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Track Changes

Version	Date	Description	Revised	Approved
1.0	22/07/2015	First version for internal review	Andrea Angioni, Antonino Riccobono, and Ferdinanda Ponci (RWTH) Hossein Hooshyar (KTH) Davide Della Giustina, and Alessio Dede (A2A) Shengye Lu, and Sami Repo (TUT) Ioannis Moschos, and Ignasi Cairo (IREC) Maite Hormigo (UFD) Juan Luis Garrotte, and Francisco Ramos (TLV)	

Project no: TREN/07/FP6EN/S07.73164/038533 /CONS

Project acronym: IDE4L

Project title: IDEAL GRID FOR ALL

Deliverable 3.2:

Architecture design and implementation

Due date of deliverable: XX.XX.20XX

Actual submission date: XX.XX.20XX

Start date of project: 01.09.2013 Duration: 36 months

Organization name of lead contractor for this deliverable: Tampere University of Technology, Finland

Revision [1.0]

Project co-funded by the European Commission within the Seventh Framework Programme (20YY-20YY)		
Dissemination level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

TABLE OF CONTENTS:

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ACRONYMS

Will be updated after finalizing the document

ARP	Address Resolution Protocol
CL	Convergence Layer
DLMS/ COSEM	Device Language Message specification / COmpanion Specification for Energy Metering
DMS	Distribution Management System
DSO	Distribution System Operator
EPA	Enhanced Performance Architecture
FSK	Frequency Shift Keying
FTP	File Transfer Protocol
GOOSE	Generic Object Oriented Substation Event
HDLC	High-Level Data Link Control
HTTP	HyperText Transfer Protocol
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
ISO	International Organization for Standardization
IT	Information Technology
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
LAN	Local Area Network
MAC	Media Access Control
MLME	MAC Layer Management Entity
OBIS	Object Identification System
OFDM	Orthogonal Frequency Division Multiplexing
PLC	Power Line Communication
PLME	Physical Layer Management Entity
POP	Post Office Protocol
PRIME	PoweRline Intelligent Metering Evolution
SCL	System Configuration Language
SCSM	Specific Communication Service Mapping
SMTP	Simple Mail Transfer Protocol
SNTP	Simple Network Time Protocol

TC	Technical Committee
TCP	Transmission Control Protocol
Telnet	Teletype Network
UDP	User Datagram Protocol
XML	EXtensible Markup Language

1. EXECUTIVE SUMMARY

Sami

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2. INTRODUCTION

IED4L architecture enables the integration of active resources as part of the system, instead of following a "fit and forget" principle. This means managing and exploiting the presence of DERs instead of tolerating their presence, thanks to residual grid capacity. The IDE4L architecture exploits DERs in the active network to optimize operational costs. In this framework synergy benefits may be achieved by coordinating the operation of DERs from the holistic system viewpoint instead of optimizing their operation individually, from a single party's viewpoint.

The IDE4L automation system has the following main features:

- AMI with integration of advanced functions and extensive use of all available measurements (SM)
- Monitoring and control capacity (mostly self-contained) at all hierarchical levels
- Span of time horizons and locations in monitoring and control
- Full harmonization of commercial and technical operations

The design of this automation system has yielded:

- the abstract definition of system automation (and all individual components, e.g. substation automation) in terms of semantic and SGAM model
- full abstract architecture design based on standards,

Real-time monitoring must be extended from primary substations only, to secondary substations too. The most extensive monitoring solution is the Advanced Metering Infrastructure based on smart metering, which is realized in few countries. Power quality meters, fault recorders and Phasor Measurement Units are examples of new sources of measurements that are integrated in the IDE4L automation system. In particular, these measurements are used in state estimation and forecasting functions, which would not be possible to implement without these additional measurement resources. Dynamic monitoring is a novelty supported by PMUs and functional to the interaction with the TSO.

The control of distribution networks, which are active at all voltage levels and equipped with pervasive monitoring, should be designed coherently: distributed, to use locally the measurements and estimates available locally, and coordinated to smoothly control over different time horizons and to harmonize commercial and technical decisions.

From the actuation standpoint, this requires Intelligent Electronic Devices (IEDs) to decentralize decision making and shift it from control center and primary substations to MV networks, secondary substations and DERs.

Scalability is a critical feature in DA, because of the large number of nodes, substations and distributed resources. The IDE4L architecture is distributed and modular to satisfy the scalability requirement. The monitoring system that supports this automation architecture is expected, within the next decade, to be able to handle millions of measurements and a large volume of measurement data. Therefore the architecture of automation system is based on a hierarchical structure, data analysis in the field and server push instead of client pull. On-line and automatic handling and analysis of data is needed to reduce the amount of data transfer to control center. Distributed data storage allows tracking every detail without

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real-time communication to control center. Same can be said for the FLISR operation, which is carried out in the substations, without resuming to the CC.

The automation system should also be based on standards. From a design standpoint, this is needed to enhance and simplify the integration of subsystems, which is an essential requirement of DSOs to develop automation systems. The IEC 61850 is now assuming the role of de-facto standard for the automation of the whole distribution grid. Data acquisition and the interfaces between the monitoring system and the peripheral devices has been implemented using standard protocol such as DLMS/COSEM for LV Smart Meters and IEC 61850 MMS Reports for substation IEDs. Quasi-static information such as the network topologies and network asset information is however not encompassed by the IEC 61850. For that purpose the CIM standard can be used.

The main, high-level features of the architecture presented here are: hierarchy, decentralization and modularity.

2.1 Hierarchy of automation

Hierarchy realizes the integration of decentralized operations, guaranteeing the link between business and technical operations, and the integration of the primary-secondary-tertiary control scheme.

Major operations involving third parties, other that the DSO, that need this hierarchy are: the realization of trading and use of flexibility services purchased from the Commercial Aggregator, the validation of winning bids of the Commercial Aggregator, and the use of grid tariffs for load shifting. These activities require upper level knowledge of the current and future condition of the grid, and must be supported by the top level of the hierarchy, i.e. the control centre.

2.2 Modular design

Modularity enables reusability (same structure of monitoring and control architecture, so same implementation of function and interfaces), partial implementation (not all features must be implemented everywhere), partial penetration (full features only in the portion of the grid where they are truly needed, e.g. with more penetration of DERs).

Modularity is achieved conceptually by separation of functions, data sources, data exchange, and by reuse of the same structure at different levels, e.g. SAU as primary or secondary substation automation unit. This modularity is expressed in the SGAM layers in Section 6 and in the semantic model in Section 5. This formulation makes it possible to trace the parts of the architecture that must be implemented for realizing a given mode of operation i.e. use case.

Modularity is achieved practically through the modularity of physical devices, IEDs, and the development of interfaces. Thanks to the conceptual modularity, the interfaces are well defined and can be reused at all levels. For example, the interface between SAU can be defined once for all, and the applied to all levels.

2.3 Decentralization of automation

Decentralization moves the automation system away from “data passing” and close to “know/act here and now”. Decentralization means that monitoring and control functions are replicated in homologous manner (like state estimation, load and state forecasting), or in complementary manner (like centralized and decentralized FLISR), at all levels, that is, at primary substation, secondary substation and control centre levels.

The practical realization of decentralization relies on IEDs and SAUs, which distribute decision making from the control centre and primary substations, down along the MV and LV networks to DERs.

The decentralization enables the use of smart meters as sensors, which would not be feasible in a centralized manner because of the amount of data, and the use of DERs spread along the MV and LV networks.

TO DO Show how hierarchy-modularity-decentralization supports:

1. Integration: hosting capacity and reliability increase
   - Congestion management and power control distributed at MV, LV and control center levels
   - FLISR: both centralized and decentralized, permit to reduce the effects in terms of duration and extension of faults in the grid
2. Participation into the automation system:
   - Directly: in case of congestions or voltage violations, via active/reactive power injection
   - Indirectly: scheduled reprofiling (SRPs) and conditional reprofiling (CRPs) traded through the aggregator.

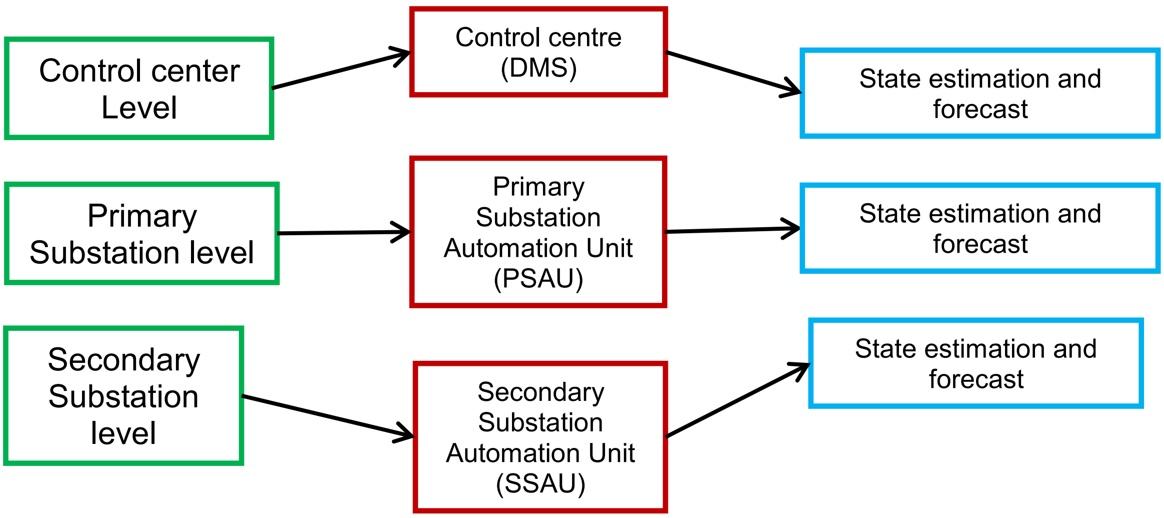

Figure 0-1: example of distribution of homologous function

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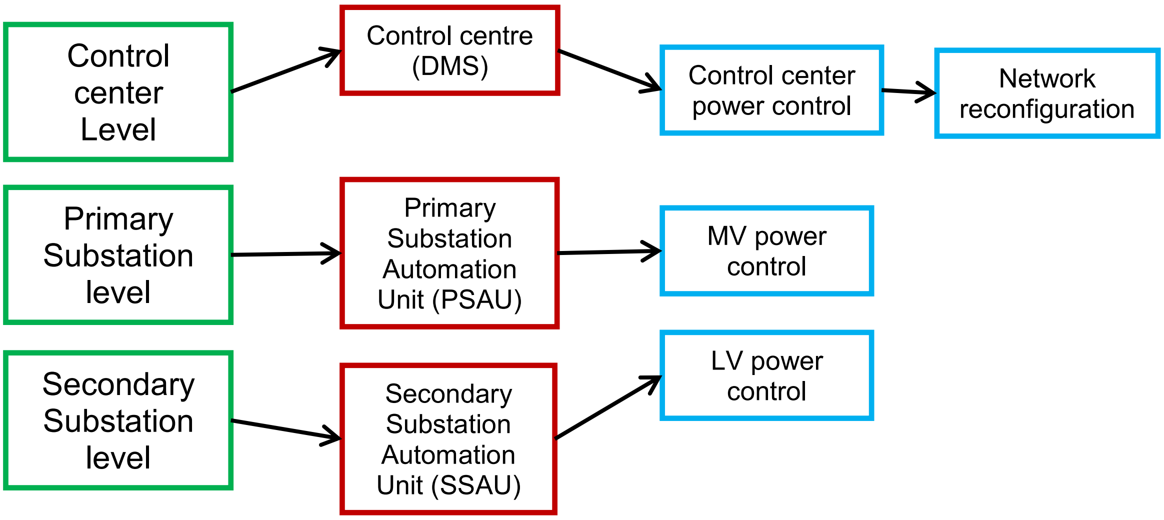

Figure 0-2: example of distribution of complementary functions

3. INPUTS TO CREATE THE IDE4L ARCHITECTURE

In deliverable 3.1 the method for the construction of the architecture has been illustrated and the architecture concept has been shown. The architecture concept was based on the short version of use cases, which included a generic description, the names of the actors and the use case diagram. Such information provided an understanding of the new actors, functions and communication exchange and a first placement of them in the smart grid plane [D3.1].

In task 3.2 the use cases have been updated to the detailed version including also the main scenarios in which the use case should operate and the steps for each scenario. In every step one or more actors run a certain function and/or exchange a piece of information.

This new information has been collected following the indication of the SGAM working group [] and permitted to obtain the SGAM architecture, presented in section 6.

As done in deliverable 3.1, also here, the clustering on monitoring, control and business use cases has been maintained. Following is a general overview of such cluster, in order for the reader to better understand the following developments of the architecture. The complete detailed description of IDE4L use cases is available in the appendix.

Following the three use cases clusters is the explanation of other information, namely the data exchange requirements and list, the database design and the semantic model, that have been used to further specify the IDE4l automation architecture.

3.1 Monitoring use cases

The monitoring use cases include the functionalities to provide reliable input data to operators and to control automation functions. By input data we mean real time measurements, estimated and forecasted state, dynamic key indexes, network data and protection configurations. IDE4L developed use cases for the update of such information. In IDE4L use cases detailed description of real time collection of data at low and medium voltage levels, algorithms of state estimation at primary and at secondary substation level respectively for medium and low voltage grid and algorithms of load and state (voltage) forecast at low and short time terms, is given. Furthermore also two use cases called networks description update and protection configuration update, performing respectively the update of network and customer database at control center, primary and secondary substation automation unit levels and the reconfiguration of the protections when changes (e.g. topology) happen in the grid, are considered in the monitoring cluster as they provide also input to the other control use cases. Eventually, a dedicated use case describes how the dynamic information of the status of the distribution grid are collected at DSO control center level and forwarded to TSO. The list of monitoring use cases and a short description is provided in Table 0-A. The complete description is provided in the appendix.

Table 0-A Monitoring cluster Use Cases

Short name	Extended name	Short description
LVSE	Low Voltage State Estimation	The state estimator combines all the available measurement information and calculates the most likely state of the network. State. The input data includes the real-time measurements for the load, production and line flows, load estimates for unmeasured loads, and the network topology. Output will be the network state

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		described with node voltages, line current flows, and node power injection values.
Dynamic Monitoring	Distribution grid dynamic monitoring for providing dynamics information to TSOs	Utilizing time-stamped PMU data and discrete traditional measurements for providing "dynamics" information on distribution grid operation to TSOs.
LVF	Low Voltage power Forecast	The low voltage load forecaster provides estimations of the load and micro-generation production in the future. The control algorithms will use this information. It receives meteorological predictions up to the forecasting horizon, flexible demand scheduling and newly available measurements.
LVRTM	Low Voltage Real Time Monitoring	The data collection for the LV grid is performed storing real-time measurements (mean values and PQ indexes), states and alarms in a unique repository – located in the Secondary Substation and LV cabinets into the SAU database.
LVSF	Low Voltage State Forecast	The algorithm provides forecasts for the states that are related to the specific secondary substation on a low voltage network.
MVF	Medium Voltage power Forecast	Same as LVF except for using input data from the medium voltage grid.
MVRTM	Medium Voltage Real Time Monitoring	Same as LVRTM except for the fact that the measurements are collected from medium voltage grid.
MVSF	Medium Voltage State Forecast	Same as MVSF except for using input data from the medium voltage grid.
NDU	Network Description Update	This update process maintains aligned the description of the network topology, the list of assets and their parameters, the list of customers and some relevant information among the main database of the DMS – located in the utility Control Center – and the distributed database of RDBMS in the Primary and Secondary Substations every time a network change is performed.
PCU	Protection Configuration Update	The use case consists in updating the configuration file of protection devices when a change is done in the network configuration (status of breakers and disconnectors).
MVSE	Medium Voltage State Estimation	Same as LVSE except for using real time measurements from the medium voltage grid.

3.2 Control use cases

The control cluster includes the functionalities that allow taking actions on the grid in order to maintain a secure state. Among the IDE4L use cases here are the ones performing control actions at low voltage, medium voltage and control center level and the coordination among them. Control actions are taken when the voltage or the power flow are reported or forecasted to exceed security limits, or when power quality limits are not respected. Moreover the fault location, isolation and restoration use cases are described, including the description of the microgrid management during and after the faults. Such control functionalities rely on the DSO owned distributed energy resources, switches and breakers to better distribute power flows and the market agent, managed by DSO to purchase flexibility services from the electrical market. The protection functions instead rely on a decentralized algorithm based on GOOSE communication between IEDs for the first fault isolation phase, whereas SAUs and Microgrid are involved during the slower restoration phases. The list of control use cases and a short description is provided in Table 0-A. The complete description is provided in the appendix.

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Table 0-A Control cluster use cases

Short name	Extended name	Short description
BOT	Block On load Tap changer	Block OLTC's of Transformers (BOT) units interacts with other units in order to generate its outputs.
CCPC offline	Control Center Power Control Offline	CCPC during offline operation manages congestions of MV distribution network for the next hours (day-ahead market or intraday market timeframe) exploiting Network related measures, in particular through network circuit reconfiguration and changes of the setting values of voltage controllers in the MV network and reactive power units; Market related measures to propose changes of scheduled generation/consumption values of DER units, through flexibility products to provide a feasible combination of schedules. These functionalities can be obtained by means of two different algorithms: Network reconfiguration and Market Agent algorithms.
CCPC real time	Control Center Power Control Real Time	CCPC working on real time manages congestions of MV distribution network exploiting Network related measures, in particular through network circuit reconfiguration and changes of the setting values of voltage controllers in the MV network and reactive power units; Market related measures to propose changes of scheduled generation/consumption values of DER units, through flexibility products to provide a feasible combination of schedules.
LVPC real time	Low Voltage Power Control Real Time	The main functionality of the LVPC is to mitigate congestion in the LV networks. The LVPC tries to achieve Reduction of the LV network losses ; Reduction of production curtailment ; Minimizing the load control actions; Reducing the voltage violation at each node.
LVPC offline	Low Voltage Power Control Offline	Offline LVPC defines cost parameters to avoid extra actions. For instance, it prevents constant operation i.e. hunting of transformer tap changers by changing the cost parameters of the real-time LVPC.
MVPC real time	Medium Voltage Power Control Real Time	MVPC mitigates congestion in the MV networks. The MVPC tries to achieve Reduction of the MV network losses; Reduction of production curtailment; Minimizing the load control actions; Reducing the cost of reactive power flow supplied by the transmission network; Reducing the cost of active power flow supplied by transmission network; Reducing the voltage violation at each node: In order to reach the above-mentioned goals, the MVPC requires interacting with other actors. The required actors are as following: • The medium voltage network intelligent electronic devices (MVIEDs)
MVPC offline	Medium Voltage Power Control Real Time Offline	Offline MVPC interacts with other actors in order to define the value of cost parameters and prevent extra control actions (e.g. to decrease the number of tap changer operations in the future states of the network).

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MVNR	Medium Voltage Network Reconfiguration	MVNR update network switches status in order to alleviate congestion problems that are related to a specific MV network. The MVNR runs on demand and also run on fixed intervals such as once a day or scheduled hours to find the optimal configuration of the network.
Microgrid FLISR	Microgrid Fault Location Isolation and Service Restoration	This use case explains the disconnection of a microgrid from the MV or LV distribution grid responding to a status change and analyzes the reconnection to the distribution grid after fault restoration. The isolation of microgrids will allow the continuity of the service in case of contingencies in the distribution network.
Power quality	Power quality	With the aim of power quality improvement, the UC explores the use of fast energy storage systems with high ramp power rates and short time responses, to rapidly exchange active and reactive power, thus smoothing power flows in LV networks and improving quality of current and voltage waveforms.
FLISR	Decentralized Fault Location Isolation and Service Restoration	The use case contemplates the detection process using relevant information for different types of faults. A distributed control functions is proposed in order to locate and isolate the part of the network that has been affected by acting on circuit breakers, switches and microgrid interconnection switches located along the feeder under test. Once the fault is located and isolated, the service restoration process will start

3.3 Business use cases

The automation control functionalities are actually applied to the grid though the trade of energy and flexibility in the electrical market. IDE4L project proposes some use case to describe the process pre and post energy trade. The preliminary phase includes the preparation of the DERs resources from the commercial aggregator in the CAEP use case and the preparation of SRPs and CRPs procurement plan from DSO. After the market clearing, the energy exchange plan is checked in the off-line validation use case by TSPs and DSOs and the forwarded to commercial aggregators. The conditional re-profiling products can then be activated during the predefined period by DSOs, through a real time validation, that check whether the activation of such flexibility product may bring issues in the distribution network. Besides also the application of grid tariff to reduce the probability of congestion in the day after is described in dedicated use cases. The list of business use cases and a short description is provided in Table 0-A. The complete description is provided in the appendix.

Table 0-A Business cluster use cases

Short name	Extended name	Short description
DADT	Day Ahead Dynamic Tariff	The day-ahead dynamic tariff algorithm determines a day-ahead tariff for the distribution network to alleviate potential congestion induced by the demand or local production. The input data are the customer day-ahead energy plan and local production forecast, the grid topology and the grid model.
DR	Day-ahead	The day-ahead demand response function runs at the DSO side

	demand response of the flexible demand	for the purpose of both demand forecast and congestion management. It receives input data, such as system price forecast, dynamic tariff (DT), weather forecast, DERs forecasts, and consumer requirements. Then a least cost demand plan will be determined.
CRP activation	Conditional Re-Profiling activation	The interaction between the flexibility buyers and the aggregators, required to activate a CRP (conditional re-profiling) flexibility product.
Load area	Load area configuration	The function of the load area is to group prosumers in terms of consumption pattern, impedance value, prosumer connectivity, and other parameters to be considered by the DSO
Off line validation	Off line validation	Used for Day-Ahead, Intra-day Market Validation. Validation in fixed steps (15 minutes steps) rather than over the whole day-ahead period. If flexibility products are not feasible during a time slot, they will be curtailed with disregard of the results for another time slot.
Real time validation	Real time validation	The core procedure is almost the same as in the OLV tool. The main difference is that this Tool is used for products traded during the intra-day market and for CRPs that are activated by the CA at any time of the day. Due to the close to real-time use of this Tool (i.e. 15 minutes before the deployment), the real description of the system is used (topology, load, generation etc.).
CAEP	Commercial aggregator asset planning	The operation of the commercial aggregator in order to evaluate the capacity of the DERs within its load area to perform scheduled Re-profiling (SRP) and conditional Re-profiling (CRP) actions (later described), then to match this availability with the requirements of the TSOs and DSO and finally to send the bids of SRPs and CRPs to the market.

3.4 Further information collected within the IDE4L project to complete the architecture implementation

In order to improve the architecture description to better fulfill the requirements of a ready to implement automation architecture , further information has been collected in IDE4L project.

Data exchange list with the classification of requirements

The data exchange has been defined in an agreed IDE4L format that contains all the needed information to exactly define the information exchange. The use case description contains the definition of the information exchange, but it is not standardized in terms of format, contents and requirements, hence the IDE4L format allowed to identify the key information.

use case	Use case where such data is exchange
step N	Number of step of the use case in order to have a 1 to 1 mapping to the use case description
function name	Functions that is using such information as input or output
information producer	Actor producing the data
information receiver	Actor receiving the data
data class	Data name

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Protocol	Communication protocol used in IDE4L demonstration to exchange such data
~~technology~~	~~The requirements of the data exchange are grouped in terms of technology. Each technology requirement Is connected to one of the four particular requirements as Transfer time, Transfer rate, Synchronization accuracy and Availability.~~
Transfer time	Time needed for the data to go from information producer to information receiver. Provided in 6 classes and measured in ms.
Transfer rate	Amount of data that will be transferred per second. Provided in 6 classes and measured in kb/s
Synchronization accuracy	Accuracy of time tag attached to the particular data. Provided in 6 classes and measured in ms.
Availability	Rate of loss of data in the communication infrastructure. Provided in 5 classes and measured as relative probability (%).

In , Table 0-A, Table 0-B, Table 0-C, Table 0-D the technology, Transfer time, Transfer rate, Synchronization accuracy and Availability are described. The transfer time, Transfer rate and Synchronization accuracy have been extracted by the IEC 61850-5 standard [].

Table 0-A Transfer time classes

Transfer Time Class	Transfer Time (ms)	Typically refers to …
TT0	> 1000	Files, events, log contents
TT1	1000	Events, alarms
TT2	500	Operator commands
TT3	100	Slow automatic interactions
TT4	20	Fast automatic interactions
TT5	10	Releases, Status changes
TT6	3	Trips, Blockings

Table 0-B Transfer Rate classes

Transfer Rate Class	Transfer Rate (kb/s)
TR0	< 1
TR1	1
TR2	10
TR3	100
TR4	1000
TR5	10000
TR6	100000

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Table 0-C Synchronization Accuracy Classes

Synchronization Accuracy Class	Synchronization Accuracy (ms)
SA0	0.001
SA1	0.100
SA2	1.000
SA3	10.000
SA4	100.000
SA5	1000.000
SA6	> 1000,000

Table 0-D Availability classes

Acronym	Value (%)	Downtime (m)
VH	99.9998	1
H	99.9981	10
M	99.9886	60
L	99.8632	720
VL	99.7268	1440

An example of a data exchange definition following the aforementioned information mapping is provided in Table 0-E.

Table 0-E

use case	ste p N	function name	information producer	information receiver	data class	protoc ol	techn ology	Transfe r time	Transf er rate	Synchronizati on accuracy	Availa bility
LVR TM	35	Data acquisiti on	IED(DIED-SM).DLMS/COS EM	SAU(SSAU).DL MS/COSEM	Voltage measureme nt	DLMS/ COSEM	Tech2	TT0	TR6	SA3	L

Database design

The information that needs to be stored in every actor's database has been collected, through the consulting of architecture developers with algorithm developers and demonstrators. The information needed to be stored has been defined in terms of content (e.g. network topology, measurements and control signals) and then mapped in standardized data models as IEC 61850 and CIM. In IDE4L the database architecture has been divided in four different schemas: Measure & Control Model, Management Mode , Network Model and Bridge Model. More detailed description is provided in appendix, 7.4 Database and in the attachment to the deliverable in order to be used as starting point for automation system development.

Semantic relations (general and singular)

A semantic model', is a simplified description of a system – in this specific case the automation architecture of the IDE4L project – which is used to clarify the meaning of the elements composing the architecture itself. Two general semantic models have been prepared in order to specify the relations among business and automation actors. Such diagrams permitted to identify the hierarchical distribution of monitoring and control functions as well as the distribution of such functionalities in business entities. Furthermore every automation actor a further semantic description has been done defining every actor in terms of interfaces, databases and functions. Further information is provided in section 5.

4. METHODS FOR ARCHITECTURE DESIGN

The architecture design has been realized exploiting the information described in the previous chapter, that are detailed use cases, data exchange requirements and list, database data and semantic model. The WP3 worked on the synthesis of such information in a project agreed architecture [5]. Such synthesis work has been simplified through the use of some tools, namely the use case repository [4] and the SGAM toolbox [10] for enterprise architect [11] that simplified such process. The architecture resulted has been validated by the review of algorithm developers and demonstrator. Eventually quantitative conclusion on the effectiveness of IDE4L architecture will be presented in the deliverable 3.3

4.1 Tools

Use case repository and methodology

The main inputs to the description of the architecture are the use cases. The Use Case Methodology was originally proposed for standardization bodies in the context of Smart Grids in response of the EU Mandate M/490 [7], [5]. In IDE4L project a total of 29 use cases have been defined, thus resulting in large amount of information as actors, functions, information exchanges and scenarios. The description is normally done on word documents, yielding long process of updates whenever some details have to be changed.

In the second task (T3.2) of WP3, the use case management repository (UCMR) on-line tool [4], in Figure 0-1, has been exploited. In the UCMR it is possible to define separately actors, information exchange and requirements and then add them to the use case description. In this way, when a change is done in a description of an actor, it is automatically changed also in all the use cases where such actor appears. This functionality improves significantly the possibility to parallelize the description of use cases and avoid overlapping in the description and inconsistencies in the description. The IDE4l project developed the detailed version of use cases in the UCMR, providing valuable feedback to the UCMR online tool, regarding possible improvements.

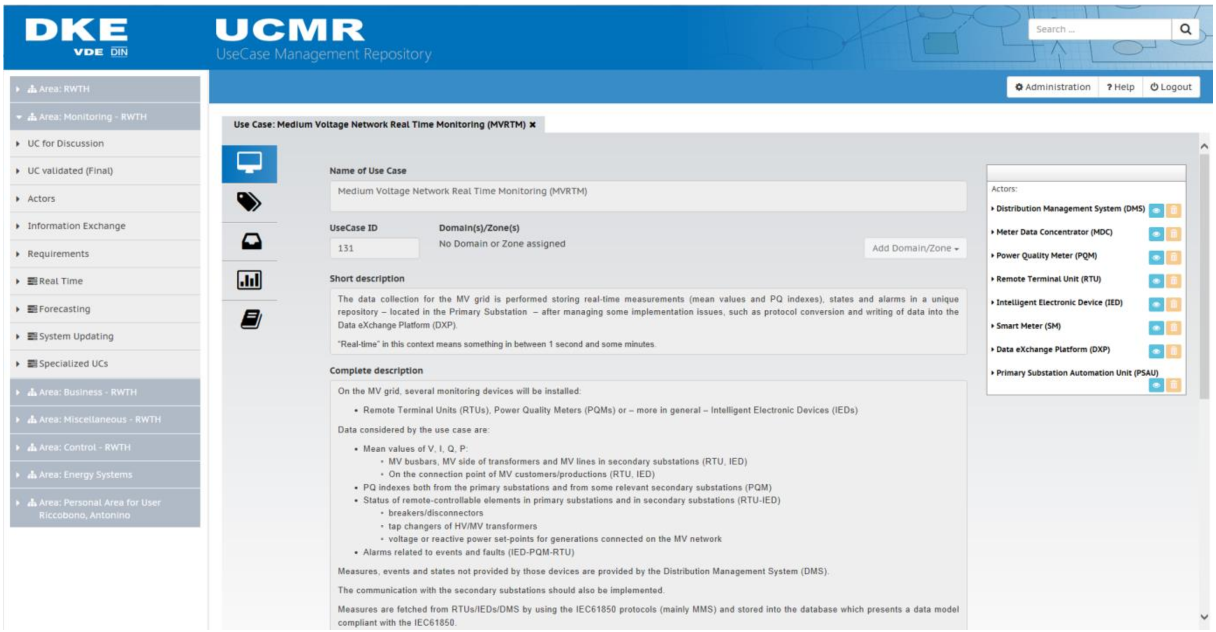

Figure 0-1 use case management repository (UCMR) on-line tool

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Enterprise Architect with SGAM toolbox

As will be shortly explained, in IDE4L the design of system architecture relies on SGAM (SmartGrid Architecture Model) framework. This is realized with the help of SGAM Toolbox [10]. SGAM Toolbox provides a visualization and modelling tool to help architecting Smart Grid Systems in reference to SGAM framework. It is implemented as an extension for the modelling tool “Enterprise Architect” from Sparx Systems [11].

SGAM Toolbox is more than just a visualization tool. It also brings best practices for a Use Case Mapping Process (UCMP)-based development as introduced by [7]. The proposed development process starts with System Analysis Phase, during which the systems functionality is to be described. This is done by executing a Use Case Analysis, developing the SGAM Function Layer and SGAM Business Layer. SGAM Toolbox facilitates Use Case Analysis by providing templates to visualize and document Business Actors, Business Goals, Business Cases, High Level Use Cases, Primary Use Cases and etc.

The second phase of UCMP is System Architecture Phase, during which the development of SGAM Component Layer, Information Layer and Communication Layer is conducted. During this phase, SGAM Toolbox provides ready-made templates to visualize and document physical components, information object flow, communication path and etc.

Aforementioned SGAM Layers will be explained in Section **Error! Reference source not found.**. As manifested by Section 6, IDE4L project develops Smart Grid applications according to UCMP process, with the help of SGAM Toolbox – actually, most screenshots in Section 6 are taken from SGAM Toolbox.

4.2 SGAM framework

The Smart Grid Architecture Model (SGAM) framework [7] is a primary importance result of the EU Mandate M/490. The SGAM framework and its methodology allow the graphical representation and analysis of Smart Grid use cases in an architectural technological neutral manner highlighting their interoperability aspects thanks to its five interoperable layers [7] as presented in Figure 0-1.

The SGAM framework is based on the concept of *Smart Grid Plane*, which constitutes the basic viewpoints of the SGAM architecture visualization. These viewpoints can be divided into the physical *domains* of the electrical energy conversion chain and the hierarchical *zones* for the electrical process management. The Smart Grid Plane spans in two dimensions: the complete electrical energy conversion chain in one dimension, i.e. Bulk Generation, Transmission, Distribution, DER and Customers Premises domains, and hierarchical levels of power system management, i.e. Process, Field, Station, Operation, Enterprise and Market. A further description of zones and domains is provided respectively in Table 0-A and Table 0-B [7].The five interoperable layers, i.e. Component, Communication, Information, Function and Business, allow to model both business and technical viewpoints and span on a third dimension.

Table 0-A Zones of smart grid plane

Zones	Description
Process	Including the physical, chemical or spatial transformations of energy (electricity, solar, heat, water, wind …) and the physical equipment directly involved. (E.g. generators, transformers, circuit breakers, overhead lines, cables, electrical loads any kind of sensors and actuators which are part or directly connected to the process,…).
Field	Including equipment to protect, control and monitor the process of the power system, e.g. protection relays, bay controller, any kind of intelligent electronic devices which

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	acquire and use process data from the power system.
Station	Representing the areal aggregation level for field level, e.g. for data concentration, functional aggregation, substation automation, local SCADA systems, plant supervision…
Operation	Hosting power system control operation in the respective domain, e.g. distribution management systems (DMS), energy management systems (EMS) in generation and transmission systems, microgrid management systems, virtual power plant management systems (aggregating several DER), electric vehicle (EV) fleet charging management systems.
Enterprise	Includes commercial and organizational processes, services and infrastructures for enterprises (utilities, service providers, energy traders …), e.g. asset management, logistics, work force management, staff training, customer relation management, billing and procurement…
Market	Reflecting the market operations possible along the energy conversion chain, e.g. energy trading, mass market, retail market.

Table 0-B Domains of smart grid plane

Domain	Description
Bulk Generation	Representing generation of electrical energy in bulk quantities, such as by fossil, nuclear and hydro power plants, off-shore wind farms, large scale solar power plant (i.e. PV, CSP)– typically connected to the transmission system
Transmission	Representing the infrastructure and organization which transports electricity over long distances
Distribution	Representing the infrastructure and organization which distributes electricity to customers
DER	Representing distributed electrical resources directly connected to the public distribution grid, applying small-scale power generation technologies (typically in the range of 3 kW to 10.000 kW). These distributed electrical resources may be directly controlled by DSO
Customer Premises	Hosting both - end users of electricity, also producers of electricity. The premises include industrial, commercial and home facilities (e.g. chemical plants, airports, harbors, shopping centers, homes). Also generation in form of e.g. photovoltaic generation, electric vehicles storage, batteries, micro turbines… are hosted

The *business layer* of the SGAM framework is used to map regulatory and economic (market) structures and policies, business models, business portfolios (products & services) of involved market parties. Business services and processes can be represented in this layer as well. In this way, this layer supports business executives in decision making related to (new) business models and specific business projects (business case) as well as regulators in defining new market models.

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The technical perspectives are modeled in SGAM framework on the lower four layers. The *function layer* describes functions and services including their relationship(s) to business need(s). Functions are represented independently from their physical implementation in systems, applications, and components. The *information layer* describes the information that is being used and exchanged between functions, services and components. It contains information objects and the underlying canonical data models. The *communication layer* is used to describe mechanisms and protocols for the interoperable exchange of information between components, functions or services and related information objects or data models. Finally, the *component layer* shows the physical distribution of all participating components. This includes power system equipment (typically located at process and field levels), protection and tele-control devices, network infrastructure (wired/wireless communication connections, routers, and switches) and any kind of computers. For a specific implementation of a use case the identified functions can be mapped onto components complementing the relationships between all layers.

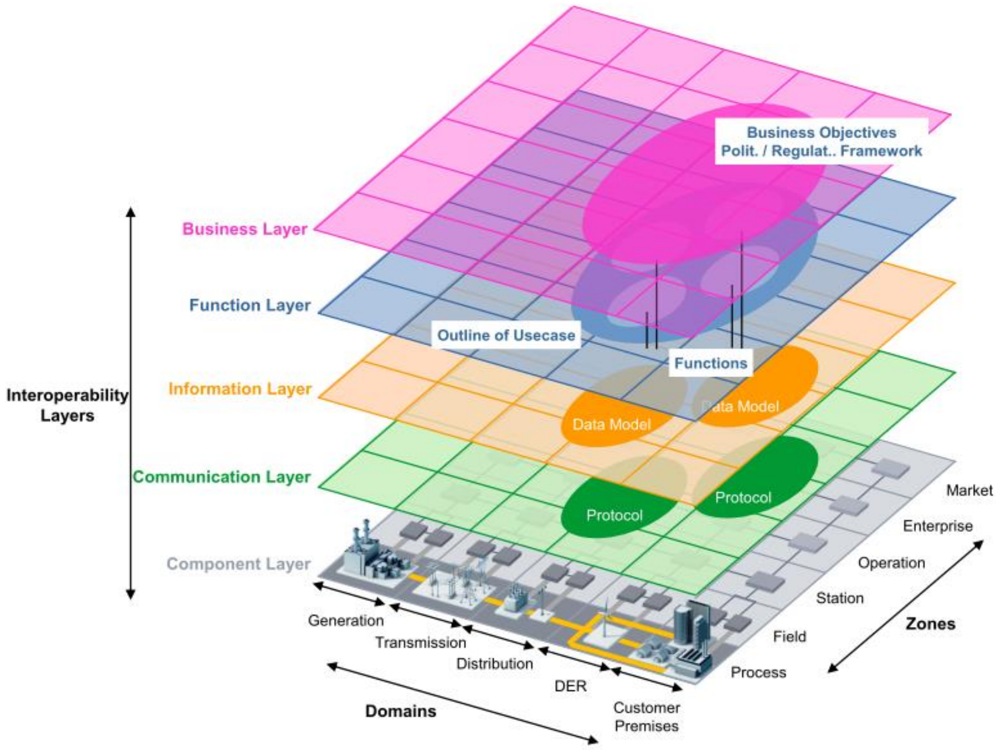

Figure 0-1: example of distribution of homologous function**: Smart Grid Architecture Model (SGAM) framework with its five interoperable layers [2].**

The use case detailed template [8], given below in the appendix, fit to the use case analysis pattern based on the SGAM framework as shown in Figure 0-1. The description of a use case in a given template should provide enough information to describe the required level of abstraction in the SGAM layer(s). The short template can be used to document the use case concept. Most of the information is contained in the narrative of the use case and the use case diagram. Actors and functions can be extracted from the narrative. Moreover, the use case can be mapped on the Smart Grid Plane of the SGAM framework in the affected domains and zones. The detailed templates may offer both a technical and business orientation of the described use case. Both business-oriented and technical-oriented actors can be described within the use case and the difference between the two types of actors consists in what they represent for use case goal/purpose: business actors play a role in the context of the enterprise scope of the use case; technical actors are usually identifiable as devices and/or systems. As suggested in [8], it is advisable not to mix

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business use case and technical use case in a single use case description, and the IDE4L Project is adopting the same viewpoint. For instance, the step-by-step analysis of a business use case can be used to define business process(es) to be mapped on the business layer of the SGAM, while the step-by-step analysis of a technical use case provides details on the information exchange and the way it is exchanged to map the communication and the information layers of the SGAM. Notice that the business and technical orientations are somehow mixed in the short template as it does not provide enough details.

