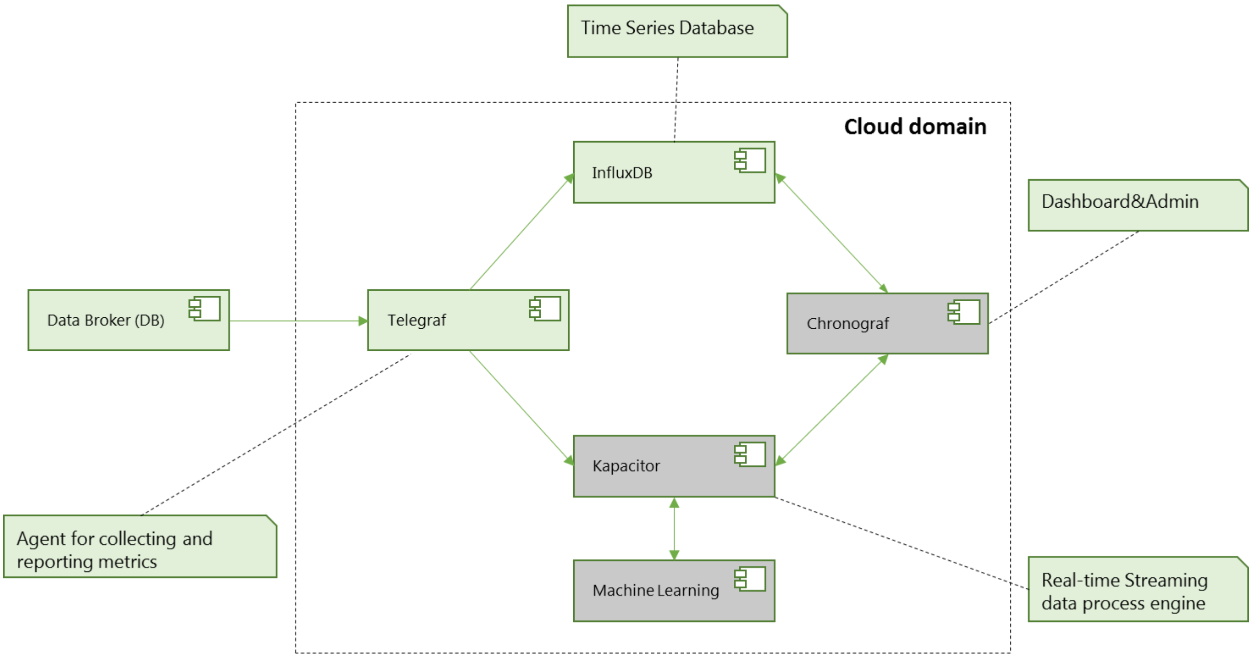

Figure 11. S4G DWH.

The main component of the DWH is InfluxDB. It is the open source time series database that is part of the TICK (Telegraf, InfluxDB, Chronograf, Kapacitor) stack. It is designed to handle high write and query loads and provides a Structured Query Language (SQL)-like query language called InfluxQL for interacting with data. InfluxDB supports millions of writes per second and can meet the demands of large monitoring and Internet of Things (IoT) deployments.
The DWH is a critical central component of the S4G architecture, consequently, it has been setup with security rules preventing access to sensitive data by design exploiting requesters addresses, authentication and authorization features with different rights in a user-based mechanism.

2.3.5.2.6.1 Telegraf

Telegraf is a plugin-driven server agent for collecting and sending metrics from the S4G systems and IoT sensors. It has been configured to acquire data through the MQTT protocol and by setting up different rules, it is able to redirect the incoming streams to different databases.

2.3.5.2.6.2 Kapacitor

Kapacitor is a native data processing engine for InfluxDB, it can process both stream and batch data from InfluxDB, acting on this data in real-time via its programming language TICKscript. It has been configured to generate email alerts warnings to all the Information Technology (IT) technicians in charge of managing the network whenever one of the known streams of data stops for a certain amount of time and when it is restored back.

2.3.5.2.6.3 Chronograf

Chronograf is the user interface and administrative component of the InfluxDB platform. Use templates and libraries to rapidly build dashboards with real-time visualizations. Chronograf is also the user interface for Kapacitor. It has been configured to show relevant data to predefined users on dedicated dashboards about the streams of interest.

3 Information Views

This section provides a focused view on data handled by the S4G system presenting their respective interfaces and the corresponding data models. In order to reduce the complexity, the S4G information views are presented from three perspectives: data collection (section 3.1), control (section 3.2), and simulation (section 3.3). Section 3.4 summarises the information and communication models used within S4G. Each perspective shows only the components involved in the respective information views.

3.1 Information data collection view

Figure 12 depicts the relationship among S4G components involved in generic data collection functionalities i.e. functionalities resulting in unidirectional collection, preserving and organizing data from the field. The identified interfaces are listed in Table 3.

Each test site where S4G-related components are deployed must have at least an Aggregator. The Aggregator receives Physical Layer devices data from SMX devices by means of various, heterogeneous wired or wireless local interfaces (ER#SMX interface, EV Charger#SMX interface, HI#SMX interface, SMM#SMX interface, SMX#Aggregator interface). Then, the Aggregator feed the data to higher-level components, through a dedicated, event-oriented interface, namely the Aggregator#Data Broker interface. Finally, Physical Layer devices data is feed directly to the DSF-DWH thanks to the Data Broker#DSF interface.

All data from field are fed to the Data Broker component, typically deployed at the premises of the entity operating S4G-based services, making them available to every S4G component, in secure and scalable fashion. The interfaces for connection with the Service Layer components must be compliant with the S4G CIM and communication protocol.

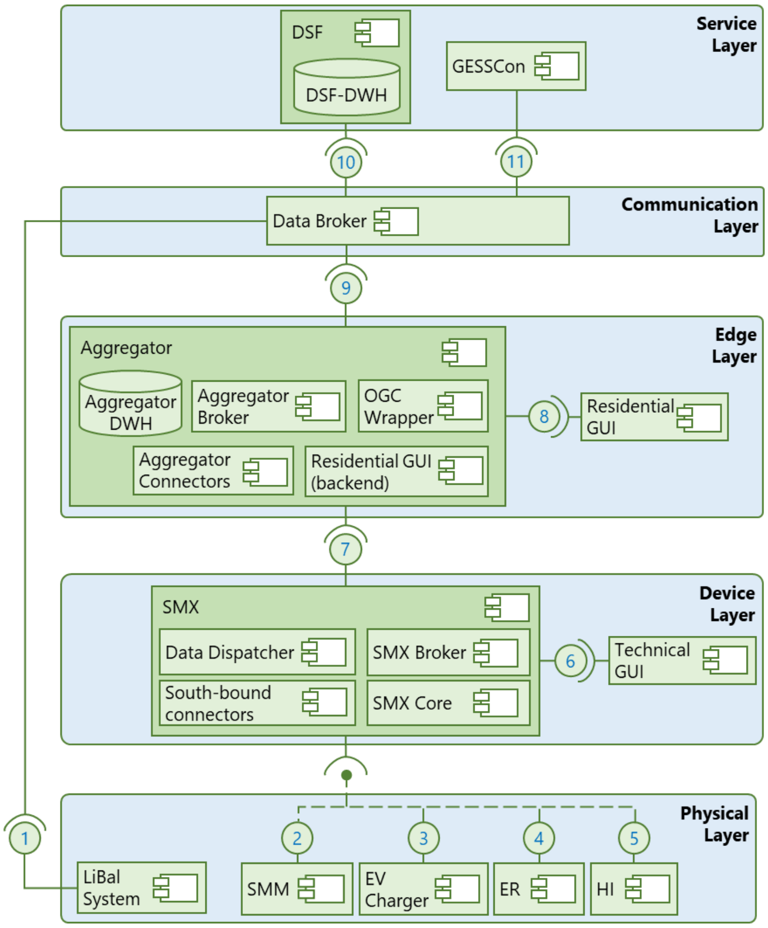

Figure 12. Information data collection view.

Table 3. S4G interfaces involved in data collection processes (Figure 12).

S4G Interface	Name
1	LiBal System#Data Broker interface
2	SMM#SMX interface
3	EV Charger#SMX interface
4	ER#SMX interface
5	HI#SMX interface
6	SMX#Technical GUI interface
7	SMX#Aggregator interface
8	Aggregator#Residential GUI interface
9	Aggregator#Data Broker interface
10	Data Broker#DSF interface
11	Data Broker#GESSCon interface

The interfaces listed in Table 3 are described as follows.

