# Methodology for the definition of the preliminary architecture of a Smart Energy System (SES)

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***Abstract* — This article describes a methodology for the definition of the preliminary architecture of the Smart Energy System (SES) platform. Unified Architectural Framework (UAF) has been used for a formal architecture description; it represents one of the first applications of UAF architectural framework to the industrial energy sector. A business process analysis, through BPMN, allowed a clear vision of the processes among actors in the energy market. Furthermore, the definition of the main platform components, through SysML, allowed to define use cases diagrams and to describe main platform components. As result there were defined the preliminary SES hardware and software architecture and the ways for the development of the system.**

***Keywords— Energy management system, DER, UAF, BPMN, SysML, UML.***

## I. Introduction

The present article shows the application of System Engineering approach to the definition of the preliminary architecture of the IoT Smart Energy System (SES) platform. SES wants to provide a flexible, reliable and scalable platform in order to manage and optimize the use of DERs (Distributed Energy Resources) for multiple purposes. It should enable connectivity, data collection, visualization, organization (filtering, grouping, scheduling, dispatch, settlement) and optimization of DERs for a variety of grid, power, energy and services management and to help the energy utility in management and decision support. SES distributed architecture and control algorithms create an 'active' distribution management system to control the renewable and distributed energy resources in support of utility and community goals. Typical SES applications include integration of renewables plants with the energy storage for carbon offset and in order to reduce costs and microgrid operations for security, resiliency and market participation.

GALA group, one of the main Italian energy provider, has requested Aster to provide system engineering support for the definition, technical-economical evaluation, and possible implementation of the data acquisition software component, smart management and decision support.

In particular, SES platform allows integration and connectivity among different DER, such as storage systems, smart electric vehicles and smart home devices and collects, organizes and visualizes all the information on the platform helping in decision support. SES integrates traditional utility tools, such as DMS and SCADA systems, aggregating and exposing the capabilities on the platform.

Main SES platform objectives are:

- Providing smart management for energy time shift, in order to store energy during low price time and discharging during high price time;
- Defining arbitrage services which provide energy trading skills and algorithms to utilities in order to obtain higher revenues than those obtainable by applying static rules;
- Providing supervision and control services for real-time monitoring of devices, systems and applications (Smart Home, Smart Building);
- Applying strategies of demand side response management;
- Providing energy community services for the optimization and maximization of self-consumption in micro-grids;
- Providing Aggregation services of virtual resources (Virtual Power Plant, Virtual Energy Storage System, Enabled Virtual Units);
- Providing electric mobility management service in order to manage the energy storage infrastructure and energy stored through the electric vehicles.

System engineering methodologies were used to define system stakeholders and their needs, to define principal services of the platform, to model business processes, to describe main components of the platform, to derive the use cases and a preliminary SES architecture. There were also considered two possible ways for the development of the system, making a comparison between the costs.

In the present work, the application of the Unified Architectural Framework (UAF) has been proposed; it represents one of the first applications of UAF architectural framework to the industrial Energy sector and highlights the capabilities of UAFP v 1.0 to [1]:

- model architectures for a broad range of complex systems which may include hardware, software, data, personnel and facility elements;
- model consistent architectures for system-of-systems (SoS);
- support the analysis, specification, design, and verification of complex systems; and
- improve the ability to exchange architecture information among related tools which are SysML based and tools that are based on other standards.

## II. Overall Methodology

The proposed approach, shown in Fig. 1, is a process starting from the definition of the stakeholders and of their user needs, proceeding with the definition of the platform services, modelling of business processes and use cases.

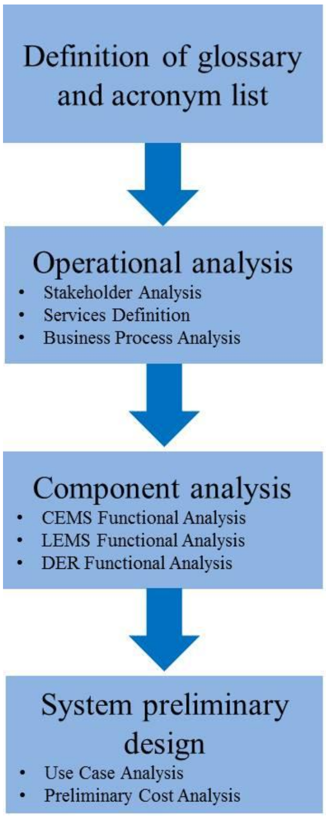



Fig. 1. SES Methodology

The final output of the work is the preliminary architecture and costs of the SES platform.