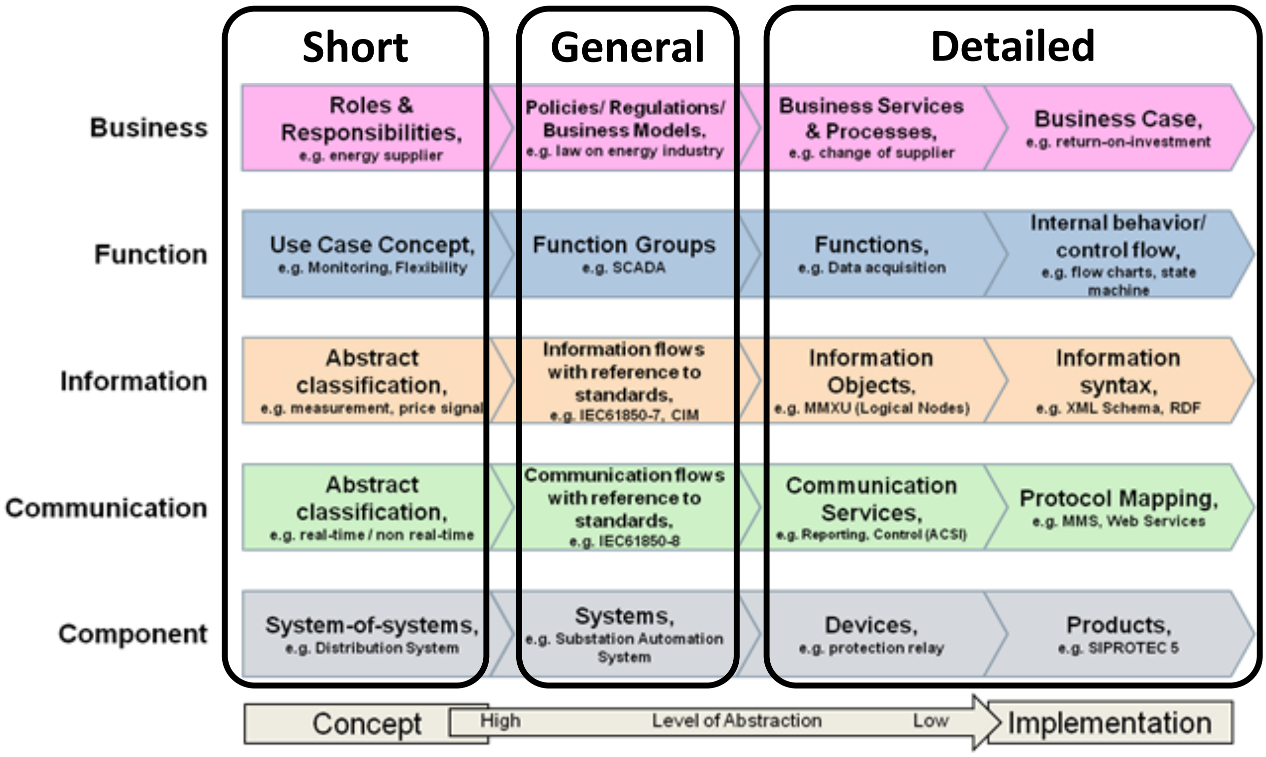

Figure 0-1 Relation of use case templates and the use case analysis pattern based on the SGAM framework

The use case detailed template is available in the appendix.

4.3 Instance of use case mapping onto SGAM architecture

In order to better understand how the use cases are influencing the construction of the SGAM architecture an example is proposed for a generic state estimation use case. Such use case and the consequent mapping on SGAM is not exactly as the one actually implemented in IDE4L, also actors and functions are different. This has to be considered as a didactic instance for the understanding of the reader. The actual SGAM development requires the presence of the whole set of use cases and their synthesis and is presented in section 5 and 6.

The following instance of state estimation use case refers to a static distribution system state estimation, that exploit computation units based in substation environment, meanwhile the visualization of the results is placed in control center environment. Different plans implementation would yield different description on the use case and consequently different SGAM architectures.

Following is the detailed description of the state estimation use case.

The objective of the state estimation is to obtain the best possible estimation for the network state. The state estimator combines all the available measurement information and calculates the most likely state of the network. Measurements are produced in field zone, through current and voltage quantity conversions to low voltages levels, analog to digital conversion of the signal is operated and a mathematical quantity of the samples, that is the measurement, is calculated. The measurement is sent by means of standardized information models and communication protocols. In station zone, the measurements are aggregated, exploiting data interfaces and databases. State estimations are calculated for present time (t=0) using the newest available input data. Finally, state estimation results are represented or used for automatic control in operation zone.

The steps in the state estimation UC are as follows:
1 Electrical voltage and current quantity in the network are converted from power system level onto low voltages (e.g. ± 100 V) by transducers in order to be accessible by electronic instrumentations
2. Analog to digital converters (in some cases included in the measurement device itself, other times as a separate device, as in the case of the merging unit proposed by the IEC 61850 standard []) convert the signal from analog to digital converters, providing samples of the signal.
3. The measurement devices calculate the measurement (voltage, current, power etc) out of set of samples
4. The measurements are tagged with time tags, whether time reference sources are available, as in the case of PMUs.
5. The measurements are available in communication standard formats and protocols (e.g. as IEC 61850, IEC 104 or C37.118.11-1)
6. Measurements are collected at the automation centre, it could be places in substation environment or control center.
7. Measurements are harmonized in time domain.
8. Bad data are rejected.
9. Measurements are stored in time series database.
10. State estimation withdraw grid topology and parameters from the database. Furthermore withdraw the current configuration (placement on the grid) of measurement devices and their expected accuracy.
11. State estimation withdraw the new set of measurements from database
12. State estimation is performed and the results provided saved in the local database
13. State estimation results are exported to other automation units or to control center (to human machine interface type of applications).

The actors involved in state estimation are:

- Transducer + merging unit. They are considered as a whole meaning an actor providing the electrical signal, either as analog or as samples.
- Measurement devices. Actor acquiring the signal in analog or digital form and providing measurements.
- Communication interface.
- Database
- Computation unit
- Control center

The functions involved are

- Electrical conversion
- Analog to digital conversion

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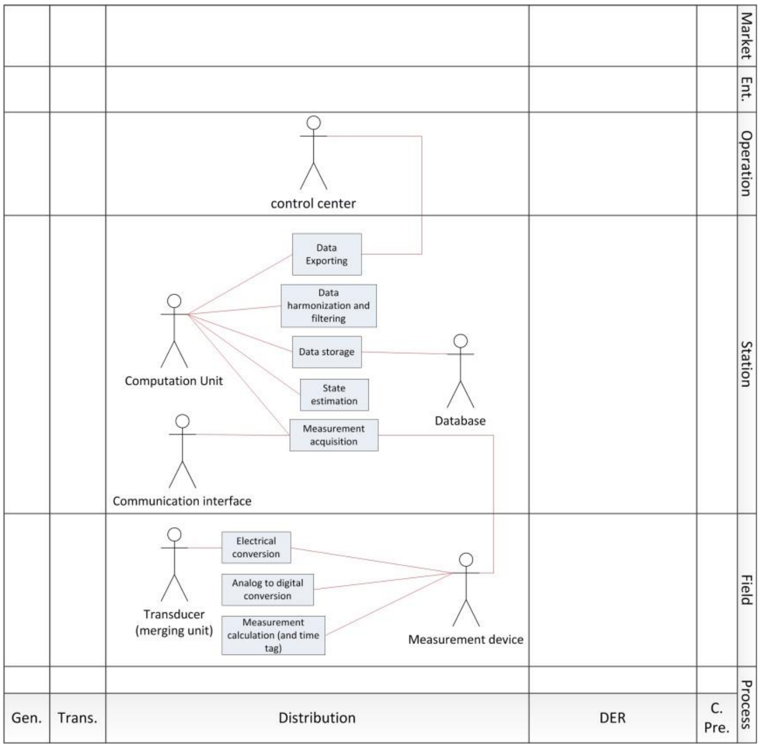
- Measurement calculation (and time tag)
- Measurement acquisition
- Data harmonization and filtering
- Data storage
- State estimation
- Data exporting

Use case diagram



Once the use case description is available, it is possible to realize the mapping in the use case layers. The business layer is intended to represent roles and responsibilities of the business actors involved, e.g. DSOs, TSOs, etc; their business goals and the regulations in which the automation functionality operates. For the case of the state estimation, it is not easy to have a one-to-one mapping in the business layer, as it requires describing the use case together with the others that are going to exploit state estimation output for a corrective action in the grid. For example, state estimation could be used as security assessment, or to visualize power quality issue, the first one is intended to preserve the components of the power system, the second to reduce the amount of money to be paid, for not respecting voltage quality regulations. These two cases represent different business goals and consequentially two different business layers that could both contain the state estimation use case. The function layer, contains the functions that will have to be implemented in order to realize the use case and their allocation in zones and domains. Functions are basically, sequences of algorithm, with a defined input and ouput. In this case the function layer is here represented:

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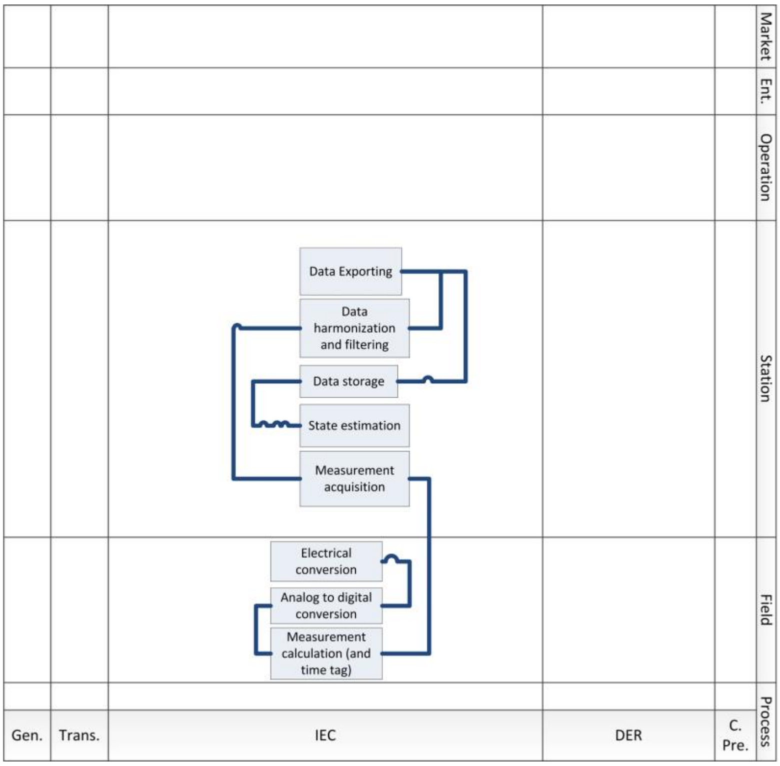

The set of functions Electrical conversion, Analog to digital conversion, Measurement calculation (and time tag) are mapped to the domain distribution and zone Field. Meanwhile the set of functions Measurement acquisition, Data harmonization and filtering, Data storage, State estimation, Data exporting are mapped to domain distribution and zone Field. This placement has been deducted from the use case general description and steps. The component layer contains the hardware components, such as devices, communication medium, power equipment and the software components. For the aforementioned state estimation use case, the SGAM component layer is here presented:

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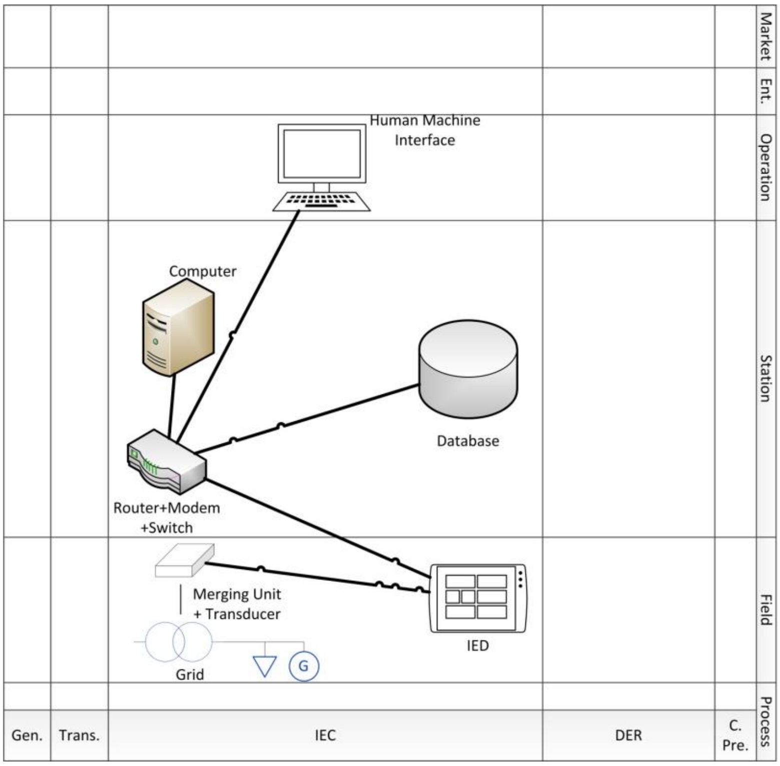
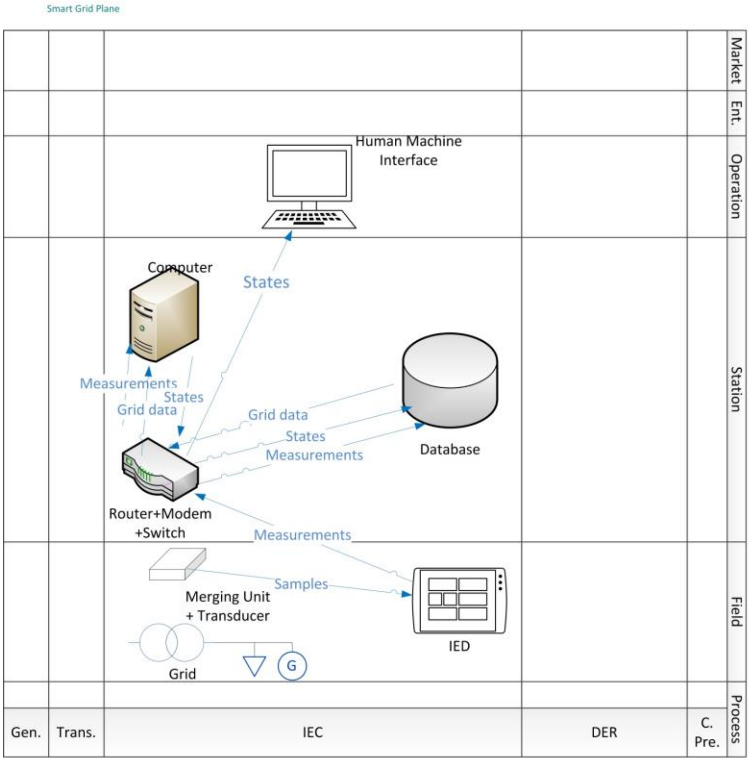
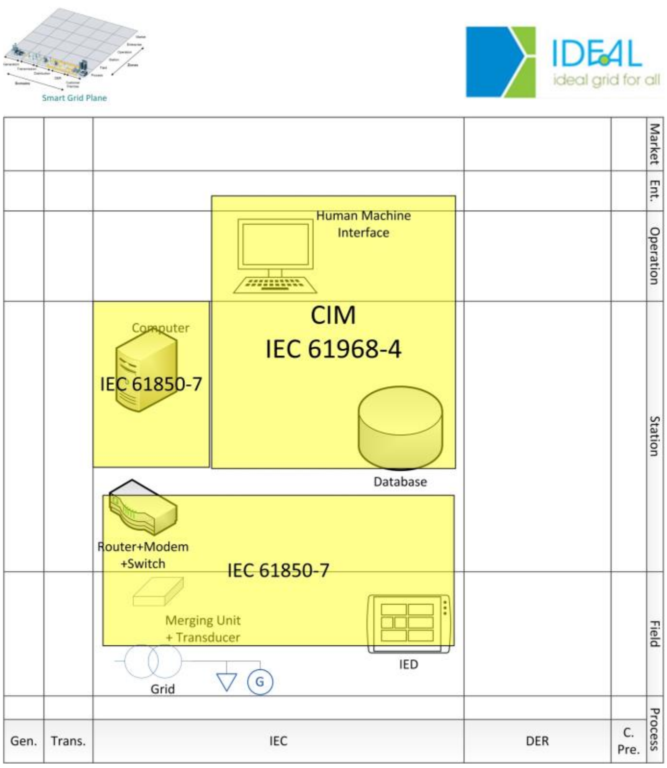


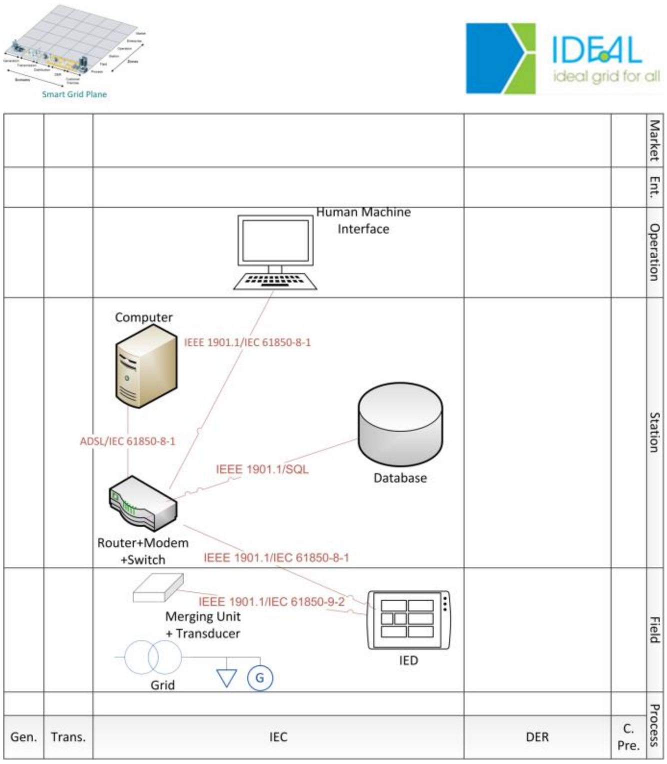
Merging unit + transducer are mapped on field devices, that depends on the available instrumentation in field zone and distribution domain. IED represents a generic measurement device, and are also mapped in field zone and distribution domain. Router+Modem+Switch represent the connection to external LANs and WANs for the communication inside and outside the substation. A generic computer runs the algorithm. A generic database saves the measurements, states, topology, parameters of the branches and measurement configuration. Database and computers for the automation are set in station domain. A human machine interface in control center environment permits to visualize the states results. Control center environment is represented by the operation domain. The information layer is composed by the business context view and the canonical data model view. The first one informs about the content of the messages exchanged between actors, the second one the standardized data model used to encapsulate such information.





The communication layer includes the definition of the communication protocol and technology. For the proposed case, the choices of the technology and protocols depend on the requirements for the information exchanged e.g. requirement on bandwidth, transfer time, synchronization accuracy, availability. Such requirements are deducted from the step descriptions. An example of requirement definition is presented in the table.

Information provider	Information receiver	Transaction description	Transfer time	Transfer rate	Synchronization accuracy	Availability
IED	Communication interface	Report of meaures	100 ms	1000 kb/s	1 μs	99.9998 %



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5. GENERAL IDE4L ARCHITECTURE OVERVIEW

IDE4L architecture includes enterprise and person entities, here called business actors, and automation actors. They are logically separated in two clusters; the interaction between the two clusters where the interface is the so-called human machine interfaces, allowing people to check the status in the system (wither power system, generation/load unit or market) and directly take control/protection actions or set parameters of automatic controllers. The business actors have a business goal, perform some business transactions and perform automation actions described in high level use cases. Such information is provided in the business cases, in paragraph 6.5 Business layer. The automation actors are computer, devices and platforms that practically performed the automation actions, their description is provided in 6.1 Component layer.

In Table 0-A, Table 0-B, Table 0-C, Table 0-D, Table 0-E, Table 0-F are shown the business and automation actors in table format, then further explained in the text below.

Table 0-A Business actors further developed in IDE4L architecture

Short name	Extended name
CA	Commercial aggregator
Prosumer	Prosumer
DSO	Distribution System Operator

Table 0-B Business actors that take part to IDE4L architecture, providing input and output, but have not being further developed within the project

Short name	Extended name
MO	Market Operator
BRP	Balance Responsible Party
SP	Service Provider
TSO	Transmission System Operator

Table 0-C Business actors not appearing in IDE4L detailed use case, but already present in automation architectures and consequently to be considered

Short name	Extended name
Retailer	Retailer

Table 0-D Automation actors further developed in IDE4L architecture

Short name	Extended name
CAS	Commercial aggregator system
DMS	Distribution management system
IED	Intelligent Electronic device
MGCC	MicroGrid central control
SAU	Substation Automation Unit

Table 0-E Automation actors that take part to IDE4L architecture, providing input and output, but have not being further developed within the project

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Short name	Extended name
Actuator	Actuator
AMM	Automatic meter management
BRPP	Balance responsible party platform
CAS	Commercial aggregator system
DMS	Distribution management system
IED	Intelligent Electronic device
MGCC	MicroGrid central control
MOP	Market operator platform
SAU	Substation Automation Unit
Sensor	Sensor
SPP	Service Provider Platform
TSOEMS	Transmission System Energy Management System

Table 0-F Other automation actors, not appearing in IDE4L detailed use case, but already present in automation architectures and consequently to be considered

Short name	Extended name
CIS	Customer Information Service
GIS	Geographical Information Service
NIS	Network Information Service
RBS	Retailer billing system

The general semantic model is split into business and automation semantic model, updating the high-level semantic model presented in Deliverable 3.1 []. From that preliminary diagram, two other representations were produced:

- The business semantic model, which contains only business entities like the Distribution System Operator (DSO), the Prosumer, the Commercial Aggregator (CA), etc.
- The system semantic model, containing the systems used by those entities and their interactions, e.g. the Distribution Management System (DMS), Intelligent Electronic Device (IED), etc.

This change was necessary because the first version of the high-level description contained the two dimensions – business and technology – mixed together.

In the business semantic model in Figure 0-1, the UML notation is adopted. Each box is an entity. Lines connecting entities imply that there is a relation between them and – therefore – a data exchange will take place. Numbers at the edge of lines indicate the cardinality of the relation between two entities. Where no number is written this implicitly means '1'.

Furthermore, solid lines and dashed line are used to represent parts of the architecture respectively fully in scope of the project and not/partially in the scope of the project. For Example, in the business semantic model only the CA, the DSO and the Prosumer are with the solid line, because their enterprise roles are further described in the project with respect to the state of the art. Below is a short description of the IDE4L business actors.

- Prosumer represents both MV and LV customers and more enhanced customers with the capability of disconnecting from the distribution grid i.e. a microgrid.
- CA – Commercial Aggregator: formulates the offers for flexibility services and energy production/consumption for its load areas, and then sends the offers to the market operator.
- DSO – Distribution System Operator is the tradition DSO which extends his responsibility including features to interact with the CA and the TSO.
- TSO – Transmission System Operator: is the manager of the transmission network.
- MO – Market Operator: matches all the bids in the market and decides the power traded by the commercial aggregator in each period of the next day.
- BRP – Balance Responsible Party: Satisfy financial responsibility for system's energy balance
- Retailer: Purchase and sells energy in the energy market.
- SP – Service Provider: is a third-party which could provide services to any of the main actors of the electricity supply chain e.g. weather forecasts, energy management services, etc.

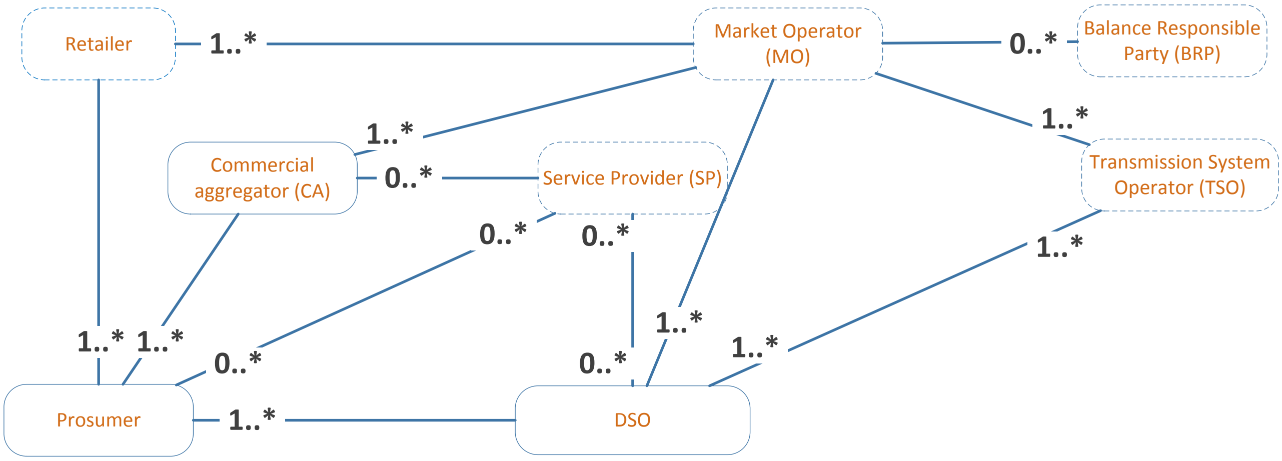

Figure 0-1. business high-level semantic diagram.

The same convention about the line was used to draw the system high-level semantic diagram, where systems not fully in scope of the project were drawn with a dashed line.

Generally speaking, each of the automation actors is managed by one or more than one business entity of the previous diagram. In Figure 0-2 the business actors are mapped onto automation actors.

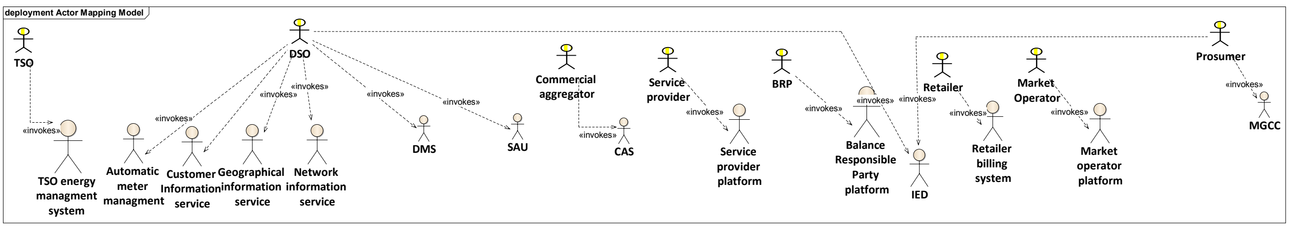

Figure 0-2 Mapping of business actors onto automation actors

An overview of the automation actors further developed in IDE4L is here given:

The DSO owns:

- the DMS i.e. the system collecting data from the field; executing algorithms to assign control center operators to manage the overall distribution network;

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- several other server application such as the Automatic Meter Management, the Customer Information System, the Geographic Information System and the Network Information System;
- Several Substation Automation Units (SAUs) which autonomously manage independent areas of the distribution network on behalf of the control center.

The Commercial Aggregator also has a software platform to implement the new algorithms described in the project, called here commercial aggregator system.

Intelligent Electronic Devices (IEDs) are all the pieces of technologies used to monitor, control and or protect a network node/area. Several actors use an IED: the DSO both in primary and in secondary substation; smart meters themselves are IEDs own by the DSO; the prosumer with a not-so-complex network (e.g. a residential customer connected in low-voltage) – uses a Home Energy Management System which is an IED; a more complex customer with a microgrid has many IEDs in its network.

IEDs collects measures by using sensors and can apply control actions by means of actuators. Both of them are considered and used in the project, but no development took place.

A component very similar to the SAU is the Micro Grid Central Controller (MGCC) which is charge of managing the microgrid.

Eventually the automation actors listed in Table 0-E take part to IDE4L architecture as the provide/receive inputs/outputs for the automation functionalities but have not been further developed in the project, whereas the automation actors listed in Table 0-F do not participate to any of the IDE4L use cases but have been considered because already present in the distribution systems or proposed by other research projects.

More detailed explanation about every automation actor is given in 6.1 Component layer. In particular, each item is described in terms of interfaces, data and applications:

- The Data Layer defines the structure of the database (entities and relations) used to store the data needed by algorithms (contained in the Function Layer) and exchanged with the external environment via interfaces (contained in the Interface Layer).
- The Function Layer defines the software which internally elaborates the data stored in the Data Layer to extract the relevant information, and carrying out the decision-making process.
- The Interface Layer defines the software used to exchange data with external devices (such as SCADA, DEMS, etc.), to store/retrieve them from the Data Layer.

The aforementioned actors are represented in Figure 0-3, the UML notation is adopted.

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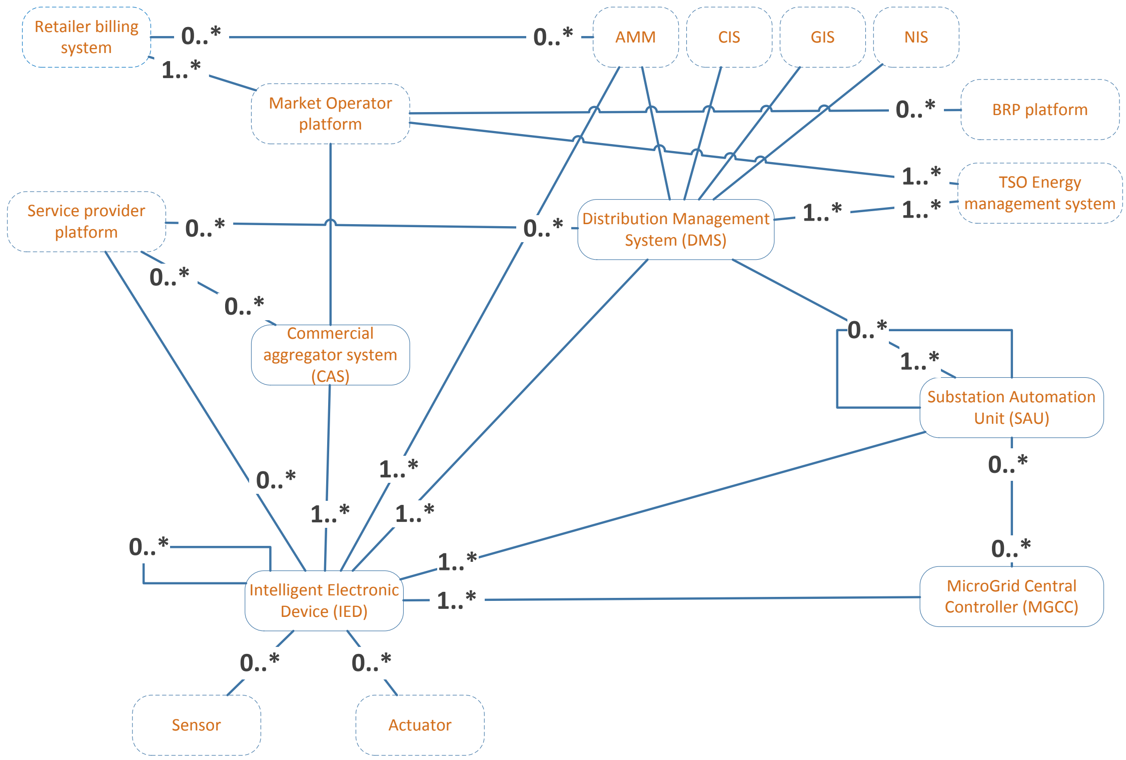

Figure 0-3. Automation actors high-level semantic diagram

Hereafter some details regarding the semantic relations:

- The DMS entity is connected to the SAU entity. The cardinality is 1 – 0..*. This means that one DMS software controlling the entire distribution grid can coordinate several SAUs, each of them controlling a portion of the grid (e.g. a SAU can control the MV network under a primary substation or the LV area under a secondary substation). The number of SAUs is arbitrary, i.e. this architecture can be deployed up to installing a SAU in all the transformation centers (*) or – on the opposite side – the architecture considers the case where none of the substations has a SAU (0).
- The SAU receives measurements and send control signals to 1..* IEDs which in turn exploit 0..* sensors and actuators.
- The loop from/to the SAU entity specifies that a SAU can communicate with none or many other SAUs. The typical example is the SAU in a PS communicating with the SAU of a down-stream secondary substation.

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6. THE SGAM IDE4L ARCHITECTURE

The IDE4L SGAM architecture has been realized through the method defined in section 4. Detailed use cases and supplementary information has been synthetized in order to obtain the SGAM layers [7], also modeled in enterprise architect [10], [11] to verify layer interoperability and for further testing phases.

6.1 Component layer

The component layer is obtained through three steps. The first one is the mapping of the business actors that are enterprises and persons onto automation actors that are the logical actors that allow the business ones to realize their automation goals. For instance, being the DSO a business actor, the automation actors that allow him to perform automation are DMS, SAUs and IEDs. The semantic relations between business actors and then between automation actors are show, in section 5. The second step is the mapping of such automation actors that are still logical actors, individuated from the use case descriptions, onto hardware and software components. The mapping of business actors onto automation actors, and the mapping of automation actors onto components are visible in the actor mapping model in Figure 0-1. The third step is the mapping of components in zones and domains, as shown in Figure 0-2.

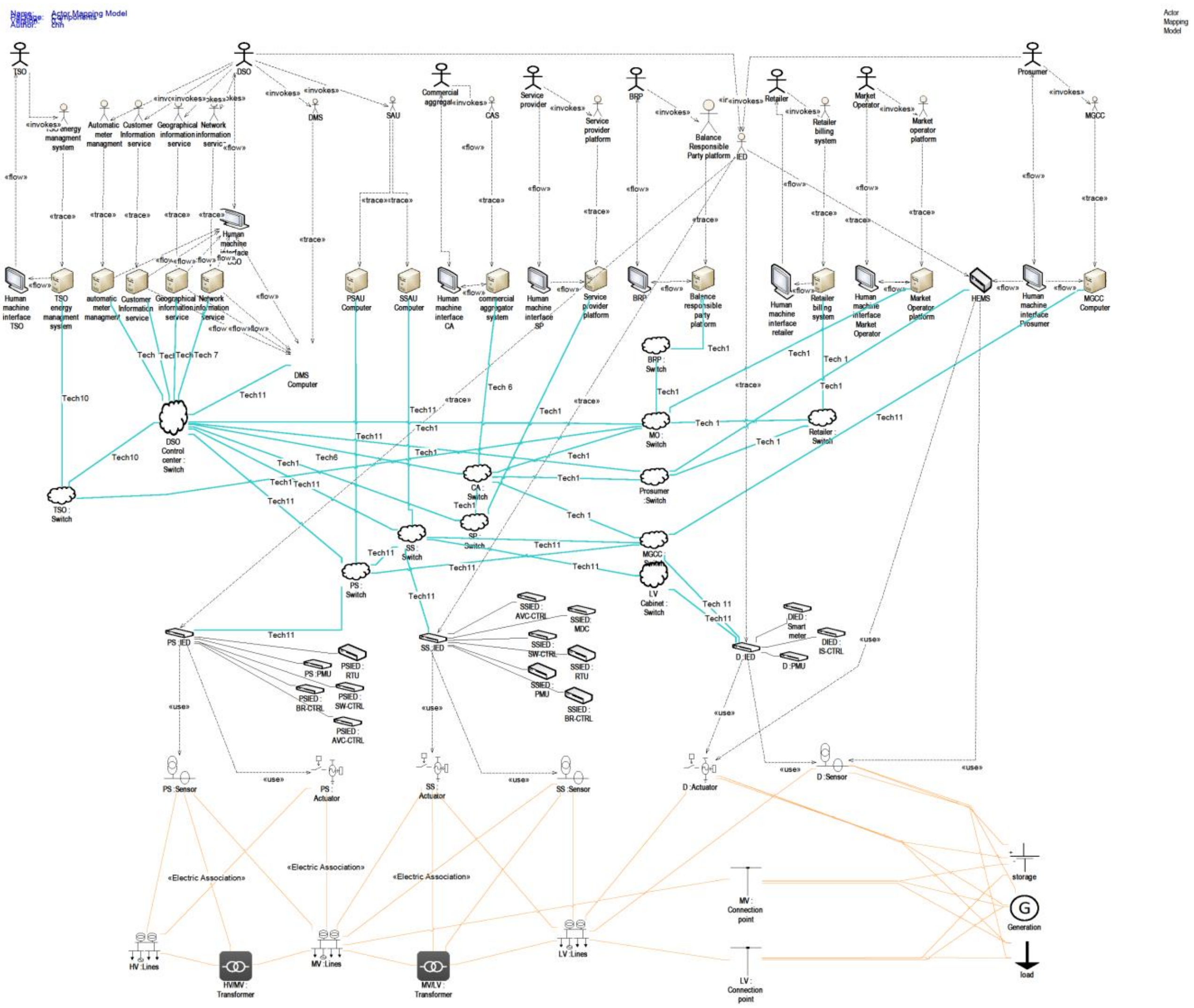

Figure 0-1 Actor mapping model

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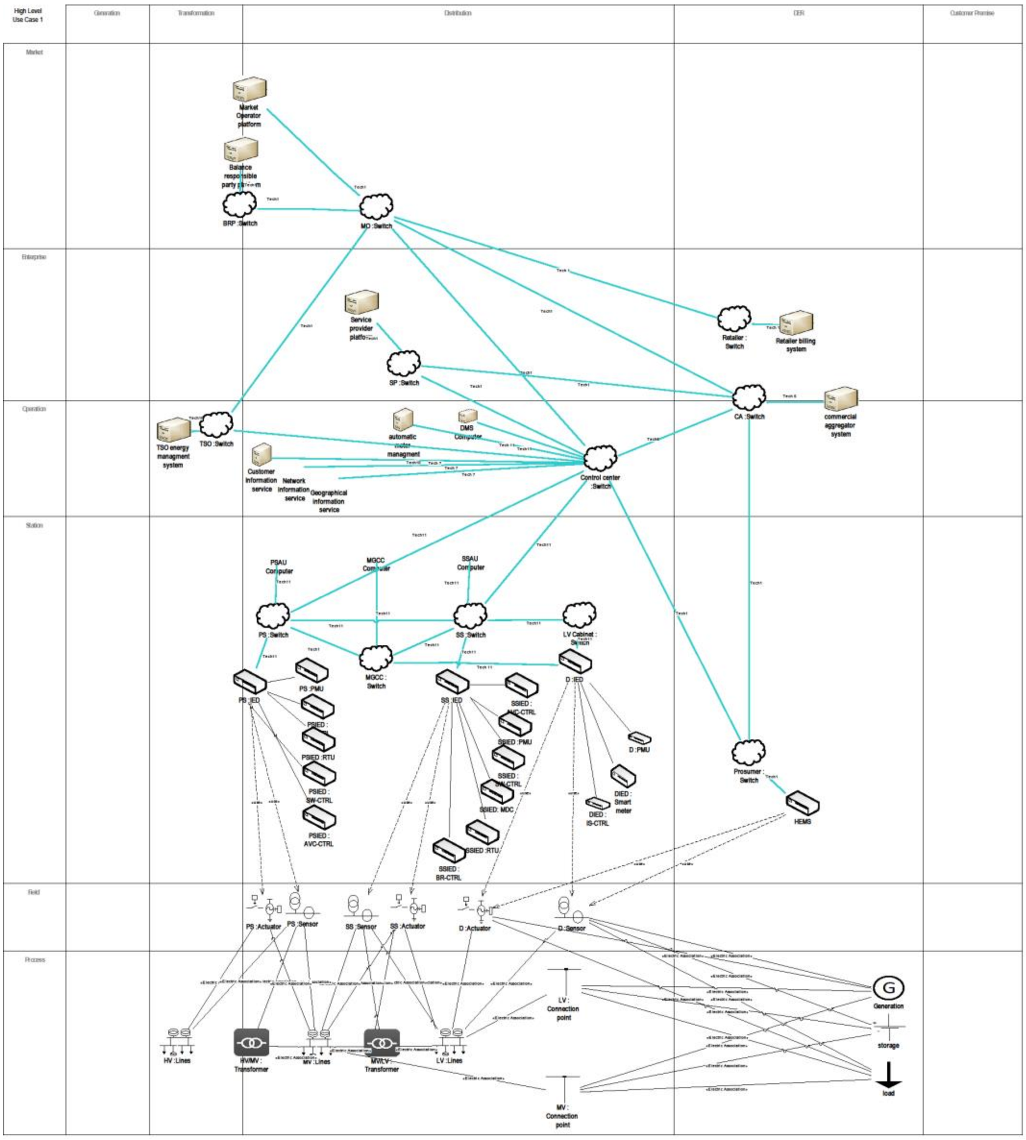

Figure 0-2 Component layer

The components represented in zones and domains are also represented in Table 0-A.