- **LiBal System#Data Broker interface and Data Broker#GESSCon interface**: These interfaces use the Sensor Measurement Lists (SenML) data format to retrieve information related to the ESS SoC from the LiBal System. The complete description of this interface is available in D4.5 [S4G-D4.5] and D5.5 [S4G-D5.5].
- **SMM#SMX interface**: The interface uses Device Language Message Specification (DLMS)/Companion Specification for Energy Metering (COSEM) transforming into bytes, electrical parameters data from, e.g., load, RES, PCC. A more detailed description of this interface is available in D4.10 [S4G-D4.10].
- **EV Charger#SMX interface**: This interface relies on the SIEMENS SCADA system that exploit the Open Charge Point Protocol (OCPP) to obtain information related to the EV CP. The EV South-bound connector provides ways to intercept the real-time messages, e.g., such as CP power measurements and charging states of the CP during a charging process, and it is described in D4.10 [S4G-D4.10]. It is up to the CP to decide when it will send meter values.
- **ER#SMX interface**: This interface uses the IEC 61850-90-7 standard to measure data from the ER. The Abstract Communication Service Interface (ACSI) GetDataValues service is used, to retrieve data from the ER according to Functional Constrained Data Attribute (FCDA) parameter. The complete list of ER measurements is available in D4.10 [S4G-D4.10].
- **HI#SMX interface**: This interface uses Modbus Transmission Control Protocol (TCP)/Internet Protocol (IP) to measure data from the HI. Single or multiple registers can be read in order to measure data from the HI. The complete description of this interface is available in D4.10 [S4G-D4.10].
- **SMX#Technical GUI interface**: This interface is able to show in real-time an associated Web link data recorded by SMX at a certain measurement point by subscribing to specific MQTT topics. A more detailed description of this interface is available in D4.10 [S4G-D4.10].
- **SMX#Aggregator interface**: This interface uses MQTT to forward messages from field devices to the Aggregator. The messages are the same as the ones published to the SMX Broker. Details about messages inside the SMX are available in D4.10 [S4G-D4.10].
- **Aggregator#Residential GUI interface**: This interface uses MQTT to send real-time data from SMX Broker to the Residential GUI. It also uses Representational State Transfer (REST) providing historical data from Aggregator DWH. The Residential GUI Backend is the component interfacing with the Residential GUI. A more detail description of this interface is available in D6.9 [S4G-D6.9].

- **Aggregator#Data Broker interface and Data Broker#DSF interface:** These interfaces use MQTT to forward Physical layer devices data adopting OGC specifications. The format of data is compliant with the DSF-DWH component. A more detail description of this interface is available in D5.5 [S4G-D5.5].

3.2 Information control view

Figure 13 depicts the relationship among S4G components from the point of view of distributed control functionalities. The identified interfaces are listed in Table 4.
The S4G control rely on LESSAg, PROFESS, and PROFEV, which are in charge of providing optimal set-points for the ER, HI, and EV, based on signals from DSO and the local devices status. GESSCon is in charge of remotely providing ESS control set-points for the next day to PROFESS/PROFEV according to the grid-side knowledge. Such control set-points are further handled by PROFESS/PROFEV to provide optimal local set-points together with its own control algorithm and data from third-party cloud-services, e.g., providing weather or price forecast, using the DSF connectors described in D5.5 [S4G-D5.5]. GESSCon are hosted in remote, cloud-premises (e.g., in facilities operated by the DSO) and associated with many local sites (i.e. to many PROFESS/PROFEV components).

The S4G control is performed top-down using open interfaces, namely GESSCon#Control Broker, Control Broker#Aggregator. These interfaces carry messages from GESSCon, as global control unit, to the related local control units (i.e., PROFESS and PROFEV) in charge of local optimization. Consecutively, the Aggregator forwards GESSCon messages to the specific SMX (Aggegator#SMX interface) attached the ESS/EV to be controlled by LESSAg/PROFESS/PROFEV.

The GESSCon collects data from the SMXs (Aggregator#Data Broker, Data Broker#GESSCon interfaces) as well as from third-party systems (e.g. price/weather forecast) (DSF#GESSCon interface) to perform high-level control. This high-level control performed by GESSCon is typically a “slower” type of control, where the set-points are sent all at once at midnight for the next 24-hours with a 60-minutes resolution. Therefore, strong reliability and real-time constraints on the communication link hosting such interfaces are not critical.

Finally, other strategies for control is performed by the Residential GUI (through the Residential GUI#Aggregator interface) enabling residential users to monitor their systems as well as to set the operational mode of local controllers. Moreover, the hybrid simulation enabling hardware-in-loop (HIL) simulation to evaluate new field components uses the DSF#Control Broker, Control Broker#Aggregator interfaces to contact specific field components.

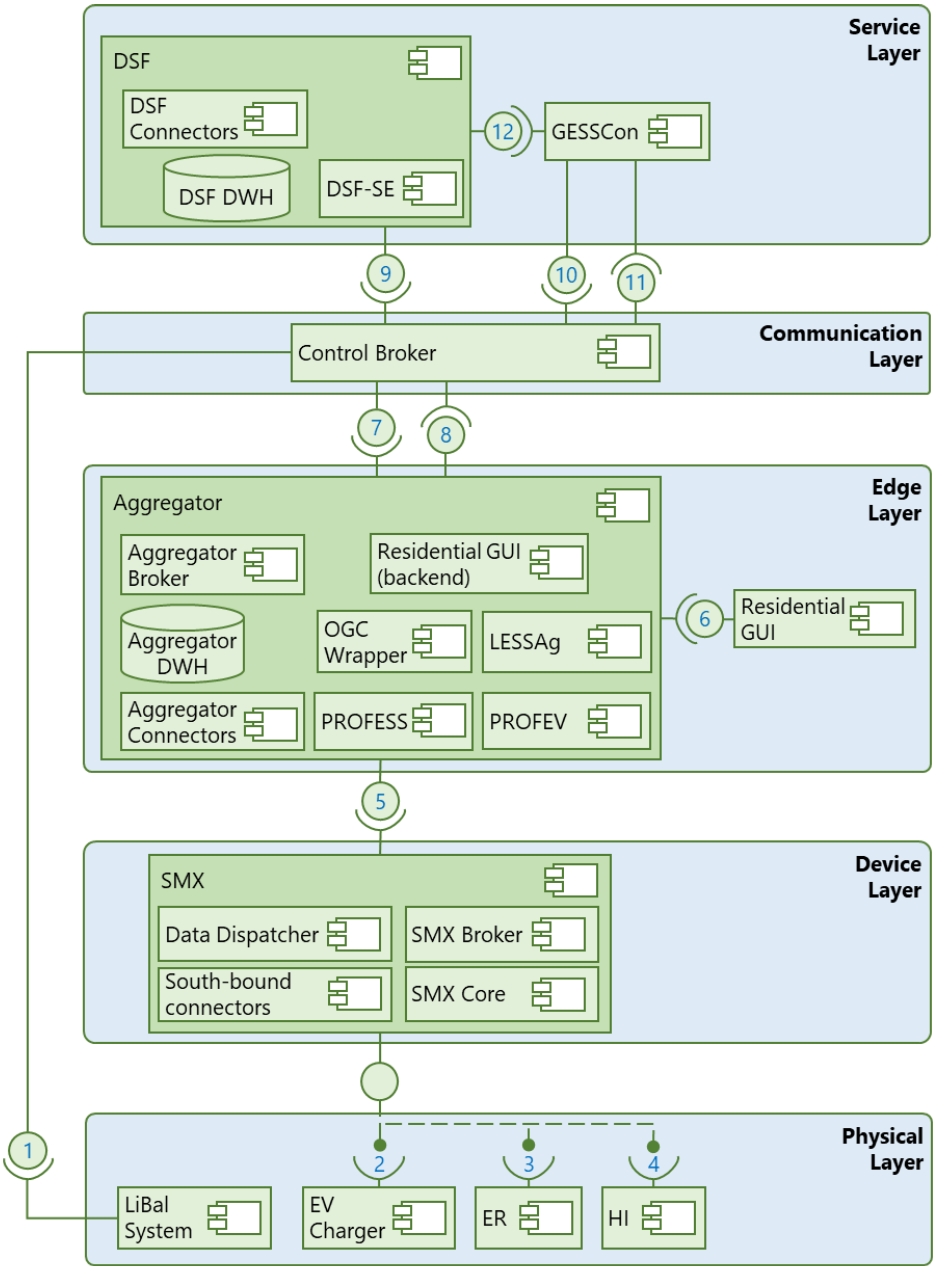

Figure 13. Information control view.

Table 4. S4G interfaces involved in control processes (Figure 13).

S4G Interface	Name
1	Control Broker#LiBal System interface
2	SMX#EV Charger interface
3	SMX#ER interface
4	SMX#HI interface
5	Aggregator#SMX interface
6	Residential GUI#Aggregator interface
7	Control Broker#Aggregator interface

S4G Interface	Name
8	Aggregator#Control Broker interface
9	DSF#Control Broker interface
10	GESSCon#Control Broker interface
11	Control Broker#GESSCon interface
12	DSF#GESSCon interface

The interfaces listed in Table 4 are described as follows.