The work has been divided in the following phases:

- Definition of glossary and acronym list: it aims to define a common language for the project;
- Operational analysis: it aims to define the stakeholders, the services and the business processes of the platform;
- Component analysis: it provides the definition of the main components for the platform, starting from some existing components;
- System preliminary design: it focuses on the platform use cases, the preliminary architecture and a cost analysis.

The UAF has been applied for a formal definition of the system architecture. An Architectural Framework establishes a common practice for creating, interpreting, analyzing and using Architecture Descriptions (AD) within a particular domain of application or stakeholder community, ensuring that the overall Enterprise Architecture is coherent [2].

The Unified Architectural Framework has been created to support a standard representation also for non-defense organizations' ADs as part of their Systems Engineering (SE) technical processes. UAF supports a standard profile that can be used to implement the UAF in UML/SysML tool [1].

Visual Paradigm is the software tool used for the SysML model of the SES platform, taking into account Unified Architectural Framework Profile (UAFP) v 1.0 prescriptions [1]. The Unified Architectural Framework Profile (UAFP) enables the extraction of specified and custom models from an integrated architecture description (AD). The models describe a system from a set of stakeholders' concerns such as security or information through a set of predefined viewpoints and associated views.

The UAFP supports the Department of Defense Architectural Framework (DoDAF) 2.02, the Ministry of Defence Architectural Framework (MODAF), Security Views from Canada's Department of National Defense Architectural Framework (DNDAF) and the North Atlantic Treaty Organization (NATO) Architectural Framework (NAF) v 3.1. UAFP is based upon the DoDAF 2.0.2 Domain Metamodel (DM2) and the MODAF ontological data exchange mechanism (MODEM).

The UAF metamodel improves the ability to exchange architecture data between related tools which are UML/SysML based and tools that are based on other standards.

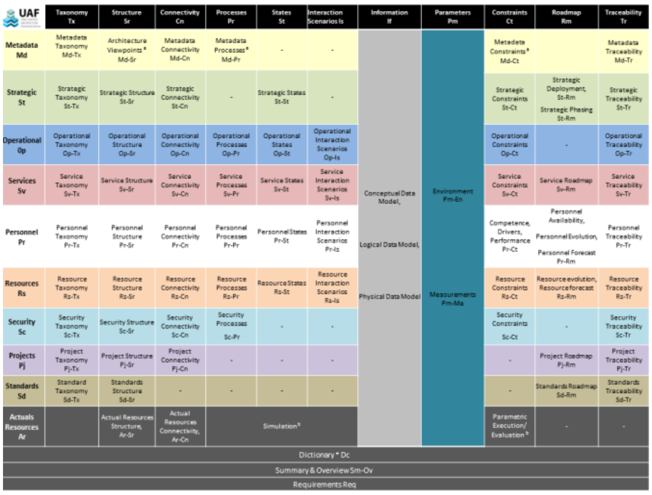
UAFP 1.0 specifies one level of compliance to $\text{SysML}_{\text{TM}}$ profile using SysML v 1.3. UAFP imports the SysML profile and defines constraints that pair together the application of SysML and UAFP stereotypes.

The UAF views are classified for types (eg. Taxonomy, structure, connectivity etc.) and domains (eg. Metadata, strategic, operational etc.); the UAF view matrix is represented in Fig. 2. It specifies the different diagram types across the top and the domains along the side. UAF views used to represent the SES architecture are [1], [3]:

- Dc: Dictionary view aims to define all the elements used in an architecture. In SES model this view has been applied to describe in tabular format the Project acronym list and the glossary;
- Md-Tx: Metadata Taxonomy view shows the taxonomy for metadata. In the present work, this view has been

used to define all the elements of the SysML model (e.g. Block, interface etc.);