Table 0-A Component layer of IDE4L architecture

Short name technology	Extended name technology	Object class	Domain1	Domain2	Zone1	Zone2
PSAU	Primary Substation Automation Unit	Computer	distribution		station	
SSAU	Secondary Substation Automation Unit	Computer	distribution		station	
PSIED	Primary Substation IED	Device	distribution	transmission	station	
SSIED	Secondary Substation IED	Device	distribution		station	

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DIED	Distributed IED	Device	distribution		station	
PSIED-RTU	Primary Substation IED Remote Terminal Unit	Device	distribution	transmission	station	
PSIED-PMU	Primary Substation IED Phasor Measurement Unit	Device	distribution	transmission	station	
PSIED-BR-CTRL	Primary Substation IED Breaker controller	Device	distribution	transmission	station	
PSIED-SW-CTRL	Primary Substation IED Switch controller	Device	distribution	transmission	station	
PSIED-AVC-CTRL	Primary Substation IED Automatic voltage controller	Device	distribution	transmission	station	
SSIED-RTU	Secondary Substation IED Remote Terminal Unit	Device	distribution		station	
SSIED-PMU	Secondary Substation IED Phasor Measurement Unit	Device	distribution		station	
SSIED-BR-CTRL	Secondary Substation IED Breaker controller	Device	distribution		station	
SSIED-SW-CTRL	Secondary Substation IED Switch controller	Device	distribution		station	
SSIED-AVC-CTRL	Secondary Substation IED Automatic voltage controller	Device	distribution		station	
SSIED-MDC	Secondary Substation IED Meter Data Concentrator	Device	distribution		station	
DIED-PMU	Distributed IED Phasor Measurement Unit	Device	distribution		station	
DIED-SM	Distributed IED Smart Meter	Device	distribution		station	
DMS	Distribution management system	Computer	distribution		operation	
Automatic meter management	Automatic meter management	Computer	distribution		operation	
Geographical Information Service	Geographical Information Service	Computer	distribution		operation	
Customer Information Service	Customer Information Service	Computer	distribution		operation	
Network Information Service	Network Information Service	Computer	distribution		operation	
Human machine interface DSO	Human machine interface DSO	Human machine interface	distribution		operation	
DSO Control center switch	DSO Control center switch	Switch	distribution		operation	
Primary Substation switch	PS switch	Switch	distribution	transmission	station	
Secondary Substation switch	SS switch	Switch	distribution		station	

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LV cabinet switch	LV cabinet switch	Switch	distribution		station	
ICT connection control center switch – PS switch	ICT connection control center switch – Primary Substation switch	ICT connection	distribution		station	operation
ICT connection control center switch – SS switch	ICT connection control center switch – Secondary Substation switch	ICT connection	distribution		station	operation
ICT connection LV cabinet – SS switch	ICT connection LV cabinet – Secondary Substation switch	ICT connection	distribution		station	
LAN control center	Local Area Network control center	ICT connection	distribution		operation	
LAN PS	Local Area Network Primary Substation	ICT connection	distribution		station	
LAN SS	Local Area Network Secondary Substation	ICT connection	distribution		station	
LAN LV cabinet	Local Area Network Low Voltage cabinet	ICT connection	distribution		station	
PS sensor	Primary Substation sensor	Sensor	distribution	transmission	field	
SS sensor	Secondary Substation sensor	Sensor	distribution		field	
D sensor	Distributed sensor	Sensor	distribution		field	
PS actuator	Primary Substation actuator	Actuator	distribution	transmission	field	
SS actuator	Secondary Substation actuator	Actuator	distribution		field	
D actuator	Distributed actuator	Actuator	distribution		field	
Commercial aggregator system	Commercial aggregator system	Computer	DER		operation	enterprise
Human machine interface CA	Human machine interface Commercial aggregator	Human machine interface	DER		operation	enterprise
CA switch	Commercial aggregator switch	Switch	DER		operation	enterprise
HEMS	Home Energy management system	Device	DER		Station	
Human machine interface Prosumer	Human machine interface Prosumer	Human machine interface	DER		Station	
Prosumer switch	Prosumer switch	Switch	DER		Station	
MGCC	MicroGrid Central Controller	Computer	Distribution		Station	
DIED.IS-CTRL	Distributed IED, Isolation switch controller	Device	Distribution		Station	
MGCC switch	MicroGrid Central Controller switch	Switch	Distribution		Station	

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TSOEMS	Transmission system energy management system	Computer	Transmission		Operation	
SPP	Service provider platform	Computer	Distribution	(Transmission, DER, Customer premises)	Enterprise	
BRPP	Balance responsible party platform	Computer	Transmission	Distribution	Market	
RBS	Retailer billing system	Computer	DER	Customer	Enterprise	
MOP	Market Operator platform	Computer	Transmission	Distribution	Market	
Human machine interface TSO	Human machine interface Transmission System Operator	Human machine interface	Transmission		Operation	
Human machine interface SP	Human machine interface Service Provider	Human machine interface	Transmission		Operation	
Human machine interface BRP	Human machine interface Balance responsible party	Human machine interface	Transmission	Distribution	Market	
Human machine interface Retailer	Human machine interface Retailer	Human machine interface	DER	Customer	Enterprise	
Human machine interface MO	Human machine interface Market Operator	Human machine interface	Transmission	Distribution	Market	
TSO switch	Transmission System Operator switch	switch	Transmission		Operation	
SP switch	Service Provider switch	switch	Distribution	(Transmission, DER, Customer premises)	Enterprise	
BRP switch	Balance responsible party switch	switch	Transmission	Distribution	Market	
Retailer switch	Retailer switch	switch	DER	Customer	Enterprise	
MO switch	Market Operator switch	switch	Transmission	Distribution	Market	
ICT connection TSO- DSO Control center	ICT connection Transmission system operator- Distribution System operator Control center	ICT connection	Transmission	Distribution	Operation	
ICT connection DSO Control center- Service provider	ICT connection Distribution System operator Control center- Service provider	ICT connection	Distribution	(Transmission, DER, Customer premises)	Operation	Enterprise
ICT connection Service provider- Commercial aggregator	ICT connection Service provider- Commercial aggregator	ICT connection	Distribution	DER(Transmission, Customer premises)	Enterprise	
ICT connection Commercial aggregator- DSO Control center	ICT connection Commercial aggregator- Distribution System operator Control center	ICT connection	Distribution		Operation	Enterprise
ICT connection Commercial aggregator- MGCC	ICT connection Commercial aggregator- MicroGrid Central Controller	ICT connection	Distribution		Station	
ICT connection MGCC- Primary substation	ICT connection MicroGrid Central Controller - Primary substation	ICT connection	Distribution		Station	
ICT connection MGCC- Secondary substation	ICT connection MicroGrid Central Controller - Secondary substation	ICT connection	Distribution		Station	

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ICT connection Commercial aggregator- Prosumer	ICT connection Commercial aggregator- Prosumer	ICT connection	DER		Station	Enterprise
ICT connection Commercial aggregator- Market operator	ICT connection Commercial aggregator- Market operator	ICT connection	DER	Distribution (Transmission)	Market	Enterprise
ICT connection DSO Control center- Market operator	ICT connection DSO Control center- Market operator	ICT connection	Distribution	(Transmission)	Operation	Control

Below, the components previously listed, are further described following the mapping on business actors and on automation actors, presented in section 5.

Automation actors invoked by business actor DSO

The DSO is a fundamental figure in IDE4L architecture. It manages a set of computers in the control center, as the DMS for the optimal control and supervision of the system, the Automatic meter management for the collection of smart meter data, the Geographical, Customer, Network information services to update periodically the models of topology, parameters and customer of the grid. Moreover at substation level dedicated computers called Substation Automation Unit realize automatically monitoring, state estimation and control of their portion of grid and its able to communicate both with IEDs and control center. Finally the DSO exploits the IEDs in MV and LV network. In Figure 0-3 the automation actors and the components managed by DSO are shown. In As instructed in the SGAM document, the emphasis of the communication layer is to describe protocols and communication technologies for the interoperable exchange of information between the use case actors.

Figure 6.2.1 shows a snapshot of an Excel table (Table 6.2.1) listing all the information exchanged between the use case actors together with the employed protocols and the requirements for communication technologies. Table 6.2.1 is attached to this document. When the information is exchanged between two parts of the same components (e.g. between function running on a software and database of the same computer) the protocol is not listed for the sake of brevity.

	A	B	C	D	E	F	G	H	I
1	Use case	Information producer	Information receiver	Data class	Protocol	Transfer time	Transfer rate	Synchronization accuracy	Availability
2	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	CIM network		TT3	TR4	SA5	H
3	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	switch status		TT3	TR2	SA5	H
4	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	Current measurement		TT2	TR3	SA5	M
5	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	Voltage measurement		TT2	TR3	SA5	M
6	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	Power/energy measurement		TT2	TR3	SA5	M
7	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	long term power forecast		TT2	TR4	SA5	M
8	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	short term power forecast		TT2	TR4	SA5	M
9	LVSE	SAU(SSAU).Functions	SAU(SSAU).RDBMS	Current measurement		TT2	TR4	SA5	M
10	LVSE	SAU(SSAU).Functions	SAU(SSAU).RDBMS	Voltage measurement		TT2	TR4	SA5	M
11	LVSE	SAU(SSAU).Functions	SAU(SSAU).RDBMS	Power/energy measurement		TT2	TR4	SA5	M
12	LVSE	SAU(PSAU).Functions	SAU(PSAU).Functions	Voltage measurement		TT2	TR4	SA5	M
13	LVSE	SAU(SSAU).Functions	SAU(SSAU).RDBMS	flag		TT2	TR4	SA5	M
14	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	flag		TT2	TR4	SA5	M
15	Dynamic Monitoring	DMS.DNP3	IED(PSIED-RTU).DNP3	Voltage measurement	DNP3	TT6	TR1	SA0	VH
16	Dynamic Monitoring	DMS.DNP3	IED(PSIED-RTU).DNP3	Current measurement	DNP3	TT6	TR1	SA0	VH
17	Dynamic Monitoring	DMS.DNP3	IED(PSIED-RTU).DNP3	Frequency and ROCOF measurement	DNP3	TT6	TR1	SA0	VH

Figure 6.2.1. Snapshot of the list of information exchanges.

Figure 6.2.2 presents a snapshot of the IDE4L SGAM communication layer on which the communication protocols, employed for the information exchanges listed in Table 6.2.1, are shown. A Visio file containing the IDE4L SGAM communication layer is attached to this document for further investigation.

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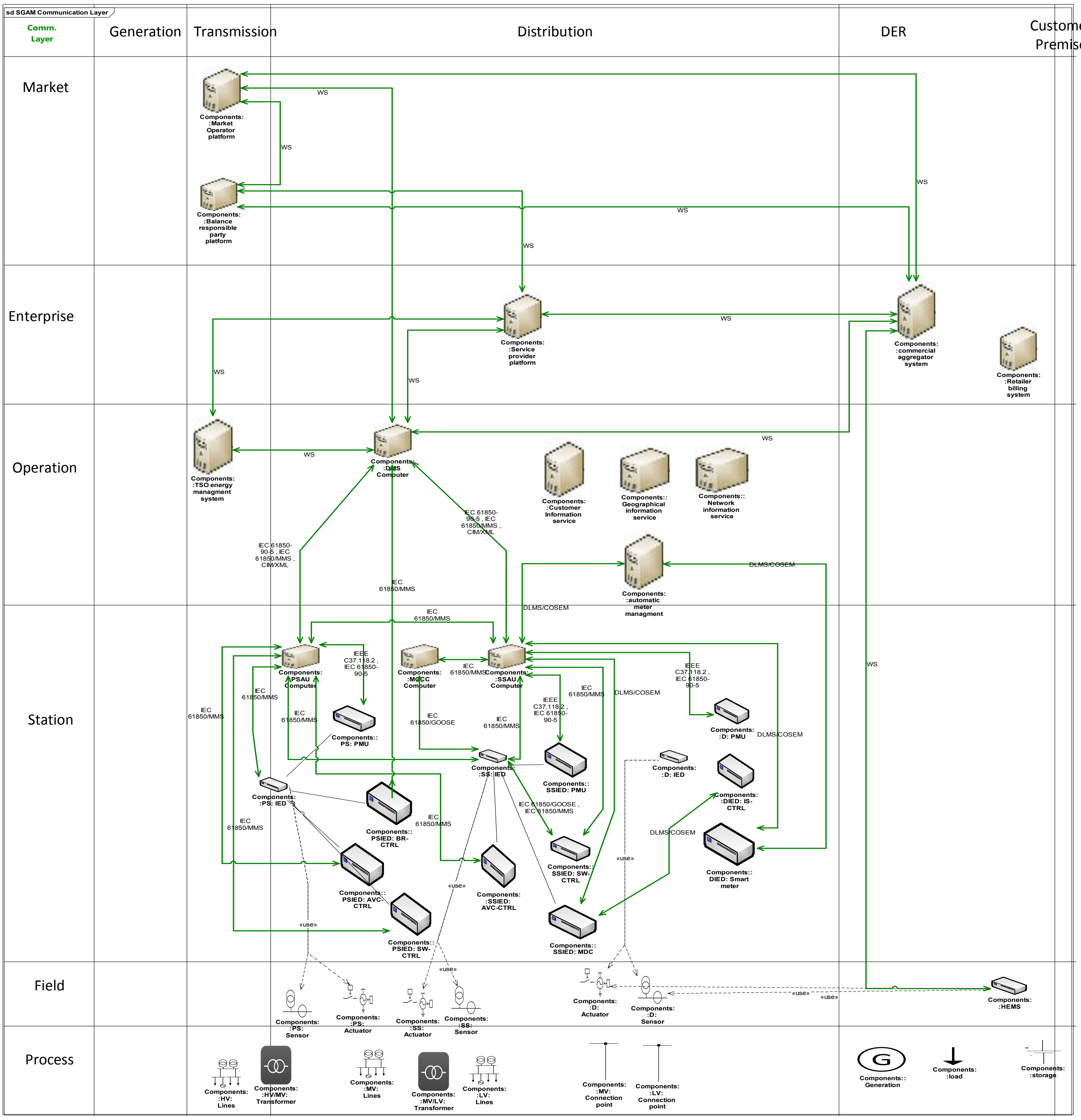

Figure 6.2.2. Communication protocols mapped on the SGAM communication layer.

As indicated in figure 6.2.1, each information exchange sets specific requirements in terms of transfer time and transfer rate on the technology employed for the communication link through which it's transmitted. Hence, for each communication link, all the corresponding information exchanges have been investigated to determine the strictest demanded requirements in terms of transfer time and transfer rate. The appropriate technology is then assigned to each communication link to satisfy the requirements imposed by the information exchanges.

Figure 6.2.3 presents a snapshot of the communication links together with the technology assigned to each of them. Table 6.2.2 lists the requirements for the technologies and also some examples of mechanisms than can implement each technology. The communication links have been included in the Visio file IDE4L SGAM communication layer for further investigation.

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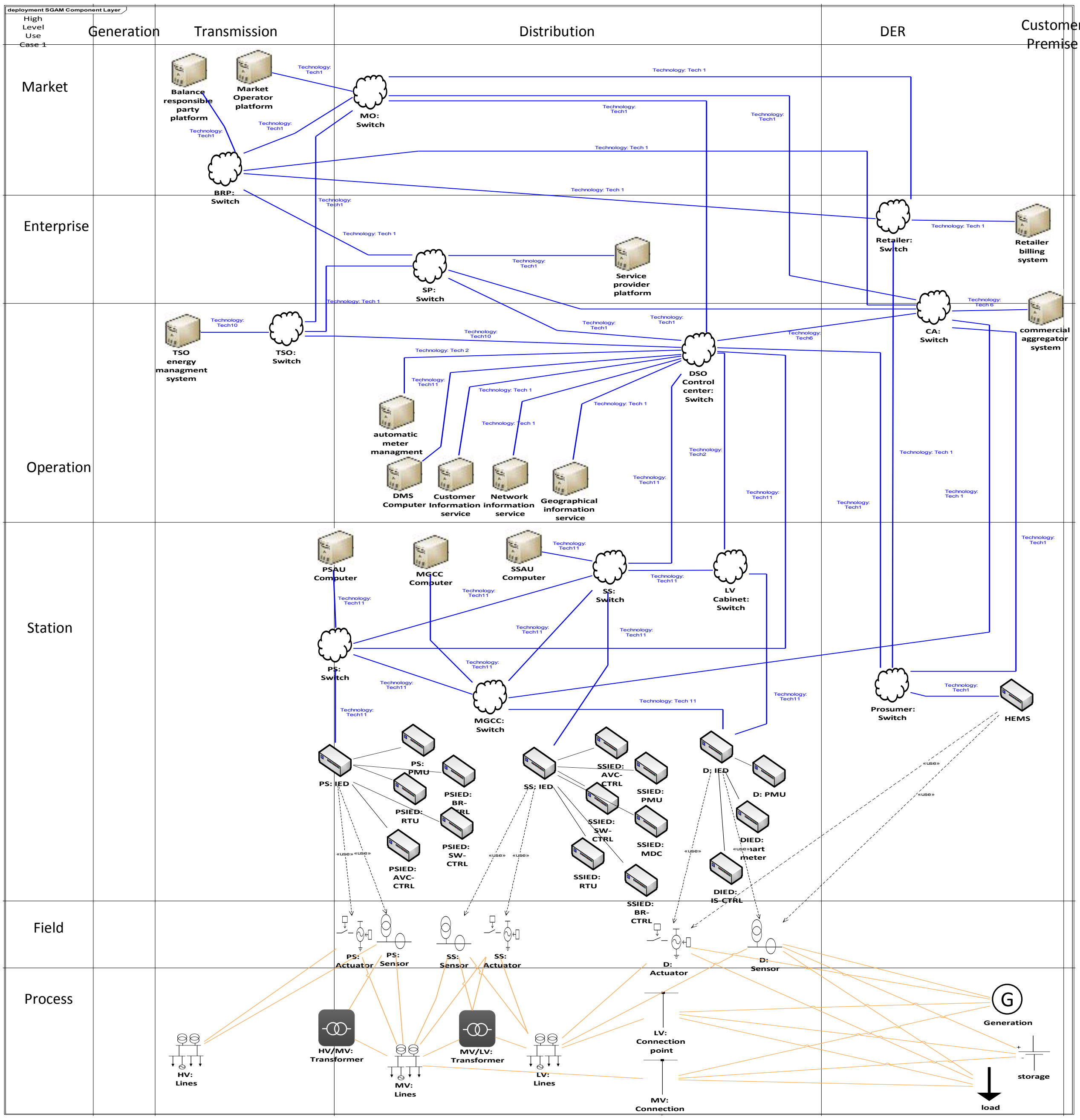

Figure 6.2.3. Communication technologies mapped on the SGAM communication layer.

Table 6.2.2. List of employed technologies.

Technology	Requirements		Example mechanisms
	Transfer time	Transfer rate	
Tech1	TT0	TR4	UMTS, BroadBand PLC on the MV grid, BB-PLC on the LV grid (cell with less than 50/100 of nodes), HiperLAN/Wi-Fi, FO
Tech2	TT0	TR6	FO

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Tech6	TT2	TR5	BroadBand PLC on the MV grid, BB-PLC on the LV grid (cell with less than 20/30 of nodes), FO, LTE, HiperLAN/Wi-Fi (with a point-to-point link)
Tech10	TT6	TR4	FO, LTE (with no traffic), HiperLAN/Wi-Fi (with no traffic and with a point-to-point link)
Tech11	TT6	TR6	FO

It should be noted that the example mechanisms, listed in Table 6.2.2, are recommended by the IDE4L DSO partners who have experienced achieving the required transfer times and transfer rates by utilizing the example mechanisms. Furthermore, part of the aforementioned mechanism, will be applied and tested in the IDE4L demo, both in laboratory and on the field.

As shown in figure 6.2.1, each information exchange requires a certain amount of availability from the underlying ICT connections. Such availability depends on the usage of the information in the use cases. Table 6.2.3 lists the ICT connections which are required by the corresponding information exchanges to have high (H) or very high (VH) availability. For these ICT connections, it's important to consider some sort of redundancy by for example constructing ICT infrastructure in parallel or utilizing other ICT connections to implement a parallel communication path.

Table 6.2.3. List of ICT connections with high or very high availability.

ICT connection between component #1 and component #2			**ICT connection between component #1 and component #2**			**ICT connection between component #1 and component #2**	
Component #1	**Component #2**		**Component #1**	**Component #2**		**Component #1**	**Component #2**
SS:IED	SS:Switch		PS:Switch	PSAU Computer		MGCC:Switch	MGCC Computer
SS:Switch	PS:Switch		MGCC:Switch	SS:Switch		SS:Switch	SSAU Computer
PS:IED	PS:Switch		PS:Switch	DMS Control Center Switch		SS:Switch	LV Cabinet Switch
DMS Computer	DMS Control Center Switch		D:IED	LV Cabinet Switch		SS:Switch	DMS Control Center Switch
TSO Switch	DMS Control Center Switch		CA:Switch	DMS Control Center Switch			
TSO Switch	TSO EMS		CA:Switch	CA System			

6.3 Information layer, the components invoked by DOS's technical actors are presented and classified in certain object classes. In Table 0-C other enabling technologies used by DSOs are presented.

Short name	**Extended name**
SAU	Substation Automation Unit

IED	Intelligent Electronic device
DMS	Distribution management system
AMM	Automatic meter management
GIS	Customer Information Service
CIS	Geographical Information Service
NIS	Network Information Service

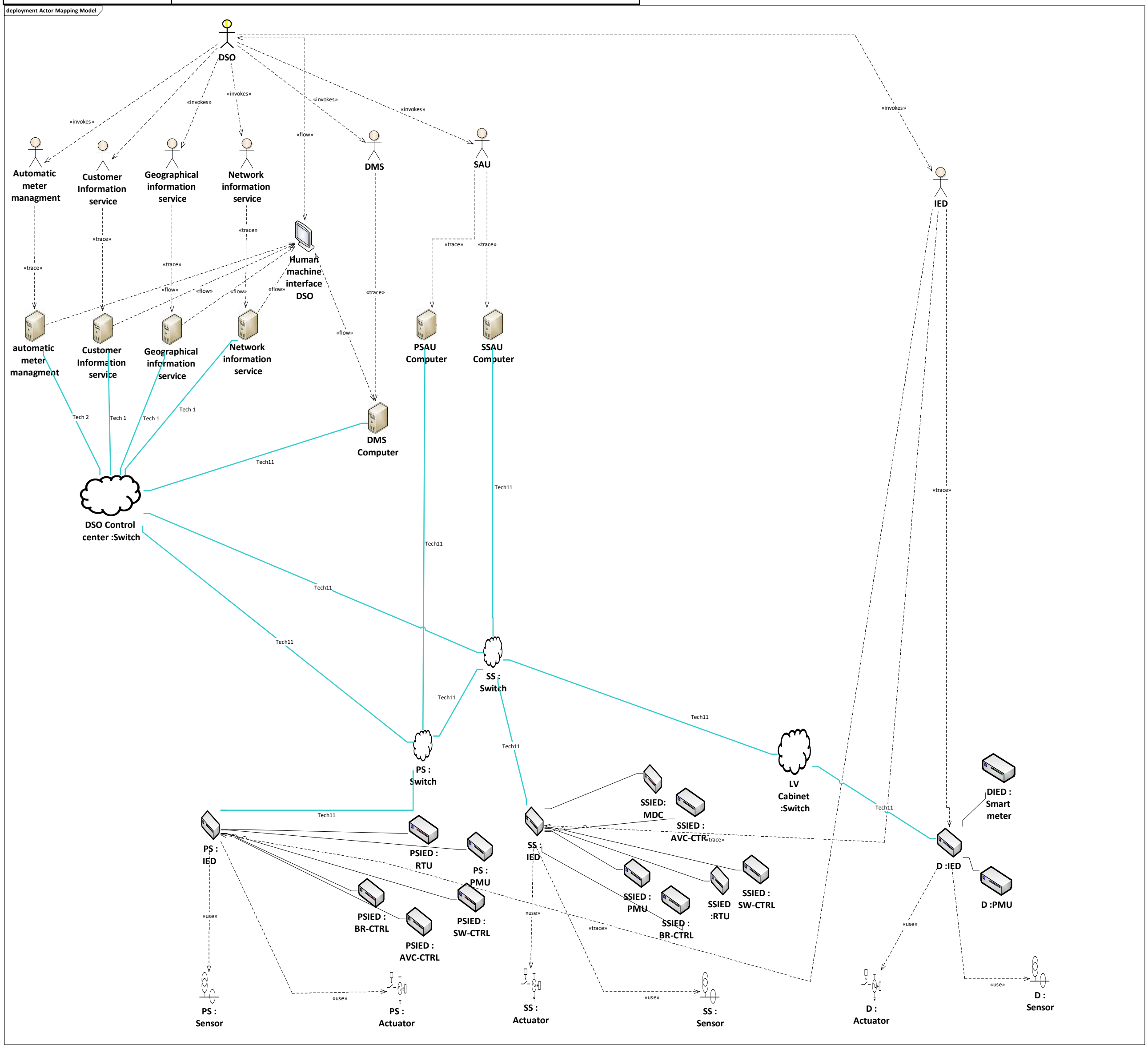

Figure 0-3 Automation actors invoked by DSO

Components, both software and hardware invoked by the automation actors of DSO are shown in

Table 0-B Components invoked by the technical actors of DSO

Short name technical actor	Short name technology	Extended name technology	Object class
SAU	PSAU	Primary Substation Automation Unit	Computer
	SSAU	Secondary Substation Automation Unit	Computer
IED	PSIED	Primary Substation IED	Device
	SSIED	Secondary Substation IED	Device

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	DIED	Distributed IED	Device
	PSIED-RTU	Primary Substation IED Remote Terminal Unit	Device
	PSIED-PMU	Primary Substation IED Phasor Measurement Unit	Device
	PSIED-BR-CTRL	Primary Substation IED Breaker controller	Device
	PSIED-SW-CTRL	Primary Substation IED Switch controller	Device
	PSIED-AVC-CTRL	Primary Substation IED Automatic voltage controller	Device
	SSIED-RTU	Secondary Substation IED Remote Terminal Unit	Device
	SSIED-PMU	Secondary Substation IED Phasor Measurement Unit	Device
	SSIED-BR-CTRL	Secondary Substation IED Breaker controller	Device
	SSIED-SW-CTRL	Secondary Substation IED Switch controller	Device
	SSIED-AVC-CTRL	Secondary Substation IED Automatic voltage controller	Device
	SSIED-MDC	Secondary Substation IED Meter Data Concentrator	Device
	DIED-PMU	Distributed IED Phasor Measurement Unit	Device
	DIED-SM	Distributed IED Smart Meter	Device
DMS	DMS	Distribution management system	Computer
AMM	Automatic meter management	Automatic meter management	Computer
GIS	Customer Information Service	Customer Information Service	Computer
CIS	Geographical Information Service	Geographical Information Service	Computer
NIS	Network Information Service	Network Information Service	Computer

Among the components required by IDE4L architecture to allow DSO to perform the automation functionalities described in the use cases, it is important underlying the developments made for the DMS, SAUs and IEDs.

The DMS actor is represented in terms of interfaces, databases and functions in Figure 0-4. The dashed line indicates that the IDE4L architecture includes new developments but also other interfaces/databases/functions present in the state of the art should be considered. The DMS is the component own by the DSO used to collect data from the field and to assist the control center operator in managing the overall distribution network. There are already several DMSs in the market. In the project the focus is on new functionalities needed to improve the interaction with other entities such as SAUs, the Commercial Aggregator and the TSO.

The DMS has several interfaces to communicate with other systems in the architecture as web services, synchrophasor standard, IEC 61850 MMS and common SCADA interfaces as IEC 104 and Modbus. It has a database where raw data and results of the processing stage are stored; and several functions defined in the detailed use cases as described in the Actors typically need to exchange information in order to realize the aforementioned use cases. This is the main focus of SGAM Information Layer. The purpose of SGAM Information Layer is to model the information object flows between actors, in terms of data content, and to identify proper data model standards that are suitable to reflect these information objects.

Business Context View

The first part of Information Layer is Business Context View, which models the information object flows between actors. Figure 6-3-1 is the screenshot from SGAM Toolbox that gives an overview of Business Context View developed for IDE4L project use cases. The blue arrows represent Information Object Flows from senders to receivers; the texts on these arrows identify Information Objects being exchanged.

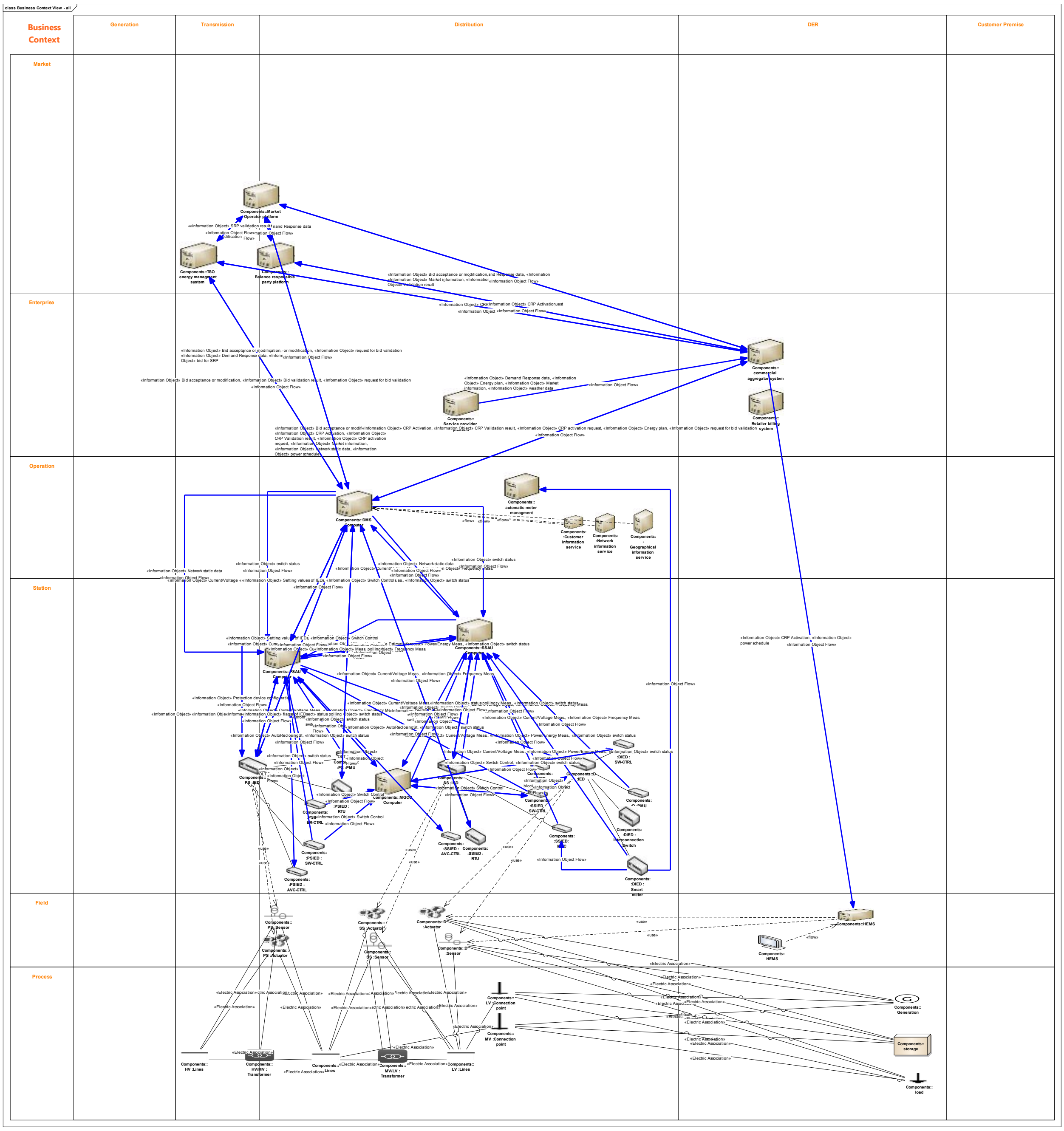

Figure 6-3-1 Overview of Business Context View

The remaining of this subsection will look into the Business Context View piece by piece, based on a series of selected message sender and receiver.

PSAU-SSAU data exchange

Figure 6-3-2 shows Information object flows between primary substation SAU and secondary substation SAU.

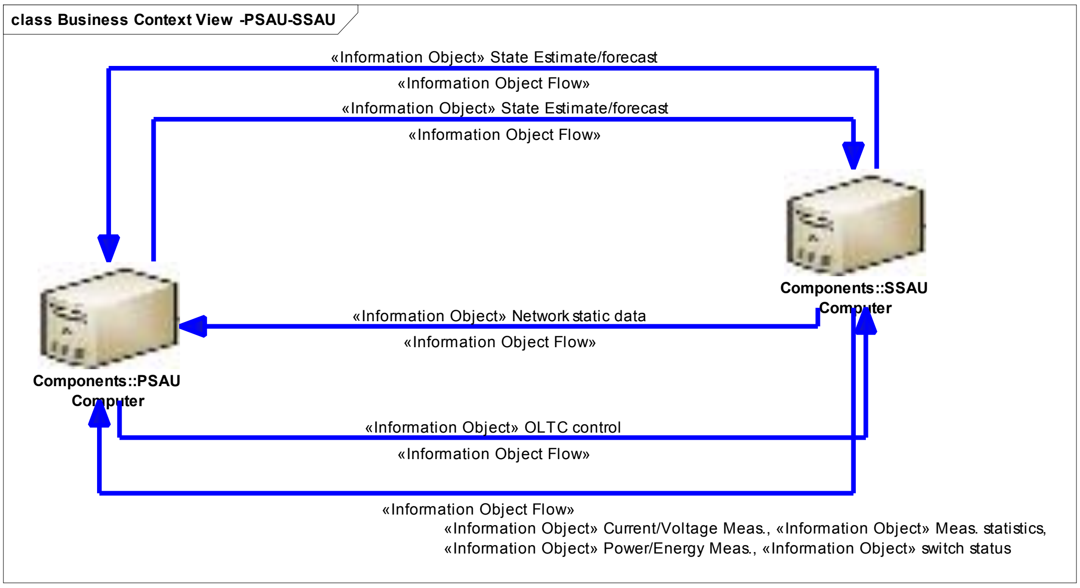

Figure 6-3-2 Information Object flows between PSAU and SSAU

Information Objects depicted in this figure are further explained in the following table. The second column describes the actual data this Information Object represents, and the third column tells in which use case and which function the Information Object/data are involved.

Table 6-3-A Information exchange between PSAU and SSAU

Information Object	data exchanged	Related Use case - Function
Current/Voltage measurement	Current phase angle	LVRTM –Data report MVRTM – Data acquisition
	Voltage phase angle	
	Voltage magnitude	
	Current magnitude	
measurement statistics	Statistical measurement	
Network static data	CIM Network Model	NDU – CIM parsing
OLTC control	OLTC block and unblock signals	BOT - data report
Power/Energy measurement	Reactive power	LVRTM – Data report MVRTM – Data acquisition
	Active power	
	Energy measurement	
State Estimate/forecast	State forecasting result	LVSF, BOT – Data report
	State Estimation results	BOT – data report
	MV connection point Voltage forecast	LVSF – Data storage
Switch status	Switch status	LVRTM – data report MVRTM – Data acquisition

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SAU(PSAU/SSAU)-DMS data exchange

Figure 6-3-3 depicts Information Object Flow between DMS and SAU, including both primary substation SAU and secondary substation SAU. Information Objects details, as well as the relevant use cases and functions, are further described by the following table.

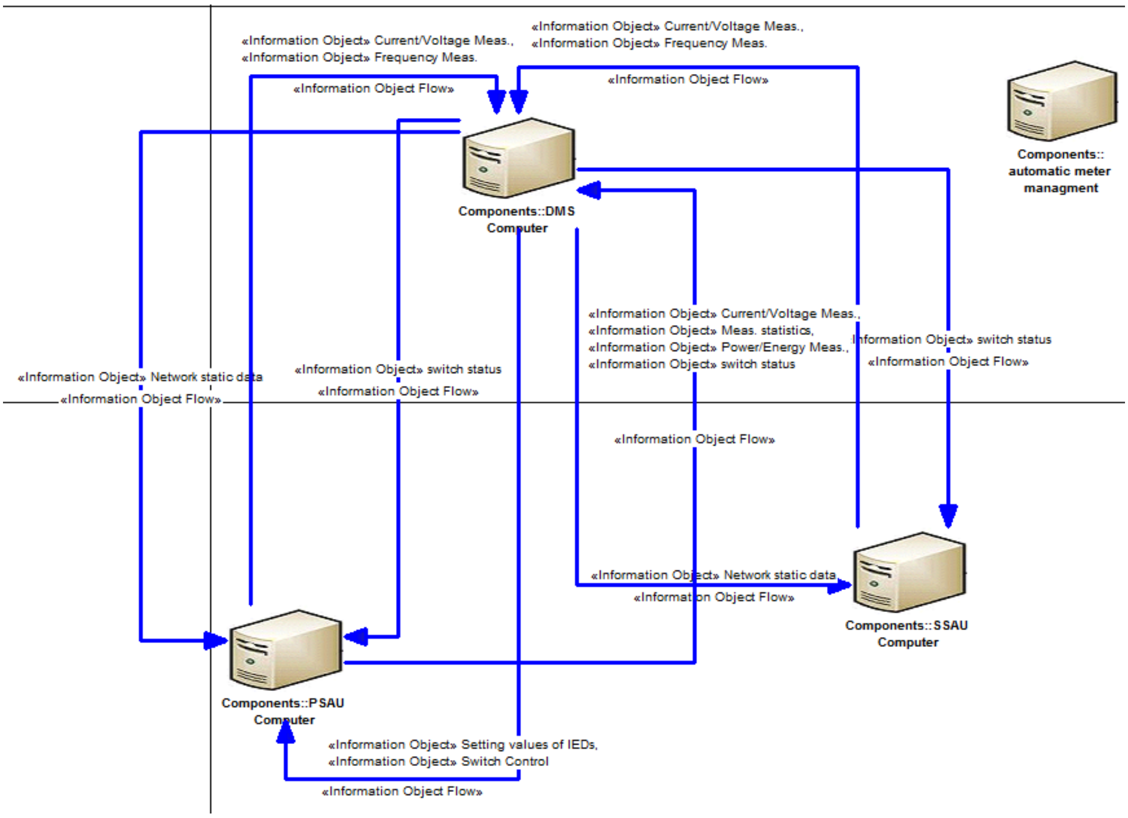

Figure 6-3-3 Information Object Flows between SAU and DMS

Table 6-3-B Information exchange between SAU and DMS

Information Object	data exchanged	Related use case - function
Current/Voltage measurement	Voltage magnitude	Dynamic Monitoring, MVRTM – Data report
	Current magnitude	
	Current phase angle	
	Voltage phase angle	
Frequency measurement	Frequency measurement	Dynamic Monitoring – Data report
measurement statistics	Statistical measurement	MVRTM – Data report
Network static data	CIM Network Model	NDU – Data report
Power/Energy measurement	Energy measurement	MVRTM – Data report
	Reactive power	
	Active power	
setting values of IEDs	Setting Values of IEDs	CCPC Realtime – Reading/Writing IEDs
Switch Control	Switch State Schedule	CCPC offline - Reading/Writing IEDs
Switch status	Switch status	LVRTM, MVRTM – Data acquisition, Data report

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DMS – IED data exchange

Figure 6-3-4 depicts Information Object Flow between DMS and IEDs. Information Objects details, as well as relevant use cases and functions, are further described by the following table.

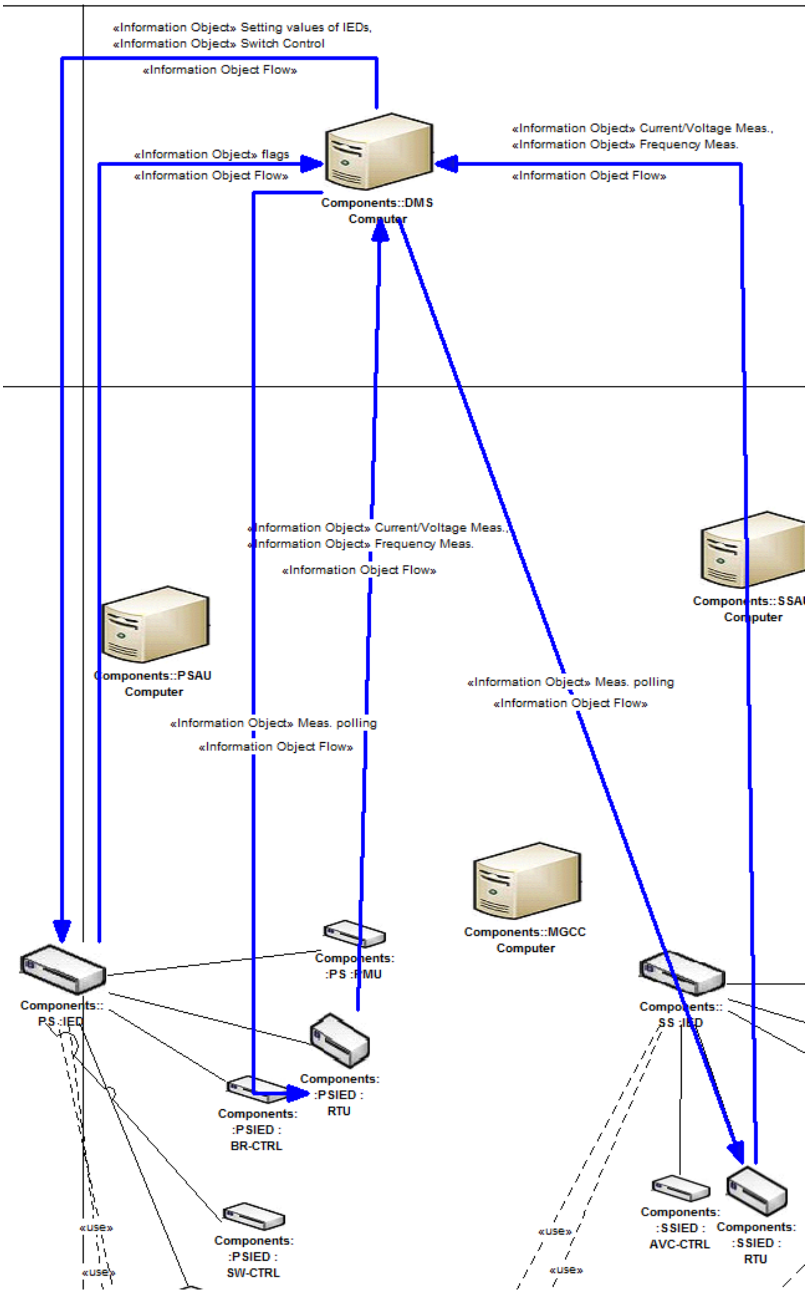

Figure 6-3-4 Information Object flows between DMS and IEDs

Table 6-3-C Information exchange between DMS and IEDs

Information Object	data exchanged	Related Use Case - Function
Current/Voltage measurement	Voltage magnitude	Dynamic Monitoring – Data acquisition
	Current magnitude	
	Current phase angle	
	Voltage phase angle	

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flags	Is data updated-Reply	CCPC offline – Check flag CCPC realtime – Reading/writing IEDs
Frequency measurement	Frequency measurement	Dynamic Monitoring - Data acquisition
measurement polling	Voltage magnitude polling	
	Current magnitude polling	
	Frequency measurement polling	
	Current phase angle polling	
	Voltage phase angle polling	
setting values of IEDs	Setting Values of IEDs	CCPC offline – Reading/Writing IEDs
Switch Control	Switch State Schedule	CCPC realtime – Reading/Writing IEDs

SSAU-IED data exchange

Figure 6-3-5 depicts Information Object Flow between secondary substation SAU and IEDs. Information Objects details, as well as relevant use cases and functions, are further described by the following table.