- **Control Broker#LiBal System interface**: This interface uses SenML data format to send set-points related to the ESS. The complete description of this interface is available in D4.5 [S4G-D4.5] and D5.5 [S4G-D5.5].
- **SMX#EV Charger interface**: This interface exploits the SIEMENS system to forward optimal set-points to the EV CPs during a recharging session. A more detailed description of this interface is available in D4.10 [S4G-D4.10].
- **SMX#ER interface**: This interface uses the IEC 61850-90-7 standard to send control commands to the ER. The ACSI SetDataValues service is used, to send control commands to the ER according to FCDA parameter. The complete list of ER control commands is available in D4.10 [S4G-D4.10].
- **SMX#HI interface**: This interface uses Modbus TCP/IP to send control commands to the HI. Single or multiple registers can be written in order to control the HI. The complete description of this interface is available in D4.10 [S4G-D4.10].
- **Aggregator#SMX interface**: This interface exploits the Aggregator/Data Dispatcher link to publish in the SMX Broker the control set-points calculated by LESSAg, PROFESS or PROFEV defining the power of the different components (e.g., EV, ER, HI). The set-points will be set to the respective components by the SMX south-bound connectors which are subscribed to the SMX Broker. A more detailed description of the physical components' interfaces and its SMX south-bound connectors is available in D4.10 [S4G-D4.10].
- **Residential GUI#Aggregator interface**: This interface allows the residential users to set the operational mode of the local controllers through the Residential GUI. Locally, the user settings will be set by the Residential GUI (backend) by contacting PROFESS APIs. Details about messages are available in D6.9 [S4G-D6.9].
- **Control Broker#Aggregator interface and DSF#Control Broker interface**: These interfaces enable the real-time hybrid simulation. In this process the DSF-SE performs simulations of specific grid models considering real-time measurements. The hybrid simulation provides outputs that are sent in real-time to the field components. A more detailed description of these interfaces is available in D4.10 [S4G-D4.10] and D5.5 [S4G-D5.5].
- **Aggregator#Control Broker interface and Control Broker#GESSCon interface**: The real-time set-points for ESS calculated by PROFESS/PROFEV will be published into the Aggregator Broker, and through the OGC Wrapper, the messages will be sent to the Control Broker. The objective is that these set-points can be received by the GESSCon for further analysis. A more detailed description of this interface is available in D4.5 [S4G-D4.5].
- **Control Broker#Aggregator interface and GESSCon#Control Broker interface**: GESSCon will send an optimized 24-hours charge schedule to Control Broker in SenML, and this charge schedule will be forwarded to PROFESS/PROFEV at Control Broker#Aggregator interface. PROFESS/PROFEV will operate the ESS according to the charge schedule and its own intelligence. A more detailed description of this interface is available in D4.5 [S4G-D4.5] and D4.7 [S4G-D4.7].
- **DSF#GESSCon interface**: This interface enables the DSF Connectors to provide data from third-party services to GESSCon. It is based on REST since the DSF Connectors act as a REST server. A more detailed description of this interface is available in D4.5 [S4G-D4.5] and D5.5 [S4G-D5.5].

3.3 Information simulation view

Figure 14 depicts the relationship among S4G components from the point of view of simulation functionalities, namely for analysis, optimization and planning tasks. The identified interfaces are listed in Table 5.
As previously mentioned, the DSF enables the analysis and planning of distributed electrical grids composed of PVs, ESS, and EVs. The core of this asset is composed by the DSF-SE and the DSF-EE. They act as cloud services and are triggered by the Professional GUI allowing professional users to perform power-flow simulations of the grid and to know its techno/economic impact. The simulation analysis is done considering DSO information, field data from DSF-DWH, and inputs from the Professional GUI. After seeing the simulation results, the professional user selects the global control option. Then, GESSCon sends ESSs schedules for the next 24h for each end-user, which will be used as inputs to the DSF-SE in a new simulation. The professional user can then visualise in the Professional GUI, the simulation results delivered by the DSF-SE. Details about DSF-SE and DSF-EE regarding analysis and planning of electrical grids with PVs, ESS, and EV, as well as of the economic analysis impact, are described in D5.2 [S4G-D5.2]. More details about the GESSCon are available in D4.5 [S4G-D4.5].

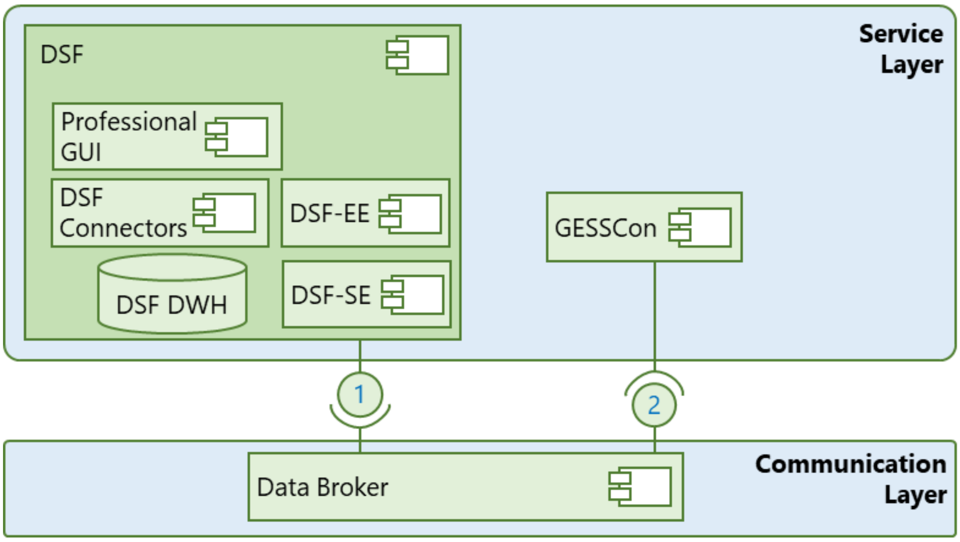

Figure 14. Information simulation view.

Table 5. S4G interfaces involved in simulation processes (Figure 14).

S4G Interface	Name
1	DSF#Data Broker interface
2	Data Broker#GESSCon interface

The interface listed in Table 5 is described as follows.

- **DSF#Data Broker interface and Data Broker#GESSCon interface**: These interfaces provide the data for transferring the configurations and inputs of the DSF to the GESSCon, in order to provide grid inputs from grid simulation activities. More details about these interfaces are provided in D4.5 [S4G-D4.5] and D5.5 [S4G-D5.5].

3.4 Information models and protocols

Table 6 shows the different Information models and protocols that are used in S4G system architecture.

Table 6. Information models and protocols.

Models and Protocols	Use in S4G
SenML[xi]	• Communication between the PROFESS/PROFEV and the GESSCon. • Communication between PROFESS/PROFEV and the SMX south-bound connectors • Communication between the LESSAg/PROFESS/PROFEV and the ER.
OCPP[xii]	• Indirect communication with the EV CPs.
IEC 61850-90-7[xiii]	• Communication between the SMX and the ER.
SunSpec Energy Storage Model Description[xiv]	• Data models and Modbus register mapping for the communication between the SMX and the Fronius System.
DMLS/COSEM[xv]	• Communication between SMX and the SMM.
INFLUX[vii]	• Communication with the DSF-DWH for data collection.

4 Communication View

The Communication view identifies the optimal channels and protocols to connect the implicated components in Local Area Network (LAN) and Wi-Fi networks considering cybersecurity aspects. Figure 15 depicts the high-level communication view for a deployment involving S4G components. Since security and privacy protections are considered key requirements in S4G, a more detailed view is provided in section 6.
In the field domain, an IP-based LAN shall be available. This is not necessarily a homogeneous network and can be optionally extended. The LAN is interconnected to the public Internet by means of a router which provides bidirectional internet connectivity from and towards every local component.

At least a SMX Hardware and an Aggregator (that can be deployed in the Aggregator Hardware or in the SMX Hardware) are available in the field domain, although it has to be observed that more than one SMX can be deployed in a single site, associated to the same or different routers.
Beyond the objective of sharing internet connectivity, the LAN has two key purposes:

1) Allow IP-enabled Local Systems to connect to their local SMXs/Aggregator components.
2) Allow SMXs/Aggregator components to run OpenVPN clients to reach the public OpenVPN server available in the cloud domain.

These two key purposes enable the established of a secure, IP-based VPN, which is used in the S4G project for all secure communications between field and cloud domains.

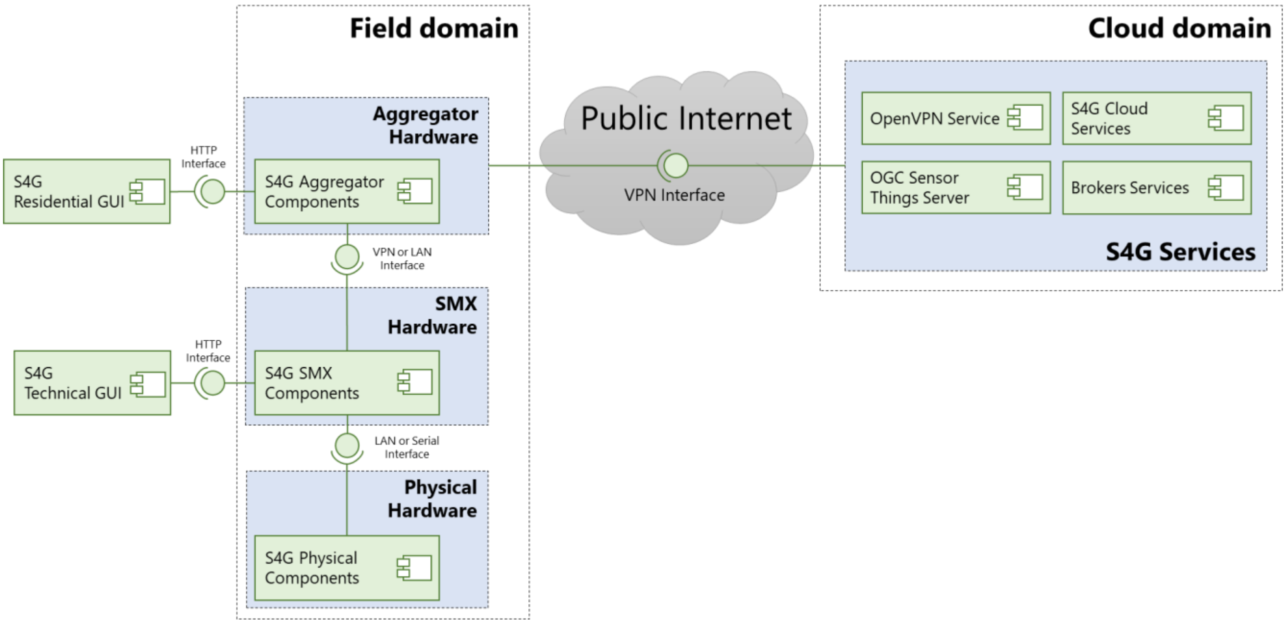

Figure 15. Deployment diagram: General communication view.