- Op-Tx: Operational Taxonomy view shows the taxonomy of types of Operational agents. It has been used to collect use cases for each platform service;
- Op-Pr: Operational Processes view describes the activities which are normally conducted in the course of achieving business goals that support a capability. In SES model this view has been used to describe, using BPMN diagrams, the typical processes in the energy market;
- Op-Tr: Operational Traceability view describes the mapping between the capabilities required by an Enterprise and the supporting operational activities and operational agents. This view has been used to describe Smart Energy System use cases;
- Pr-Tx: Personnel Views Taxonomy view shows the taxonomy of types of organizational resources. In SES model this view has been used to define system stakeholders;
- Rq: Requirement view is used to represent requirements, their properties and relationships between each other and to UAF architectural elements. In the present work, this has been chosen to list in tabular format stakeholder needs;
- Rs-Sr: Resource Structure view defines the physical resources, e.g. capability configuration(s)/system(s) and interactions necessary to implement a specific set of Operational Performer(s). In SES model this view describes the capabilities of the main platform components, using SysML Internal Block Diagram;
- Rs-Tx: Resource Taxonomy view shows the taxonomy of types of resources. In SES model this view depicts the principal capabilities of platform components, using SysML Block Definition Diagram;
- Sd-Tx: Standards Taxonomy view shows the taxonomy of types of technical, operational, and business standards, guidance and policy applicable to the architecture. It has been used to list the reference standards;
- Sm-Ov: Summary & Overview view provides executive-level summary information to allow quick reference and comparison among architectural descriptions. ). In SES model this view has been applied to describe system context;
- Sv-Tx: Services Taxonomy view shows Service Specifications and required and provided services levels of these specifications needed to exhibit a Capability or to support an Operational Activity. In SES model this view describes system services, using SysML Block Definition Diagram.



| UAF | Taxonomy Tx | Structure Sr | Connectivity Cn | Processes Pr | States St | Interaction Scenarios Is | Information If | Parameters Pm | Constraints Ct | Roadmap Rm | Traceability Tr |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Metadata Md | Metadata Taxonomy Md-Tx | Architecture Viewpoints ª Md-Sr | Metadata Connectivity Md-Cn | Metadata Processes ª Md-Pr | - | - | | | Metadata Constraints ª Md-Ct | | Metadata Traceability Md-Tr |
| Strategic St | Strategic Taxonomy St-Tx | Strategic Structure St-Sr | Strategic Connectivity St-Cn | - | Strategic States St-St | - | | | Strategic Constraints St-Ct | Strategic Deployment, St-Rm Strategic Phasing St-Rm | Strategic Traceability St-Tr |
| Operational Op | Operational Taxonomy Op-Tx | Operational Structure Op-Sr | Operational Connectivity Op-Cn | Operational Processes Op-Pr | Operational States Op-St | Operational Interaction Scenarios Op-Is | | | Operational Constraints Op-Ct | - | Operational Traceability Op-Tr |
| Services Sv | Service Taxonomy Sv-Tx | Service Structure Sv-Sr | Service Connectivity Sv-Cn | Service Processes Sv-Pr | Service States Sv-St | Service Interaction Scenarios Sv-Is | Conceptual Data Model, | Environment Pm-En | Service Constraints Sv-Ct | Service Roadmap Sv-Rm | Service Traceability Sv-Tr |
| Personnel Pr | Personnel Taxonomy Pr-Tx | Personnel Structure Pr-Sr | Personnel Connectivity Pr-Cn | Personnel Processes Pr-Pr | Personnel States Pr-St | Personnel Interaction Scenarios Pr-Is | Logical Data Model, | | Competence, Drivers, Performance Pr-Ct | Personnel Availability, Personnel Evolution, Personnel Forecast Pr-Rm | Personnel Traceability Pr-Tr |
| Resources Rs | Resource Taxonomy Rs-Tx | Resource Structure Rs-Sr | Resource Connectivity Rs-Cn | Resource Processes Rs-Pr | Resource States Rs-St | Resource Interaction Scenarios Rs-Is | Physical Data Model | Measurements Pm-Me | Resource Constraints Rs-Ct | Resource evolution, Resource forecast Rs-Rm | Resource Traceability Rs-Tr |
| Security Sc | Security Taxonomy Sc-Tx | Security Structure Sc-Sr | Security Connectivity Sc-Cn | Security Processes Sc-Pr | - | - | | | Security Constraints Sc-Ct | - | Security Traceability Sc-Tr |
| Projects Pj | Project Taxonomy Pj-Tx | Project Structure Pj-Sr | Project Connectivity Pj-Cn | - | - | - | | | - | Project Roadmap Pj-Rm | Project Traceability Pj-Tr |
| Standards Sd | Standard Taxonomy Sd-Tx | Standards Structure Sd-Sr | - | - | - | - | | | - | Standards Roadmap Sd-Rm | Standards Traceability Sd-Tr |
| Actuals Resources Ar | | Actual Resources Structure, Ar-Sr | Actual Resources Connectivity, Ar-Cn | Simulation ᵇ | | | | | Parametric Execution/ Evaluation ᵇ | - | - |
| Dictionary * Dc | | | | | | | | | | | |
| Summary & Overview Sm-Ov | | | | | | | | | | | |
| Requirements Req | | | | | | | | | | | |