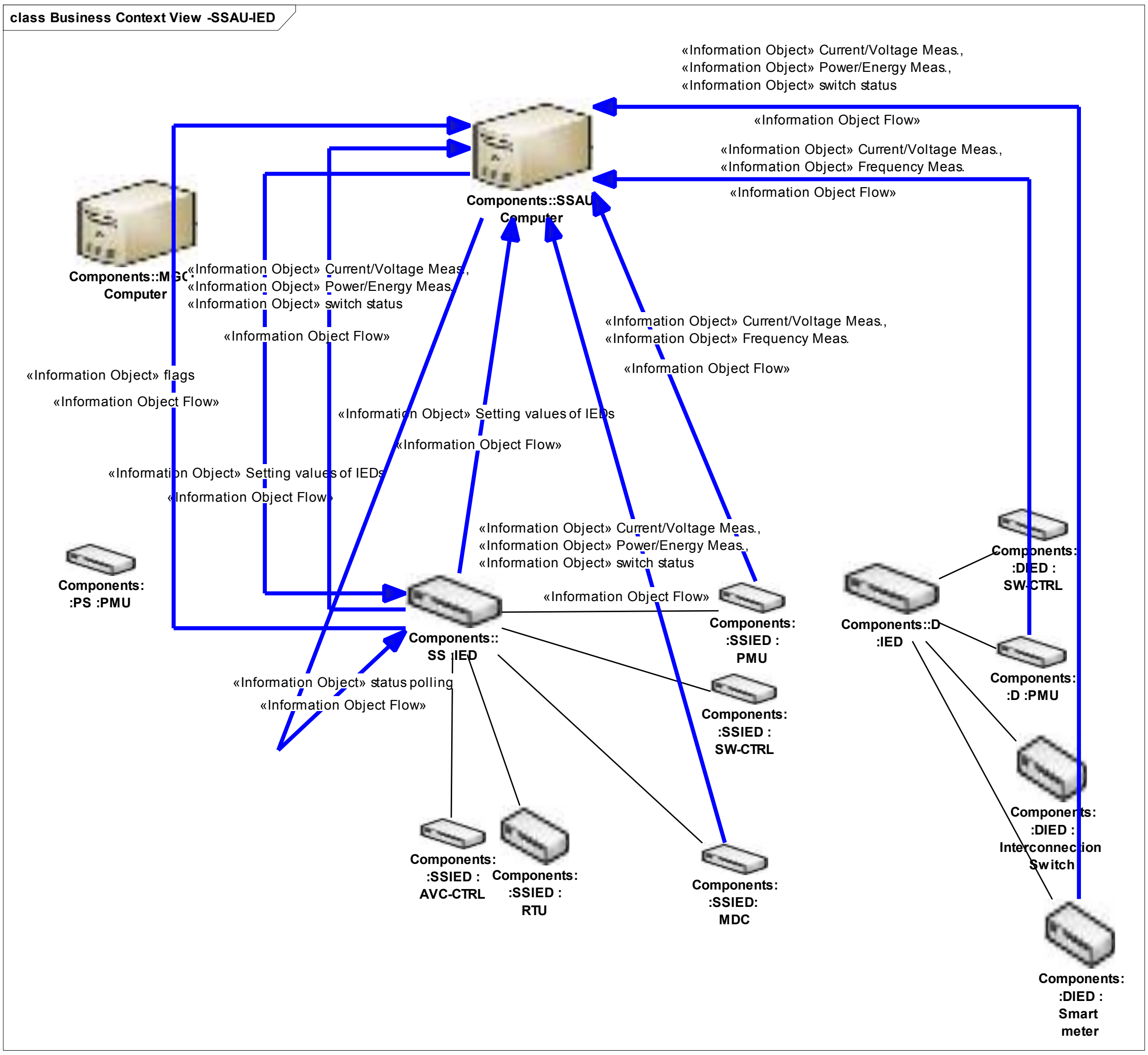

Figure 6-3-5 Information Object flows between SSAU and IED

Table 6-3-D Information Exchange between SSAU and IED

Information Object	data exchanged	Related Use Case - Function
Current/Voltage measurement	Voltage magnitude	Dynamic Monitoring – Data report LVRTM – Data acquisition
	Current magnitude	
	Current phase angle	
	Voltage phase angle	
flags	Confirmation of new IED settings	LVPC realtime – Check flag
Frequency measurement	Frequency measurement	Dynamic Monitoring – Data report
Power/Energy measurement	Reactive power	LVRTM – Data acquisition
	Active power	
	Energy measurement	
setting values of IEDs	Setting Values of IEDs	LVPC realtime – Reading/Writing IEDs
status polling	Setting Values of IEDs-Request	
Switch status	Switch status	LVRTM – Data acquisition

PSAU-IED data exchange

Figure 6-3-6 depicts Information Object Flow between primary substation SAU and IEDs. Information Objects details, as well as relevant use cases and functions, are further described by the following table.

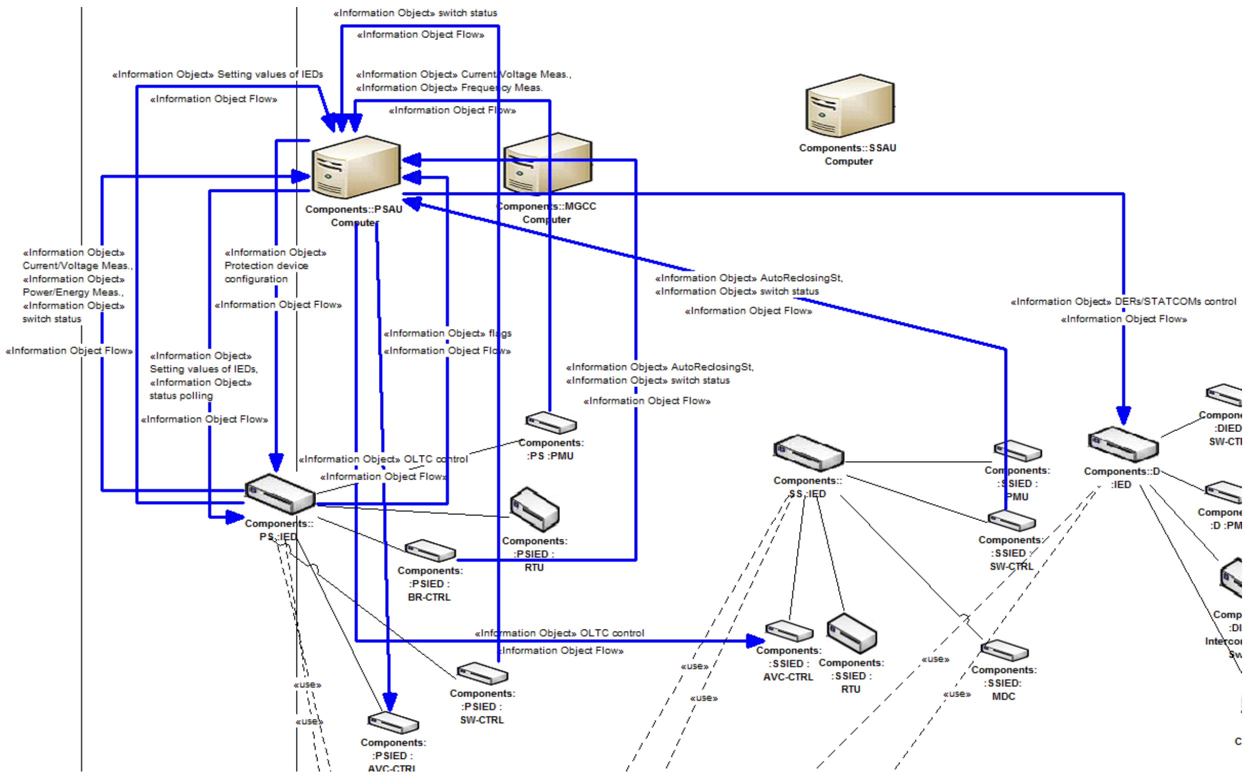

Figure 6-3-6 Information Object flows between PSAU and IED

Table 6-3-E Information exchange between PSAU and IED

Information Object	data exchanged	Related Use case - Function
AutoReclosingSt	AutoReclosingSt	FLISR – second fault isolation
Current/Voltage	Voltage magnitude	Dynamic Monitoring – Data report

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measurement	Current magnitude	MVRTM – Data acquisition
	Current phase angle	
	Voltage phase angle	
DERs/STATCOMs control	ON/OFF signal for function CF to other functions	Power Quality – Reading/Writing IEDs setting
flags	Is data updated-Reply	CCPC offline – Check flag CCPC realtime – Reading/Writing IEDs setting
	Confirmation of new IED settings	MVPC real time – Reading/Writing IEDs setting
Frequency measurement	Frequency measurement	Dynamic Monitoring – Data report
OLTC control	OLTC block and unblock signals	BOT – Reading/Writing IEDs setting
Power/Energy measurement	Energy measurement	MVRTM – Data acquisition
	Reactive power	
	Active power	
Protection Device Configuration	Protection Device Configuration	PCU – Protection update
setting values of IEDs	Setting Values of IEDs	MVPC realtime – Reading/Writing IED setting
status polling	Setting Values of IEDs-Request	
Switch status	Switch status	MVRTM – Data acquisition
	Breaker or switch status (Open)	FLISR – Fault isolation, Secondary Fault isolation
	Breaker or switch status (Trouble)	FLISR – Secondary Fault isolation

MGCC-others data exchange

Figure 6-3-7 depicts Information Object Flow between MGCC and other actors. Information Objects details, as well as relevant use cases and functions, are further described by the following table.

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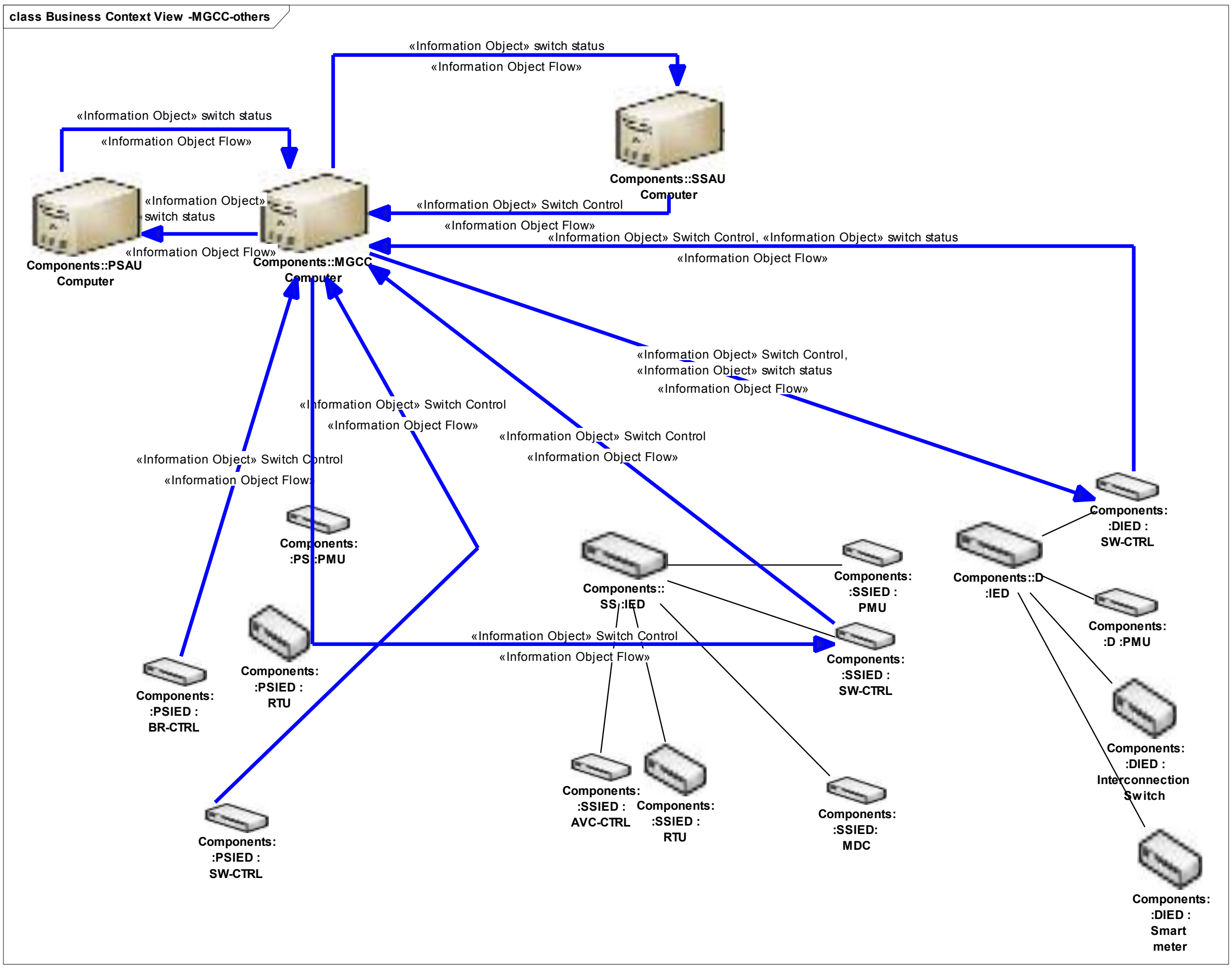

Figure 6-3-7 Information Object flows between MGCC and others

Table 6-3-F Information exchange between MGCC and others

Information Object	data exchanged	Related Use case - Function
Switch Control	Block message	Microgrid FLISR – Reading/Writing IEDs setting
	Block message (block disconnection)	FLISR – Fault isolation, Second fault isolation
	Block message (block connection)	
	Block message (unblock connection)	
Switch status	Breaker or switch status	Microgrid FLISR – Data report, Reading/Writing IEDs setting, synchronization
	Breaker or switch status (Open)	FLISR - Secondary Fault isolation

CA – others (MO, TSO excluded)

Figure 6-3-8 depicts Information Object Flows between Commercial Aggregator System (CA) and other actors. Information Objects details, as well as relevant use cases and functions, are further described by the following table. Note that this figure and table do not include Information Object Flows between CA and TSO or Market Operator Platform (MO), because they will be presented in other subsections.

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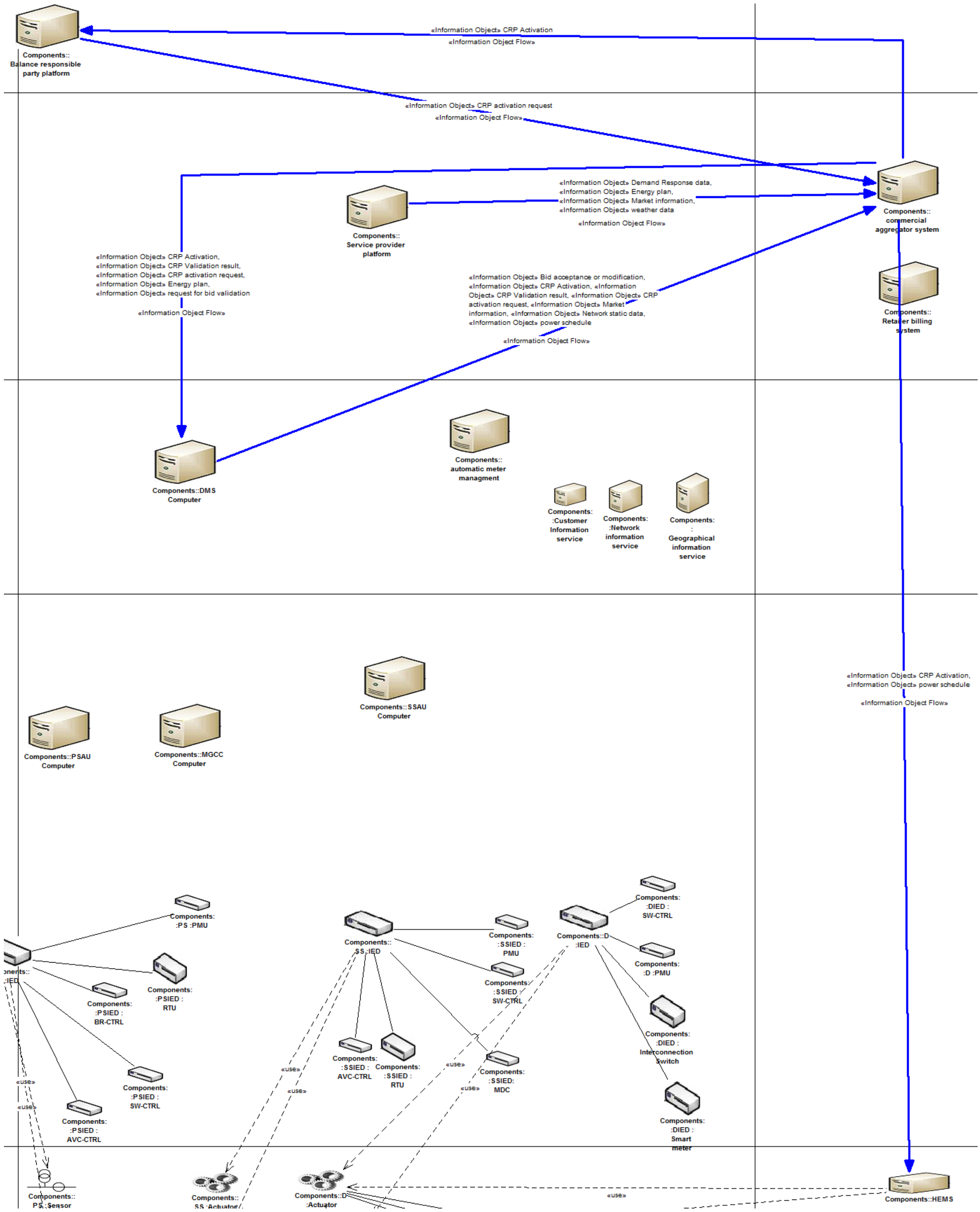

Figure 6-3-8 Information Object flows between CA and others

Table 6-3-G Information exchange between CA and others

Information Object	data exchanged	Related Use case - Function
Bid Acceptance or Modification	Bid Acceptance or Modification	Real time validation – validation reply
bid validation request	validation request	Real time validation – validation request

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CRP Activation	ON/OFF CRP	CCPC real time – CRP activation UC
	CRP Activation	CRP activation – Data report, Reading/Writing IEDs setting
CRP activation request	Request for CRP Activation	Real time validation – validation request CRP activation – CRP activation request
CRP validation result	validation results	CRP activation – CRP validation request, Real time validation UC
Energy plan	Energy plan	DR – Data report
	DER and switch schedules	CAEP – Data storage
Demand Response data	Demand data	CAEP – Data storage
Market information	Grid tariff	DR – Data report
	Forecasted energy price	DR – Data storage
Network static data	Configuration of the Load Areas	Load area – Data report
Power schedule	Power schedule	CCPC offline – CRP activation UC CAEP – Reading/Writing IEDs setting
Weather data	Environment temperature	DR – Data storage
	Meteorological Forecast	CAEP – Data storage

TSO-others

Figure 6-3-9 depicts Information Object Flows between TSO and other actors. Information Objects details, as well as relevant use cases and functions, are further described by the following table.

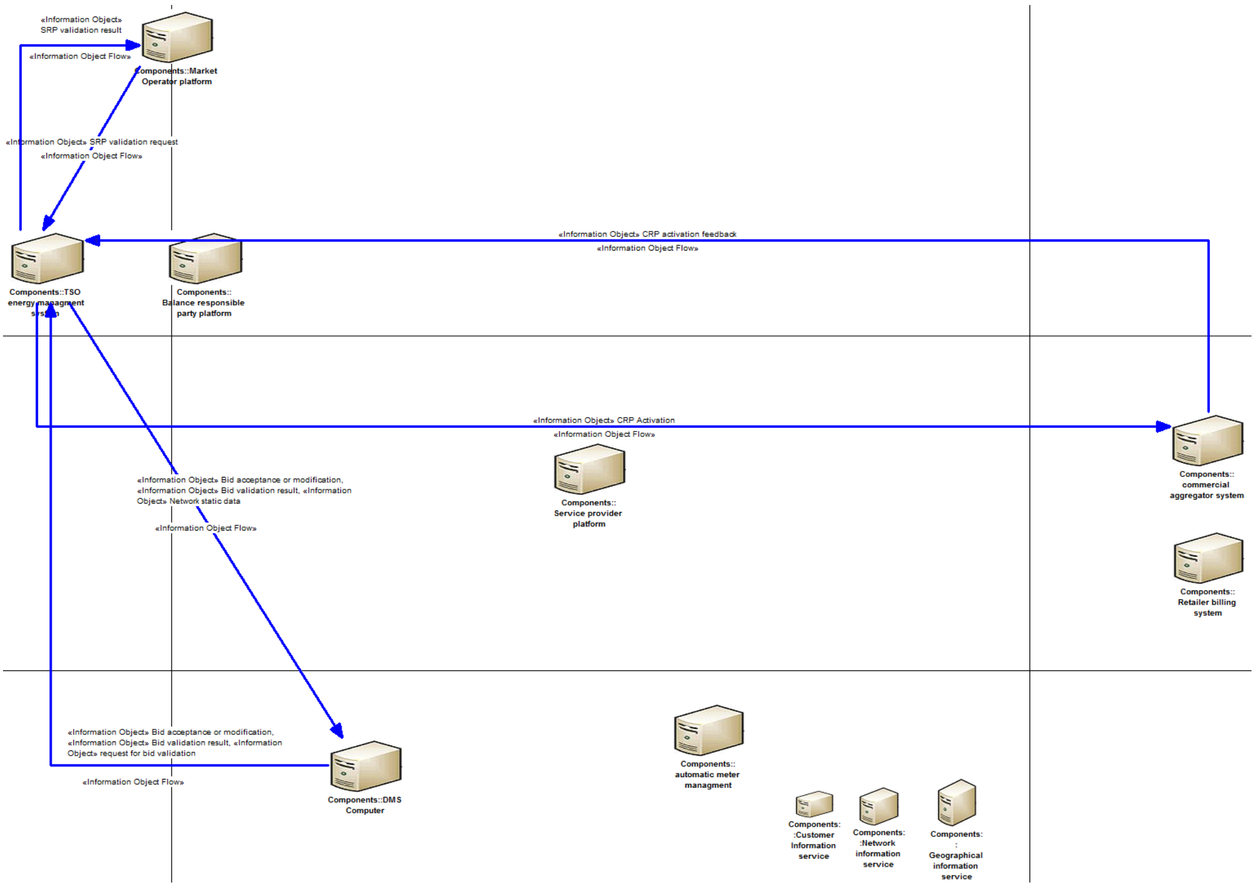

Figure 6-3-9 Information Object flows between TSO and others

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Table 6-3-H Information exchange between TSO and others

Information Object	data exchanged	Related Use case - Function
Bid Acceptance or Modification	Bid Acceptance or Modification	Off line validation – Data report, Validation reply, Power flow
bid validation request	Request for Validation (by TSO)	Off line validation – Power flow Real time validation – Data report
bid validation result	Response of TSO	Real time validation – Data report, Power flow, Validation reply
Network static data	Configuration of the Macro Load Areas	Load area – Data report
SRP validation request		As TSO is out of the scope of IDE4L project, these information flows are not implemented.
SRP validation result		
CRP Activation		
CRP Activation feedback		

MO – others (TSO excluded)

Figure 6-3-10 depicts Information Object Flows between Market Operator Platform (MO) and other actors. Information Objects details, as well as relevant use cases and functions, are further described by the following table. This figure and table do not include Information Object Flows between MO and TSO, because they are presented in other subsection.

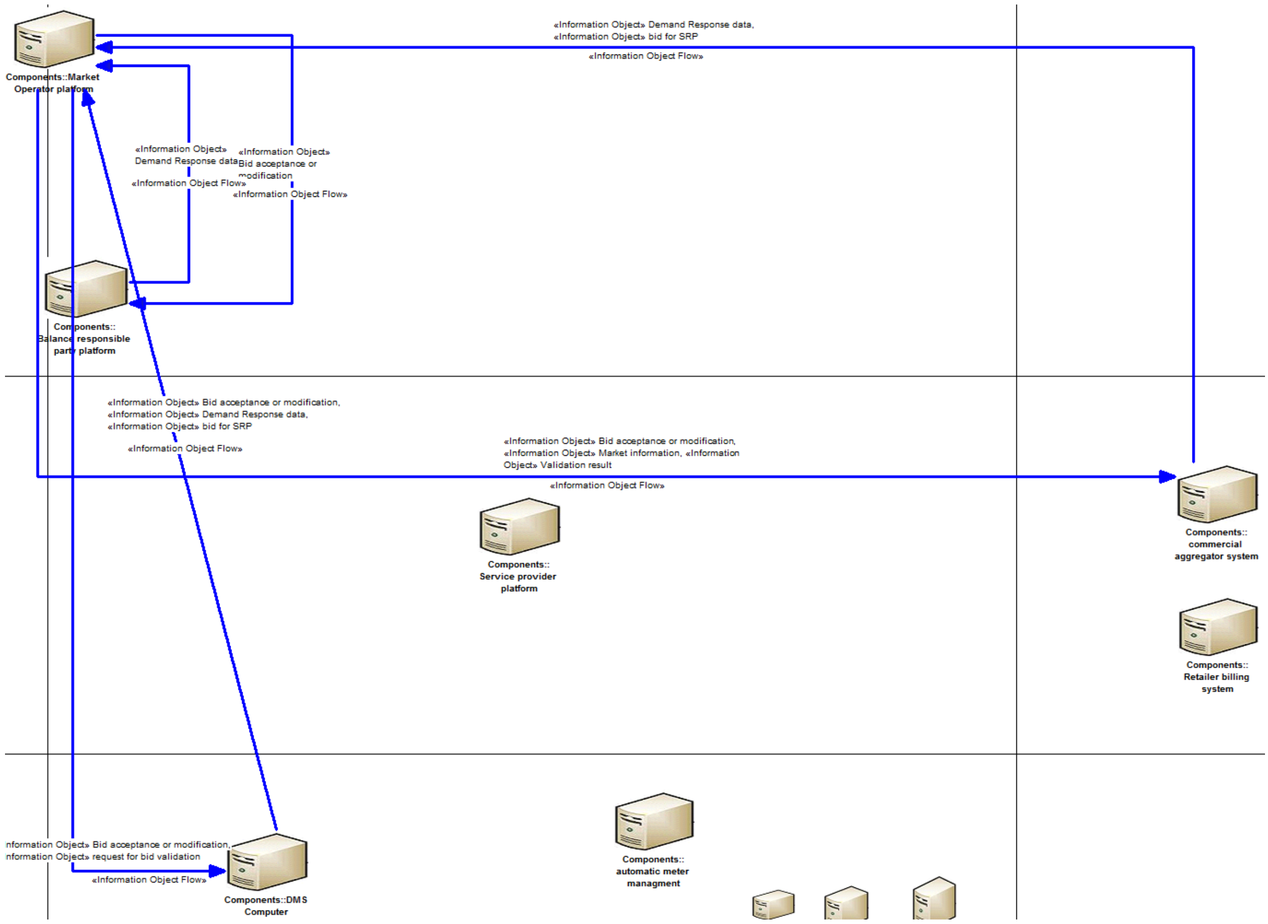

Figure 6-3-10 Information Object flows between MO and others

Table 6-3-I Information exchange between MO and others

Information Object	data exchanged	Related Use Case - Function
Bid Acceptance or Modification	Bid Acceptance or Modification	SRP procurement – Bid acceptance/modification. Off line validation – Validation reply
Demand Response Data	Flexibility Demand	SRP procurement – Bid submission
	Flexibility Offer	
bid validation request	Request for bid Validation (by DSO.Technical aggregator)	Off line validation – Validation request
Validation result	Validation result	CAEP – Offline validation UC, Real-time validation UC
Market information	Market Gate-opening signal	SRP procurement – Market infos
	Market Gate closure	
SRP bid	Bid for SRP	CCPC realtime – SRP day-ahead and intra-day market procurement UC. CAEP – bid submission

Utilization of Standards

The second part of Information Layer is Canonical Data Model view, which identifies suitable data model standards to describe these Information Objects. From the following SGAM Toolbox screenshot, you can see that IDE4L project uses three data model standards: DLMS/COSEM, IEC 61850-7-4 and 420, and CIM model.

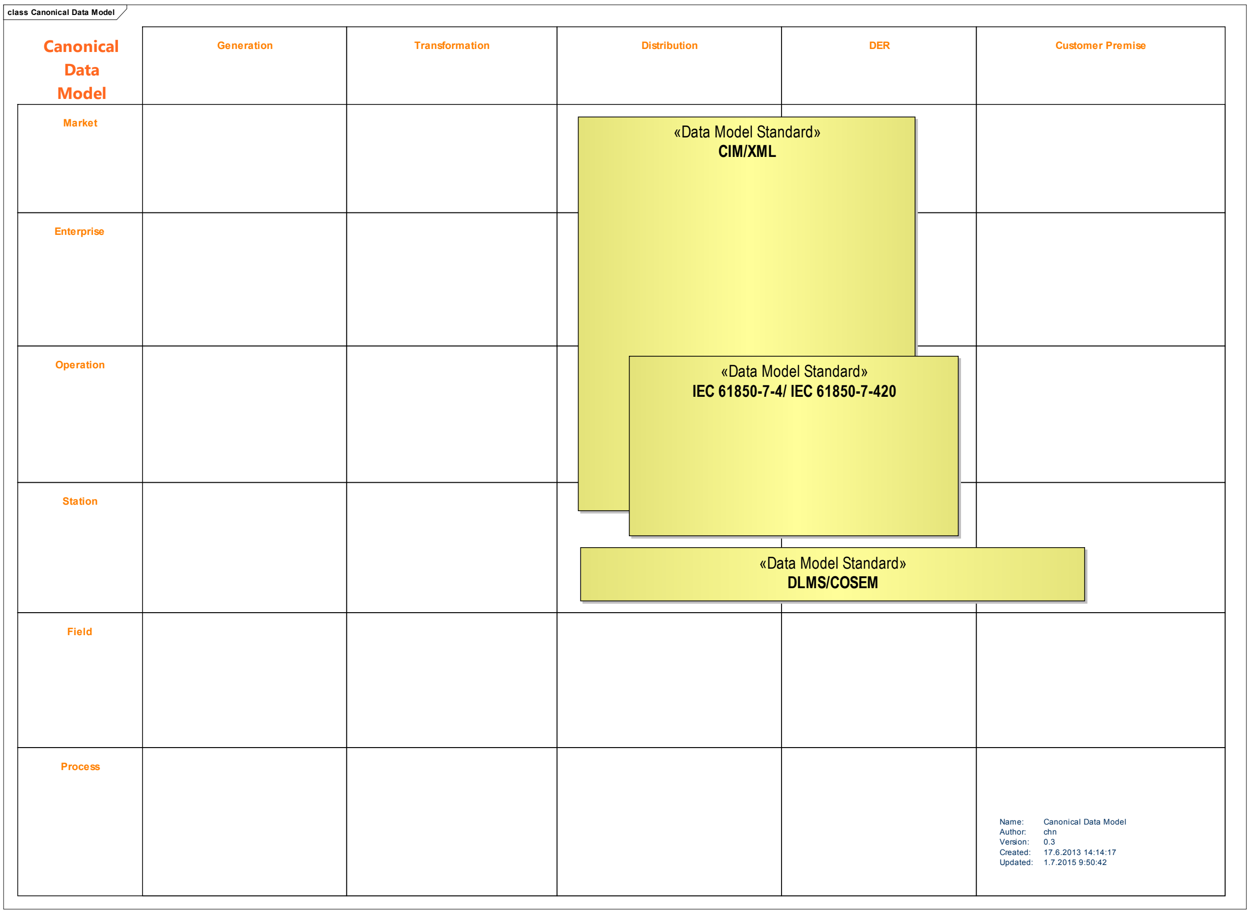

Figure6-3-11 Canonical Data Model view

DLMS/COSEM

COSEM uses object modelling techniques to model all functions of the meter. The utility meter is modelled as a server application. The server offers means to retrieve the functions supported, i.e., the COSEM objects instantiated. COSEM Interface classes are defined in IEC 62056-6.

In IDE4L project, SAU uses COSEM Interface classes to read smart meter from customers' premises and from DER. Hence, it covers SGAM Zone of Station, Domain of Distribution down to Customer's premises.

IEC 61850 data model

IEC 61850 data model is defined in IEC 61850-7-3, IEC 61850-7-4 and IEC 61850-7-420 standards. IDE4L project heavily relies on IEC 61850 data model, using it for exchanging data in SGAM Zone of Station and Operation, Domain of Distribution and DER.

As manifested in Section 7.1, Appendix D3.2-S8-MonLNs.xlsx and D3.2-S8-CtrlLNs.xlsx, IEC 61850 data model is used by Monitor and Control cluster use cases, to allow SAU, MGCC and IEDs - in some case also DMS – communicate with each other using IEC 61850/MMS communication protocol. Besides, inside SAU database where different internal software components exchange input/output, data are also presented according to 61850 data model.

CIM model

CIM model is defined in IEC 61970-301, IEC 61968-11, and IEC 62325-301 standards. As shown in the Canonical Data Model view, CIM model covers SGAM Domains of Distribution and DER, from Station Zone up till Market Zone. In IDE4L use cases, the application of CIM model falls into two categories. The first is for describing the static feature of the network, such as topology, asset information and customer information. This is needed by use cases like "NDU" and "Load Area", etc. The integration technology is relational database. For details, see Section 7.4. The second application of CIM model is for messaging among DSO enterprise systems. This is needed by most of Business cluster use cases, e.g., "Demand Response", "SRP procurement", etc. The integration technology is Web Service. The detail is presented in Section 7.2.

6.4 Function layer.

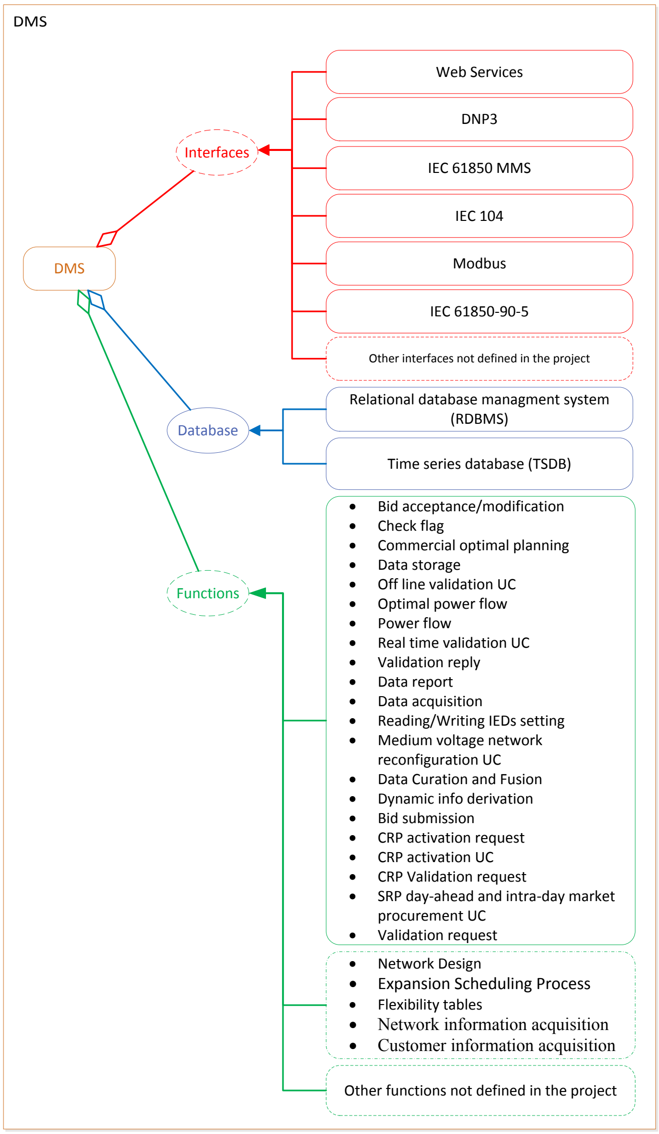

Figure 0-4 DMS interfaces, databases and functions

The substation automation unit, shown in Figure 0-5, is a unit taking care of measurement collection, state estimation and forecast and network control. It represents a level of automation between control center and IED, and allows the DSO to better distribute the burden of information and computation. The Substation Automation Unit is the device in charge of managing the distribution network fed by the substation where it is located on behalf of the control center. The SAU come in to flavors:

- The PSAU located into a primary substation and managing the MV grid
- The SSAU located into a secondary substation and managing the LV grid

The SAU contains several interfaces to communicate both with DSO's IEDs and prosumers' IEDs:

- The MMS – recommended by the IEC 61850 – as a protocol for the telecontrol of the network
- The IEC 104 – by means of a dedicated gateway that realizes the translation from IEC 104 to IEC 61850 MMS
- The DLMS/COSEM to communicate with smart meters
- Web services where smart meters are not directly accessible. In that case the SAU collects these data through the Meter Data Concentrator (another IED) or through the AMM.
- The 61850-90-5/C37.118 to exchange data with PMUs
- The Modbus to communicate with some primary controllers not available today with a native 61850 interface
- Also the IEC 104 interface is considered. It should be noticed however that in practical IDE4L DEMOs the interface is realized through a dedicated device that act as gateway IEC 104 to IEC 61850 MMS.

The database of the SAU is mainly a relational database management system, but the SAU also supports a time-series database for managing PMU data.

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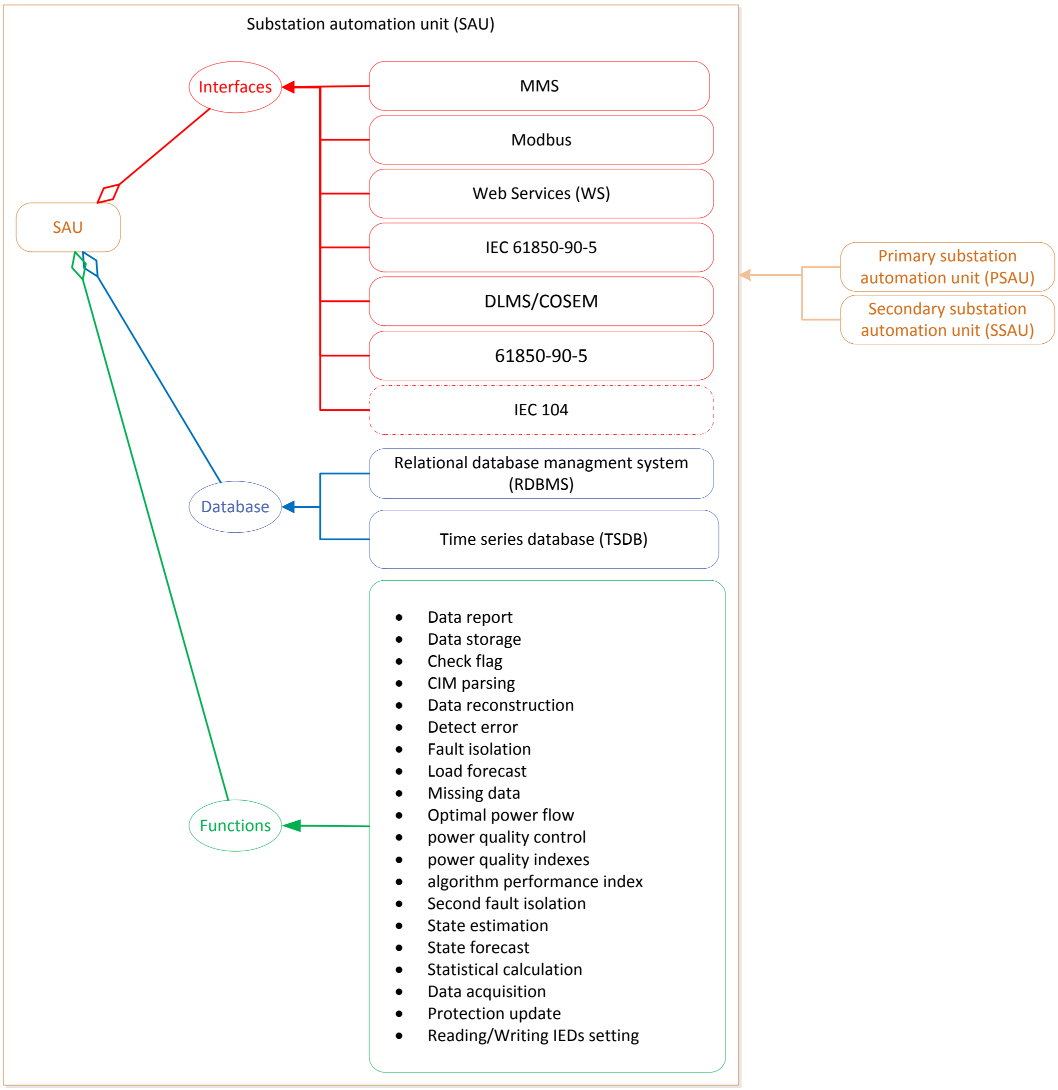

Figure 0-5 SAU interfaces, databases and functions

The IED is a generic electronic device used for monitoring, controlling or protecting the distribution grid and a microgrid. Fall into this category, RTUs, PMUs, Smart Meter and the Home Energy Management System.