The described VPN is used for additional security, but it is not considered the main instrument used to provide secure, tamper-proof communication. Figure 7 summarises the used communication protocols and provides more details about other security mechanism considered within S4G for each communication protocol and location (details about each test site deployment are provided in section 5).

Table 7. S4G Communication protocols summary.

Protocol	Segment	Use in S4G	Security mechanism employed
IP over wired or wireless LAN Protocols, e.g., Wi-Fi[xvi], Ethernet[xvii].	LAN Interfaces	LAN in field locations at user premises.	Basic security features in place in Wired/Wireless LANs including WPA2[xviii].
IP over wired LAN Protocols e.g. Ethernet	LAN Interfaces	LAN in field locations at user premises at substation level.	Closed, wired networks, L2 security mechanisms (e.g. MAC filtering), Intrusion Detection Systems (IDS).
IP	Public Internet	Bridging Field Locations with Cloud Locations.	Provider/Transport dependant.
VPN Protocols	LAN, Public Internet	Additional layer of security to ensure that only authorized device can access the system.	State-of-the-art OpenVPN security mechanisms.
Transport protocols (any)	VPN	Direct connection between field components (the majority running within the SMX and Aggregator) and Cloud components, as well as among cloud components.	State-of-the-art transport security layers including, e.g., TLS[xix], DTLS[xx], typically used in conjunction with security features of upper-layer application protocols (e.g., MQTT) when available.
Application protocols. e.g., HTTP[xxi], HTTPS[xxii], MQTT[xxiii]	VPN or LAN Interfaces	Inter-communication of the Device, Edge, Communication, and Services layers. Intra-communication of the Aggregator/SMX components. Communication with Web services.	State-of-the-art security layers (e.g. TLS, authentication and authorization).

5 Deployment Views

In this view, it is generally described the hardware deployed on the field. Details about the specific test sites plans are described in D6.3 [S4G-D6.3].
The deployment viewpoint focuses on the physical environment in which the S4G project components will be deployed and running. It covers the hardware environment, technical environment requirements for each node of the S4G system and the mapping of all software components to the runtime environment that will execute them. Only the main S4G components are presented for a better understanding. For instance, the Aggregator component contains several S4G components as presented in Figure 7. The same happens for the DSF and SMX main components.

In the deployment diagrams of this section, it is considered that the USM component is composed by a SMM and a SMX Hardware, containing all the components of the Device Layer (described in section 2.3.2).

5.1 Bucharest test site: Advanced cooperative storage system scenario

The advanced cooperative storage system scenario deployment is depicted in Figure 16. This test site features a single-phase ER connected to DC loads in a neighbourhood laboratory through a 400 V DC bus. There are two USM, one is only composed by the SMX and the SMM (USM1), while the other one composed by the SMM, SMX, and Aggregator (USM1), featuring also the LESSAg component.
Besides, the DSF is available providing support and used to simulate scenarios of interest. Monitored data is also fed in the DSF.
Table 8 outlines the number and models of different physical components in this scenario.

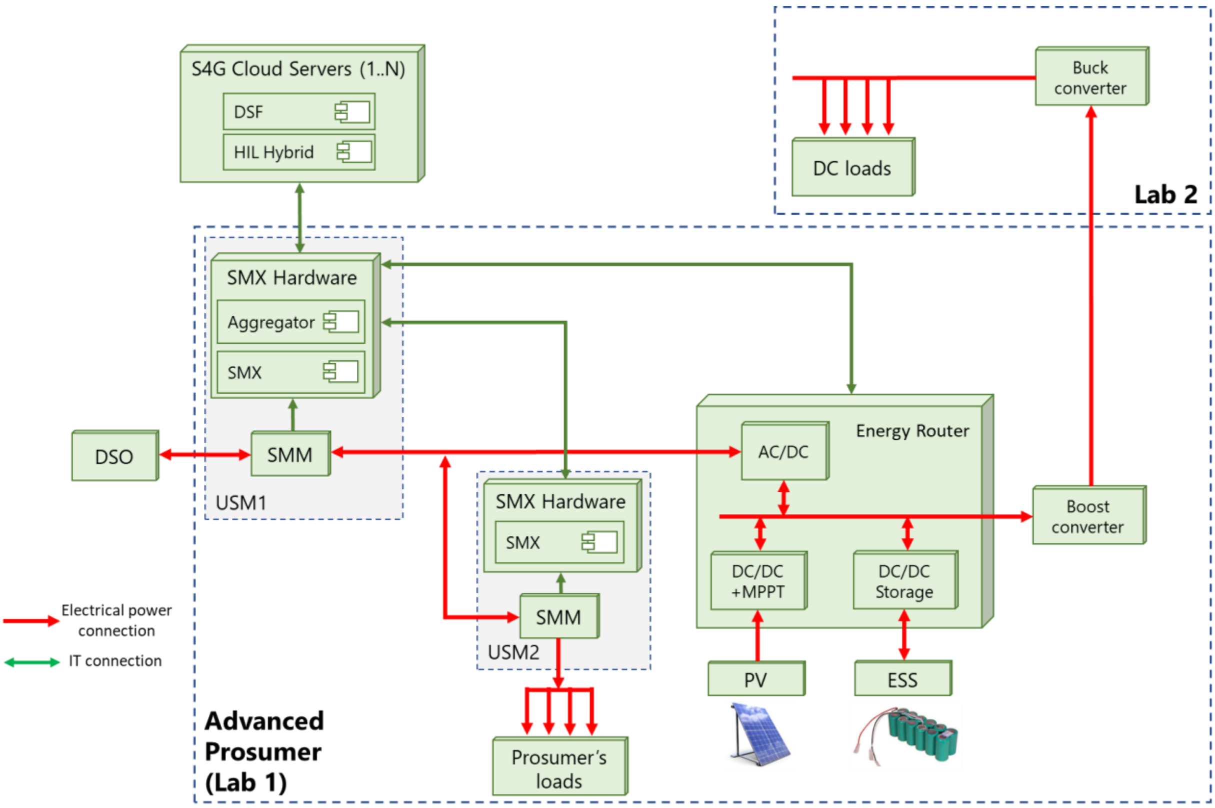

Figure 16. Deployment diagram: Bucharest test site.

Table 8. Physical components deployed: Bucharest test site.

Component	Brand/Model	# of components deployed
SMX Hardware	Raspberry PI model 3	2
SMM	DLMS-COSEM-based meter (ZMG310CT)	2
Single-phase ER	S4G prototype	1

5.2 Bolzano test site: Cooperative EV charging

This section describes the deployment views for the cooperative EV charging scenario, which is divided in the residential and commercial cases, both sharing the majority of data collection and control components.

5.2.1 Residential case

The cooperative EV charging scenario deployment in the residential test site is depicted in Figure 17. Four dedicated USMs are deployed to monitor the prosumer's loads, EV charger, PV production, and the Fronius System energy exchange.

All USMs are feeding data to the Aggregator (Aggregator Hardware), which is hosting the PROFEV component and also acts as main endpoint for the Residential GUI.

The S4G Cloud Server contains: the GESSCon to coordinate together with PROFEV the ESS charging/discharging; the DSF to receive the USMs measurements through the Aggregator, and the EDYNA SCADA system that was not developed within the project but is used to retrieve real-time information regarding substation measurements.

In this test site, the Aggregator is hosted in an individual Aggregator Broker to ensure that the necessary computational resources are available to run the necessary Aggregator components and receive data from the USMs.

The residential test site is a three-phase system, where the EV charger is connected in phase 1, the PV production is distributed in phase 1 and phase 2, the Fronius System and the prosumer's loads are connected to the 3 phases.

Table 9 outlines the number and models of different physical components in this scenario.