Fig. 2. UAF Matrix View

In the operational analysis, first of all system stakeholders and their user needs have been defined. In Fig. 3 all the SES stakeholders are depicted. During the analysis, a particular attention has been given to the emergent actors in the energy market. It has been examined the role of the Aggregator in other European countries, in order to understand the future role of this actor in the Italian market. The aggregator is a demand service provider that combines multiple short-duration consumer loads for sale or auction in organized energy markets [7].

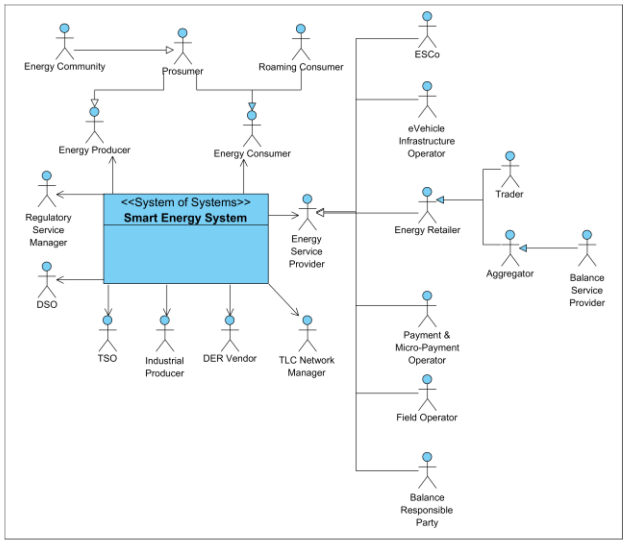



Fig. 3. Stakeholder Analysis

Furthermore SES services have been identified; the SES platform should provide the following services:

- Energy efficiency service;
- Demand-side response service;
- Micro-grid management service;
- Energy pool management services;
- Electric mobility management service.

As represented in Fig. 4, services are divided between services behind the meter and services beyond the meter. A service Behind The Meter (BTM) is referred to a renewable energy generating facility installed on the customer's property and, on the customer's side, of the utility meter that produces power intended for on-site use in a home, office building, or other commercial facilities. The use of a BTM service, therefore, can reduce the customer utility bill. Services beyond the meter, instead, allow integration with the grid providing ancillary services, load balancing, peak shaving, capacity planning, etc.

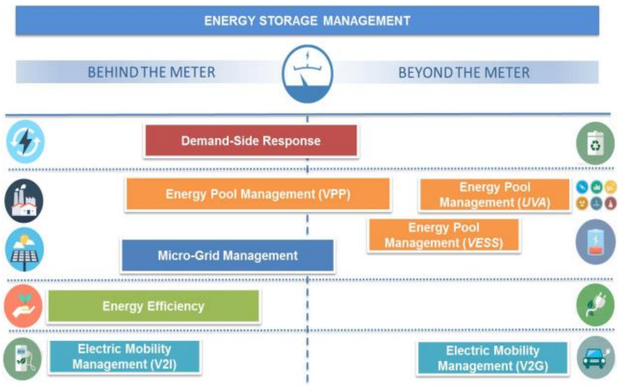



Fig. 4. SES services

After defining system services, it has been possible to analyze Business Model, in order to define the exchange of data, documents and energy among the various actors involved in the energy system.

The definition of the Business Model requires a focus on the system context (its boundaries, external actors, external interfaces). The system context diagram shows the system environment and the system boundary. It is not a predefined diagram of SysML or UML, but a variant of block diagram. In the center of the diagram there is the system under development. All currently known interaction partners are denoted all around the system and associations are used to connect them.