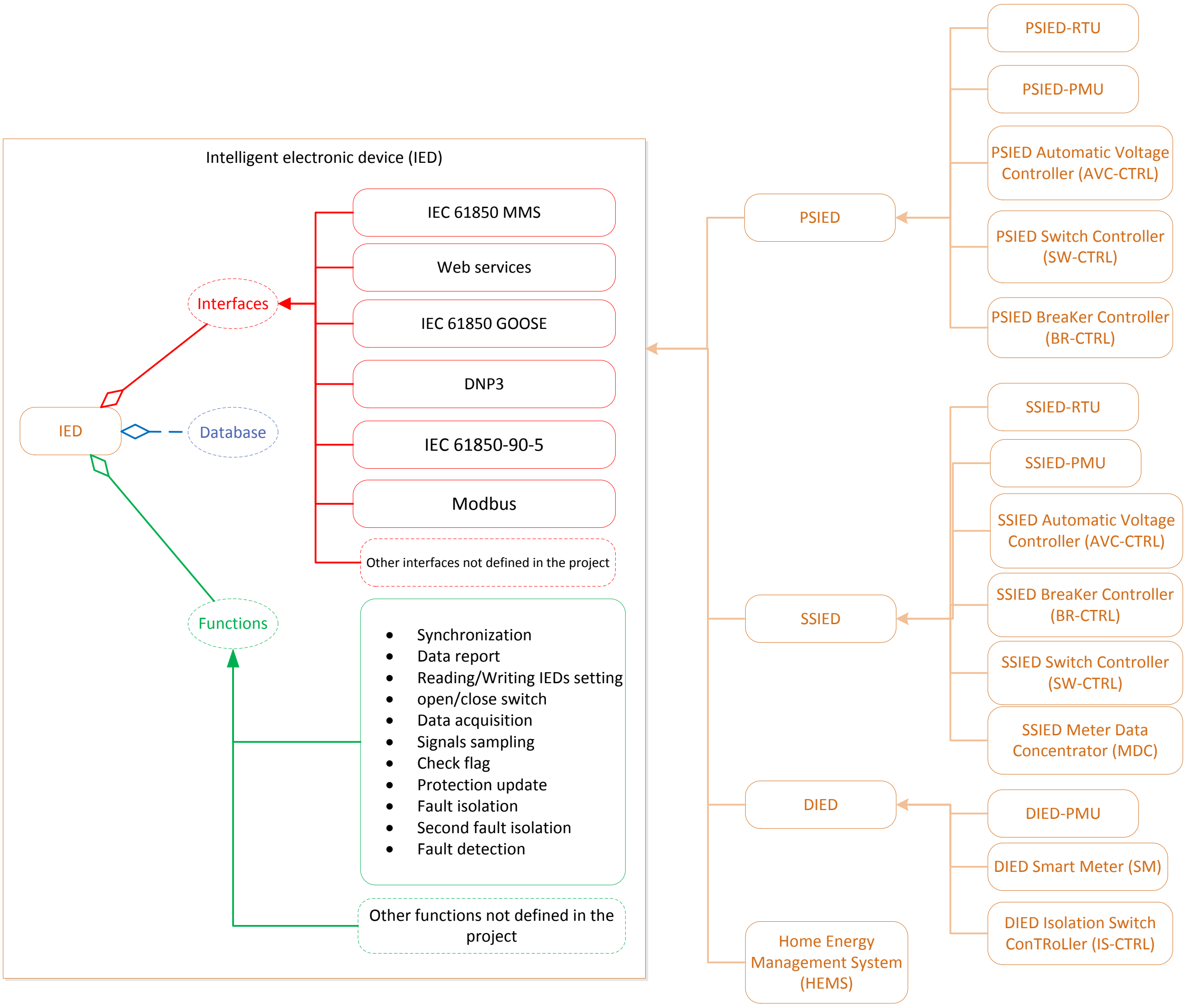

Figure 0-6 IED interfaces, database and functions

IEDs may have several instances: a first classification has been done based on the location of the IED. In this way there are the Primary Substation IED (PSIED), the Secondary Substation IED (SSIED), the distributed IED (DIED) representing out of substation IEDs and the Home Energy Management System (HEMS) that represent the interface of the user to the commercial aggregator and the platform that the prosumer may use to manage its own DERs. PSIED, SSIED and DIED may have other classes as switch and breakers controllers, Automatic Voltage Controllers (AVCs) at On- Load Tap Changers (OLTCs); moreover several type of IEDs instances in terms of measurement devices are possible, such as Smart Meters (SMs), Meter Data Concentrators (MDCs), Remote Terminal Units (RTUs), Phasor Measurement Units (PMUs).

Smart Meters are devices normally used to measure electrical energy for billing purposes, but in iDE4L project intended to provide to meter data concentrators, AMMs and SAUs, other power system quantities such as voltage and current magnitudes and active and reactive power consumption, through DLMS/COSEM protocols and wireless, PLC and communication technologies.

RTUs are electronic devices, interfaced with the distribution management system (in other cases called supervisory control and data acquisition (SCADA), but for the sake of IDE4L project ,correspondent to DMS) with Modbus or DNP3 protocol [], providing substation measurements , such as active and reactive power flows and voltage magnitude.

PMUs are electronic devices, providing voltage and current phasors with high reporting rates (up to 50 per second [] in 50 Hz systems) exploiting the Global positioning system (GPS) Coordinated Universal Time (UTC) as reference for the phase angle information. It allows to realize high precision real time and off line monitoring both for distribution and transmission operators. In IDE4L project dynamic information's are collected by the DSO, through the automation actor DMS, and forwarded to transmission system operator energy management system regularly.

DSO's owned resources for low voltage and medium voltage power control may be OLTCs, photovoltaic systems and wind generators. They should all have dedicated IEDs connected with IEC 61850 MMS protocol to SAUs in order to send measurements and receive control set points.

Other important automation actors managed by DSOs are the AMM, which collects the measurements from smart metering devices. The IDE4L architecture proposed initially the secondary SAU aggregation level for such measurements, given that it is technically complex to concentrate a large number of measurements with fast reporting rates in a single point at the control center; but considering that some existing architectures leverage already on AMMs, also this possibility is considered.

The CIS is the system where the customer information is stored and may be updated. The GIS contains geographic information about the distribution network. The NIS finally contains information about topologies, cables and other components in the network.

Table 0-C Other enabling technologies for DSO

Short name technology	Extended name technology	Object class
Human machine interface DSO	Human machine interface DSO	Human machine interface
DSO Control center switch	DSO Control center switch	Switch
Primary Substation switch	PS switch	Switch
Secondary Substation switch	SS switch	Switch
LV cabinet switch	LV cabinet switch	Switch
ICT connection control center switch – PS switch	ICT connection control center switch – Primary Substation switch	ICT connection
ICT connection control center switch – SS switch	ICT connection control center switch – Secondary Substation switch	ICT connection
ICT connection control center switch – SS switch	ICT connection control center switch – Secondary Substation switch	ICT connection
ICT connection LV cabinet – SS switch	ICT connection LV cabinet – Secondary Substation switch	ICT connection
LAN control center	Local Area Network control center	ICT connection
LAN PS	Local Area Network Primary Substation	ICT connection
LAN SS	Local Area Network Secondary Substation	ICT connection
LAN LV cabinet	Local Area Network Low Voltage cabinet	ICT connection

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PS sensor	Primary Substation sensor	Sensor
SS sensor	Secondary Substation sensor	Sensor
D sensor	Distributed sensor	Sensor
PS actuator	Primary Substation actuator	Actuator
SS actuator	Secondary Substation actuator	Actuator
D actuator	Distributed actuator	Actuator

Automation actors invoked by commercial aggregator

The commercial aggregator is a key business actor proposed in several European projects [] and further developed in IDE4L project. The only automation actor exploited is the so-called “commercial aggregator system” which represent a generic hardware able to carry the optimization algorithm to manage the distributed energy resources and prepare SRPs and CRPs bills, the interfaces, mainly web services, to electrical markets, for selling SRPs and CRPs, to DSOs and TSOs to receive the response of validation procedures, and home energy management systems to activate the products sold in the market. This last interface is also critical as it is important to activate the sold bills with sufficient time accuracy. Such computation effort, is in IDE4L, generically mapped in a computer, but as proposed in [], it can be more efficiently performed on distributed clouds platforms, where the business actor commercial aggregator can access to set the main economic parameters.

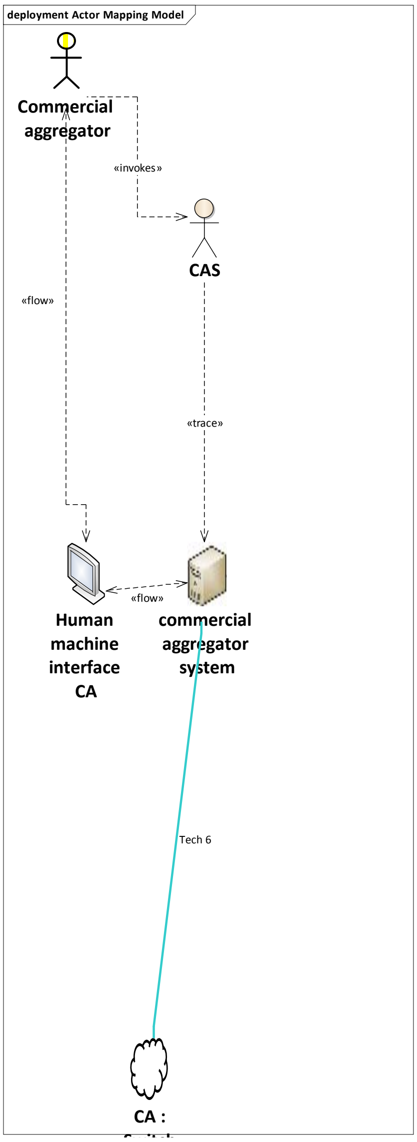

Figure 0-7 Automation actors invoked by Commercial aggregator

Table 0-D Components invoked by technical actor of DSO

Short name technical actor	Short name technology	Extended name technology	Object class
CAS	Commercial aggregator system	Commercial aggregator system	Computer

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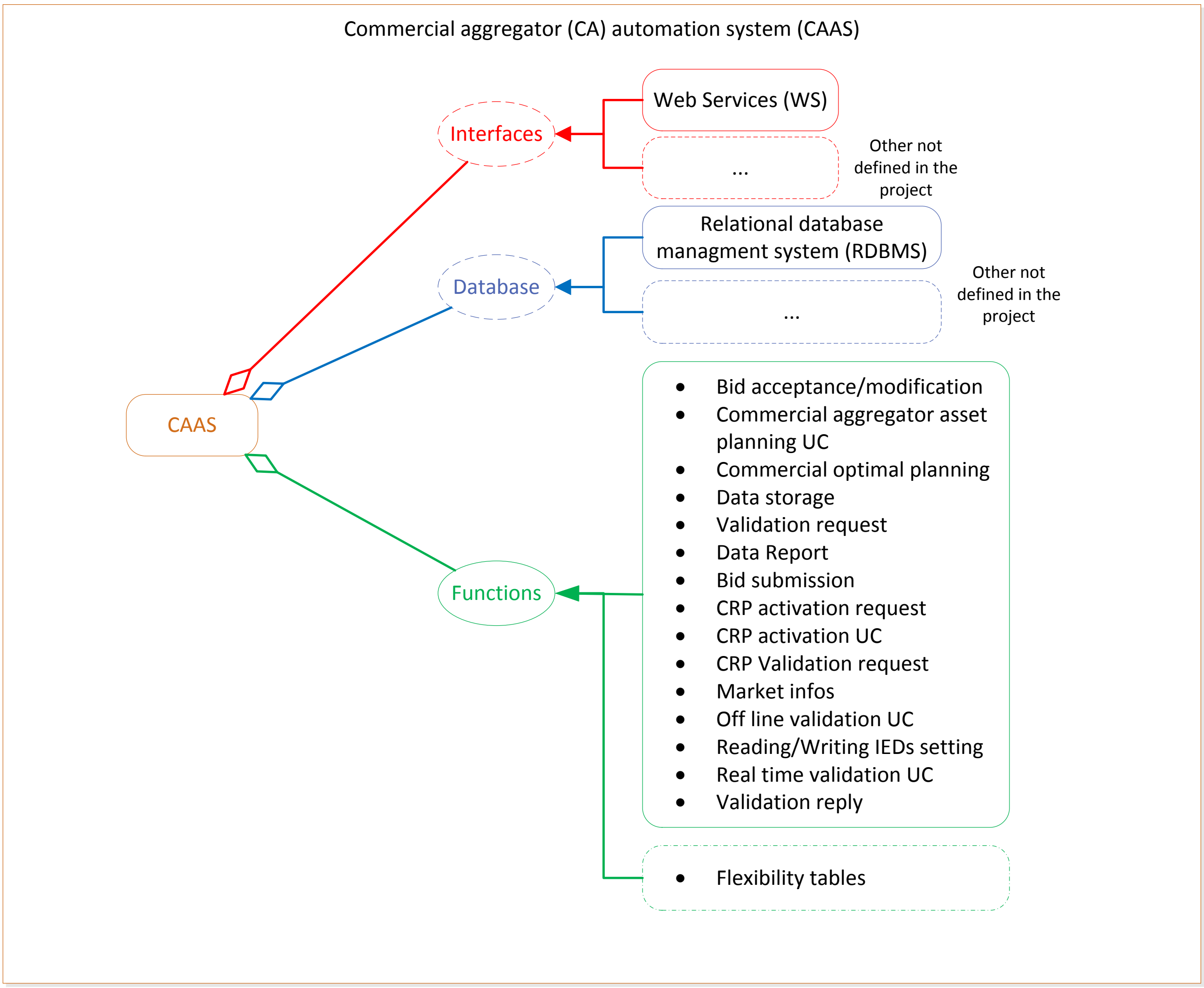

Table 0-E Other enabling technologies for commercial aggregator

Short name technology	Extended name technology	Object class
Human machine interface CA	Human machine interface Commercial aggregator	Human machine interface
CA switch	Commercial aggregator switch	Switch

Automation actors invoked by Prosumer business actor

Prosumer can manage its own domestic private grid or a so called “micro-grid”. In both the cases the prosumer is served by some optimal functions either in Home energy management system or in micro-grid central controller for the optimal management of the prosumer distributed energy resources, and sold to a commercial aggregator. The micro-grid can be disconnected in case of fault and its reconnection being coordinated by the primary substation automation unit. Consequently the micro-grid could be managed as a power island in case of faulty condition in the main grid.

Technical actors invoked by Prosumer as single customer

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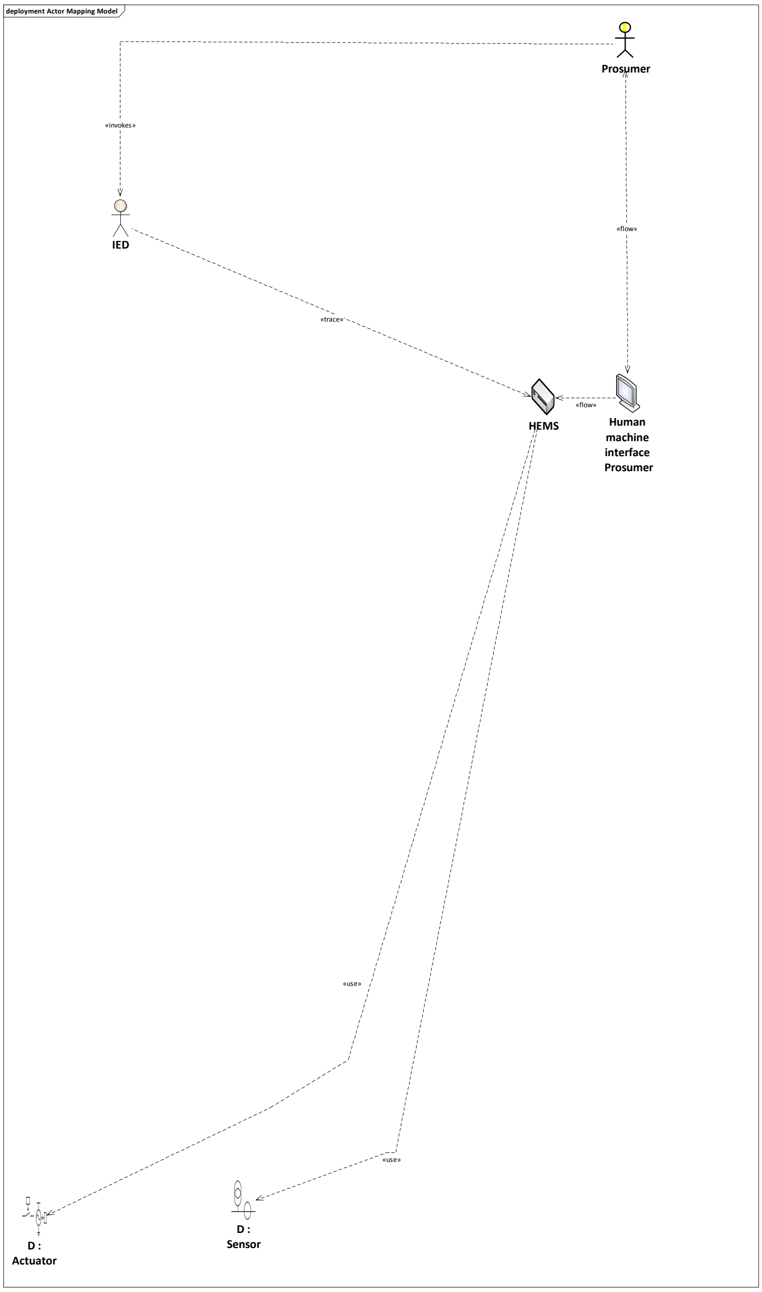

Figure 0-8 Automation actors invoked by Prosumer as single customer

The Home Energy Management System is an instance of IED as shown in Figure 0-6. Its main features should be to provide the prosumer the possibility to set its preferences with regard to his DERs exploitation. Such plan should be converted in terms of flexibility offers and energy offers to commercial aggregator. Then the accepted offers, both flexibility and energy, will be communicated back from commercial aggregator to HEMS, that will activate them through the determined actuators, such as electric vehicles, PVs, wind generators, CHPs, HPs, electrical storage or controllable loads actuators.

Figure 0-9 Technical actors invoked by Prosumer as single customer

Short name technical actor	Short name technology	Extended name technology	Object class

IED	HEMS	Home Energy management system	Device

Other enabling technologies for commercial aggregator

Short name technology	Extended name technology	Object class
Human machine interface Prosumer	Human machine interface Prosumer	Human machine interface
Prosumer switch	Prosumer switch	Switch
D sensor	Distributed sensor	Sensor
D actuator	Distributed actuator	Actuator

Technical actors invoked by Prosumer as Microgrid manager

Prosumers that manage a microgrid, not only have the right to control and sell energy and flexibility services from their owned DERs, but also the possibility to operate in island mode during faults or congestions in the main distribution grid. The microgrid is involved during the FLISR phases by IEDs and SAUs, provoking isolation from the main grid; consequently the microgrid is reconnected during the recovery phase through the isolation switch. The management of the microgrid during the island mode and the process of synchronization to the main grid before the reconnection are taken by the microgrid central controller, whose interfaces, database and functions are shown in Figure 0-11. In particular among the actuators, the switch controlled by the Isolation switch controller has to be taken into account.

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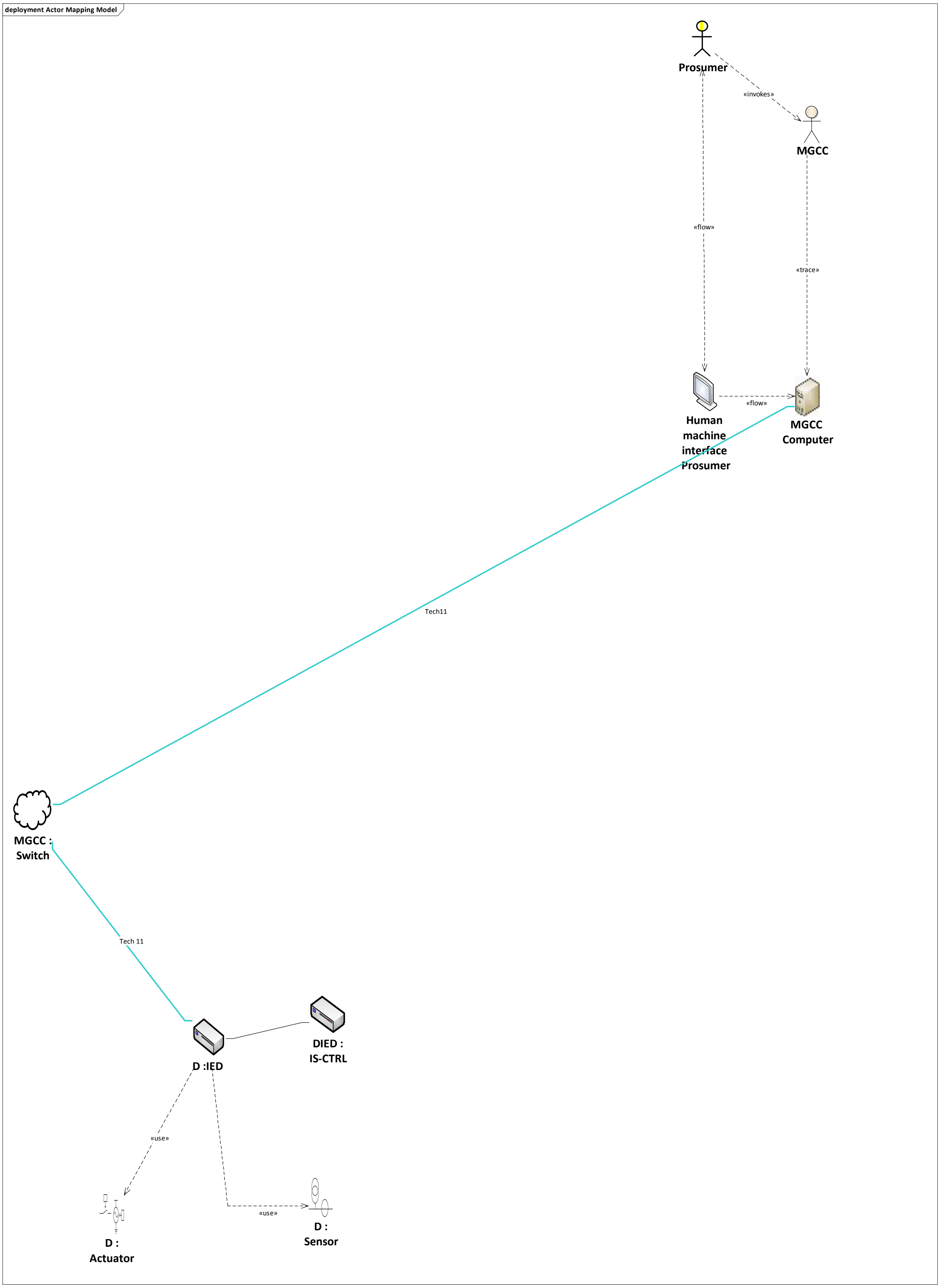

Figure 0-10 Automation actors invoked by Prosumer as Microgrid manager

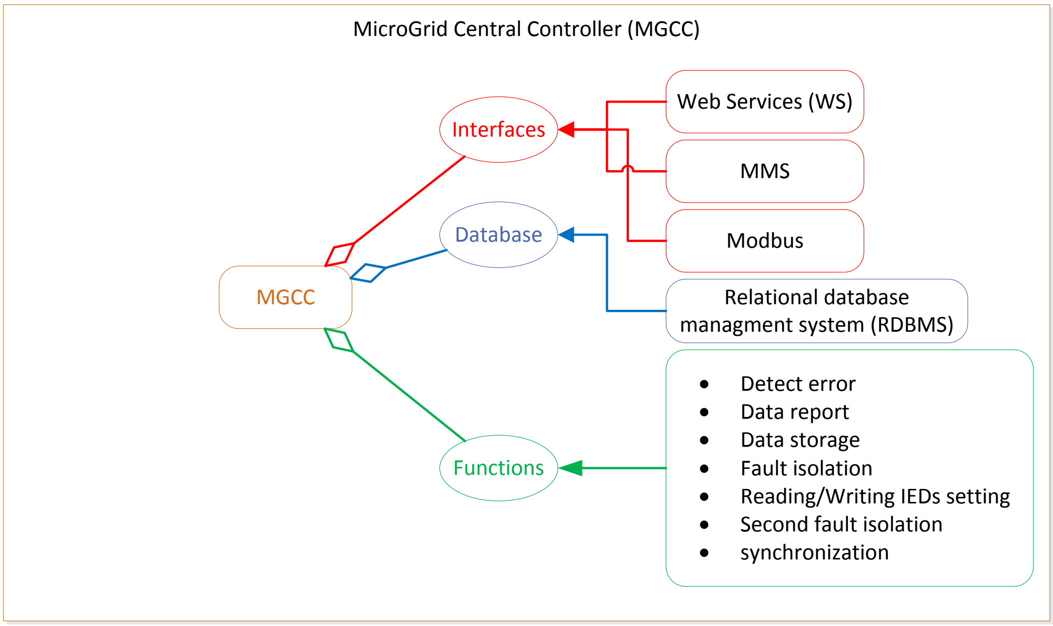

Figure 0-11 Microgrid central controller interfaces, database, functions

Short name technical actor	Short name technology	Extended name technology	Object class
MGCC	MGCC	MicroGrid Central Controller	Computer
IED	DIED.IS-CTRL	Distributed IED, Isolation switch controller	Device

Table 0-F Other enabling technologies for Prosumer as Microgrid manager

Short name technology	Extended name technology	Object class
Human machine interface Prosumer	Human machine interface Prosumer	Human machine interface
MGCC switch	MicroGrid Central Controller switch	Switch
D sensor	Distributed sensor	Sensor
D actuator	Distributed actuator	Actuator

Other business actors such as Transmission System Operator, Service providers, Balance responsible Party, Market Operator and Retailer, that have been not further developed in IDE4L project, but have found to provide inputs and outputs in the automation system are mapped onto components in Figure 0-12. For all the actors a human interface is needed to permit the enterprise to set its own parameters, then a computation unit, here represented as a computer, but that could also be realized in cloud platform, takes care of running the functions, interfaces and databases.

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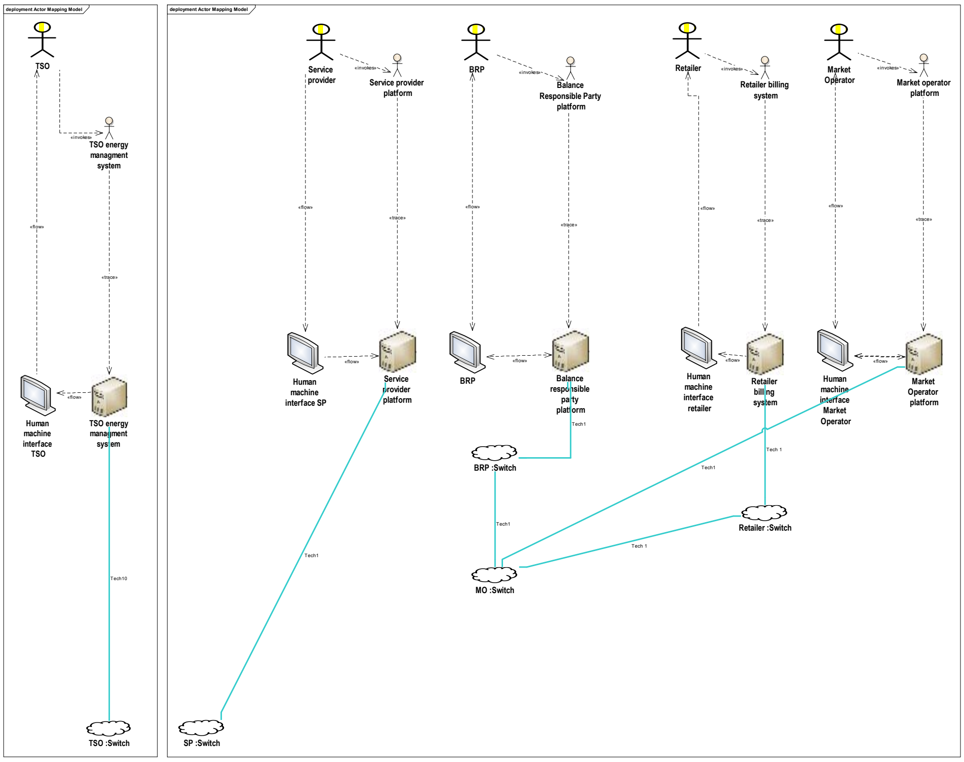

Figure 0-12 Automation actors invoked by Transmission System Operator, Service providers, Balance responsible Party, Market Operator and Retailer

Table 0-G

Short name technical actor	Short name technology	Extended name technology	Object class
TSOEMS	TSOEMS	Transmission system energy management system	Computer
SPP	SPP	Service provider platform	Computer
BRPP	BRPP	Balance responsible party platform	Computer
RBS	RBS	Retailer billing system	Computer
MOP	MOP	Market Operator platform	Computer

Table 0-H Other technologies used by Transmission System Operator, Service providers, Balance responsible Party, Market Operator and Retailer

Short name technology	Extended name technology	Object class
Human machine interface TSO	Human machine interface Transmission System Operator	Human machine interface
Human machine interface SP	Human machine interface Service Provider	Human machine interface
Human machine interface BRP	Human machine interface Balance	Human machine interface

	responsible party	
Human machine interface Retailer	Human machine interface Retailer	Human machine interface
Human machine interface MO	Human machine interface Market Operator	Human machine interface
TSO switch	Transmission System Operator switch	switch
SP switch	Service Provider switch	switch
BRP switch	Balance responsible party switch	switch
Retailer switch	Retailer switch	switch
MO switch	Market Operator switch	switch

It may be noticed that no further details are given on sensors and actuators as this is not the main interest of IDE4L project. Practical instances will be provided in the lab and field demo sites. Voltage and current sensors are required at the substations and LV cabinets where smart meters are connected. Switches and breakers are also used at substation level. The micro-grid should be equipped with voltage and current sensor and the isolation switch in order to synchronize the voltage angle with the one in the main grid and operate the reclosing. Prosumers equipped with HEMS should have sensors, as irradiation and temperature sensors, and actuators, as inverters and switches, to operate the distributed energy resources. The same applies to the DSO owned distributed energy resources.

6.2 Communication layer

As instructed in the SGAM document, the emphasis of the communication layer is to describe protocols and communication technologies for the interoperable exchange of information between the use case actors.

Figure 6.2.1 shows a snapshot of an Excel table (Table 6.2.1) listing all the information exchanged between the use case actors together with the employed protocols and the requirements for communication technologies. Table 6.2.1 is attached to this document. When the information is exchanged between two parts of the same components (e.g. between function running on a software and database of the same computer) the protocol is not listed for the sake of brevity.

	A	B	C	D	E	F	G	H	I
1	Use case	Information producer	Information receiver	Data class	Protocol	Transfer time	Transfer rate	Synchronization accuracy	Availability
2	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	CIM network		TT3	TR4	SA5	H
3	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	switch status		TT3	TR2	SA5	H
4	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	Current measurement		TT2	TR3	SA5	M
5	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	Voltage measurement		TT2	TR3	SA5	M
6	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	Power/energy measurement		TT2	TR3	SA5	M
7	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	long term power forecast		TT2	TR4	SA5	M
8	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	short term power forecast		TT2	TR4	SA5	M
9	LVSE	SAU(SSAU).Functions	SAU(SSAU).RDBMS	Current measurement		TT2	TR4	SA5	M
10	LVSE	SAU(SSAU).Functions	SAU(SSAU).RDBMS	Voltage measurement		TT2	TR4	SA5	M
11	LVSE	SAU(SSAU).Functions	SAU(SSAU).RDBMS	Power/energy measurement		TT2	TR4	SA5	M
12	LVSE	SAU(PSAU).Functions	SAU(PSAU).Functions	Voltage measurement		TT2	TR4	SA5	M
13	LVSE	SAU(SSAU).Functions	SAU(SSAU).RDBMS	flag		TT2	TR4	SA5	M
14	LVSE	SAU(SSAU).RDBMS	SAU(SSAU).Functions	flag		TT2	TR4	SA5	M
15	Dynamic Monitoring	DMS.DNP3	IED(PSIED-RTU).DNP3	Voltage measurement	DNP3	TT6	TR1	SA0	VH
16	Dynamic Monitoring	DMS.DNP3	IED(PSIED-RTU).DNP3	Current measurement	DNP3	TT6	TR1	SA0	VH
17	Dynamic Monitoring	DMS.DNP3	IED(PSIED-RTU).DNP3	Frequency and ROCOF measurement	DNP3	TT6	TR1	SA0	VH

Figure 6.2.1. Snapshot of the list of information exchanges.

Figure 6.2.2 presents a snapshot of the IDE4L SGAM communication layer on which the communication protocols, employed for the information exchanges listed in Table 6.2.1, are shown. A Visio file containing the IDE4L SGAM communication layer is attached to this document for further investigation.

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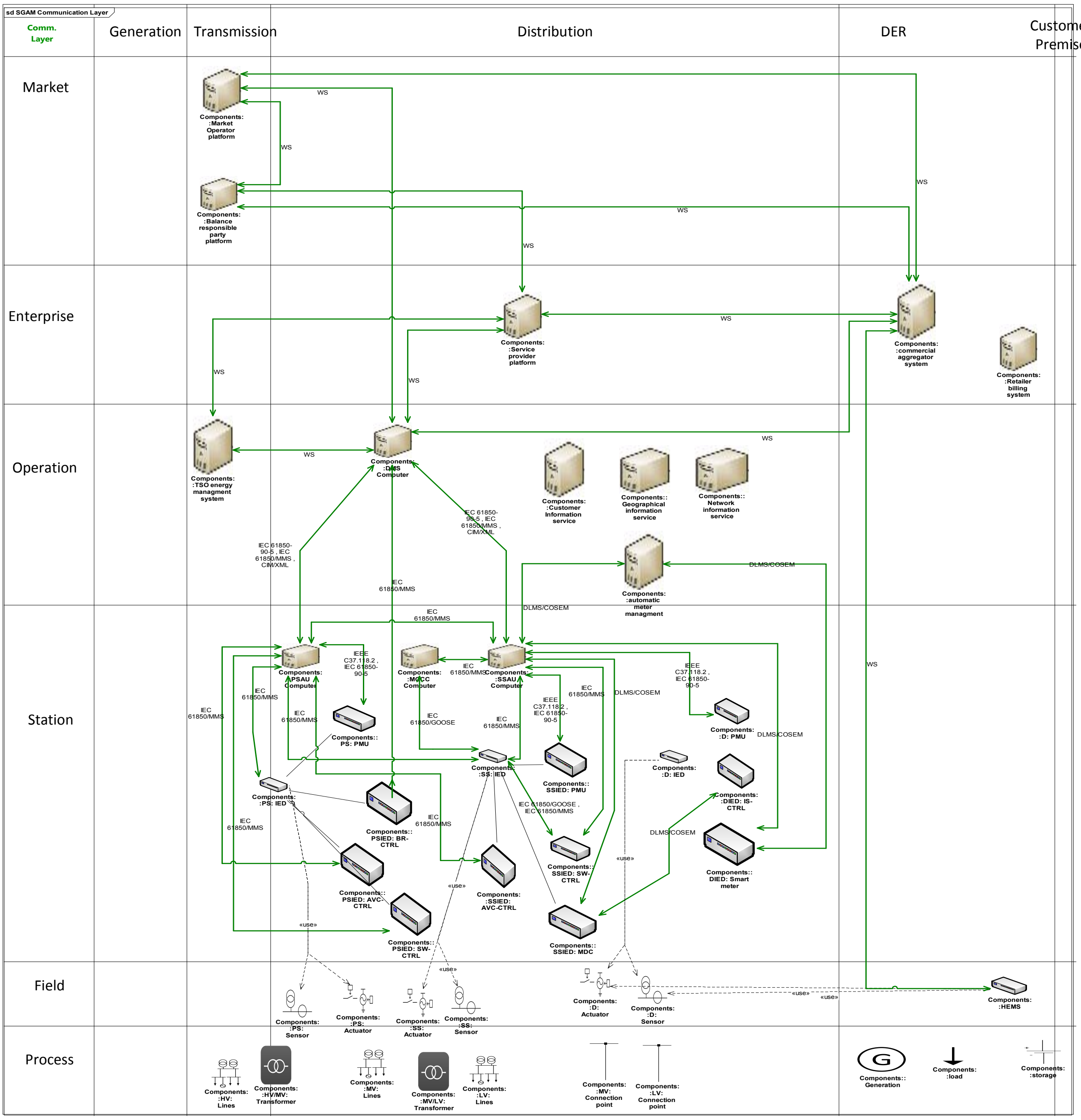

Figure 6.2.2. Communication protocols mapped on the SGAM communication layer.

As indicated in figure 6.2.1, each information exchange sets specific requirements in terms of transfer time and transfer rate on the technology employed for the communication link through which it's transmitted. Hence, for each communication link, all the corresponding information exchanges have been investigated to determine the strictest demanded requirements in terms of transfer time and transfer rate. The appropriate technology is then assigned to each communication link to satisfy the requirements imposed by the information exchanges.

Figure 6.2.3 presents a snapshot of the communication links together with the technology assigned to each of them. Table 6.2.2 lists the requirements for the technologies and also some examples of mechanisms than can implement each technology. The communication links have been included in the Visio file IDE4L SGAM communication layer for further investigation.