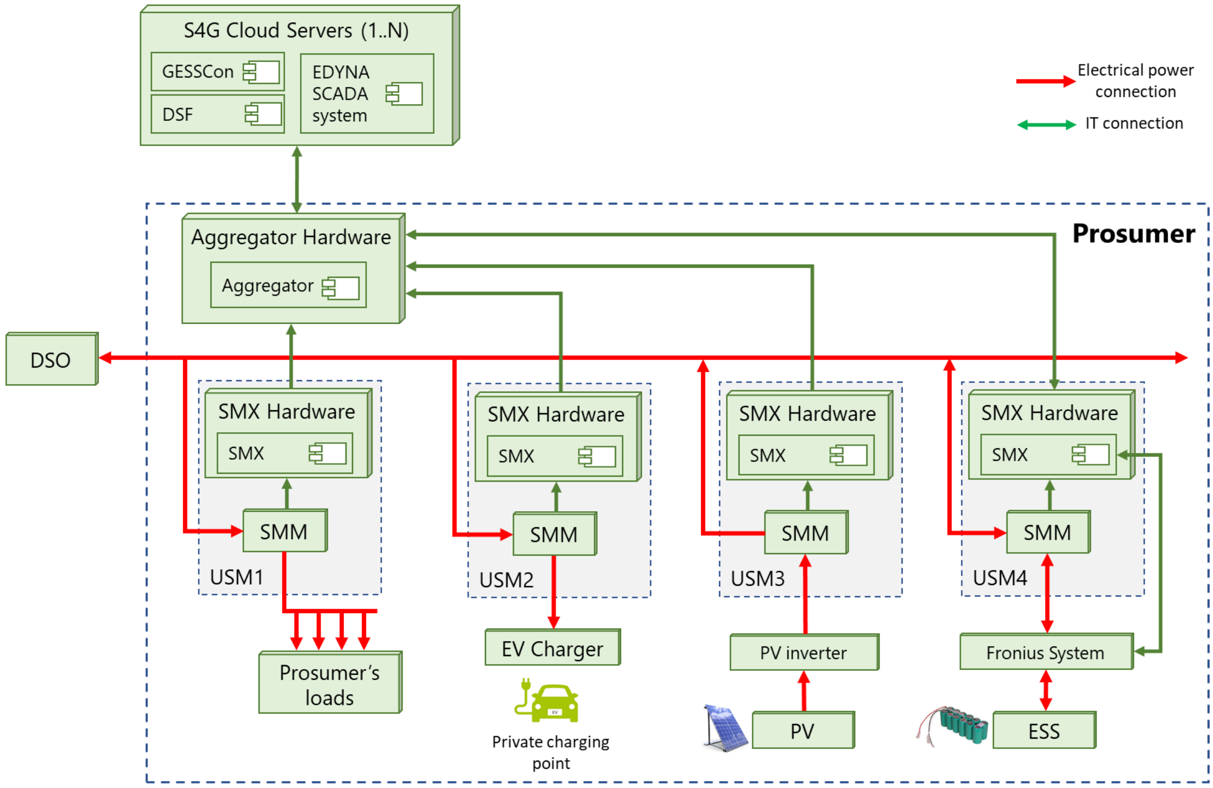

Figure 17. Deployment diagram: Bolzano residential test site.

Table 9. Physical components deployed: Bolzano residential test site.

Component	Brand/Model	# of components deployed
Fronius Hybrid Inverter	Fronius Symo Hybrid 5.0-3-S	1
Fronius ESS	Fronius Solar Battery 12.0	1
Aggregator Hardware	Raspberry PI model 3	1
SMX Hardware	Raspberry PI model 3	4
SMM	Landis+Gyr ZMG310	4
EV Charger	Circontrol Wall Box smart	1
EDYNA SCADA System	SELTA Scada eXPert	1

5.2.2 Commercial case

The cooperative EV charging scenario deployment in the commercial test site is depicted in Figure 18, where a number of EV CPs (1 … M) is deployed. Three Dummy EV Chargers are associated with USM1, and each of the USM2 to USM6 are associated to a Smart EV charger, which are responsible of monitoring the load of each CP (via the SMM), as well as hosting the EV CP connector enabling interoperability towards the local OCPP endpoint available on the CP (SMX#EV Charger and EV Charger#SMX interfaces). This component also acts as proxy to allow the legacy EV SCADA system in place to keep functioning in transparent way, while still allowing the CP to be locally controlled. USM7 measures all EV chargers' consumption and the LiBal System energy exchange.

USM8 and USM9 are measuring the PV production of the 50 kW and 99 kW, respectively.
USM10 is measuring the Edyna's warehouse PCC (including the 99 kW PV). Lastly, USM11 is measuring the LiBal System energy exchange with the DSO.

The Aggregator Hardware is deployed, hosting the PROFEV component, and acting as main data collector of the commercial test site. The Aggregator also serves the Service Layer components, most notably GESSCon, DSF, and the SIEMENS SCADA system, which was not developed within the project, but is used to retrieve real-time information regarding EV CP measurements, enabling also their control.
Similar to the residential case, in this test site, the Aggregator Broker is hosted in an individual Aggregator to ensure that the necessary computational resources are available to run the necessary Aggregator components and receive data from the USMs.
Table 10 outlines the number and models of different physical components in this scenario.

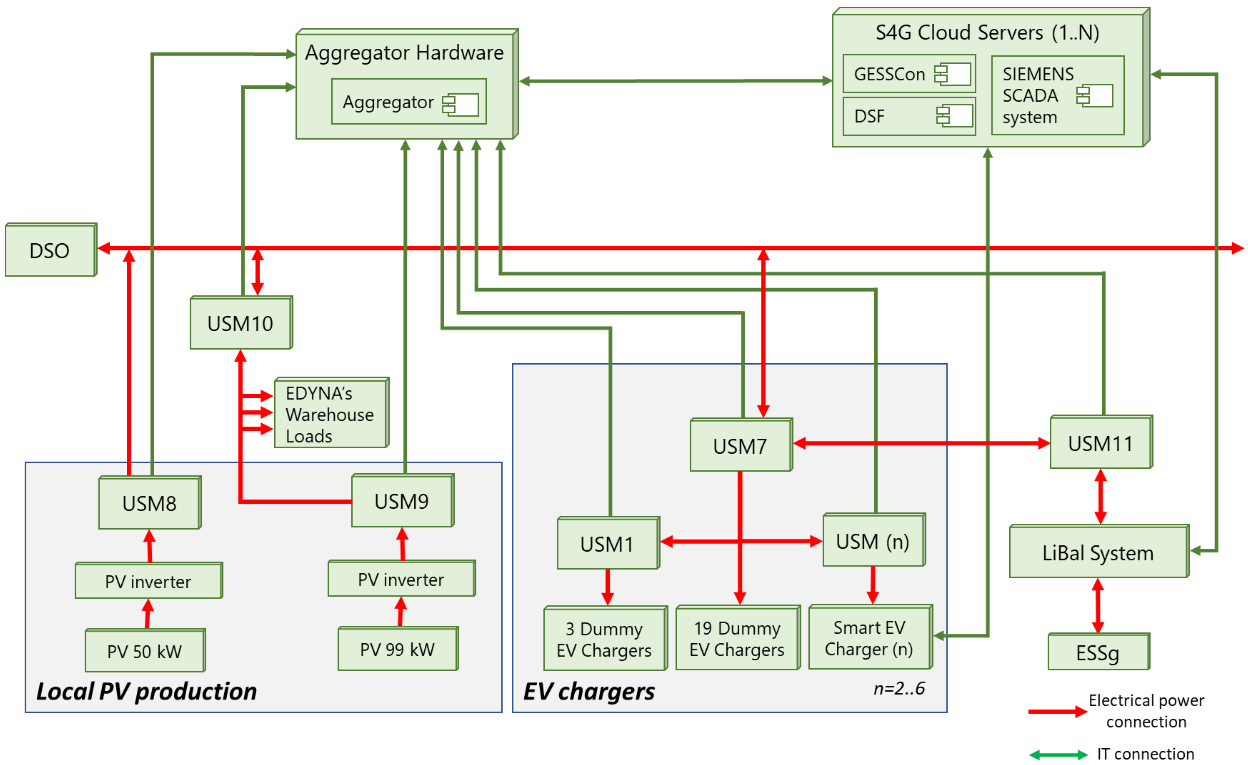

Figure 18. Deployment diagram: Bolzano commercial test site.

Table 10. Physical components deployed: Bolzano commercial test site.

Component	Brand/Model	# of components deployed
SIEMENS SCADA system	Siemens Ecar operation center	1
Aggregator Hardware	Raspberry PI model 3	1
SMX Hardware	Raspberry PI model 3	11
SMM	Landis+Gyr	11
Dummy EV Charger	Circontrol Wall Box	3 + 19
Smart EV Charger	Circontrol Wall Box smart	5
LiBal System	Xolta BAT-79 (indoor)[xxiv]	1

5.3 Fur/Skive test site: Storage coordination scenario

This section describes the deployment views for the storage coordination scenario, which is divided in the local and grid cases, as described in the following sections.

5.3.1 Local case

The storage coordination scenario deployment in the local test site is depicted in Figure 19. The local test site is composed by 6 houses featuring a PVs, inverter and its ESS. The Fronius System and a Fronius ESS is deployed in 5 houses and integrated in USM using a dedicated connector implementing the Fronius System interface described in section 3.4. One house features the three-phase ER and its ESS, similarly connected like the Fronius System but using its IEC61850-90-7 connector.
The USM is placed in the house PCC, and has the Aggregator running the PROFESS component. All the data is forwarded to the DSF, deployed in the S4G Cloud Server.
Table 11 outlines the number and models of different physical components in this scenario.