The context of SES system is represented in Fig. 5. The upper part of the figure indicates the main Actors that interact with the system, while the section below illustrates external systems exchanging information with the SES itself. An actor is not a concrete system or a concrete individual, but has to be intended as a role.

The language chosen to formally describe the business process is the BPMN (Business Process Model and Notation), a standard defined by the OMG (Object Management Group). It provides a graphical representation to specify individual processes through a Business Process Diagram (BPD), with a standard, effective and intuitive notation for all the stakeholders involved in the processes. The BPMN diagrams are able to provide a common framework upon which it is possible to describe interactions among different operators working in the energy market [4]. The adoption of the BPMN language allows to offer a clear vision of the processes among actors which have heterogeneous characteristics and different responsibilities, also contributing to the modeling of the interactions that take place within the Energy market. A very important feature of the BPMN standard is that it often allows tight integration with software development systems. Indeed, applications that allow the BPMN designer to represent the process details using BPMN and then to translate that model into software programs for the process management, are now available.

In the present study the processes have been modelled by Orchestration diagrams which represent the detailed information and energy exchange between the actors of each block.

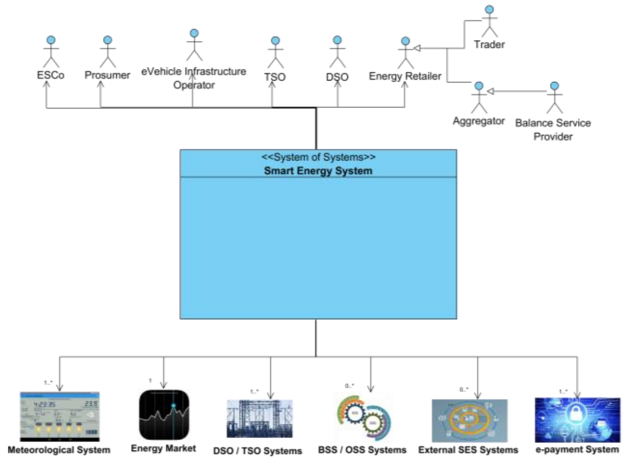



Fig. 5. SES Context diagram

At this point, a component analysis for the definition of the functions of the main components of the SES architecture (CEMS, LEMS, DER) has been conducted; this activity is fundamental for the definition of system use cases. The components have been represented using the SysML approach.

The Systems Modeling Language (OMG SysML™) is a general-purpose modeling language that supports the specification, design, analysis, and verification of systems [5]. These systems may include hardware, software, data, personnel, procedures, and facilities. SysML is an extension of the Unified Modeling Language (UML), version 2, the standard software modeling language. This approach also facilitates the integration of systems and software modeling. Each component has been described using both a block definition diagram (bdd) and an internal block diagram (ibd).

The block is the modular unit of structure in SysML that is used to define a type of system, system component, or item that flows through the system, as well as conceptual entities or logical abstractions. The block describes a set of uniquely identifiable instances that share the block's definition. The block definition diagram is used to define block characteristics in terms of their structural and behavioral features, and the relationships between the blocks such as their hierarchical relationship. The internal block diagram is otherwise used to describe the internal structure of a block in terms of how its parts are interconnected [5].

Furthermore, System Use Case diagrams have been used to represent the goal of a system from the user's perspective [5].

Using the SysML language, formal Use Case diagrams are drawn, showing the complete list of actors (primary and secondary), as well as a full text description for each of them, in order to illustrate the goal of the primary actor and the role of the secondary actors.

The result of these activities is the preliminary system architecture; two different ways of development for the platform were proposed, focusing on the pros and cons of the two solutions. Lastly, the preliminary costs of the two solution have been analyzed.

## III. Modelling of processes in the energy Market

The processes, that the platform has to implement to guarantee each of the key services defined above, have been validated through dedicated technical meetings with different operators.

These processes have been modelled through the BPMN language by Orchestration diagrams which represent the detailed information exchange between the actors of each block. The BPMN diagrams offer a clear vision of the processes among actors with different characteristics and responsibilities, also contributing to model the interactions that take place within the Energy market.