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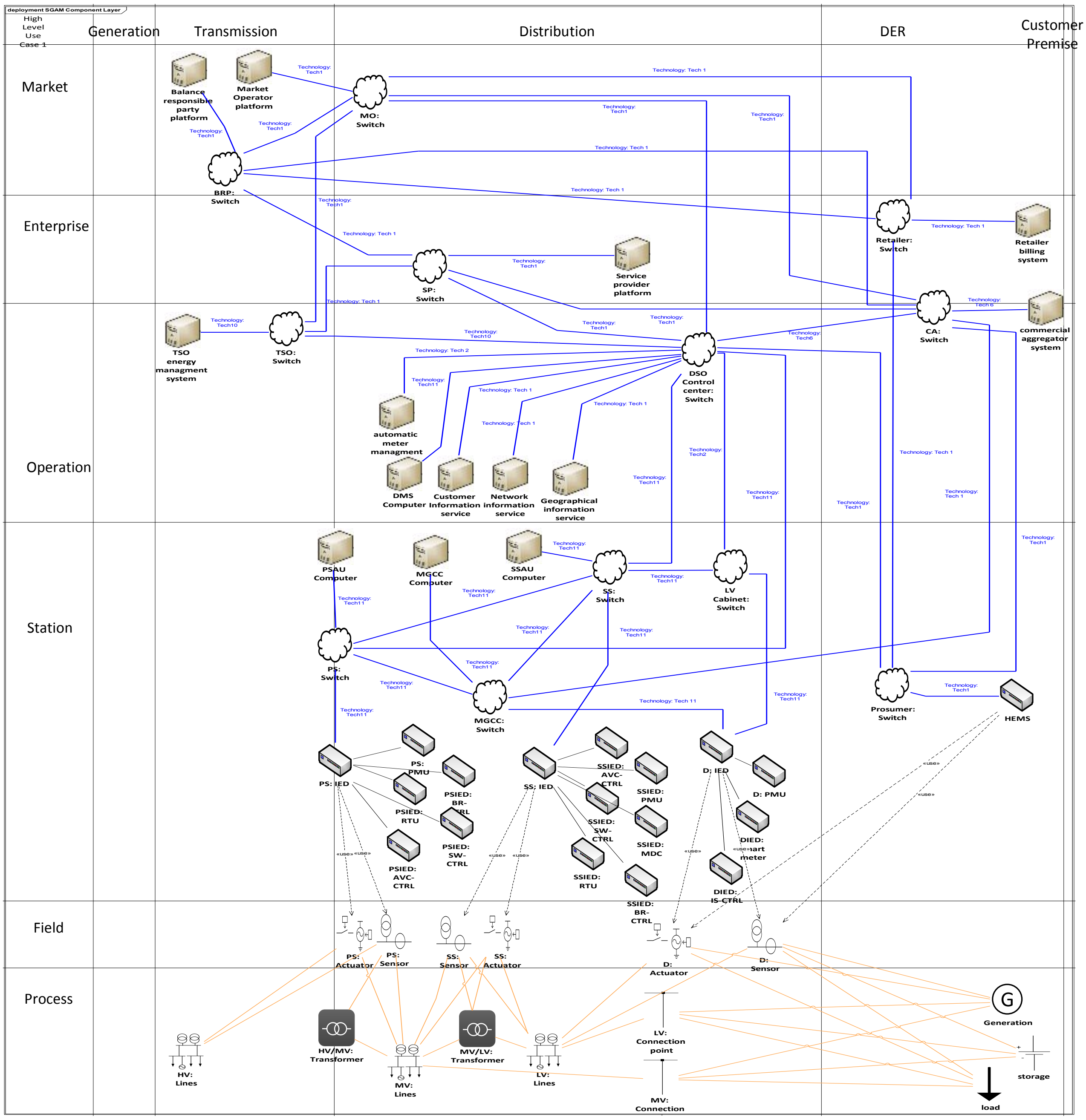

Figure 6.2.3. Communication technologies mapped on the SGAM communication layer.

Table 6.2.2. List of employed technologies.

Technology	Requirements		Example mechanisms
	Transfer time	Transfer rate	
Tech1	TT0	TR4	UMTS, BroadBand PLC on the MV grid, BB-PLC on the LV grid (cell with less than 50/100 of nodes), HiperLAN/Wi-Fi, FO
Tech2	TT0	TR6	FO

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Tech6	TT2	TR5	BroadBand PLC on the MV grid, BB-PLC on the LV grid (cell with less than 20/30 of nodes), FO, LTE, HiperLAN/Wi-Fi (with a point-to-point link)
Tech10	TT6	TR4	FO, LTE (with no traffic), HiperLAN/Wi-Fi (with no traffic and with a point-to-point link)
Tech11	TT6	TR6	FO

It should be noted that the example mechanisms, listed in Table 6.2.2, are recommended by the IDE4L DSO partners who have experienced achieving the required transfer times and transfer rates by utilizing the example mechanisms. Furthermore, part of the aforementioned mechanism, will be applied and tested in the IDE4L demo, both in laboratory and on the field.

As shown in figure 6.2.1, each information exchange requires a certain amount of availability from the underlying ICT connections. Such availability depends on the usage of the information in the use cases. Table 6.2.3 lists the ICT connections which are required by the corresponding information exchanges to have high (H) or very high (VH) availability. For these ICT connections, it’s important to consider some sort of redundancy by for example constructing ICT infrastructure in parallel or utilizing other ICT connections to implement a parallel communication path.

Table 6.2.3. List of ICT connections with high or very high availability.

ICT connection between component #1 and component #2			ICT connection between component #1 and component #2			ICT connection between component #1 and component #2	
Component #1	**Component #2**		**Component #1**	**Component #2**		**Component #1**	**Component #2**
SS:IED	SS:Switch		PS:Switch	PSAU Computer		MGCC:Switch	MGCC Computer
SS:Switch	PS:Switch		MGCC:Switch	SS:Switch		SS:Switch	SSAU Computer
PS:IED	PS:Switch		PS:Switch	DMS Control Center Switch		SS:Switch	LV Cabinet Switch
DMS Computer	DMS Control Center Switch		D:IED	LV Cabinet Switch		SS:Switch	DMS Control Center Switch
TSO Switch	DMS Control Center Switch		CA:Switch	DMS Control Center Switch			
TSO Switch	TSO EMS		CA:Switch	CA System			

6.3 Information layer

Actors typically need to exchange information in order to realize the aforementioned use cases. This is the main focus of SGAM Information Layer. The purpose of SGAM Information Layer is to model the

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information object flows between actors, in terms of data content, and to identify proper data model standards that are suitable to reflect these information objects.

Business Context View

The first part of Information Layer is Business Context View, which models the information object flows between actors. Figure 6-3-1 is the screenshot from SGAM Toolbox that gives an overview of Business Context View developed for IDE4L project use cases. The blue arrows represent Information Object Flows from senders to receivers; the texts on these arrows identify Information Objects being exchanged.

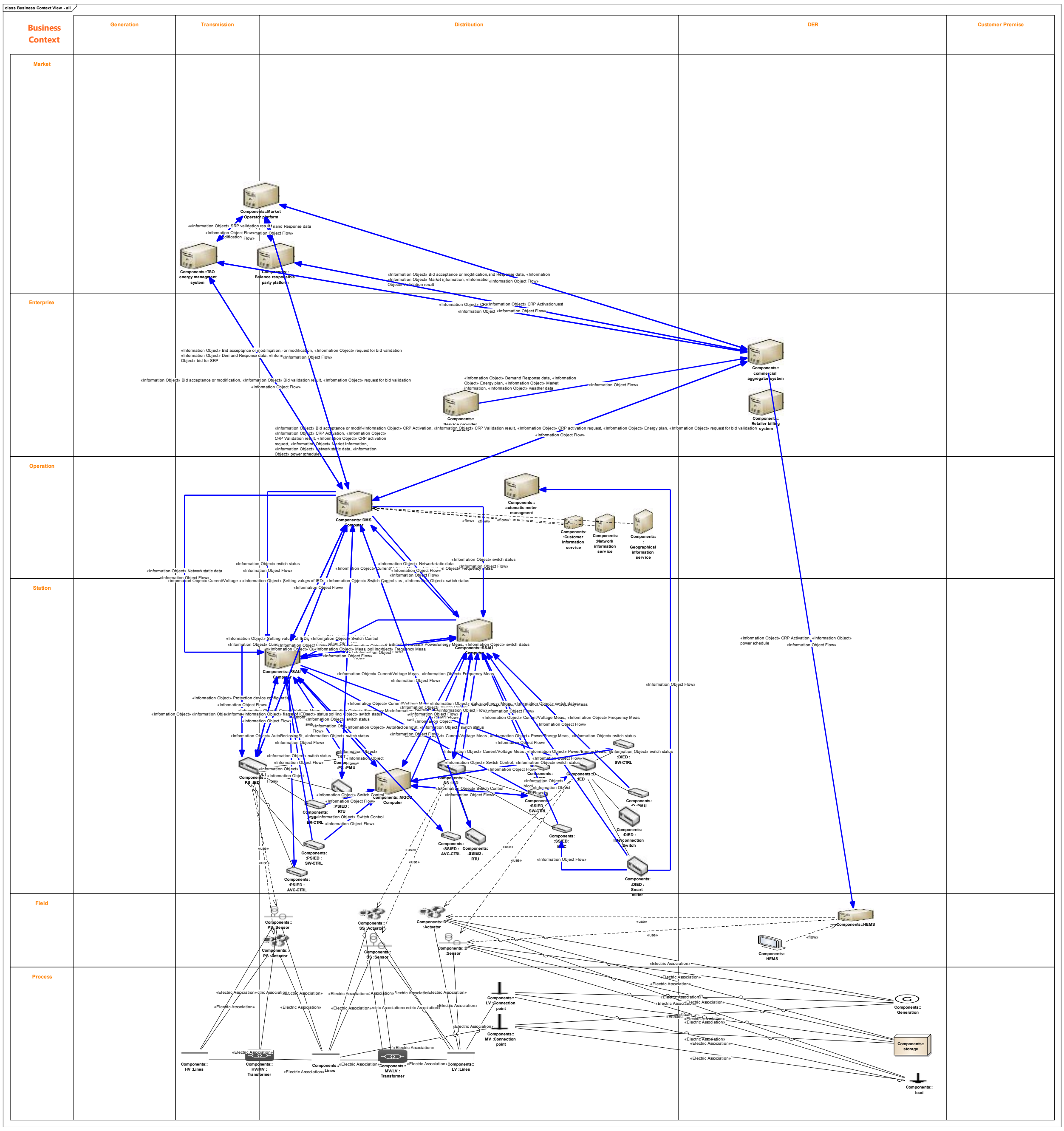

Figure 6-3-1 Overview of Business Context View

The remaining of this subsection will look into the Business Context View piece by piece, based on a series of selected message sender and receiver.

PSAU-SSAU data exchange

Figure 6-3-2 shows Information object flows between primary substation SAU and secondary substation SAU.

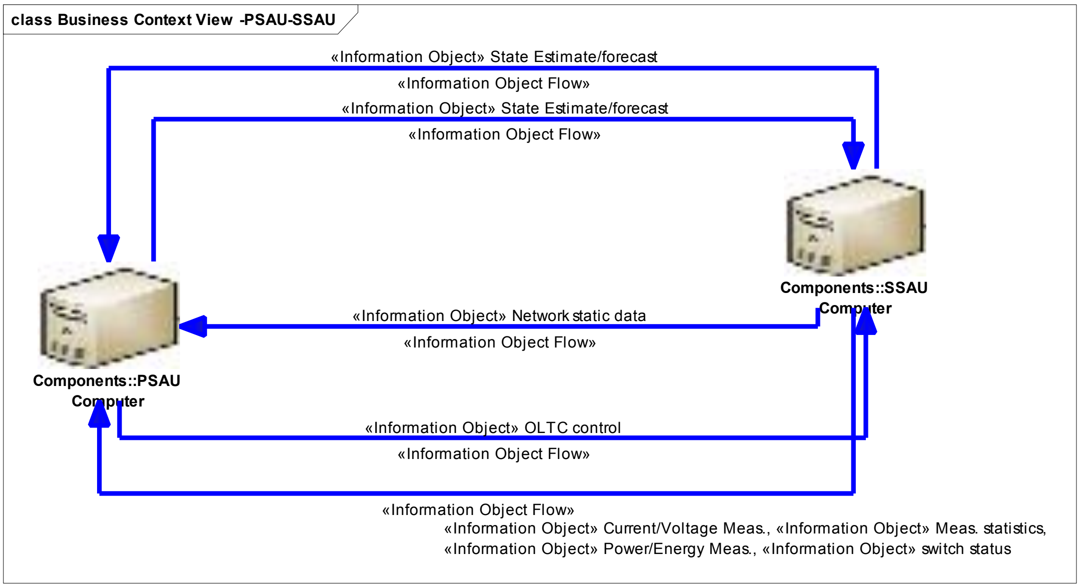

Figure 6-3-2 Information Object flows between PSAU and SSAU

Information Objects depicted in this figure are further explained in the following table. The second column describes the actual data this Information Object represents, and the third column tells in which use case and which function the Information Object/data are involved.

Table 6-3-A Information exchange between PSAU and SSAU

Information Object	data exchanged	Related Use case - Function
Current/Voltage measurement	Current phase angle	LVRTM –Data report MVRTM – Data acquisition
	Voltage phase angle	
	Voltage magnitude	
	Current magnitude	
measurement statistics	Statistical measurement	
Network static data	CIM Network Model	NDU – CIM parsing
OLTC control	OLTC block and unblock signals	BOT - data report
Power/Energy measurement	Reactive power	LVRTM – Data report MVRTM – Data acquisition
	Active power	
	Energy measurement	
State Estimate/forecast	State forecasting result	LVSF, BOT – Data report
	State Estimation results	BOT – data report
	MV connection point Voltage forecast	LVSF – Data storage
Switch status	Switch status	LVRTM – data report MVRTM – Data acquisition

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SAU(PSAU/SSAU)-DMS data exchange

Figure 6-3-3 depicts Information Object Flow between DMS and SAU, including both primary substation SAU and secondary substation SAU. Information Objects details, as well as the relevant use cases and functions, are further described by the following table.

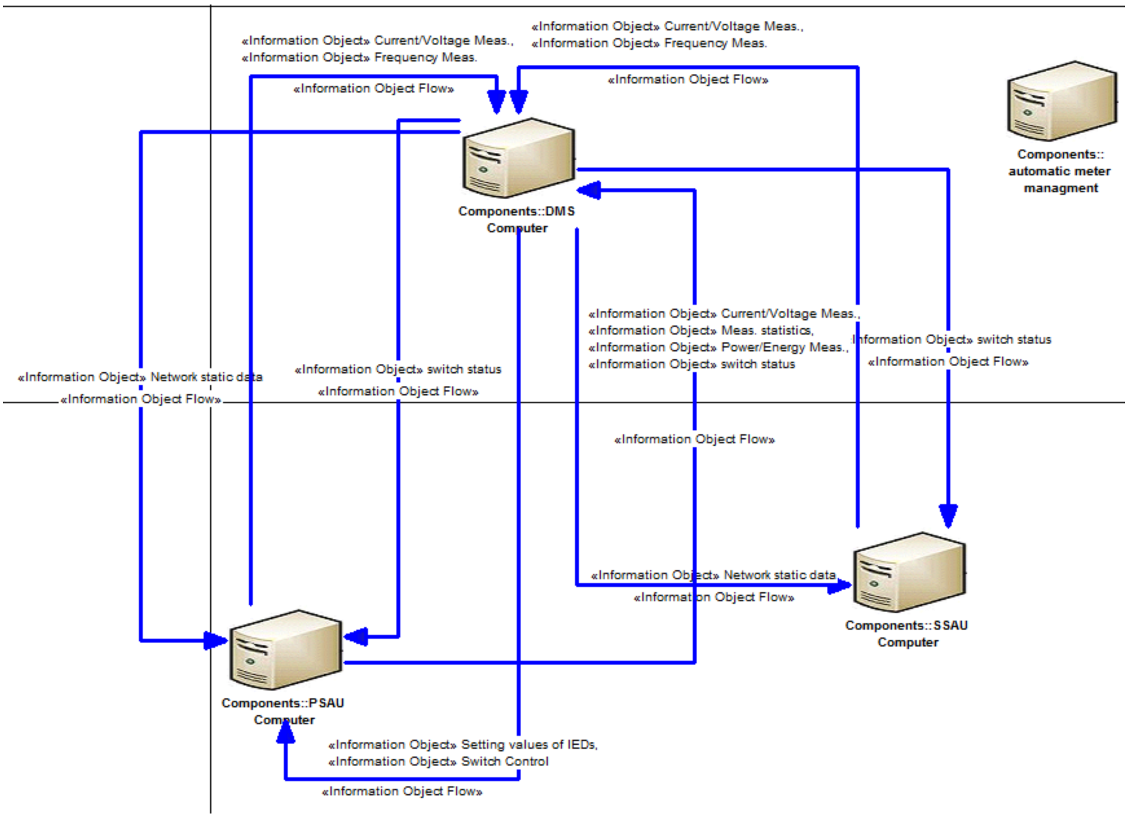

Figure 6-3-3 Information Object Flows between SAU and DMS

Table 6-3-B Information exchange between SAU and DMS

Information Object	data exchanged	Related use case - function
Current/Voltage measurement	Voltage magnitude	Dynamic Monitoring, MVRTM – Data report
	Current magnitude	
	Current phase angle	
	Voltage phase angle	
Frequency measurement	Frequency measurement	Dynamic Monitoring – Data report
measurement statistics	Statistical measurement	MVRTM – Data report
Network static data	CIM Network Model	NDU – Data report
Power/Energy measurement	Energy measurement	MVRTM – Data report
	Reactive power	
	Active power	
setting values of IEDs	Setting Values of IEDs	CCPC Realtime – Reading/Writing IEDs
Switch Control	Switch State Schedule	CCPC offline - Reading/Writing IEDs
Switch status	Switch status	LVRTM, MVRTM – Data acquisition, Data report

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DMS – IED data exchange

Figure 6-3-4 depicts Information Object Flow between DMS and IEDs. Information Objects details, as well as relevant use cases and functions, are further described by the following table.

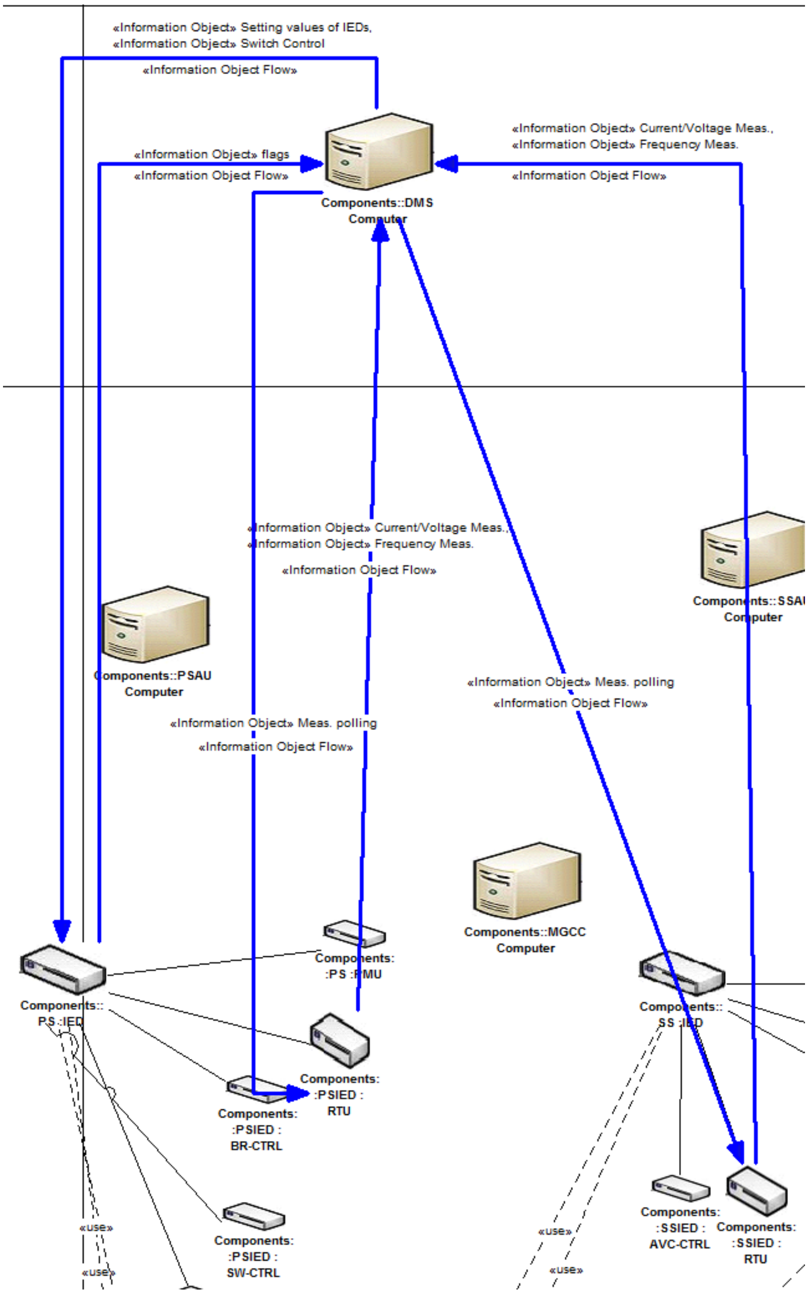

Figure 6-3-4 Information Object flows between DMS and IEDs

Table 6-3-C Information exchange between DMS and IEDs

Information Object	data exchanged	Related Use Case - Function
Current/Voltage measurement	Voltage magnitude	Dynamic Monitoring – Data acquisition
	Current magnitude	
	Current phase angle	
	Voltage phase angle	

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flags	Is data updated-Reply	CCPC offline – Check flag CCPC realtime – Reading/writing IEDs
Frequency measurement	Frequency measurement	Dynamic Monitoring - Data acquisition
measurement polling	Voltage magnitude polling	
	Current magnitude polling	
	Frequency measurement polling	
	Current phase angle polling	
	Voltage phase angle polling	
setting values of IEDs	Setting Values of IEDs	CCPC offline – Reading/Writing IEDs
Switch Control	Switch State Schedule	CCPC realtime – Reading/Writing IEDs

SSAU-IED data exchange

Figure 6-3-5 depicts Information Object Flow between secondary substation SAU and IEDs. Information Objects details, as well as relevant use cases and functions, are further described by the following table.

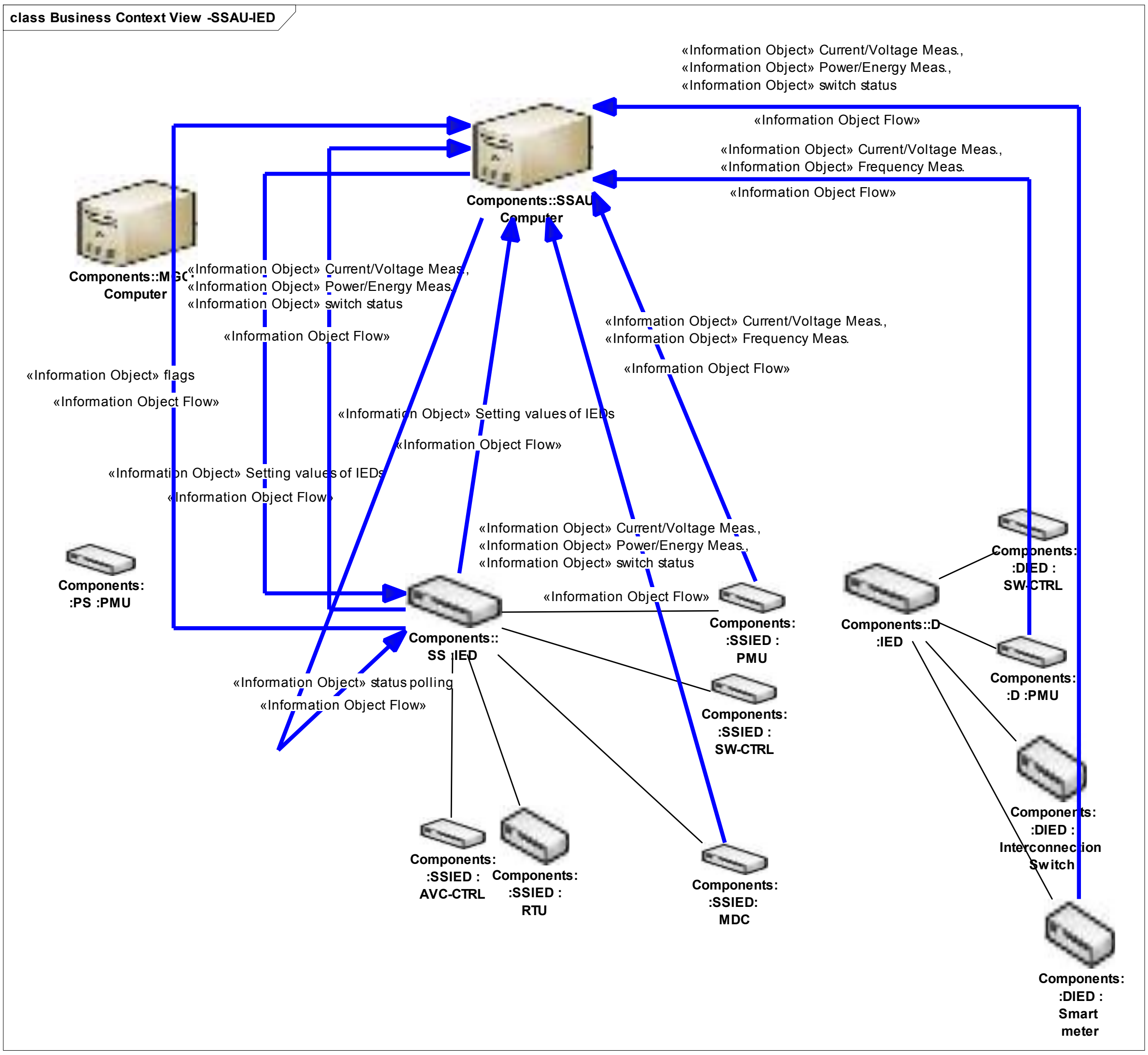

Figure 6-3-5 Information Object flows between SSAU and IED

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Table 6-3-D Information Exchange between SSAU and IED

Information Object	data exchanged	Related Use Case - Function
Current/Voltage measurement	Voltage magnitude	Dynamic Monitoring – Data report LVRTM – Data acquisition
	Current magnitude	
	Current phase angle	
	Voltage phase angle	
flags	Confirmation of new IED settings	LVPC realtime – Check flag
Frequency measurement	Frequency measurement	Dynamic Monitoring – Data report
Power/Energy measurement	Reactive power	LVRTM – Data acquisition
	Active power	
	Energy measurement	
setting values of IEDs	Setting Values of IEDs	LVPC realtime – Reading/Writing IEDs
status polling	Setting Values of IEDs-Request	
Switch status	Switch status	LVRTM – Data acquisition

PSAU-IED data exchange

Figure 6-3-6 depicts Information Object Flow between primary substation SAU and IEDs. Information Objects details, as well as relevant use cases and functions, are further described by the following table.

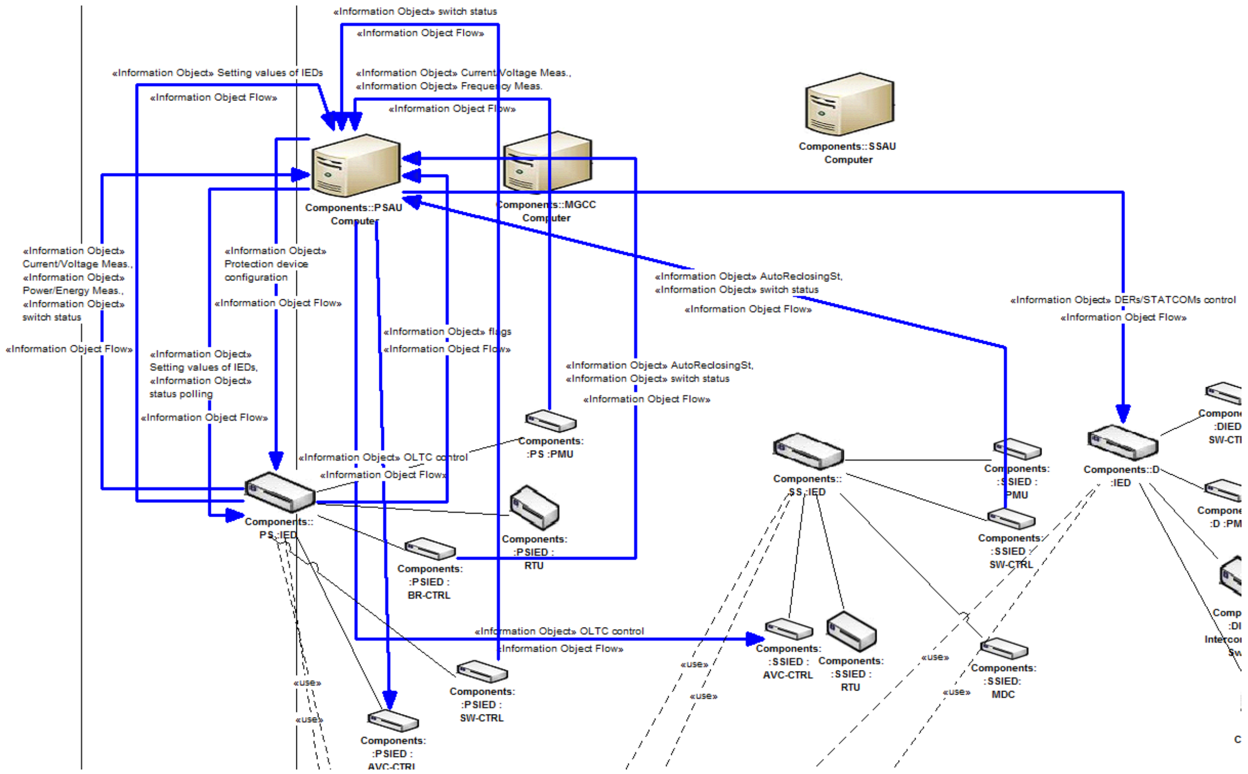

Figure 6-3-6 Information Object flows between PSAU and IED

Table 6-3-E Information exchange between PSAU and IED

Information Object	data exchanged	Related Use case - Function
AutoReclosingSt	AutoReclosingSt	FLISR – second fault isolation
Current/Voltage	Voltage magnitude	Dynamic Monitoring – Data report

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measurement	Current magnitude	MVRTM – Data acquisition
	Current phase angle	
	Voltage phase angle	
DERs/STATCOMs control	ON/OFF signal for function CF to other functions	Power Quality – Reading/Writing IEDs setting
flags	Is data updated-Reply	CCPC offline – Check flag CCPC realtime – Reading/Writing IEDs setting
	Confirmation of new IED settings	MVPC real time – Reading/Writing IEDs setting
Frequency measurement	Frequency measurement	Dynamic Monitoring – Data report
OLTC control	OLTC block and unblock signals	BOT – Reading/Writing IEDs setting
Power/Energy measurement	Energy measurement	MVRTM – Data acquisition
	Reactive power	
	Active power	
Protection Device Configuration	Protection Device Configuration	PCU – Protection update
setting values of IEDs	Setting Values of IEDs	MVPC realtime – Reading/Writing IED setting
status polling	Setting Values of IEDs-Request	
Switch status	Switch status	MVRTM – Data acquisition
	Breaker or switch status (Open)	FLISR – Fault isolation, Secondary Fault isolation
	Breaker or switch status (Trouble)	FLISR – Secondary Fault isolation

MGCC-others data exchange

Figure 6-3-7 depicts Information Object Flow between MGCC and other actors. Information Objects details, as well as relevant use cases and functions, are further described by the following table.

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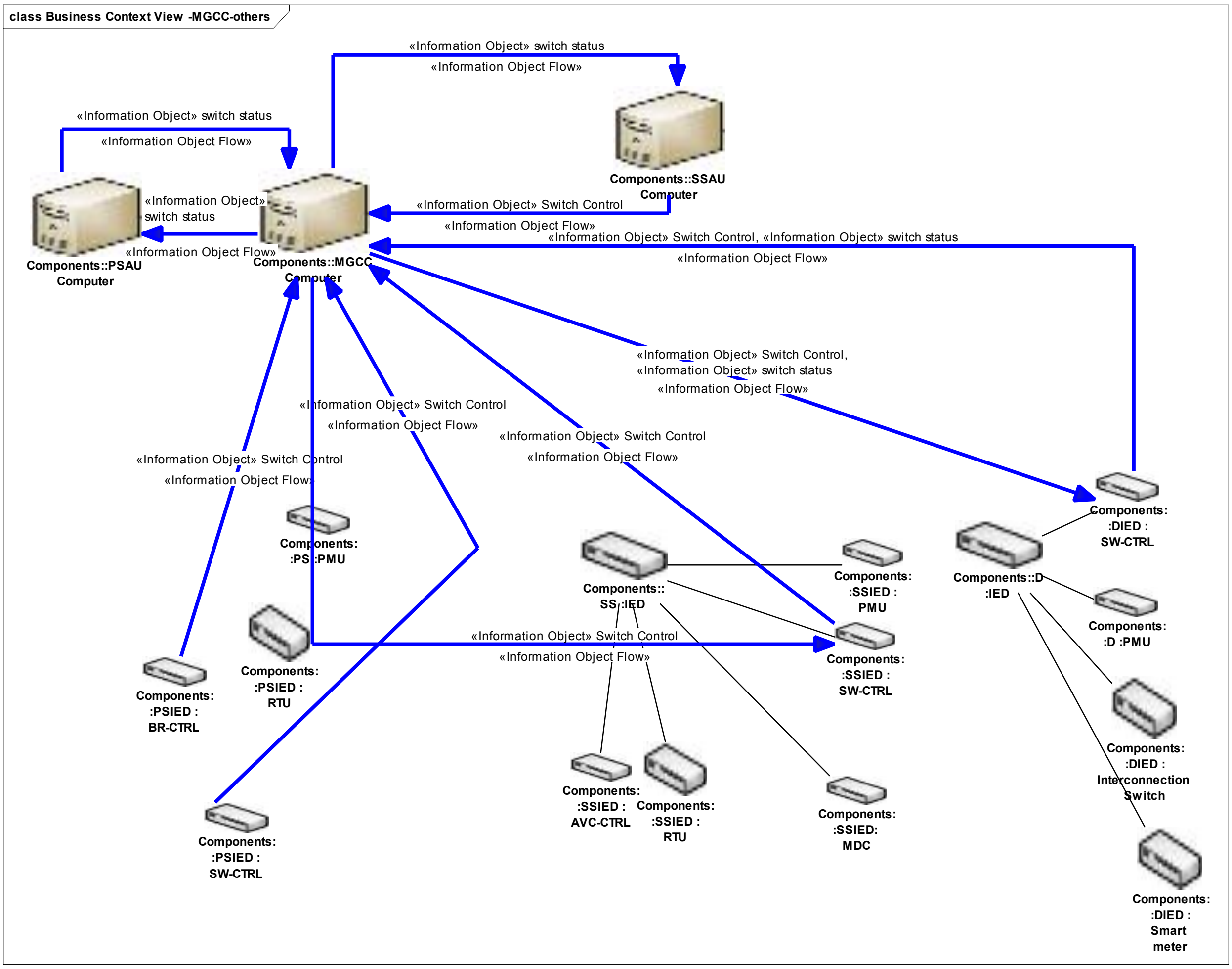

Figure 6-3-7 Information Object flows between MGCC and others

Table 6-3-F Information exchange between MGCC and others

Information Object	data exchanged	Related Use case - Function
Switch Control	Block message	Microgrid FLISR – Reading/Writing IEDs setting
	Block message (block disconnection)	FLISR – Fault isolation, Second fault isolation
	Block message (block connection)	
	Block message (unblock connection)	
Switch status	Breaker or switch status	Microgrid FLISR – Data report, Reading/Writing IEDs setting, synchronization
	Breaker or switch status (Open)	FLISR - Secondary Fault isolation

CA – others (MO, TSO excluded)

Figure 6-3-8 depicts Information Object Flows between Commercial Aggregator System (CA) and other actors. Information Objects details, as well as relevant use cases and functions, are further described by the following table. Note that this figure and table do not include Information Object Flows between CA and TSO or Market Operator Platform (MO), because they will be presented in other subsections.

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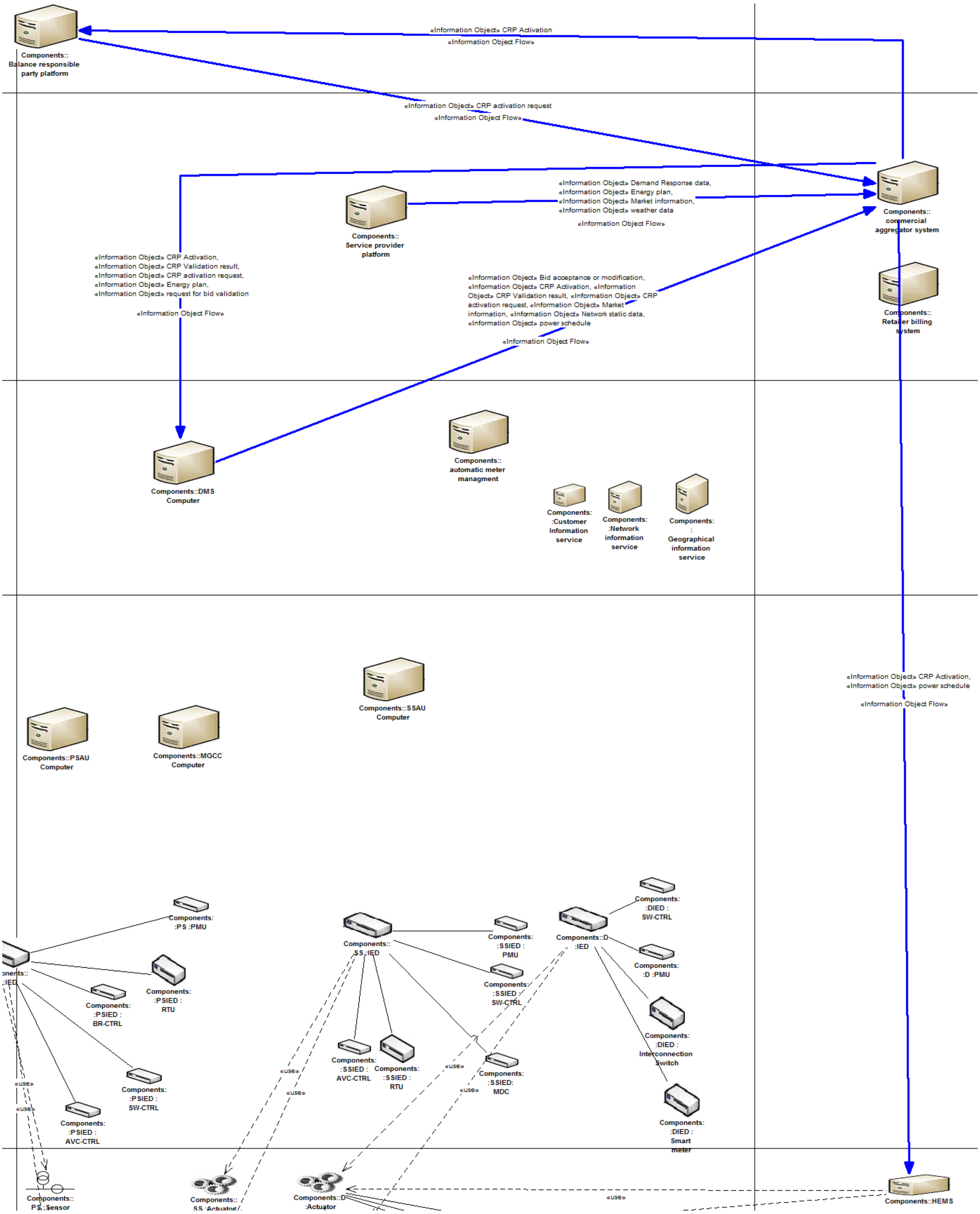

Figure 6-3-8 Information Object flows between CA and others

Table 6-3-G Information exchange between CA and others

Information Object	data exchanged	Related Use case - Function
Bid Acceptance or Modification	Bid Acceptance or Modification	Real time validation – validation reply
bid validation request	validation request	Real time validation – validation request

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CRP Activation	ON/OFF CRP	CCPC real time – CRP activation UC
	CRP Activation	CRP activation – Data report, Reading/Writing IEDs setting
CRP activation request	Request for CRP Activation	Real time validation – validation request CRP activation – CRP activation request
CRP validation result	validation results	CRP activation – CRP validation request, Real time validation UC
Energy plan	Energy plan	DR – Data report
	DER and switch schedules	CAEP – Data storage
Demand Response data	Demand data	CAEP – Data storage
Market information	Grid tariff	DR – Data report
	Forecasted energy price	DR – Data storage
Network static data	Configuration of the Load Areas	Load area – Data report
Power schedule	Power schedule	CCPC offline – CRP activation UC CAEP – Reading/Writing IEDs setting
Weather data	Environment temperature	DR – Data storage
	Meteorological Forecast	CAEP – Data storage

TSO-others

Figure 6-3-9 depicts Information Object Flows between TSO and other actors. Information Objects details, as well as relevant use cases and functions, are further described by the following table.