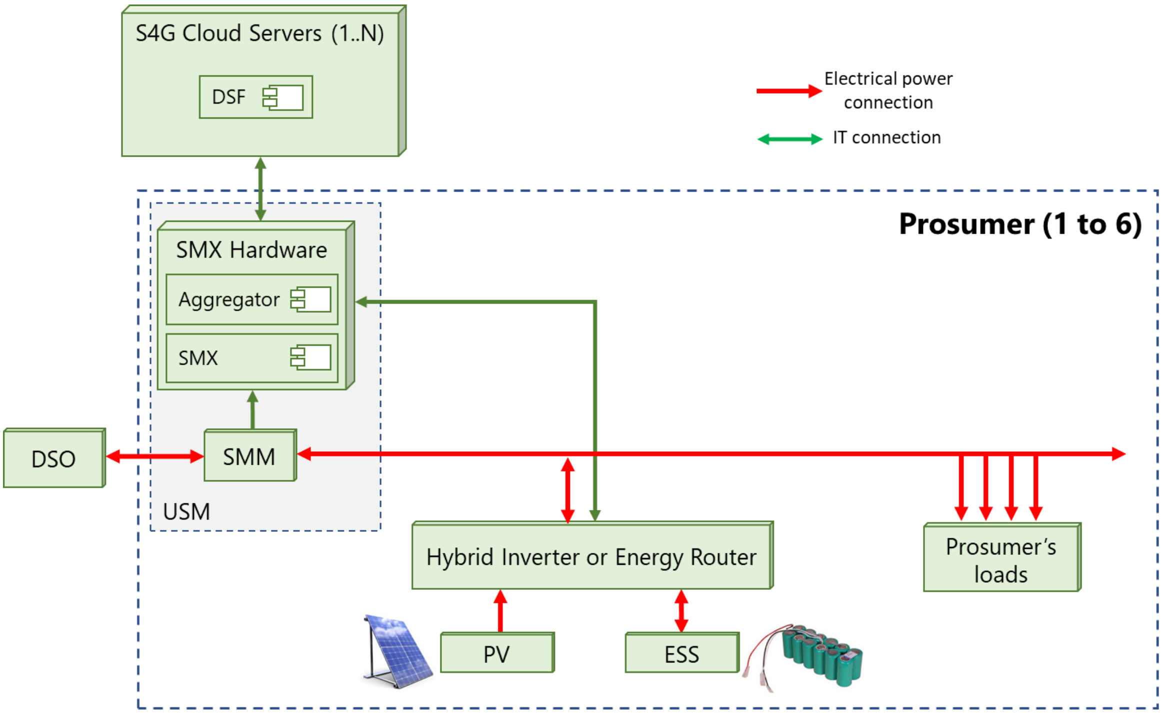

Figure 19. Deployment diagram: Fur/Skive local test site.

Table 11. Physical components deployed: Fur/Skive local test site.

Component	Brand/Model	# of components deployed
Fronius System	Fronius Symo Hybrid 5.0-3-S	1 per house (5 in total)
Fronius ESS	Fronius Solar Battery 12.0	1 per house (5 in total)
SMX Hardware	Raspberry PI model 3	1 per house (6 in total)
SMM	Landis+Gyr ZMD310	1 per house (6 in total)
Three-phase ER	S4G prototype	1

5.3.2 Grid case

The storage coordination scenario deployment in the grid test site is depicted in Figure 20, featuring a grid-side ESS, locally controlled by the LiBal System and able to communicate with the S4G Cloud Servers. The USM used in the grid case uses the same components as the one deployed in the local case.
This scenario is controlled by LiBal System locally. GESSCon is connected to the LiBal System for the purpose of changing operational strategy and monitoring.
Table 12 outlines the number and models of different physical components in this scenario.

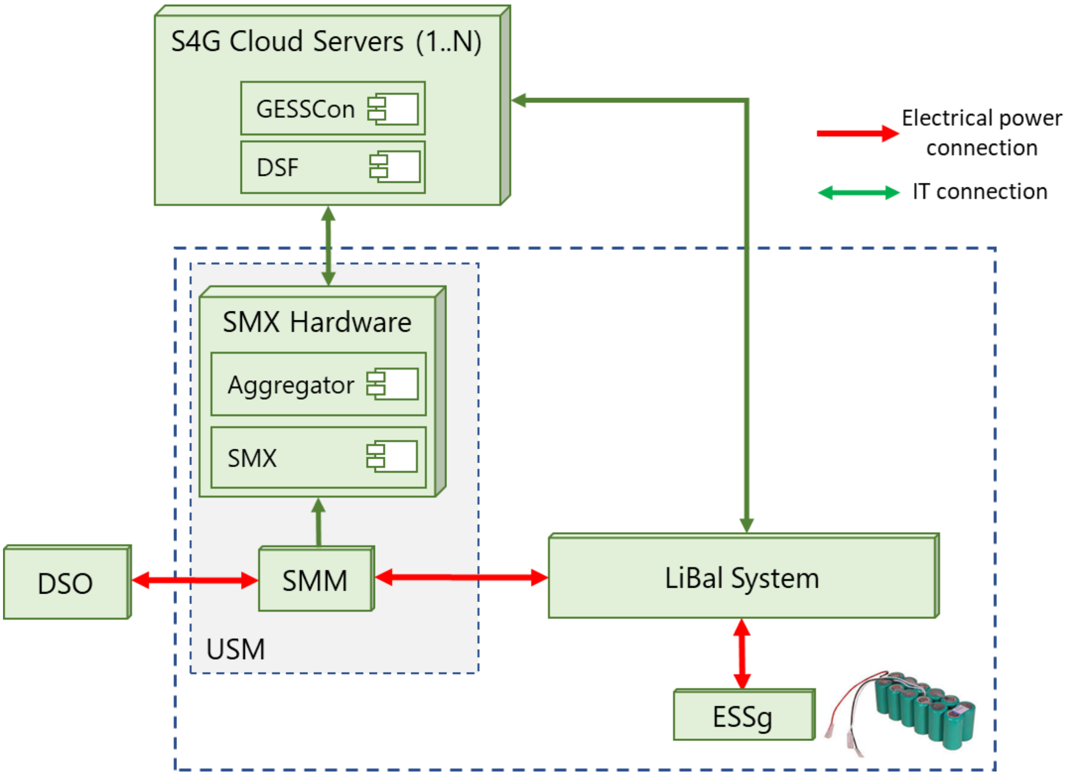

Figure 20. Deployment diagram: Fur/Skive grid test site.

Table 12. Physical components deployed: Fur/Skive local test site.

Component	Brand/Model	# of components deployed
SMX Box	Raspberry PI model 3	1
SMM	Landis+Gyr ZMD310	1
LiBal System	Xolta BAT-79 (outdoor)[xxv]	1

6 Information Security View

S4G adopts secure-by-design communication protocols, which are in line with the General data protection regulation (EU) 2016/679 (GDPR)[xxvi] and D8.1 [S4G-D8.1]. The choice of secure communication protocols, guarantees levels of security compliant with the requirements of the proposed infrastructure, in conjunction with two system security best practices adopted by the S4G design, namely:

1) The use of secure services and systems built adopting open source components.
2) The unique use of certificate-based authentication against less secure password-oriented security approaches for all remote systems.

Figure 21 highlights the network/communication view how secure domains are handled within S4G. As depicted in Figure 21, the LAN security is delegated to security features specific of each site, trusted S4G services are only conveyed over secure transports (i.e. TLS) and over dedicated VPN interfaces. In other words, trusted S4G services running in the cloud, are logically insulated from the public networks using secure VPN configurations.

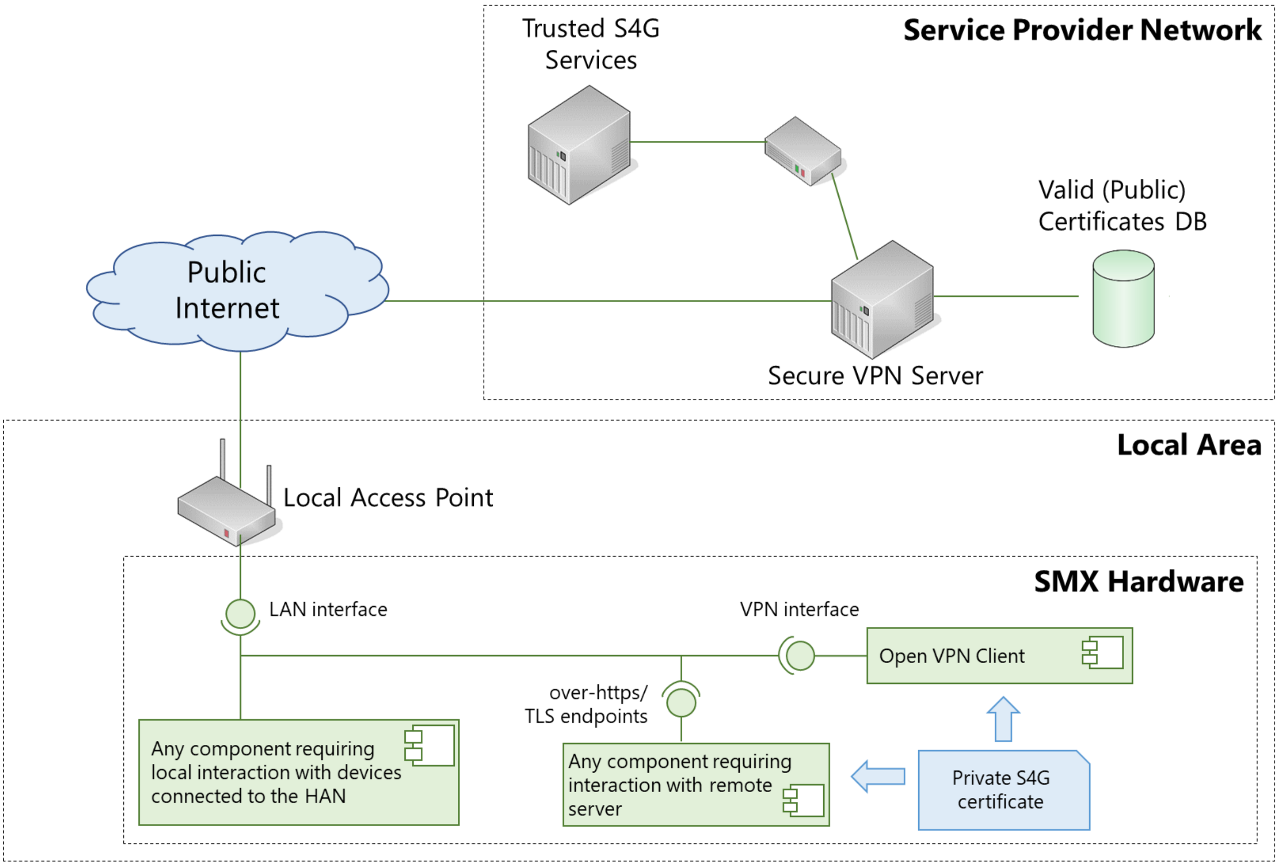

Figure 21. Network diagram: Network security view.