Three main processes have been modelled:

- Energy distribution process: it's the process which characterizes the electricity transport through low voltage distribution systems, analyzing its delivery to customers. The energy distribution is managed by the DSO (Distribution System Operator) who is a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity [6];
- Energy aggregation process: the energy aggregation is managed by the aggregator, who exchanges information with the prosumers he intends to aggregate and classify according to consumer, geographic, or common characteristics related to generation and consumption of electricity. Through its systems, the Aggregator, in addition to providing additional end-user services, will collect and monitor aggregate energy data that will also be available to external users.
- Energy trading process: it describes the process of energy trading in which the energy trader, who buys or sells shares of energy at a given price, plays a primary role.

The orchestration diagrams show clearly the user tasks, the interaction with other actors, the information exchanged and energy exchanges (physical flows). Furthermore the orchestration diagrams describe the existing processes and point out possible future modifications in the actors roles, taking into account others European countries and directives.

## IV. Component analysis

The functional characteristics of the main components of the SES architecture have been analyzed on the basis of the technical documents provided by GALA and on all the information collected during technical meetings. The principal components are:

- Local Energy Management System (LEMS): collects and elaborates signals from DERs and implements possible actions. LEMS can work stand-alone or interconnected with other LEMS and with the CEMS;
- Distributed Energy Resources (DER): these are electricity generation units located within the electricity distribution system at or near the end users [8]. DERs could be aggregated to supply energy demand;
- Central Energy Management System (CEMS): monitors, controls, manages and optimizes the energy system, in the attempt to reduce energy costs and environmental impacts.

SES can be composed of one or more LEMS which can work autonomously or can be interconnected with the CEMS.

The components have been modelled by using the SysML approach [5] and Visual Paradigm as a software tool. Each component has been depicted using both a block definition diagram (bdd) and an internal block diagram (ibd).

The LEMS block definition diagram is shown in Fig. 6. LEMS modules allow the visualization, monitoring and control of all the energy resources managed, the elaboration of all data from DERs and external systems through algorithms which aim to optimize the energy management. Furthermore LEMS provides a smart management of electric mobility infrastructure and of battery charging / discharging processes for vehicles.

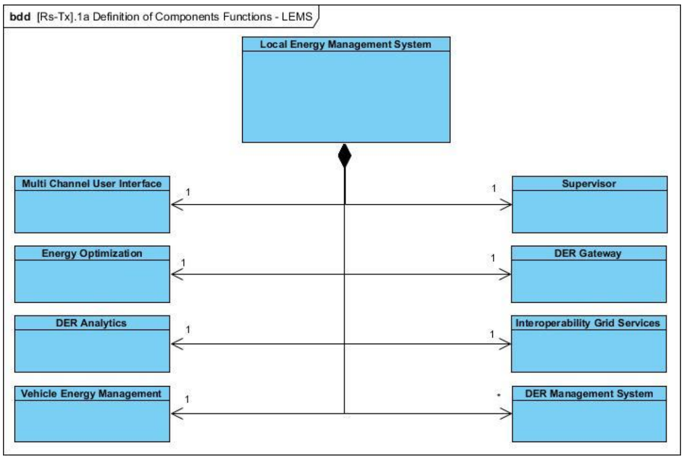



Fig. 6. LEMS Block Definition Diagram

LEMS can be interconnected to DERs in three different ways:

- Unmanaged Distributed Energy Resource;
- Managed Distributed Energy Resource;
- Smart Energy Resource.

Fig. 7 shows the internal block diagram of the LEMS.