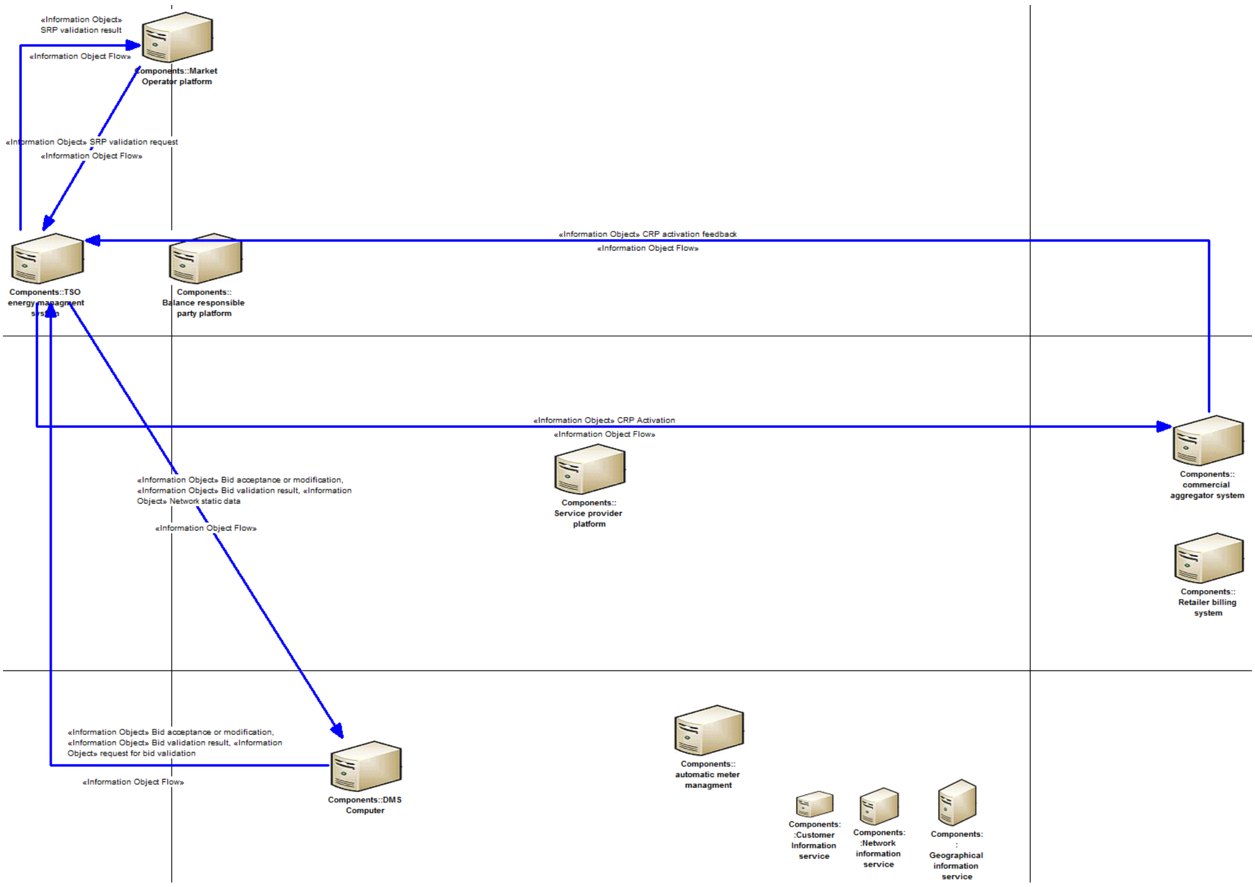

Figure 6-3-9 Information Object flows between TSO and others

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Table 6-3-H Information exchange between TSO and others

Information Object	data exchanged	Related Use case - Function
Bid Acceptance or Modification	Bid Acceptance or Modification	Off line validation – Data report, Validation reply, Power flow
bid validation request	Request for Validation (by TSO)	Off line validation – Power flow Real time validation – Data report
bid validation result	Response of TSO	Real time validation – Data report, Power flow, Validation reply
Network static data	Configuration of the Macro Load Areas	Load area – Data report
SRP validation request		As TSO is out of the scope of IDE4L project, these information flows are not implemented.
SRP validation result		
CRP Activation		
CRP Activation feedback		

MO – others (TSO excluded)

Figure 6-3-10 depicts Information Object Flows between Market Operator Platform (MO) and other actors. Information Objects details, as well as relevant use cases and functions, are further described by the following table. This figure and table do not include Information Object Flows between MO and TSO, because they are presented in other subsection.

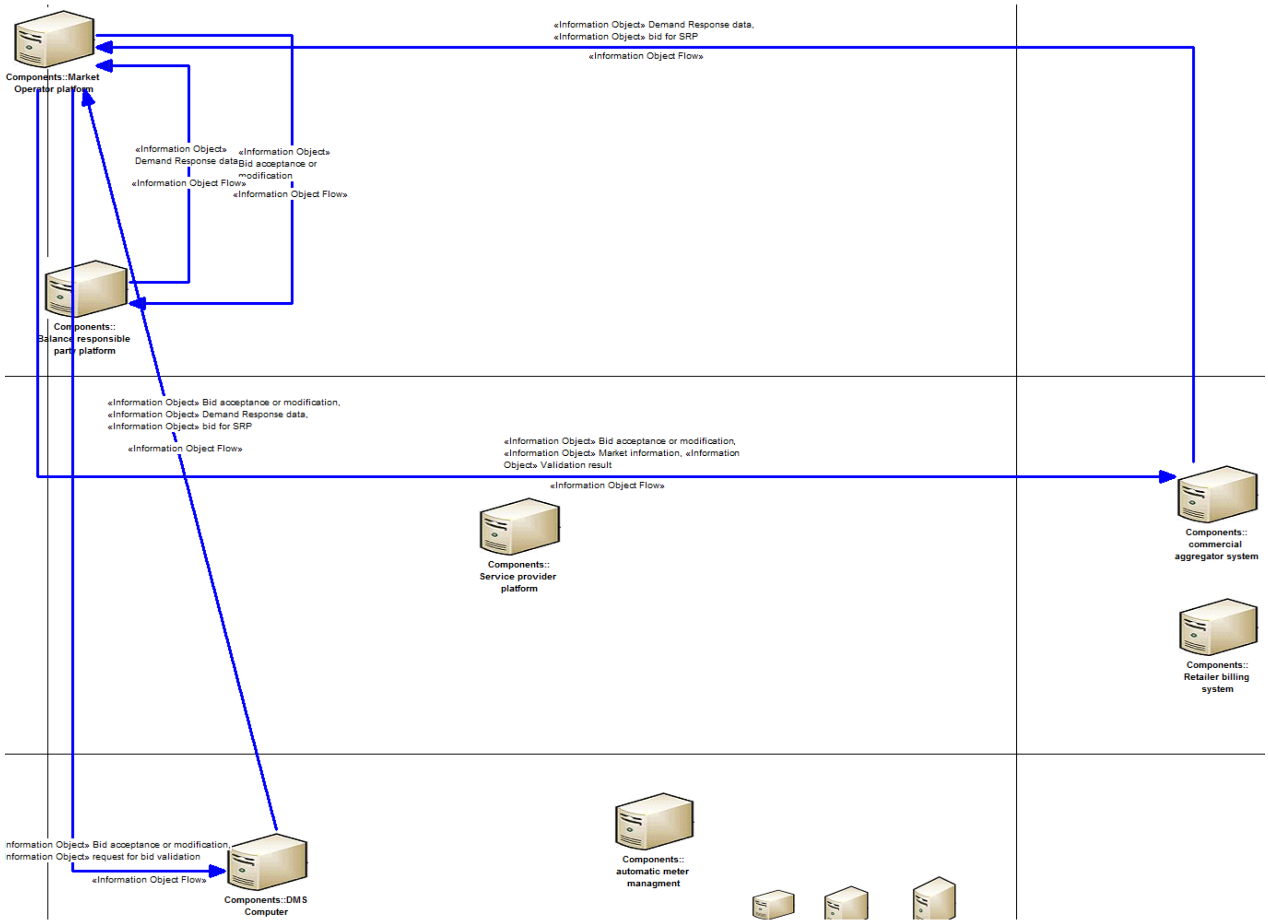

Figure 6-3-10 Information Object flows between MO and others

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Table 6-3-I Information exchange between MO and others

Information Object	data exchanged	Related Use Case - Function
Bid Acceptance or Modification	Bid Acceptance or Modification	SRP procurement – Bid acceptance/modification. Off line validation – Validation reply
Demand Response Data	Flexibility Demand	SRP procurement – Bid submission
	Flexibility Offer	
bid validation request	Request for bid Validation (by DSO.Technical aggregator)	Off line validation – Validation request
Validation result	Validation result	CAEP – Offline validation UC, Real-time validation UC
Market information	Market Gate-opening signal	SRP procurement – Market infos
	Market Gate closure	
SRP bid	Bid for SRP	CCPC realtime – SRP day-ahead and intra-day market procurement UC. CAEP – bid submission

Utilization of Standards

The second part of Information Layer is Canonical Data Model view, which identifies suitable data model standards to describe these Information Objects. From the following SGAM Toolbox screenshot, you can see that IDE4L project uses three data model standards: DLMS/COSEM, IEC 61850-7-4 and 420, and CIM model.

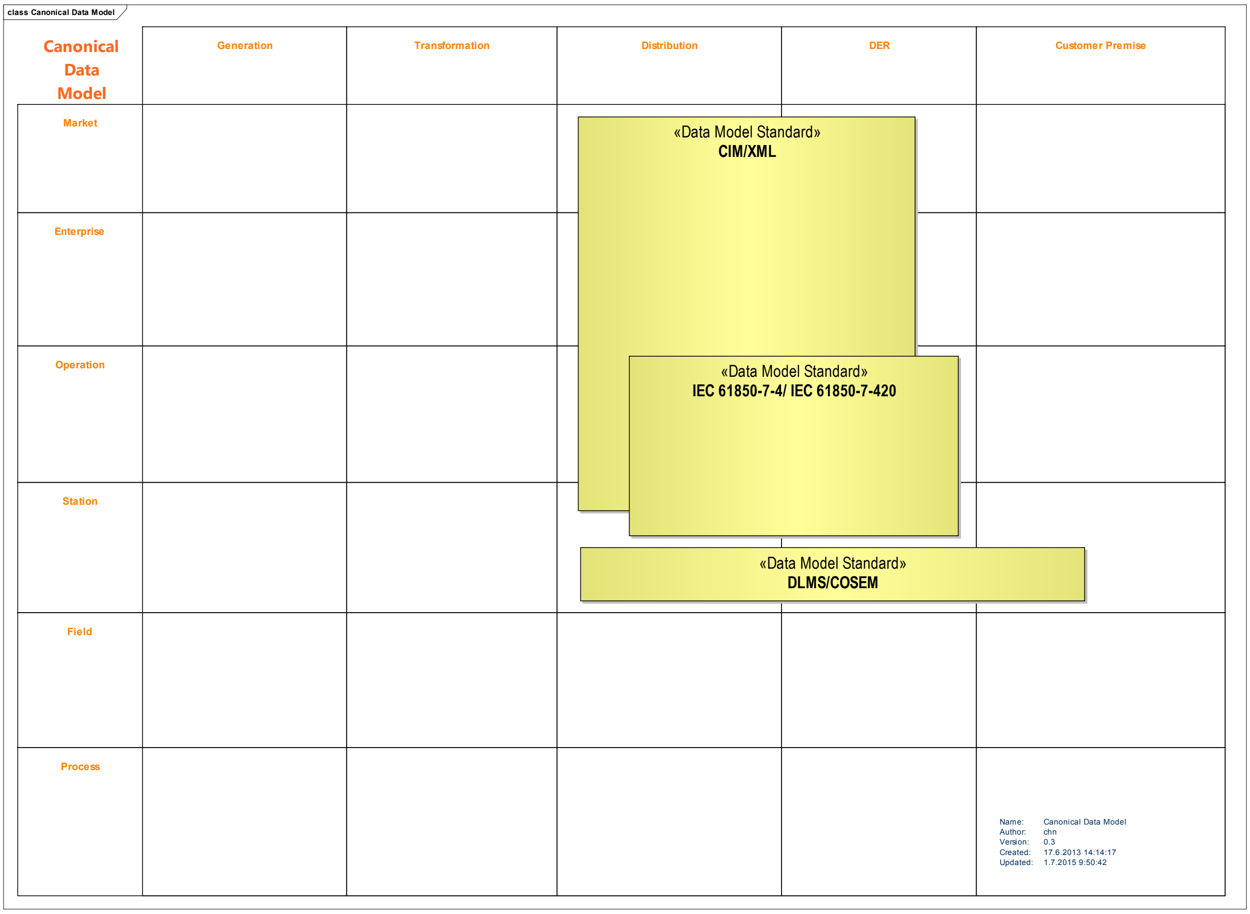

Figure6-3-11 Canonical Data Model view

(4) DLMS/COSEM

COSEM uses object modelling techniques to model all functions of the meter. The utility meter is modelled as a server application. The server offers means to retrieve the functions supported, i.e., the COSEM objects instantiated. COSEM Interface classes are defined in IEC 62056-6.

In IDE4L project, SAU uses COSEM Interface classes to read smart meter from customers' premises and from DER. Hence, it covers SGAM Zone of Station, Domain of Distribution down to Customer's premises.

(5) IEC 61850 data model

IEC 61850 data model is defined in IEC 61850-7-3, IEC 61850-7-4 and IEC 61850-7-420 standards. IDE4L project heavily relies on IEC 61850 data model, using it for exchanging data in SGAM Zone of Station and Operation, Domain of Distribution and DER.

As manifested in Section 7.1, Appendix D3.2-S8-MonLNs.xlsx and D3.2-S8-CtrlLNs.xlsx, IEC 61850 data model is used by Monitor and Control cluster use cases, to allow SAU, MGCC and IEDs - in some case also DMS – communicate with each other using IEC 61850/MMS communication protocol. Besides, inside SAU database where different internal software components exchange input/output, data are also presented according to 61850 data model.

(6) CIM model

CIM model is defined in IEC 61970-301, IEC 61968-11, and IEC 62325-301 standards. As shown in the Canonical Data Model view, CIM model covers SGAM Domains of Distribution and DER, from Station Zone up till Market Zone. In IDE4L use cases, the application of CIM model falls into two categories. The first is for describing the static feature of the network, such as topology, asset information and customer information. This is needed by use cases like "NDU" and "Load Area", etc. The integration technology is relational database. For details, see Section 7.4. The second application of CIM model is for messaging among DSO enterprise systems. This is needed by most of Business cluster use cases, e.g., "Demand Response", "SRP procurement", etc. The integration technology is Web Service. The detail is presented in Section 7.2.

6.4 Function layer

Functions in IDE4L represent a block elaborating information coming from one or more actors, and providing it to one or more other actors. They can be implemented in the hardware belonging to one or more actors. The functions in Table 0-A are extracted from the detailed description of use cases and mapped to the function layer in terms of zones and domains. Moreover, in Table 0-B, the functions obtained from the short description of use case and then not further developed, because out of the IDE4L automation scope, are presented.

Table 0-A List of functions derived from detailed UC description and

Function name new	Domain1	Domain2	Zone1	Zone2
Bid acceptance/modification	DER	Distribution	Operation	Market
Bid submission	Distribution		Enterprise	Market
Check flag	Distribution		Field	Station
CIM parsing	Distribution		Station	
Commercial optimal planning	DER	Distribution	Enterprise	Market
CRP activation request	Distribution	DER	Market	
CRP Validation request	Distribution	DER	Market	
Data acquisition	Distribution		Station	Operatio n
Data Curation and Fusion	Distribution		Station	
Data reconstruction	Distribution		Station	
Data report	Distribution		Station	Operatio n
Data storage	Distribution		Station	Operatio n
Detect error	Distribution		Station	Field
Dynamic info derivation	Distribution	Transmission	Enterprise	Operatio n
Fault detection	Distribution		Station	Field
Fault isolation	Distribution		Station	Field
Load area configuration	Distribution	Transmission	Operation	
Load forecast	DER		Station	
Market clearance	Distribution		Market	
Market infos	Distribution		Market	

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Missing data	Distribution		Station	
Non-convergence detection	Distribution		Station	
open/close switch	Distribution		Field	
Optimal power flow	Distribution		Operation	Station
power flow	Distribution	Transmission	Operation	Station
power quality control	DER	Distribution	Station	Field
power quality indexes	DER	Distribution	Station	
Protection update	Distribution		Station	Field
algorithm performance index	Distribution		Station	
Reading/Writing IEDs setting	Distribution		Station	
Second fault isolation	Distribution		Field	
Signals sampling	Distribution		Station	
State estimation	Distribution		Station	
State forecast	Distribution		Station	
Statistical calculation	Distribution		Station	
synchronization	Distribution		Station	
Validation reply	Distribution		Operation	Station
Validation request	Distribution		Operation	Station

Table 0-B List of functions

Function name new	**Domain1**	**Domain2**	**Zone1**	**Zone2**
Flexibility tables	DER		Operation	
Network design	Distribution		Enterprise	
Network information acquisition	Distribution		Station	
Customer information acquisition	DER	Customer	Station	
Expansion scheduling process	Distribution		Enterprise	

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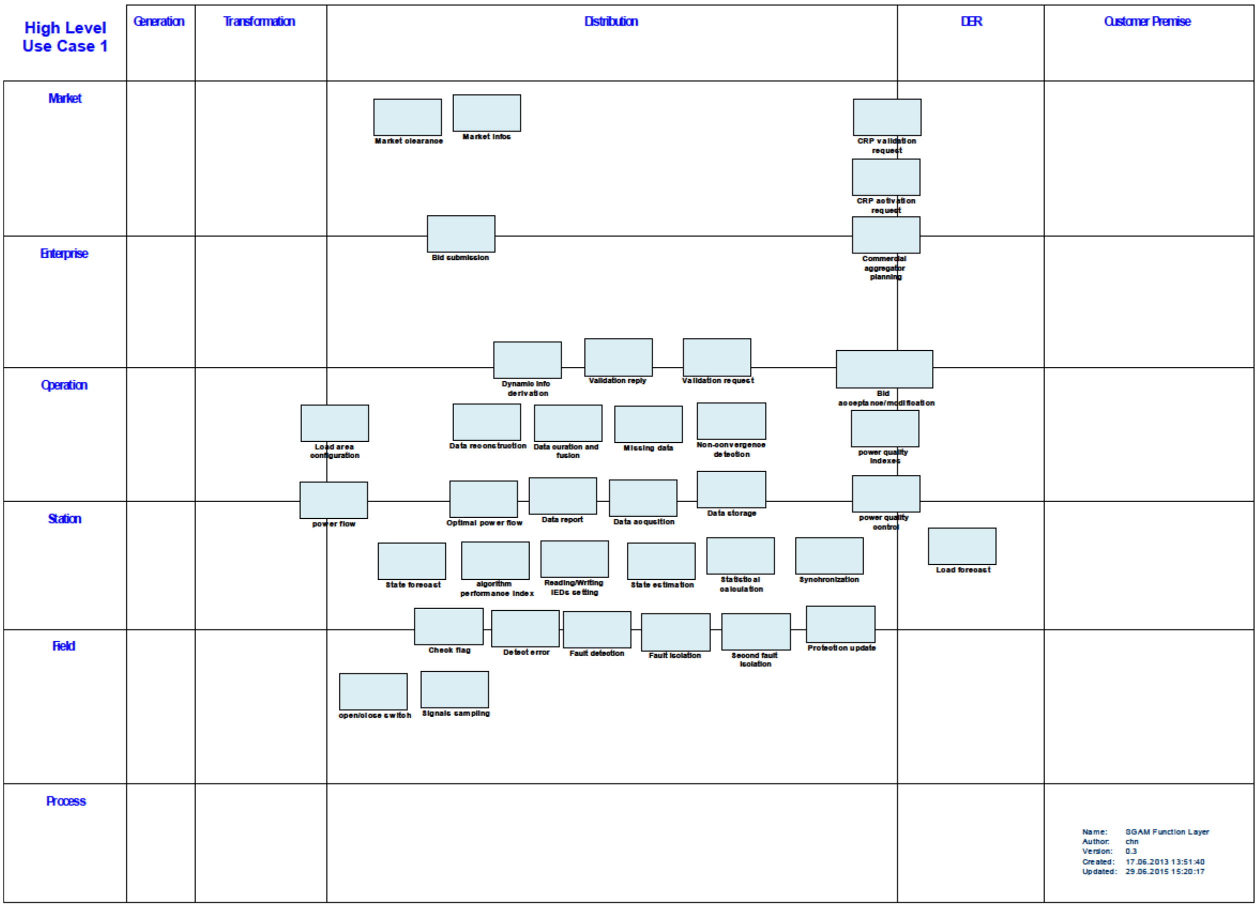

Figure 0-1 Function layer

Description of functions

Function name	Function description
algorithm performance index	When state estimation algorithms are terminated, both in case of successful and erroneous calculations performance indexes of the algorithms are estimated. In case of problems, like real-time measurements (some or all), load and production estimates and some or all secondary substation measurements, pseudo measurements are missing the status flag can be set to “error, execution not possible" or "executed, but with limited accuracy".
Bid acceptance/modification	The SRP bids are accepted or modified depending on the results of the validation use cases. The output of this function are the accepted or modified SRPs.
Bid submission	This function includes the preparation and delivery of SRP bids to market operator. SRP bids may come from commercial aggregator, Balance responsible parties, TSOs or DSOs. Executed in parallel with step 81
Check flag	When DADT, CAEP, BOT, CCPC, MVPC or LVPC algorithms have not generated output, both because their operation is not needed or because of errors a flag is generated. Also when the algorithms check for new data to be updated in database and to send updates of data ready flags are exchanged and checked.
CIM parsing	PSAU or SSAU Topology Manager algorithms parse the received CIM model.
Commercial optimal planning	CAEP UC, for the commercial aggregator side, and CCPC real time UC for the DSO side, are functions to optimize the resources for the current and near future time. With this function commercial aggregator seen the forecasts of power

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	consumption, generation, market price and weather prepares the bids to be submitted to the market operator. The CCPC evaluates the power flow results and if there are congestions problem activates in order Network reconfiguration, bids purchase and dynamic tariffs.
CRP activation request	The BRP, TSO or DSO request for a CRP (already purchased) to be activated by the CA
Data acquisition	DMS, PSAUs or SSAUs acquire data with the reading/writing communication scheme. The devices providing measurements are IEDs, PMUs, RTUs or also the SAUs. Data acquisition may happen on periodic base, or triggered by some events as threshold crossed.
Data Curation and Fusion	Points of data aggregation as PSAUs, SSAUs or DMS may perform data harmonization with regards to time stamps and geographic location and filtering in order to store the data in a time series database. An example could be the harmonization of RTUs and PMUs measurements.
Data reconstruction	In case of degradation of data or data missing from the database an algorithm can interpolate other data or historical data in order to have a reliable input to forecaster algorithms. LVF algorithm sends forecasted values to the DXP
Data report	Devices and SAUs may send data using the report type of data communication scheme. Data report may be used not only to send measurements but also for exchanging information important for the architecture as bids and control set points.
Data storage	This function represent the operations of queries and writing onto databased, both the relational databases and the time series database. Similar types of operation are performed in DMS, PSAU and SSAU databases.
Detect error	Such functions represent the algorithms to process input/outputs of algorithms and evaluate the presence of bad data. Also the identification and cancellation of such bad data is part of this function. Furthermore flags to trigger other algorithms as data reconstruction may be created. Moreover the case of algorithms no convergence or control conflicts from different actors is evaluated by this function.
Dynamic info derivation	Deriving low-frequency oscillations, sub-synchronous oscillations, voltage stability indices, reduced model synthesis, etc. out of the harmonized data.
Fault detection	Such function covers the operation needed to detect the presence of fault. It includes the validation of quantitates from the sensor and the evaluation of the trip time. It regards basically the IEDs that realized the decentralized FLISR
Fault isolation	Such function covers the following operation: • Trip reporting • Communication in order to connect/disconnect microgrids • Communication in order to connect/disconnect DGs • Evaluation of fault event from other IEDs controlling circuit breakers • Breaker fail report It regards basically the IEDs that realized the decentralized FLISR
Load area configuration	This functions regards the evaluation of assignment of load areas to CAs and Macro load areas to DSOs
Load forecast	Forecast algorithms generate forecasts of consumption and generation for the requested horizon.
Market clearance	The market operator matches the bid by means of a dedicated algorithm/software
Market infos	The market is open or closed and the market operator forward such information to CAs, BRPs, DSOs, TSOs, retailer, power generation companies etc.
Missing data	DMSs, PSAUs, SSAUs detect that some data are missing in database, because of erroneous writing or because it has not received updates from devices. In such

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	case the status flag of the algorithms that need such data may be set to "error, execution not possible". Several cases as real time measurements, pseudo measurements or grid data may be missing.
off line validation	After trading is complete the MO asks the TSOs and the DSOs to evaluate the market clearance result with regards to their physical constraints. The trading is completed
open/close switch	Breaker or switch open/close command.
Optimal power flow	Control center power controller, medium voltage power controller and low voltage power controller run the OPF to select the optimal solution as network reconfiguration, DSO owned DERs, flexibility offer or dynamic tariffs solving the congestion.
Power flow	Run power flow to check the feasibility of current state or future state of the grid based on real time measurement or forecasts, or to evaluate provisional schedule (hourly based) after the market clearing. It is run by TSO at energy management system level or by DSO at DMS level.
power quality control	In case some indexes are not satisfying control functions are run in order to obtain some effective control actions, through the function CF
power quality indexes	Power quality indexes are calculated and compared with the threshold indicated by power quality standards (e.g. EN 50160), through the function CSEV
Protection update	PSAU and SSAU retrieve a new network configuration from database, they build a new protection device configuration and send it using IEC61850 MMS and SCL file transfer to the involved IEDs.
Reading/Writing IEDs setting	In this function the interfaces of DMSs and SAUs, take care of writing and reading the settings of IEDs. Basically the control set point of OLTCs, DERs inverters, STATCOMs and status of breakers/switches. Also some schedule for future operation can be sent.
Second fault isolation	Such function covers the operations after the first fault isolation operation. The main operations are: • Autoreclosing time calculation • Communication in order to connect/disconnect microgrids • Communication in order to connect/disconnect DGs • Evaluation of fault event from other IEDs controlling circuit breakers • Breaker reclosing process • Switch fail report • Communication to SAU of isolation complete It regards basically the IEDs that realized the decentralized FLISR
Signals sampling	SM and IEDs samples sensors signals (voltages and currents) and calculate currents, voltages, powers and energies
State estimation	Calculate the steady state of the network. Such function it is realized for the MV grid at PSAU level and for the LV grid at SSAU level.
State forecast	Calculate the state forecast of the network. Such function it is realized for the MV grid at PSAU level and for the LV grid at SSAU level.
Statistical calculation	PSAU and SSAU aggregate measurements on time and grid levels and send averages and uncertainty of important grid information as voltage and power flows to DMS level.
synchronization	The Microgrid central controller commands the IED managing the isolation switch to sync the microgrid voltage with the one of the distribution grid.
Validation reply	The validation results of the TSO are sent to the DSO.
Validation reply	The combined validation results of TSOs and DSOs are sent to the MO and then

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	forwarded to retailers and commercial aggregators.
Validation request	The bids to be validated are sent by MO to TSO and to DSO

Use cases require the usage of several functions. In Table 0-C there is the mapping of functions onto use cases and the functions used by every use case.

Table 0-C Function allocations in use cases

Functions →	**Use cases**
Bid acceptance/modification	SRP procurement
Bid submission	CAEP
Bid submission	SRP procurement
Check flag	BOT
	CCPC offline
	CCPC real time
	DADT
	DR
	LVPC offline
	LVPC real time
	MVPC offline
	MVPC real time
CIM parsing	NDU
Commercial optimal planning	CAEP
	CCPC real time
CRP activation request	CRP activation
	CCPC offline
	CCPC real time
CRP Validation request	CRP activation
Data acquisition	Dynamic Monitoring
	LVRTM
	MVRTM
Data Curation and Fusion	Dynamic Monitoring
Data reconstruction	LVF
	MVF
Data report	BOT
	CRP activation
	DR
	Dynamic Monitoring
	Load area
	LVRTM
Data Report	LVSF
	Microgrid FLISR
	MVRTM
	NDU
	Off line validation

Use cases →	**Functions**
BOT	Check flag
	Data report
	Data storage
	Missing data
	Reading/Writing IEDs setting
CAEP	Bid submission
	Commercial optimal planning
	Data storage
	Market clearance
	Reading/Writing IEDs setting
CCPC offline	Check flag
	CRP activation use case
	Data storage
	Optimal power flow
	Power flow
	Reading/Writing IEDs setting
CCPC real time	Check flag
	Commercial optimal planning
	CRP activation use case
	Data storage
	Optimal power flow
	Power flow
	Reading/Writing IEDs setting
CRP activation	CRP activation request
	CRP Validation request
	Data report
	Reading/Writing IEDs setting
DADT	Check flag
	Data storage
	Optimal power flow
DR	Check flag
	Data Report
	Data storage
Dynamic Monitoring	Data acquisition
	Data Curation and Fusion
	Data report

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	Real time validation
Data storage	LVSE
	BOT
	CAEP
	CCPC offline
	CCPC real time
	DADT
	DR
	Dynamic Monitoring
	Load area
	LVF
	LVPC offline
	LVPC real time
	LVRTM
	LVSF
	Microgrid FLISR
	MVF
	MVNR
	MVPC offline
	MVPC real time
	MVRTM
	MVSE
	MVSF
	NDU
	PCU
	Power quality
Detect error	LVF
	LVPC offline
	LVSE
	Microgrid FLISR
	MVF
	MVPC offline
	MVSE
Dynamic info derivation	Dynamic Monitoring
Fault detection	FLISR
Fault isolation	FLISR
Load area configuration	Load area
Load forecast	LVF
	MVF
Market clearance	CAEP
	SRP procurement
Market infos	SRP procurement
Missing data	BOT
	LVF
	LVPC offline

	Data storage
	Dynamic info derivation
FLISR	Fault detection
	Fault isolation
	open/close switch
	Second fault isolation
Load area	Data report
	Data storage
	Load area configuration
LVF	Data reconstruction
	Data storage
	Detect error
	Load forecast
	Missing data
LVPC offline	Check flag
	Data storage
	Detect error
	Missing data
	Optimal power flow
LVPC real time	Check flag
	Data storage
	Optimal power flow
	Reading/Writing IEDs setting
LVRTM	Data acquisition
	Data report
	Data storage
	Signals sampling
	Statistical calculation
LVSE	Data storage
	Detect error
	Missing data
	algorithm performance index
	State estimation
LVSF	Data Report
	Data storage
	State forecast
Microgrid FLISR	Data report
	Data storage
	Detect error
	open/close switch
	Reading/Writing IEDs setting
	synchronization
MVF	Data reconstruction
	Data storage
	Detect error

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	LVSE
	MVF
	MVPC offline
	MVSE
off line validation	SRP procurement
open/close switch	FLISR
	Microgrid FLISR
Optimal power flow	CCPC offline
	CCPC real time
	DADT
	LVPC offline
	LVPC real time
	MVPC offline
	MVPC real time
Power flow	CCPC offline
	CCPC real time
	Off line validation
	Real time validation
power quality control	Power quality
power quality indexes	Power quality
Protection update	PCU
algorithm performance index	LVSE
	MVSE
Reading/Writing IEDs setting	BOT
	CAEP
	CCPC offline
	CCPC real time
	CRP activation
	LVPC real time
	Microgrid FLISR
	MVPC real time
	Power quality
Second fault isolation	FLISR
Signals sampling	LVRTM
	MVRTM
State estimation	LVSE
	MVSE
State forecast	LVSF
	NDU
Statistical calculation	LVRTM
	MVRTM
synchronization	Microgrid FLISR
Validation reply	Off line validation
	Real time validation
Validation request	Off line validation

	Load forecast
	Missing data
MVNR	Data storage
MVPC offline	Check flag
	Data storage
	Detect error
	Missing data
	Optimal power flow
MVPC real time	Check flag
	Data storage
	Optimal power flow
	Reading/Writing IEDs setting
MVRTM	Data acquisition
	Data report
	Data storage
	Signals sampling
	Statistical calculation
MVSE	Data storage
	detect error
	Missing data
	algorithm performance index
	State estimation
MVSF	Data storage
NDU	CIM parsing
	Data report
	Data storage
	State forecast
Off line validation	Data report
	Power flow
	Validation reply
	Validation request
PCU	Data storage
	Protection update
Power quality	Data storage
	power quality control
	power quality indexes
	Reading/Writing IEDs setting
Real time validation	Data report
	Power flow
	Validation reply
	Validation request
SRP procurement	Bid acceptance/modification
	Bid submission
	Market clearance
	Market infos

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	Real time validation		off line validation

Actors exploit some functions that can be dedicated to the single actor or distributed among several actors. In Table 0-D an overview is given about the mapping of functions onto actors and the functions that are exploited by every actor.

Table 0-D Functions allocation in actors

Function →	**Actor**
algorithm performance index	SAU
Bid acceptance/modification	BRPP
	CAS
	DMS
	MOP
Bid submission	BRPP
	CAS
	DMS
	MOP
Check flag	DMS
	IED
	SAU
CIM parsing	SAU
Commercial optimal planning	CAS
	DMS
CRP activation request	BRPP
	CAS
	DMS
CRP Validation request	CAS
	DMS
Data acquisition	DMS
	IED
	SAU
	AMM
Data Curation and Fusion	DMS
Data reconstruction	SAU
Data report	BRPP
	CAS
	DMS
	IED
	MGCC
	SAU
	TSOEMS
Data storage	CAS
	DMS
	MGCC

Actor →	**Function**
Actuator	open/close switch
AMM	Data acquisition
BRPP	Bid acceptance/modification
	Bid submission
	CRP activation request
	Data report
CAS	Bid acceptance/modification
	Bid submission
	Commercial optimal planning
	CRP activation request
	CRP Validation request
	Data Report
	Data storage
	Market infos
	Reading/Writing IEDs setting
	Validation reply
	Validation request
DMS	Bid acceptance/modification
	Bid submission
	Check flag
	Commercial optimal planning
	CRP activation request
	CRP Validation request
	Data acquisition
	Data Curation and Fusion
	Data report
	Data storage
	Dynamic info derivation
	Optimal power flow
	Power flow
	Reading/Writing IEDs setting
	Validation reply
	Validation request
IED	Check flag
	Data acquisition
	Data report

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	SAU
	SPP
Detect error	MGCC
	SAU
Dynamic info derivation	DMS
Fault detection	IED
Fault isolation	IED
	MGCC
	SAU
Load forecast	SAU
Market clearance	MOP
Market infos	CAS
	MOP
Missing data	SAU
off line validation	MOP
open/close switch	Actuator
	IED
Optimal power flow	DMS
	SAU
Power flow Power flow	DMS
	TSOEMS
power quality control	SAU
power quality indexes	SAU
Protection update	IED
	SAU
Reading/Writing IEDs setting	CAS
	DMS
	IED
	MGCC
	SAU
Second fault isolation	IED
	MGCC
	SAU
Signals sampling	IED
	Sensor
State estimation	SAU
State forecast	SAU
Statistical calculation	SAU
Synchronization	IED
	MGCC
Validation reply	CAS
	DMS
	MOP
	TSOEMS
Validation request	CAS

	Fault detection
	Fault isolation
	open/close switch
	Protection update
	Reading/Writing IEDs setting
	Second fault isolation
	Signals sampling
	synchronization
MGCC	Data report
	Data storage
	Detect error
	Fault isolation
	Reading/Writing IEDs setting
	Second fault isolation
	synchronization
MOP	Bid acceptance/modification
	Bid submission
	Market clearance
	Market infos
	off line validation
	Validation reply
	Validation request
SAU	algorithm performance index
	Check flag
	CIM parsing
	Data acquisition
	Data reconstruction
	Data report
	Data storage
	Detect error
	Fault isolation
	Load forecast
	Missing data
	Optimal power flow
	power quality control
	power quality indexes
	Protection update
	Reading/Writing IEDs setting
	Second fault isolation
	State estimation
	State forecast
	Statistical calculation
Sensor	Signals sampling
SPP	Data storage
TSOEMS	Data report

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	DMS			Power flow
	MOP			Validation reply

6.5 Business layer

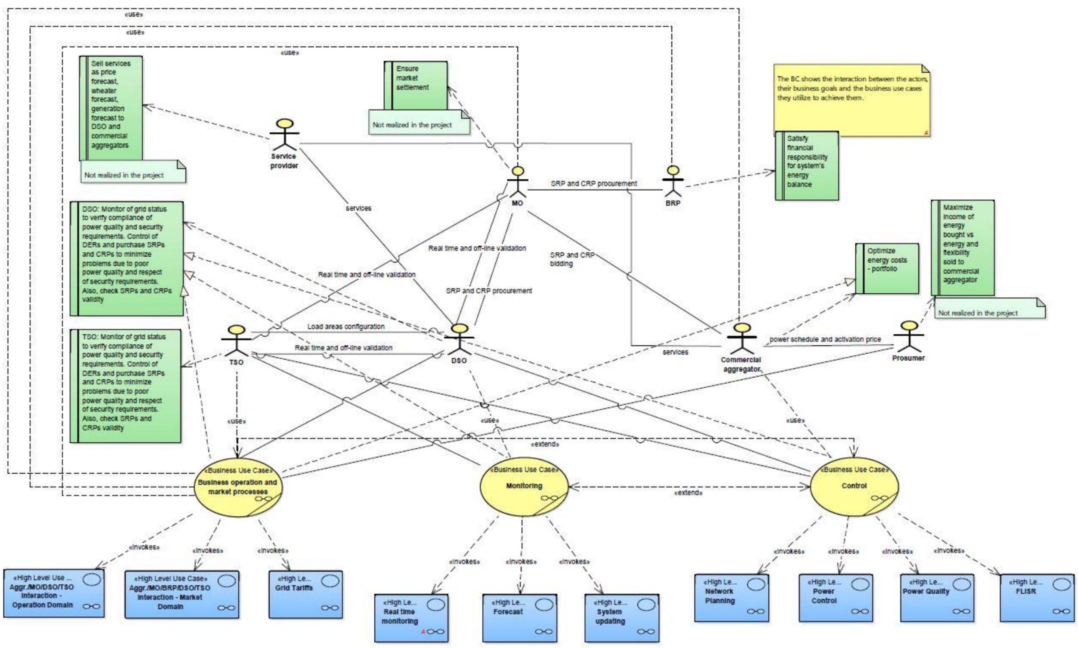
The business layer of the SGAM framework is used to map regulatory and economic market structures and policies, business models, business portfolios (products and services) of involved market parties.

Business Actors (BA), Business Goals (BG), Business Cases (BC), as well as High Level Use Cases (HLUC) are mapped on the business case analysis diagram and their interactions are shown with association-extension-dependency links. Then the BCs and HLUCs are mapped as elements on the SGAM plane domains and zones, creating the business layer.

Modeling the Business Case Analysis Diagram

Using the 'dependency' relation, the Business Actors are related with their corresponding Business Goals. Business Actors use Business Cases, in order to realize their Business Goals. Thus, the connection between Business Actors and Business Cases are of type 'use'. Also, the High Level Use Cases (HLUCs) that are included in the different Business Cases, are connected to them using the 'invoke' relation. The Business Case Analysis diagram created for the purposes of the IDE4L project is seen below:

IDE4L Business Case Overview



In the following pages an explanation of the elements and connections of this diagram will be derived.

Since not all Business Goals are actually implemented and realized in IDE4L project, we remark these goals as 'not realized in the project'. High Level Use Cases (HLUC) describes a general requirement, idea or concept independently from a specific architectural solution. 10 HLUCs are defined in IDE4L architecture. The Actors that are included in the Business Case Analysis Diagram are the ones that participate in the market interactions and also the ones that provide the flexibility:

- Transmission System Operator (TSO)

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- Distribution System Operator (DSO)
- Market Operator (MO)
- Balance Responsible Player (BRP)
- Commercial Aggregator (CA)
- Prosumer
- Service Provider

Business Cases defined in IDE4L

Business Operation and Market Processes: By participating in the demand response scheme through the Commercial Aggregator, the Prosumer can maximize his income of energy bought vs energy and flexibility sold. The Commercial Aggregator optimizes his profits by participating in the energy market schemes by selling their flexibility products, here called as Scheduled Reprofilings Products (SRPs) and Conditional Reprofiling Products (CRPs). TSOs and DSOs can acquire flexibility products through the markets and overcome network constraints, while also assuring that the flexibility products are compliant with the system requirements. Other market participants can acquire flexibility products as well for portfolio optimization processes.

Monitoring: In Active distribution networks, the DSO has an interest in monitoring these parts of the network where the hosting capacity may occasionally be exceeded or the continuity of supply is a concern. An advanced monitoring architecture, included in the HLUCs of IDE4L, provides the DSO with the capability to monitor the grid status to verify compliance of power quality and security requirements.

Control: The DSO can provide direct control actions on grid elements, based on the measured quantities coming from the Monitoring Business Case. Most of the small scale DERs however are under the supervision of the Commercial Aggregator, thus in this case, this entity is responsible for providing inputs from the Business Operations and Market Processes business case to the Control one.

The following Table depicts the Business Cases that realize the Business Goals of each Actor. Some BGs are not realized by any BC in this project, so they are left blank:

Business Actor	Business Goal	Realized by (Business Cases)
TSO	Monitor of grid status to verify compliance of power quality and security requirements. Control of DERs and purchase of SRPs and CRPs to minimize problems due to poor power quality and respect of security requirements. Also, check SRPs and CRPs validity	**Monitoring** **Control** **Business Operation and Market Processes**

DSO	Monitor of grid status to verify compliance of power quality and security requirements. Control of DERs and purchase of SRPs and CRPs to minimize problems due to poor power quality and respect of security requirements. Also, check SRPs and CRPs validity	**Monitoring** **Control** **Business Operation and Market Processes**
MO	Ensure market settlement	-
BRP	Satisfy financial responsibility for system's energy balance	**Business Operation and Market Processes**
Aggregator	Optimize energy costs – portfolio	**Business Operation and Market Processes**
Prosumer	Maximize income of energy bought vs energy and flexibility sold to Commercial Aggregator	**-**
Service Provider	Sell services as price forecast, weather forecast, generation forecast, generation forecast to the DSO and Commercial Aggregators	-

High Level Use Cases defined in IDE4L

Business Operation and Market Processes BC

Aggr./MO/DSO/TSO Interaction – Operation Domain: This use case describes the interaction between the TSO and the DSO, and between the DSO and the CA needed to produce offerings of ancillary and flexibility services in load and (distributed) generation areas and eventually to activate them.