Access to VPN is controlled using certificates maintained by a dedicated Certification Authority (CA), maintained by the S4G project in an offline domain, and deployed manually in each authorized gateway, as depicted in Figure 22.

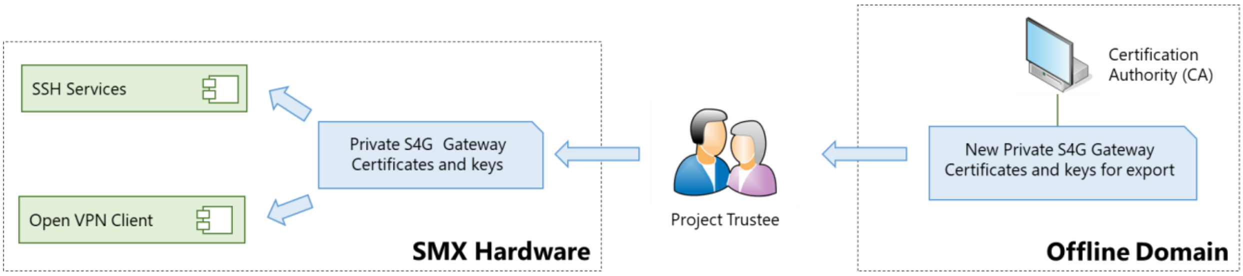

Figure 22. CA workflow.

As foreseen in state-of-the-art VPN solutions, the S4G project maintains a Certificate Revocation List (CRL) to enable the possibility of de-authorizing specific (e.g. compromised) gateways or systems.

7 Standards Overview

In order to facilitate adoption and reuse of generated outcomes, whereas feasible, S4G aims for adoption of existing standards. An overview of the full set of Smart Grid standards is reported in "*Final report of the CEN/CENELEC/ETSI Joint Working Group on Standards for Smart Grids*" [xxvii], which has been extended in "*SGCG/M490/G_Smart Grid Set of Standards*" [xxviii], 2014.
S4G uses the standards and protocols described in Table 13.

Table 13. S4G adopted standards and protocols.

Standard ID and title	Short Description	Domain(s)	Where and how it is used in S4G
DLMS/COSEM[xv]	• An object model, to view the functionality of the meter, as it is seen at its interface(s). • An identification system for all metering data. • A messaging method to communicate with the model and to turn the data to a series of bytes. • A transporting method to carry the information between the metering equipment and the data collection system.	Smart metering / Smart grids	Readout of SMM in USM
IEC 61850-90-7[xiii]	Describes the functions for power converter-based distributed energy resources (DER) systems, focused on DC-to-AC and AC-to-AC conversions and including PV systems, battery storage systems, EV, charging systems, and any other DER systems with a controllable power converter.	Smart grids	Communication between the SMX and the ER.
MQTT[xxiii]	Is a lightweight messaging protocol that provides resource-constrained network clients with a simple way to distribute telemetry information. The protocol, which uses a publish/subscribe	ICT	• Inter-communication of the Device, Edge, Communication, and Services layers. • Intra-communication of the Aggregator components. • Intra-communication of the SMX components.

Standard ID and title	Short Description	Domain(s)	Where and how it is used in S4G
	communication pattern, is used for machine-to-machine (M2M) communication and plays an important role in the IoT.		
OCPP[xii]	Application protocol for communication between EV charging stations and a central management system, also known as a charging station network, similar to cell phones and cell phone networks.	EV charging standard	Communication between the SMX and the EV CP. The standard uses REST over HTTP for data exchange, in a Simple Object Access Protocol (SOAP) or JavaScript Object Notation (JSON) implementation
IEC 60038[xxix]	Specifies standard voltage values which are intended to serve as preferential values for the nominal voltage of electrical supply systems, and as reference values for equipment and system design.	Voltage level	Standard for voltage levels on AC and DC, used for the ER design
OGC SensorThings[viii]	Designed for sensors in the IoT application domain. It is an open standard addressing the syntactic interoperability and semantic interoperability of IoT.	ICT (IoT)	It has been adopted for the S4G architecture, enabling the standardization of data required in the S4G system. It allows to stablish a CIM for S4G.
IEC 60870-5-104[xxx]	Telecontrol companion standard that enables interoperability among compatible telecontrol equipment. Applies to telecontrol equipment and systems with coded bit serial data transmission for monitoring and controlling geographically widespread processes.	Smart grid	Communication between the DSF and the DSO SCADA system.
SenML[xi]	Sensor Measurement Lists (SenML) defines a format for representing simple sensor measurements (e.g., smart meters) and device	ICT (IoT)	Communication with PROFESS/PROFEV. Set-points from these components are delivered in SenML.

Standard ID and title	Short Description	Domain(s)	Where and how it is used in S4G
	parameters. Representations are defined in JSON format.		

The set of used standards and protocols are covering the S4G needs and no gaps which may need additional work on standardization have been identified. However, based on the project activity, the following proposals could be considered on HLUC-1, to be more refined during the project activities:

- The project addresses LV DC network and analysing the existing standardization, it was realized that there is no power quality standard adapted for DC networks and such standard needs to be elaborated.
- The Bucharest demonstrator is using different LV loads, including white appliances and computers, some of them being already tested in lab that they work in both 230 V AC and 220 V DC. However, there is no obligation at the time for the LV equipment manufacturers to declare not only 230 V AC functionalities, but also if the equipment can handle DC power supply and in which range. It is proposed that the manufacturers should specify which are the DC power supply characteristics (if possible, to be DC supplied). By asking the manufacturers to declare the DC supply capability, the loads can be safely connected also to DC grids, which are an emerging technology in hybrid networks). The declarations should be based on specific tests made by the manufacturers in-house, thus bringing commercial guarantee that the equipment can be also used safely in DC networks.

8 Future oriented architectures sustained by large storage resources

Advanced prosumers have been addressed in HLUC-1, with focus on resilience and low impact on distribution grid, storage resources having an essential role for both targets. Moreover, large renewables penetration in a distribution grid was also addressed in HLUC-1, using the storage as a service concepts, allowing the advanced prosumer either to absorb excess RES energy during high RES production or to help avoiding grid congestions by releasing the stored energy during peak consumption hours. Distribution grid was considered in a traditional architecture, as being part of the main synchronous grid.

A more holistic view has been seen during the second part of the project, targeting a new "microgrid-by-design architecture", using the storage for a microgrid connected to the main grid through a Solid State Transformer (SST) , having grid-storage means to incorporate the SST and giving not only full-time energy balancing services in the microgrid, but also contributing to the microgrid-by-design dynamic stability through the combination of capacitor and storage resource to control the SST DC busbar. The microgrid has 100% inverter-based generation (to allow 100% RES connection) and always an asynchronous connection with the main grid through the SST, which provides full time microgrid energy balance and dynamic stability, by using appropriate design with batteries and supercapacitors (all storage means), as shown in Figure 23.

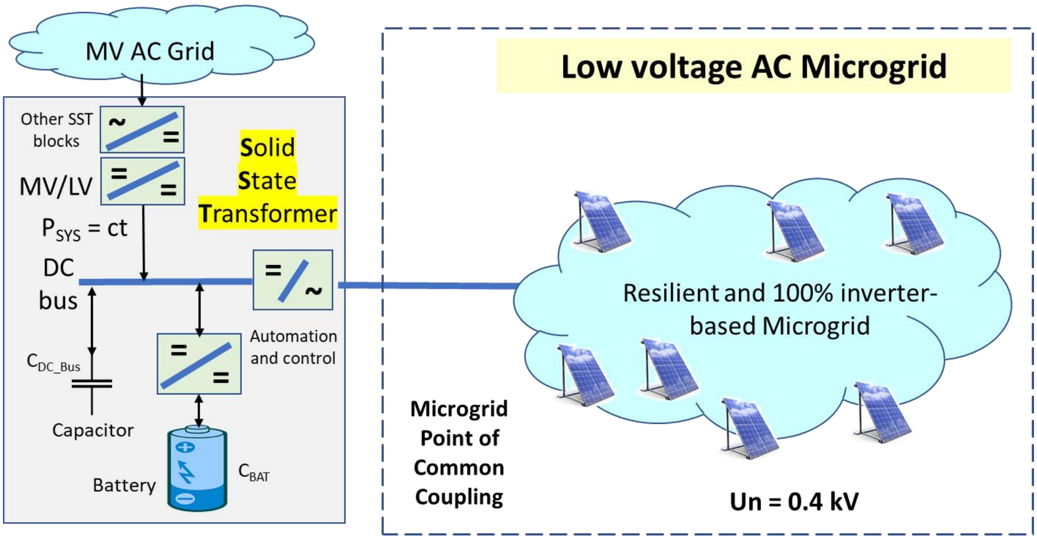

Figure 23. Microgrid architecture using special SST for resiliency and 100% inverter-based generation.