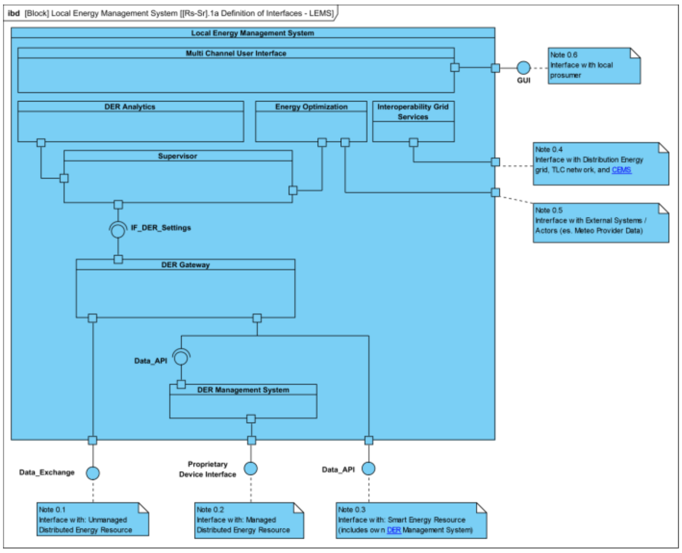



Fig. 7. LEMS Internal Block Diagram

Distributed Energy Resources (DERs) are energy sources that can be aggregated to provide the power needed to meet network demand. In the block definition diagram depicted in Fig. 8, DERs have been grouped (using the Generalization connection type and a dedicated structure in Visual Paradigm to group the connections) by type of connection to LEMS (Unmanaged, Managed, Smart), in the lower part of the diagram and by DER function in the upper part of the diagram.

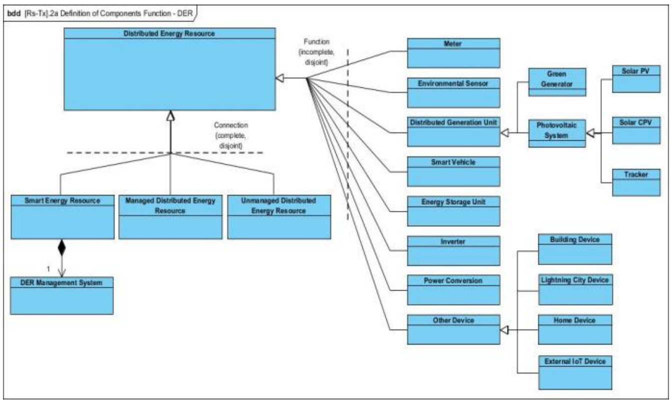
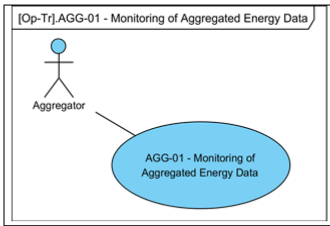



Fig. 8. DER Block Definition Diagram

## V. System Use Cases Definition

The following step is the identification of the system Use Cases, representing the goals of a system from the perspective of the users, from the analysis of the business processes and of the main platform components. Use Case diagrams show the primary and secondary actors and a full text description for each of them in order to illustrate the goal of the primary actor and the role of the secondary actors. The Diagram provides a high-level view of a system functionality, depending on how the actors use the system itself [5]. A typical use case description may include the Preconditions, i.e. the conditions that must hold for the use case to begin, Post conditions, the conditions that must hold once the use case has completed, and the Trigger, which identifies the event that causes the activation of the use case.

Fig. 9 shows one example of Use Case Diagram, representing the monitoring of aggregated energy data. One or more use cases have been considered for all the platform services. In the use case description, there have been highlighted all the platform functionalities which need to be used.




| | |
|---|---|
| TITLE | Monitoring of aggregated energy data. |
| LEAD ACTOR | Aggregator |
| PRE CONDITION | Service agreement stipulated with the prosumer and connection with prosumer's devices performed by field operator. |
| POST CONDITION | Central connection of energy distributed resources. |
| SCOPE | The aggregator through the CEMS collects and coordinates the distributed energy resources. |
| DESCRIPTION | The aggregator logs in to the CEMS through the User Interface. Through the capability Monitoring & Control, the aggregator monitors the connected LEMS and DERs. The aggregator can visualize energy shared among different LEMS involved (e.g, energy stored, consumed etc.). Through the connection to a LEMS an aggregator can configure, command and control different DERs. |

Fig. 9. Use case description: Monitoring of Aggregated Energy Data

After defining all system use cases, it has been derived a traceability matrix between use cases and system modules, which allows to relate the actors and the LEMS and CEMS modules involved in each use case. The matrix has been useful in the architecture development phase.

## VI. Software and Hardware Architecture Definition

From the previous activities of component analysis and use case definition, it has been derived a preliminary architecture of the SES platform. The Software architecture is characterized by five different layers (Data Layer, Integration Layer, Application Layer, Presentation Layer and Security Layer), which define system software applications and the data security infrastructure. Fig. 10 shows the preliminary software application of SES system.