At the moment, the findings were theoretically approached, and two journal papers have been published with the new concepts [xxxi, xxxii]. While the enhanced microgrid resiliency has been demonstrated in the new architecture, an essential contribution was to show by simulations that a new dynamic stability concept applies in microgrid-by-design architectures, which is based on the "electrostatic energy inertia", as a different stability principle than the classic "mechanical inertia" which is present in the main grid.

Table 14 briefly presents some basic differences between the classical grid with rotating machines and microgrids with inverter-based only resources, with emphasis on the mechanism for ensuring the dynamic stability of each system. The work is related to HLUC-1, as a possible solution for making neighbourhoods electrical communities in AC networks which are supplied from a DC connection, and not synchronously connected to the main grid – while not islanded, as classic microgrids design.

Table 14. Comparison between classical grid with rotating machines and microgrid with inverter-based only resources

Description	Classical (legacy) grid with rotating machines	Microgrid with inverter-based only resources
Inertial mechanism	Mechanical inertia	Electrostatic inertia
Energy source for dynamic stability	Kinetic energy of rotating machines of the generators	Electrostatic energy of capacitors on DC bus behind inverters
Energy used for the dynamic stability	$E_{kin} = \frac{1}{2} J\omega^2$	$E_{Cap} = \frac{1}{2} CU^2$
Inertia constant	$H = \frac{E_{kin}}{S_b} = \frac{1}{2}\frac{J\omega_{0m}^2}{S_b} = \frac{J(2\pi f_m)^2}{2S_b}$	$H_C = \frac{E_C}{P_{base}} = \frac{1}{2}\frac{C_{DCbus}U_{DCnom}^2}{P_{base}}$
Reaction time	Instantaneous - natural occurring	Instantaneous - natural occurring
Relation with grid frequency	Yes	No
Grid Architecture	Fully connected synchronous grid architecture	Microgrid asynchronously connected to classic grid through SST or other DC mediated connection
High share, up to 100% RES penetration scenarios		
Problem with high RES penetration	Reduction of mechanical inertia reduces grid dynamic stability	No problems with a microgrid-by-design architecture
Mitigation of large RES penetration	Simulation of rotating machines e.g. with Virtual Synchronous Machine (VSM)	By design: 100% RES using inverter-based only connection
Mechanism of mitigation	Synthetic inertia through an automation loop (VSM or other types), man-made	Natural occurring, like with the mechanical inertia in classic grids
Reaction time	Limited by measurements and automation loop	Instantaneous (natural occurring)
Resilience	By islanding from main grid, a grid zone and build-up a microgrid	Microgrid-by-design
Immunity from main grid outages	Usually not, as resupplying can be done with short outages	Yes, through the microgrid-by-design architecture
Enabling technologies for mitigating high RES penetration	Power electronics, storage means	Power electronics, storage means (capacitor with backup storage)

UPB and UNINOVA contributors to this concept, consider this findings as an important and new grid architectural approach, which allows at the same time microgrid resiliency (and even immunity from main grid outages) and accommodation of 100% inverter-based generation, based on appropriate storage use for the microgrid.

9 Conclusions

This deliverable presented the final specifications of the S4G components, interfaces and architectural views to facilitate the integration between components over the third period of the project. The final S4G architecture has been done with by updating the initial (D3.1 [S4G-D3.1]) and the updated (D3.2 [S4G-D3.2]) S4G architecture specifications.

The document presented different architectural views following the ISO/IEC/IEEE 42010:2011 standard[i]. The architectural views have been divided in Functional, Information, Communication, Deployment, and Information Security views. The functional view has been extended, with respect to the previous version, by following the SGAM view. The S4G functional view is based on SGAM and provides a more detail functional view including important ICT aspects, such as a middleware level, not included in the SGAM views. Besides, the integration with middleware allowed to introduce the OGC SensorThings server enabling a S4G CIM.
The Information, Communication, Deployment, and Information Security views have been updated according to the final S4G components included in this document, and inputs from other deliverables, namely D2.6 [S4G-D2.6] and D6.3 [S4G-D6.3].

Standard protocols and data models are key objectives of the S4G project. Therefore, this deliverable included a dedicated section describing the used information models and the integration of vendor specific protocols needed and deployed on specific interfaces. A gap was identified by analysing the standardisation regarding LV connected appliances which can be supplied on both 230 V AC and LV DC. Moreover, there are not power quality standards for DC networks, and this is another identified gap which need to be covered by standardisation bodies. No other gaps were identified in the other HLUCs.

Moreover, a new theoretical development validated by simulations and published in a peer-review journal shows the potential for using storage in a SST in order to obtain a microgrid-by-design architecture, which has resiliency and immunity towards main grid outages while accommodating inverter-based only generation specific to high RES penetration. In this approach, the classic mechanical inertia, which is totally missing in a grid with 100% inverter-based generation, is shown to be fully substituted by the electrostatic inertia, in order to keep grid dynamic stability. The architecture has been inspired by the project HLUC-1 and is an additional contribution to the S4G applications, to be developed further in new projects. Based on the project HLUC-1 focus on resilience, the theoretical solution at TRL 2-3 level need future work for advancing towards microgrids by design, as one of the solutions to mitigate reduction of mechanical inertia in main grids and advance with new means towards carbon neutral energy systems and local communities empowerment.

Acronyms

Acronym	Explanation
AC	Alternative Current
ACSI	Abstract Communication Service Interface
ADS	Active Demand and Supply
API	Application Programming Interface
BESS	Battery Energy Storage System
BMS	Battery Management System
CA	Certification Authority
CAN	Controller Area Network
CIM	Common Information Model
COSEM	Companion Specification for Energy Metering
CP	Charging Point
CRL	Certificate Revocation List
DC	Direct Current
DER	Distributed Energy Resources
DLMS	Device Language Message Specification
DMS	Distribution Management System
DoA	Description of Action
DSF	Decision Support Framework
DSF-DWH	Decision Support Framework Data Warehouse
DSF-EE	Decision Support Framework Economic Engine
DSF-SE	Decision Support Framework Simulation Engine
DSO	Distribution System Operator
DTLS	Datagram Transport Layer Security
DTLS	Datagram Transport Layer Security
DWH	Data Warehouse
EC	European Commission
ER	Energy Router
ESG	External Stakeholders Group
ESS	Energy Storage System
EU	European Union

Acronym	Explanation
EV	Electric Vehicle
FCDA	Functional Constrained Data Attribute
GDPR	General Data Protection Regulation
GESSCon	Grid Side Energy Storage System Controller
GOST	Go-SensorThings
GPL	General Public License
GUI	Graphical User Interface
HI	Hybrid Inverter
HIL	Hardware-in-the-Loop
HLUC	High-Level Use-Case
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
HTTPS	HyperText Transfer Protocol Secure
ICAN	Industry Controller Area Network
ICT	Information and Communication Technology
ID	Identification
IDS	Intrusion Detection Systems
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IP	Internet Protocol
ISO	International Organization for Standardization
IT	Information Technology
JSON	JavaScript Object Notation
KPI	Key Performance Indicators
LAN	Local Area Network
LEMS	Local Energy Management System
LESSAg	Local Energy Storage System Agent
LV	Low Voltage
M2M	Machine-to-machine
MAC	Medium Access Control

Acronym	Explanation
MQTT	Message Queuing Telemetry Transport
MV	Medium Voltage
NIST	National Institute of Standards and Technology
OCPP	Open Charge Point Protocol
OGC	Open Geospatial Consortium
PCC	Point of Common Coupling
PHY	Physical Layer
POPD	Processing Of Personal Data
PROFESS	Professional Realtime Optimization Framework for Energy Storage Systems
PROFEV	Professional Realtime Optimization Framework for Electric Vehicles
PROSIT	PROfiles SImiLarity Tool
PUC	Primary Use Case
PV	Photovoltaic
RBAC	Role Based Access Control
RES	Renewable Energy Sources
REST	Representational State Transfer
RTU	Remote Terminal Unit
S4G	Storage4Grid
SCADA	Supervisory Control and Data Acquisition
SCADA	Supervisory Control And Data Acquisition
SenML	Sensor Markup Language
SGAM	Smart Grids Architecture Model
SMM	Smart Metrology Meter
SMX	Smart Meter eXtension
SOAP	Simple Object Access Protocol
SoC	State of Charge
SQL	Structured Query Language
SSH	Secure Shell (SSH)
SST	Solid State Transformer
TCO	Total Cost of Ownership
TCP	Transmission Control Protocol

Acronym	Explanation
TLS	Transport Layer Security
TOC	Table of Contents
TRL	Technology Readiness Levels
UML	Unified Modelling Language
USEF	Universal Smart Energy Framework
USM	Unbundled Smart Meter
VPN	Virtual Private Network
VSM	Virtual Synchronous Machine

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