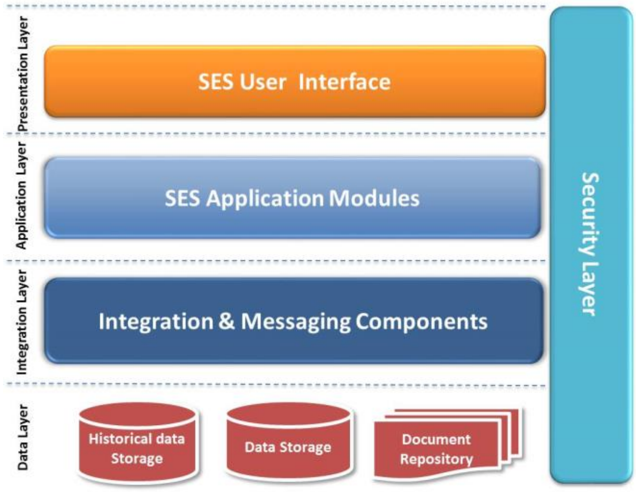



Fig. 10. SES Software Architecture

Two different solutions have been defined for the system hardware architecture. The first solution is a cloud based architecture with only two physical servers used for the LEMS data collection. The other solution, otherwise, is based on proprietary servers (Fig. 11). Preliminary costs have been estimated for each solution.

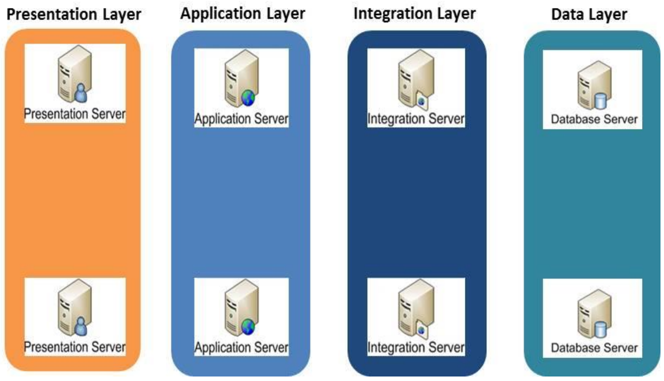



Fig. 11. SES HW Architecture

## VII. System development Approach

Two possible approaches of system development have been proposed:

- *Waterfall approach*: the SES platform is developed simultaneously, using the classical waterfall method which is a sequential design process, in which progress is seen as flowing steadily downwards;
- *Agile approach*: the SES platform is developed iteratively; there are defined four different products composing the SES system and each of them implements some of the platform services. This allows an incremental development of SES modules.

The waterfall development has been organized in different work packages:

- LEMS Specification and design;
- CEMS Specification and design;
- LEMS development;
- CEMS development;
- SES integration;
- SES Verification and Validation.

This approach is characterized by one final release without previous intermediate results with consequent big risks in the implementation phase.

The agile approach, otherwise, is characterized by an incremental development of products with fewer risks in the implementation phase. The process has been organized for the development of the following products:

- DER management: platform for DERs management. It aims to the integration, monitoring, command and control of all DERs. The Analytics module suggests the most efficient settings to guarantee security and stability of the energy aggregated resources network;
- Energy storage management (Behind the Meter): platform for the efficient energy management in micro-grids. "Demand Response side" algorithms are used to predict energy demand patterns and energy costs while storage system are used to store or provide energy to the prosumers, for energy time shift;
- Energy storage management (Beyond the Meter): platform allows the efficient management of virtual energy pools, in order to support ancillary services in transmission and distribution systems;
- E-Mobility Energy Management: the platform allows the smart management of e-mobility infrastructure. It optimizes vehicles recharge times and brings the V2G (Vehicle to Grid) connection in order to provide energy to the grid for the demand side response.

For every step of development the goals, the services provided by the product, the stakeholders involved, the uses cases implemented, and the software modules developed, have been described.

## Conclusions

The present article shows the application of System Engineering approach to the definition of the preliminary architecture of the IoT Smart Energy System (SES) platform to help energy utility in energy management and decision support.

This paper represents one of the first applications of the UAF (Unified Architectural Framework) for the definition of architectures also in Industrial context. It highlights the UAF capabilities in a formal description of system architecture.

BPMN models allowed a clear definition of the main processes of the platform, while SysML allowed to describe main platform components and to depict use cases diagrams.

As result of the work, it has been defined the preliminary SES architecture and two possible ways for the development of the system, making a comparison between the costs.

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