Aggr./MO/BRP/DSO/TSO Interaction – Market Domain: This HLUC describes the interaction between the flexibility buyers (DSO and/or TSO) and the aggregator on how they make market offerings, accept and assign demand or generation flexibility. The central concept of the approach is the flex-offer specification. Essentially, a flex-offer is a request for demand or
supply of energy with specified flexibilities. These offerings are negotiated by a process of offering, accepting or rejecting, possibly followed by providing a different offering. Reasons for accepting and rejecting include suitability of the offered flexibility (the expected value of the flexibility in e.g. a portfolio) and financial aspects.

Grid Tariffs: This HLUC suggests a way to deal with grid congestions by enabling the demand response scheme, through dynamic pricing.

Monitoring BC

Real time monitoring: In the active distribution network scheme, increasing DER penetration in the lower voltage levels create the need for better and faster monitoring and supervision of critical grid measurements. The DSO is the actor responsible for acquiring and analyzing these measurements.

Forecast: The DSO has to be able to forecast generation and consumption profiles, in order to monitor and plan short term distribution system operation.

System updating: Events such as grid topology changes should be recorded by the DSO, in order to perform correctly algorithms such as State Estimation, Optimal Power Flow and to plan control actions for increasing network reliability and performance.

Control BC

Network planning: The DSO design and plans the operation of distribution networks. The prosumers have to be also considered in the planning process.

Power control: This HLUC illustrates the optimization of the voltage profile and power flow to maintain stable voltage at customer site in a defined area of the distribution grid with distributed generators, flexible loads and other deployed power equipment.

Power quality: The aim is to propose methods to improve power quality in LV/MV networks with high penetration of power electronics-based generating units and/or other equipment. Regulations indicate mínimum threshold power quality levels that installations have to fulfill for their network connection.

FLISR: This HLUC depicts the automation of fault management in the distribution grid. It supports the localization of the fault, the isolation of the fault and the restoration of the energy system delivery. FLISR may help improving performance indexes such as SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index).

The following Table explains the connections between the different Actors and which business goal these links are related with:

Actor 1	Actor 2	Link	Description	Relates with
MO	TSO	Offline & Realtime Validation	After market gate closure, TSO checks the validity of the flexibility bids.	TSO – check SRPs and CRPs validity
MO	DSO	Offline & Realtime Validation	After market gate closure, DSO checks the validity of the flexibility	DSO – check SRPs and CRPs validity

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			bids.	
MO	BRP	SRP & CRP Procurement	The BRP can provide his flexibility buy bids after gate opening	BRP - Satisfy financial responsibility for system's energy balance
MO	CA	SRP and CRP bidding	The CA can provide his flexibility sell bids after gate opening	CA - Optimize energy portfolio
CA	TSO	CRP Activation	The TSO sends an explicit signal to the CA, to activate a CRP product	TSO - respect network security requirements
CA	DSO	CRP Activation	The DSO sends an explicit signal to the CA, to activate a CRP product	DSO - respect network security requirements
CA	BRP	CRP Activation	The BRP sends an explicit signal to the CA, to activate a CRP product	BRP - Satisfy financial responsibility for system's energy balance
CA	Prosumer	Power schedule and activation price	CA sends price and power signals to activate prosumers' flexibility. CA also forecasts energy schedule of the Prosumer	CA - Optimize energy portfolio
CA	Service Provider	Services	Service provider sells services to the	Service provider – sell

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			CA	services
DSO	TSO	Load areas configuration, Real time and Off line Validation	DSO and TSO exchange information about Load Areas and Offline and Real time Validation results	TSO, DSO - check SRPs and CRPs validity
DSO	Service Provider	Services	Service provider sells services to the DSO	Service provider – sell services

Modeling the Business Layer

IDE4L SGAM function layer defines which domains and zones of the business layer are affected by each related HLUCs (e.g. no BC and HLUC will be included in Transmission domain, as this is out of scope of the IDE4L project). The involved HLUCs are included in the Business Layer as model elements.

For each Business Case a Business Layer Diagram is created, using the SGAM Business Layer template. The Business Layers are created through a bottom-up approach, by identifying the functions that comprise each HLUC (see next Table) and checking the domain/zone that each function belongs to:

Function name	Use Case	HLUC
Activation CRP	CRP activation	Aggr./MO/DSO/TSO Interaction - Market Domain
Bid Acceptance/Modification	SRP procurement	Aggr./MO/DSO/TSO Interaction - Market Domain
Bid matching	CAEP	Aggr./MO/DSO/TSO Interaction - Market Domain
Bid preparation	CAEP	Aggr./MO/DSO/TSO Interaction - Market Domain
Bid submission	CAEP	Aggr./MO/DSO/TSO Interaction - Market Domain
CRP Activation request	CRP activation	Aggr./MO/DSO/TSO Interaction - Market Domain
CRP activation use case	CCPC real time	Aggr./MO/DSO/TSO Interaction - Market Domain
CRP validation request	CRP activation	Aggr./MO/DSO/TSO Interaction - Market Domain
Data storage	CAEP	Aggr./MO/DSO/TSO Interaction - Market Domain
Market Clearance	SRP procurement	Aggr./MO/DSO/TSO Interaction - Market Domain
Market infos	SRP procurement	Aggr./MO/DSO/TSO Interaction - Market Domain
power schedules	CAEP	Aggr./MO/DSO/TSO Interaction - Market Domain
Real Time Validation Use case	CRP activation	Aggr./MO/DSO/TSO Interaction - Market Domain
SRP trading	SRP procurement	Aggr./MO/DSO/TSO Interaction - Market Domain

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Check flag	DR	Aggr./MO/DSO/TSO Interaction - Market Domain
Data Storage	DR	Aggr./MO/DSO/TSO Interaction - Market Domain
Load Area Configuration	Load area	Aggr./MO/DSO/TSO Interaction - Operation Domain
Off line and Real Time Validation Use case	CAEP	Aggr./MO/DSO/TSO Interaction - Operation Domain
Off line validation use case	SRP procurement	Aggr./MO/DSO/TSO Interaction - Operation Domain
Validation reply	Off line validation use case	Aggr./MO/DSO/TSO Interaction - Operation Domain
Validation	Off line validation use case	Aggr./MO/DSO/TSO Interaction - Operation Domain
Validation	Real Time Validation Use case	Aggr./MO/DSO/TSO Interaction - Operation Domain
Validation reply	Real Time Validation Use case	Aggr./MO/DSO/TSO Interaction - Operation Domain
Validation Request	Off line validation use case	Aggr./MO/DSO/TSO Interaction - Operation Domain
Validation Request	Real Time Validation Use case	Aggr./MO/DSO/TSO Interaction - Operation Domain
Day ahead dynamic tariff calculation	DADT	Dynamic Tariff
Control function	Microgrid FLISR	FLISR
Data report	Microgrid FLISR	FLISR
Fault detector	FLISR	FLISR
Fault information	Microgrid FLISR	FLISR
Fault isolation	FLISR	FLISR
inform IS	Microgrid FLISR	FLISR
open/close switch	Microgrid FLISR	FLISR
Reading/Writing IEDs setting	Microgrid FLISR	FLISR
Second fault isolation	FLISR	FLISR
synchronization	Microgrid FLISR	FLISR
Reading/Writing IEDs setting	Microgrid FLISR	FLISR
Data reconstruction	LVF	Forecast
Data report	LVSF	Forecast
Data Storage	LVF	Forecast
Data Storage	LVSF	Forecast
Data Storage	MVF	Forecast
Detect error	LVF	Forecast
Load Forecast	LVF	Forecast
Load Forecast	MVF	Forecast
State forecast	LVSF	Forecast
Data Storage	MVSF	Forecast

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Data acquisition	Power quality	Power Quality
Check flag	CCPC offline	Power Control
Check flag	CCPC real time	Power Control
Check flag	LVPC real time	Power Control
Check flag	LVPC offline	Power Control
Check flag	MVPC real time	Power Control
Check flag	MVPC offline	Power Control
Control function	CCPC offline	Power Control
Control function	CCPC real time	Power Control
Control function	LVPC real time	Power Control
Control function	LVPC offline	Power Control
Control function	MVPC real time	Power Control
Control function	MVPC offline	Power Control
Data storage	CCPC offline	Power Control
Data storage	CCPC real time	Power Control
Data Storage	LVPC real time	Power Control
Data Storage	LVPC offline	Power Control
Data storage	MVPC real time	Power Control
Data storage	MVPC offline	Power Control
Detect error	LVPC offline	Power Control
Detect error	MVPC offline	Power Control
Medium voltage network reconfiguration use case	CCPC offline	Power Control
Medium Voltage Network Reconfiguration Use Case	CCPC real time	Power Control
Off line validation use case	CCPC offline	Power Control
Reading/Writing IEDs setting	CCPC real time	Power Control
Reading/Writing IEDs setting	CCPC offline	Power Control
Reading/Writing IEDs setting	LVPC real time	Power Control
Reading/Writing IEDs setting	MVPC real time	Power Control
Real Time Validation Use case	CCPC real time	Power Control
Report error	LVPC offline	Power Control
Report error	MVPC offline	Power Control
SRP confirmation	CCPC offline	Power Control
SRP Day-ahead and intra-day market procurement use case	CCPC real time	Power Control
Control function	MVNR	Power Control
Data Storage	MVNR	Power Control
Calculation of power quality indexes	Power quality	Power Quality
Control function	Power quality	Power Quality
Data storage	Power quality	Power Quality
Reading/Writing IEDs setting	Power quality	Power Quality
Bad data detection	MVSE	Real Time Monitoring

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Bad data identification	MVSE	Real Time Monitoring
Data acquisition	LVRTM	Real Time Monitoring
Data acquisition	MVRTM	Real Time Monitoring
Data Concentration	Dynamic Monitoring	Real Time Monitoring
Data Curation and Fusion	Dynamic Monitoring	Real Time Monitoring
Data presentation	LVRTM	Real Time Monitoring
Data presentation	MVRTM	Real Time Monitoring
Data storage	LVSE	Real Time Monitoring
Data storage	LVRTM	Real Time Monitoring
Data storage	MVRTM	Real Time Monitoring
Data Storage	MVSE	Real Time Monitoring
Detection non-convergence	MVSE	Real Time Monitoring
Dynamic Info Derivation	Dynamic Monitoring	Real Time Monitoring
Missing data	MVSE	Real Time Monitoring
No measurements available	MVSE	Real Time Monitoring
Non-convergence detection	MVSE	Real Time Monitoring
Pseudo measurements missing	MVSE	Real Time Monitoring
Quality index	MVSE	Real Time Monitoring
Quality index	MVSE	Real Time Monitoring
Real-time measurements missing	MVSE	Real Time Monitoring
Signals sampling	LVRTM	Real Time Monitoring
Signals sampling	MVRTM	Real Time Monitoring
State estimation	LVSE	Real Time Monitoring
State estimation	MVSE	Real Time Monitoring
Statistical calculation	LVRTM	Real Time Monitoring
Statistical calculation	MVRTM	Real Time Monitoring
CIM Parsing	NDU	System Updating
Customer/DER change	NDU	System Updating
Data Storage	NDU	System Updating
Grid change	NDU	System Updating
Protection update	PCU	System Updating
State forecast	NDU	System Updating
Data Storage	PCU	System Updating

According to the above Table, and having in mind the function Layer SGAM Template, we extract the Business Layer Diagrams, depicted in the following Figures:

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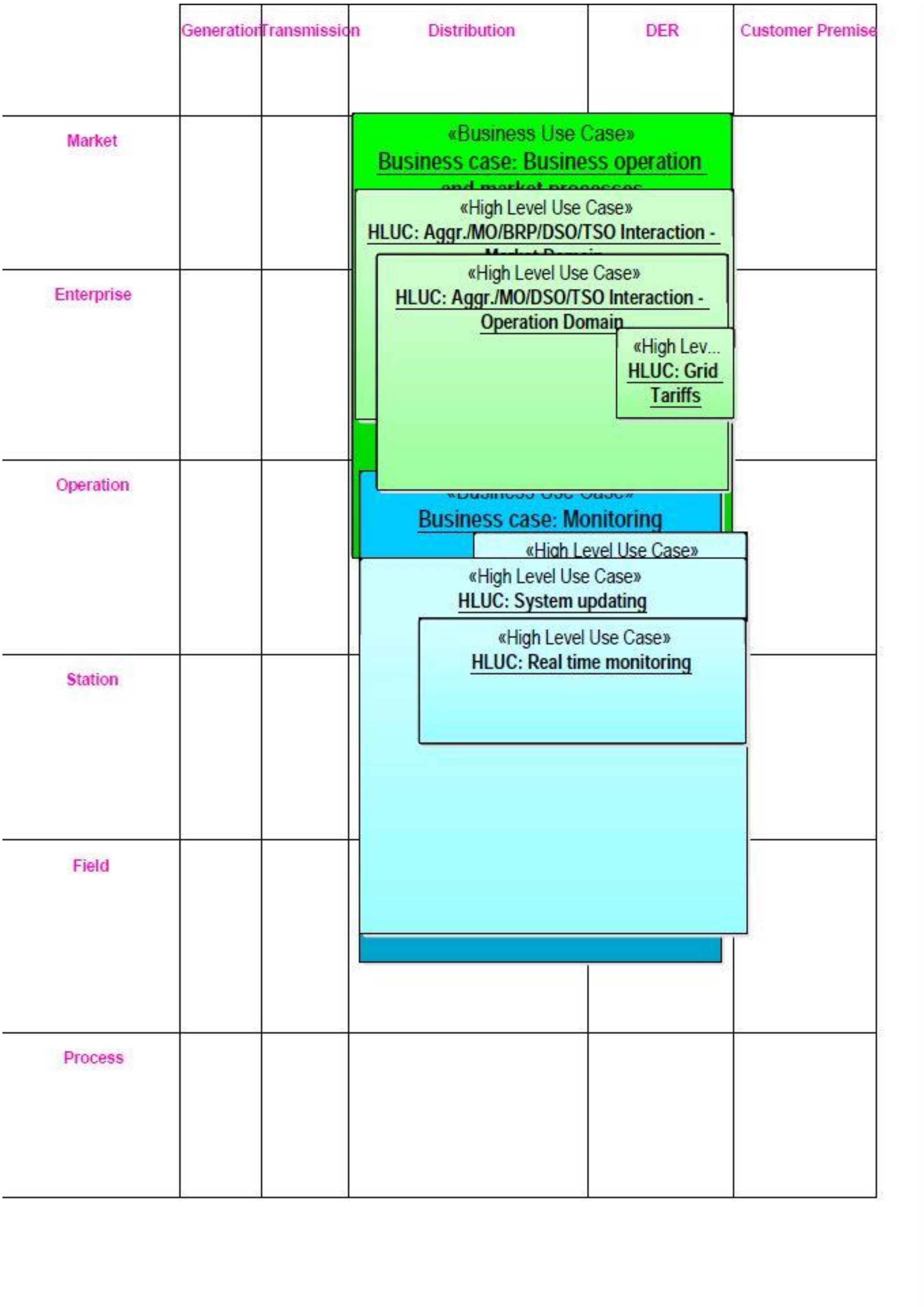

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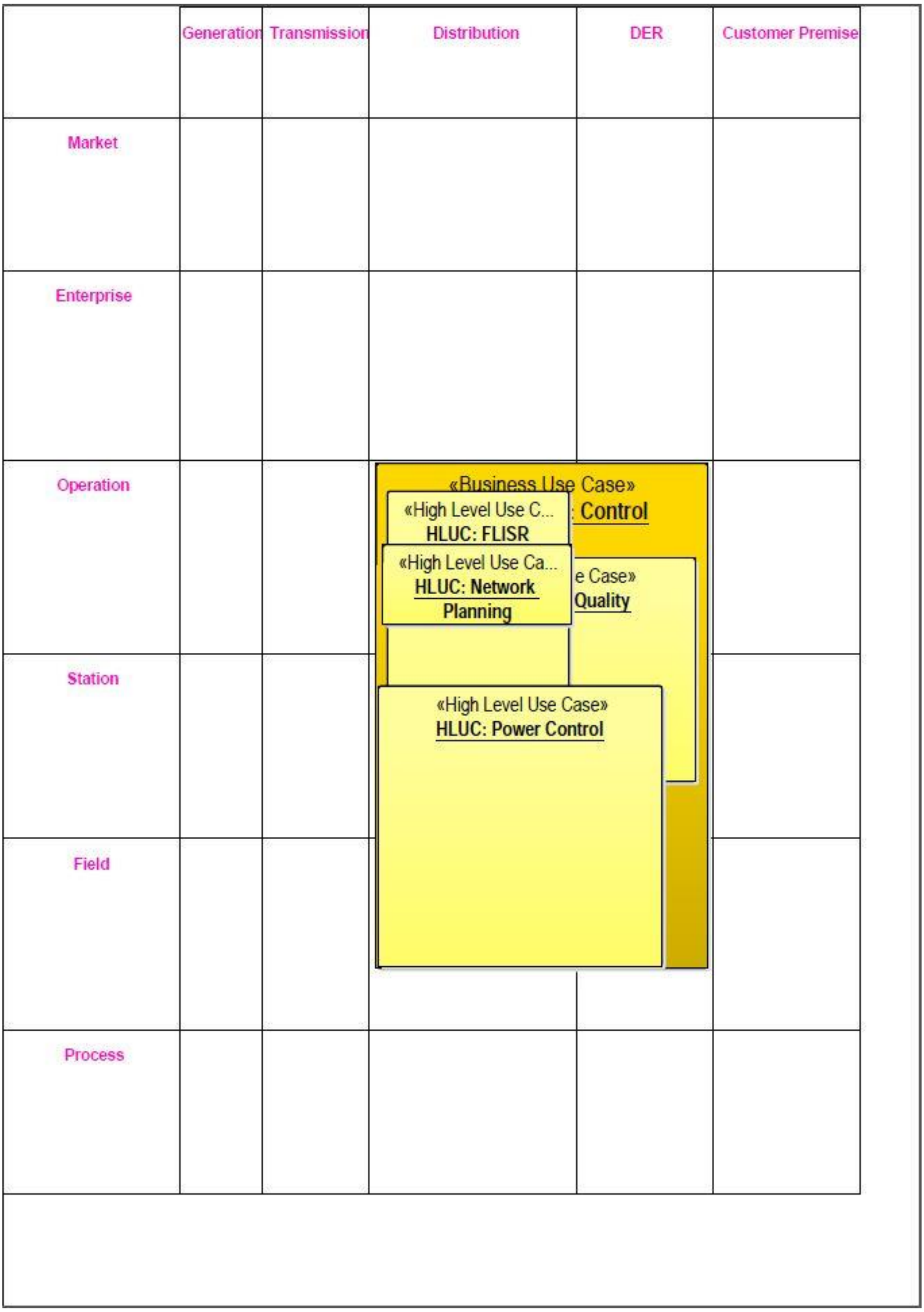
Generation
Transmission
Distribution
DER
Customer Premise
Market
Enterprise
Operation
Station
Field
Process
«Business Use Case»
: Control
«High Level Use C...
HLUC: FLISR
«High Level Use Ca...
HLUC: Network Planning
e Case»
Quality
«High Level Use Case»
HLUC: Power Control

6.6 Integration of SGAM layers

The integration of the SGAM layer, has been already widely shown in the previous paragraph, but it is worth underlying here, the main conclusion on such integration. Every layer set some constraints on the other or requires some further work to be consistent with the others, further details are provided below:

Business layer and component layer

The business layer contains the business actors and their business goals. The latter should represent the main motivation for the development of any automation feature, as the initial expense should be covered during the time with the achievement of the business goal. The business actors are normally persons or enterprises, as for IDE4L: TSOs, DSOs, prosumers, commercial aggregators etc. They cannot operate any automation, without the needed components, consequently the connection between the component layer and the business layer is provided in the business case, where the mapping of business goals to HLUCs is given and in the actor mapping model, where business actors are mapped to automation actors and then to components. An evaluation on the expenses on components, such as computer, devices and communication infrastructures and their allocation in zones and domains, may help in the definition of the business plan. Some numerical results regarding such aspects will be provided in D3.3.

Component layer and function layer

Through the automation actor semantic model and the placement of functions in zones and domains a one to one mapping of component-functions was provided. This will mean, that once algorithms and consequently software/hardware requirements are defined it would be possible to choose adequate components. For example the processor/RAM requirements will be provided for specific algorithms, e.g. state estimation, and consequently adequate computers will be chosen to perform SAU functionalities. Numerical details about such investigations will be provided in D3.3.

Component layer and communication layer

Seen the requirements for data exchange defined in the use cases and provided in the communication layer, adequate communication infrastructures and interfaces should be defined in the component layer. A proper business plan should also take into account either the construction and management of dedicated communication system or the expenses to exploit other available infrastructures.

Component and information layer

The decisions on data models and supported standard will require the installation of proper software in computer and devices in the automation architecture.

7. IMPLEMENTATION OF IDE4L ARCHITECTURE

The implementation of IDE4L architecture required to obtain further details that go toward a practical implementation of the automation architecture. In particular the WP3 individuated the necessity to identify an agreed set of data models, which map exactly the data exchanges defined in the use cases; the interfaces both between internal actor layers and among different actors and finally a database structure that fit with the requirement to have a straightforward and agreed data mapping. The aforementioned information has been built based on the requirements coming from the use case developers, the indication already obtained in the SGAM framework and the specifications of field devices and infrastructure were such automation architecture should be implemented. The aim of the authors with this chapter is to provide ready to use instruction on how to build an instance of IDE4L architecture in real field.

7.1 Logical nodes

Figures 7.1 and 7.2 show snapshots of two Excel tables (Table 7.1 and 7.2) listing all information objects, modeled as IEC 61850 logical nodes, which are exchanged between the actors within the IDE4L architecture. Table 7.1, including the logical nodes used in monitoring use cases, and Table 7.2, including the logical nodes used in control use cases, are attached to this document. The exchanged information objects are derived from the data exchange list presented in section 6.2. The information objects, modeled as IEC 61850 logical nodes, are the same as those described in SGAM information layer in section 6.3 (figures ? to ?); however, it should be noted that the logical nodes, listed in attached Excel tables, represent only the types of the information objects, exchanged between the actors, whereas the SGAM information layer describes both types and instances of each type of the exchanged information objects. For example, as shown in Figure 7.1, the logical node PMU_MMXU1 represent the information object provided by a PMU to other actors in the IDE4L architecture; however, as shown in the SGAM information layer figures, PMU_MMXU1 has instances in different IEDs such as PSIED.PMU, SSIED.PMU, and DIED.PMU.

Needed by UC	Logical node		Data object		Attribute		Attribute		Attribute		Attribute		FC	Description
	name	type	name	type	name	type	name	type	name	type	name	type		
Distribution grid dynami	PMU_MMXU1	MMXU	Hz	MV	instMag	AnalogueV	f	FLOAT32	-	-	-	-	MX	Frequency
Distribution grid dynami	PMU_MMXU1	MMXU	Hz	MV	q	Quality	-	-	-	-	-	-	MX	Frequency quality
Distribution grid dynami	PMU_MMXU1	MMXU	Hz	MV	t	Timestamp	-	-	-	-	-	-	MX	Frequency timestamp
Distribution grid dynami	PMU_MMXU1	MMXU	HzRte	MV	instMag	AnalogueV	f	FLOAT32	-	-	-	-	MX	Rate of Change of Frequency
Distribution grid dynami	PMU_MMXU1	MMXU	HzRte	MV	q	Quality	-	-	-	-	-	-	MX	Rate of Change of Frequency quality
Distribution grid dynami	PMU_MMXU1	MMXU	HzRte	MV	t	Timestamp	-	-	-	-	-	-	MX	Rate of Change of Frequency timestamp
Distribution grid dynami	PMU_MMXU1	MMXU	A	WYE	phsA	CMV	instCVal	Vector	mag	AnalogueValue	f	FLOAT32	MX	Phase current magnitude
Distribution grid dynami	PMU_MMXU1	MMXU	A	WYE	phsA	CMV	instCVal	Vector	ang	AnalogueValue	f	FLOAT32	MX	Phase current angle
Distribution grid dynami	PMU_MMXU1	MMXU	A	WYE	phsA	CMV	q	Quality	-	-	-	-	MX	Phase current quality
Distribution grid dynami	PMU_MMXU1	MMXU	A	WYE	phsA	CMV	t	Timestamp	-	-	-	-	MX	Phase current timestamp
Distribution grid dynami	PMU_MMXU1	MMXU	A	WYE	phsB	CMV	instCVal	Vector	mag	AnalogueValue	f	FLOAT32	MX	Phase current magnitude
Distribution grid dynami	PMU_MMXU1	MMXU	A	WYE	phsB	CMV	instCVal	Vector	ang	AnalogueValue	f	FLOAT32	MX	Phase current angle

Figure 7.1. Snapshot of logical nodes modeled for monitoring cluster of use cases.

Needed by UC	Logical node		Data object		Attribute		Attribute		Attribute		Attribute		FC	Description
	name	type	name	type	name	type	name	type	name	type	name	type		
LVPC/MVPC Real-time	VMMXU1	MMXU	PhV	WYE	phsB	CMV	cVal	Vector	mag	AnalogueValue	f	FLOAT32	MX	UL2 Amplitude, magnitude of inst
LVPC/MVPC Real-time	VMMXU1	MMXU	PhV	WYE	phsC	CMV	cVal	Vector	mag	AnalogueValue	f	FLOAT32	MX	UL3 Amplitude, magnitude of inst
LVPC/MVPC Real-time	OLATCC1	ATCC	BndCtr	ASG	setMag	AnalogueValue	f	FLOAT32					SG	Band center voltage Us
LVPC/MVPC Real-time	MMXU1	MMXU	TotW	MV	instMag	AnalogueValue	f	FLOAT32					MX	Total active power (total P)
LVPC/MVPC Real-time	MMXU1	MMXU	TotVAr	MV	instMag	AnalogueValue	f	FLOAT32					MX	Total reactive power (total Q)
LVPC/MVPC Real-time	MMXU1	MMXU	AvPPVPhs	MV	instMag	AnalogueValue	f	FLOAT32					MX	Arithmetic average of the magnit phase voltage of the 3 phases.
LVPC/MVPC Real-time	OLATCC1	ATCC	LTCBlk	SPC	stVal	BOOLEAN							ST	External signal for blocking

Figure 7.2. Snapshot of logical nodes modeled for control cluster of use cases.

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7.2 CIM classes

Figure 7.3 shows a snapshot of an Excel table (Table 7.3) listing all exchanged information objects between the IDE4L actors, also described in Section 6.3 in the IDE4L SGAM information layer. As shown in the snapshot, each information object has been modeled by either an IEC 61850 logical node (listed in Table 7.1 and 7.2) or a CIM class (listed in XXXX). Table 7.3 is attached to this document.

Use case	Function name	information producer (new)	information receiver (new)	data exchanged	Information Object	Logical node IDE4L type
LVRTM	Data report	SAU(SSAU).MMS	SAU(PSAU).MMS	Statistical measurement	measurement statistcs	MMXU2
LVRTM	Data report	SAU(SSAU).MMS	SAU(PSAU).MMS	Reactive power	Power/Energy measurement	MMTN1
LVRTM	Data report	SAU(SSAU).MMS	SAU(PSAU).MMS	Current phase angle	Current/Voltage measurement	MMXU1
LVRTM	Data report	SAU(SSAU).MMS	SAU(PSAU).MMS	Voltage phase angle	Current/Voltage measurement	MMXU1
LVRTM	Data report	SAU(SSAU).MMS	SAU(PSAU).MMS	Voltage magnitude	Current/Voltage measurement	MMXU1
LVRTM	Data report	SAU(SSAU).MMS	SAU(PSAU).MMS	Current magnitude	Current/Voltage measurement	MMXU1
LVRTM	Data report	SAU(SSAU).MMS	SAU(PSAU).MMS	Active power	Power/Energy measurement	MMTN1
LVRTM	Data report	SAU(SSAU).MMS	SAU(PSAU).MMS	Energy measurement	Power/Energy measurement	MMTN1

Figure 7.3. Snapshot of exchanged information objects linked to logical node IDE4L type/CIM classes.

7.3 Interfaces

For the implementation of the automation actors and consequently of the automation functionalities, it is necessary to develop two sets of interfaces. The first are the “external” interfaces that are the interfaces among different actors; the second are the “internal” interfaces that are the interfaces among the interface, data and application layer that every automation actor has.

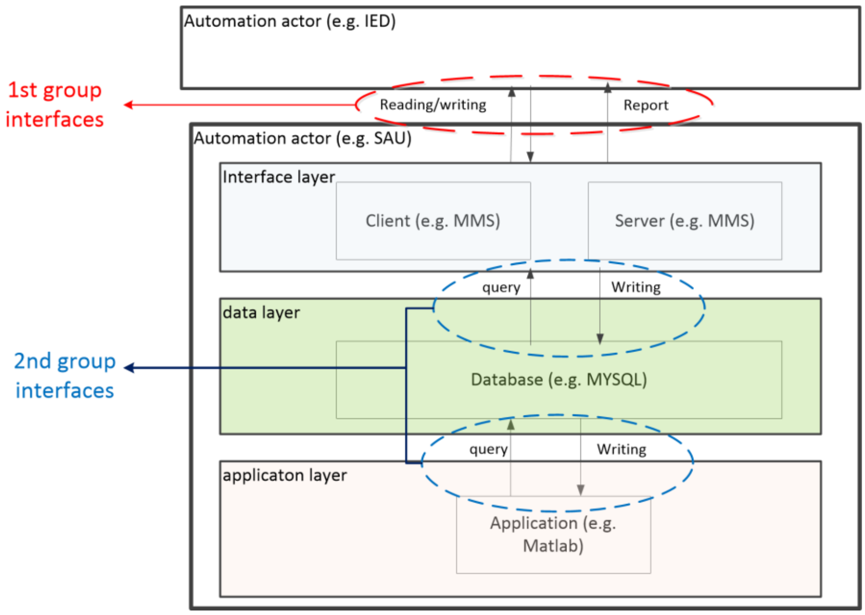

Figure 7.4. Internal and external interfaces of SAU.

Regarding the second group, an agreed format of database has been realized in IDE4L, facilitating the creation of queries and writing from interface to data layer. Moreover, every demonstrator and algorithm developer will participate in the preparation of the so-called “management model” tables, which maps the database data with the data used in the algorithm working space, allowing a straightforward interface between application and data layer. More details will be given in 7.4 Database.

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Regarding the first group of interfaces, in the semantic model of the automation actors in 6.1 Component layer, it has been shown that all the actors have been developed with one or more interfaces to allow communication between actors. IDE4L do not recommend particular technological choices for the development architecture but proposes some instances that will be also tested in demonstration. The type of interfaces listed for IDE4l demonstrations and their implementation in the automation actors is shown in Table 0-A.

Table 0-A IDE4L interfaces' typs

Short Name	Extended name and description	Type	Automation actors using it:
IEC 61850 MMS	IEC 61850 specific communication service mapping to Manufacturing Message Specification (IEC 61850-8-1)	Client-server mechanism	SAU DMS IED MGCC
IEC 61850 GOOSE	IEC 61850 Generic Object Oriented Substation Events	Publisher-subscriber mechanism on multicast or broadcast MAC addresses.	IED
IEC 61850-90-5	Also see IEEE C37.118.2 protocols for synchrophasor measurements	Publisher-subscriber mechanism on multicast or broadcast MAC addresses.	IED SAU DMS
IEC 104	IEC 60870-5-104. SCADA protocol	Master-Slave mechanism	SAU DMS
Modbus	Modbus. SCADA protocol	Master-slave mechanism	SAU DMS IED MGCC
DLMS/COSEM	Device Language Message specification, COmpanion Specification for Energy Metering. It is a standard defining the communication exchange for energy metering devices.	Client-server mechanism	AMM SAU IED
DNP3	Distributed Network Protocol for process	Master-slave	DMS

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	automation systems, included electrical systems.	mechanism	SAU IED
Web Services	It refers generically to computer networks	TCP/IP or UDP/IP client-server mechanism	DMS SAU MGCC IED CAS

The interfaces needed for the sake of the demonstration are partially available from devices' manufacturers and partially will be developed in IDE4L in the so-called integration lab, as shown in Table 0-B, where each laboratory or field demonstration takes care of the development of some interfaces, to be realized with agreed features in order to be used also in other lab and field tests. What appears clearly from the table is that :

- the main new automation actor introduced by IDE4L, that are the SAU and the MGCC, require the development of new 61850 MMS interfaces with other SAUs, IEDs and DMS to realize the main automation functionalities.
- DMSs and IEDs are instead already well known and developed devices, hence only some integration is needed to be plugged in the architecture
- CAS relies mainly on web services

Table 0-B Interfaces developers

Location	Interface	Another end	Developer
AMM	DLMS/COSEM client	IED(SM)	Manufacturer
AMM	WebService	SAU(SSAU)	Manufacturer
CAS	WebService	MGCC	IDE4L
DMS	104 master	IED.104/61850 gateway	Manufacturer
DMS	104 master	IED.104/61850 gateway	Manufacturer
DMS	61850 MMS server	SAU(SSAU)	Manufacturer
DMS	Modbus/TCP master	IED(WT CTRL)	Manufacturer
DMS	61850 MMS client	SAU(PSAU)	IDE4L
DMS	61850 MMS client	SAU(PSAU)	IDE4L
IED	61850 MMS server	IED.104/61850 gateway	IDE4L
IED	Modbus TCP slave	MGCC	IDE4L
IED	61850 MMS client	MGCC	IDE4L
IED	61850 MMS server	SAU(PSAU)	IDE4L
IED	61850 MMS server	SAU(PSAU)	IDE4L
IED	61850 GOOSE publisher	IED	IDE4L
IED	61850 GOOSE subscriber	IED	IDE4L
IED(CRB-CTRL)	Modbus slave	IED.61850/Modbus gateway	Manufacturer

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IED(DG CTRL)	Modbus client	IED.61850/Modbus gateway	Manufacturer
IED(Dynamic Voltage Regulator CTRL)	61850 MMS server	SAU(SSAU)	Manufacturer
IED(electrical storage CTRL)	Modbus TCP slave	MGCC	IDE4L
IED(EV CTRL)	61850 MMS server	SAU(SSAU)	IDE4L
IED(IED(PV-CTRL))	Modbus slave	SAU(SSAU)	Manufacturer
IED(MDC)	DLMS/COSEM client	IED(SM)	Manufacturer
IED(ML CTRL)	Modbus TCP slave	MGCC	IDE4L
IED(OLTC CTRL)	61850 MMS server	SAU	Manufacturer
IED(PMU)	IEC 61850-90-5	SAU(PSAU)	Manufacturer
IED(PMU)	IEC 61850-90-5	SAU(SSAU)	Manufacturer
IED(SM)	DLMS/COSEM server	DLMS/COSEM client	Manufacturer
IED(SM)	DLMS/COSEM server	MDC	Manufacturer
IED(SM)	DLMS/COSEM server	MDC	Manufacturer
IED(SM)	DLMS/COSEM server	SAU(SSAU)	Manufacturer
IED(SM)	DLMS/COSEM server	SAU(SSAU)	Manufacturer
IED(SSIED).IED.61850/Modbus gateway	Modbus master	IED(CRB_CTRL)	Manufacturer
IED(STATCOM CTRL)	61850 MMS server	SAU(SSAU)	Manufacturer
IED.104/61850 gateway	104 slave	DMS	Manufacturer
IED.104/61850 gateway	61850 MMS client	SAU(PSAU)	Manufacturer
IED.104/61850 gateway	104 slave	DMS	Manufacturer
IED.104/61850 gateway	61850 MMS client	IED	Manufacturer
IED.61850/Modbus gateway	61850 MMS server	SAU	IDE4L
IED.61850/Modbus gateway	Modbus master	DG CTRL	IDE4L
MDC	DLMS/COSEM client	IED(SM)	Manufacturer
MDC	DLMS/COSEM client	AMM	Manufacturer
MDC	DLMS/COSEM client	IED(SM)	Manufacturer
MGCC	61850 MMS server	SAU(SSAU)	IDE4L
MGCC	Modbus TCP master	IED	IDE4L
MGCC	61850 MMS server	IED	IDE4L
MGCC	Modbus TCP master	IED(ML CTRL)	IDE4L
MGCC	Modbus TCP master	ES CTRL	IDE4L
MGCC	WebService	CAS	IDE4L
OLTC CTRL	61850 MMS server	SAU(PSAU)	IDE4L
OLTC CTRL	61850 MMS server	SAU(SSAU)	IDE4L
PSIED	61850 MMS server	SAU(PSAU)	IDE4L
SAU	61850 MMS client	OLTC CTRL	IDE4L
SAU	61850 MMS client	IED.61850/Modbus gateway	IDE4L
SAU(PSAU)	61850 MMS server	IED.104/61850 gateway	IDE4L
SAU(PSAU)	61850 MMS client	SAU(SSAU)	IDE4L
SAU(PSAU)	61850 MMS client	IED	IDE4L
SAU(PSAU)	61850 MMS server	DMS	IDE4L
SAU(PSAU)	61850 MMS client	SAU(SSAU)	IDE4L
SAU(PSAU)	61850 MMS server	SAU(PSAU)	IDE4L

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SAU(PSAU)	IEC 61850-90-5	IED(PMU)	IDE4L
SAU(PSAU)	61850 MMS client	OLTC CTRL	IDE4L
SAU(PSAU)	61850 MMS server	DMS	IDE4L
SAU(PSAU)	61850 MMS client	SAU(SSAU)	IDE4L
SAU(PSAU)	61850 MMS client	IED	IDE4L
SAU(PSAU)	61850 MMS client	IED	IDE4L
SAU(SSAU)	61850 MMS server	SAU(PSAU)	IDE4L
SAU(SSAU)	DLMS/COSEM client	IED(SM)	IDE4L
SAU(SSAU)	Modbus/TCP master	IED(PV-CTRL)	IDE4L
SAU(SSAU)	61850 MMS client	IED(DVR CTRL)	IDE4L
SAU(SSAU)	61850 MMS client	STATCOM CTRL	IDE4L
SAU(SSAU)	61850 MMS client	IED.61850/Modbus gateway	IDE4L
SAU(SSAU)	61850 MMS server	?	IDE4L
SAU(SSAU)	WebService	AMM	IDE4L
SAU(SSAU)	61850 MMS server	DMS	IDE4L
SAU(SSAU)	WebService	MDC	IDE4L
SAU(SSAU)	61850 MMS client	DMS	IDE4L
SAU(SSAU)	61850 MMS client	MGCC	IDE4L
SAU(SSAU)	DLMS/COSEM client	IED(SM)	IDE4L
SAU(SSAU)	61850 MMS client	OLTC CTRL	IDE4L
SAU(SSAU)	61850 MMS client	IED(EV CTRL)	IDE4L
SAU(SSAU)	IEC 61850-90-5	IED(PMU)	IDE4L
SAU(SSAU)	61850 MMS server	SAU(PSAU)	IDE4L
SAU(SSAU)	DLMS/COSEM client	IED(SM)	IDE4L
SAU(SSAU)	RTDS sockets	IED(PV-CTRL)	IDE4L
IED.61850/Modbus gateway	61850 MMS server	SAU(SSAU)	Manufacturer

7.4 Database

This section presents a short overview of the SAU database schema designed in IDE4L. The description is focused on the modular concept used to design the final version of the database. In this approach each sub-model of the database schema is connected with the others through a dedicated set of tables identified by a bridge model which is used to map information.

In the IDE4L architecture the SAU is in charge to manage a piece of network (in LV or MV layer) connected to a substation (Primary Substation – PS – or Secondary Substation – SS). In order to perform a specific calculation, such as state estimation, forecast or power control, it needs static information mainly related to the network topology and dynamic information related to the measures and commands that it must exchange with the field devices installed in its grid.
For this reason, and considering the needed management of the running algorithms, the database architecture has been divided in four different schemas. Each of them reports the relations and entities which permit to manage a part of the information in charge of a SAU. In particular the four schemas are:

- **Measure & Control Model:** it is focused on the storage and management of measurements and control signals exchanged with the field devices. It has been designed following the IEC61850 data model in which a specific parameterization model has been added in order to configure the communication interface for a specific physical device;

- **Management Model:** it represents the models related to an algorithm. It can be used to instantiate, parameterize and control the execution of a specific algorithm. It stores also the log profile and the state of an algorithm instance and it permits to force an execution or a restart of an algorithm;
- **Network Model:** it contains the network topology representation in which feeder, connections, customers, etc. are modeled with related characteristics and parameters (impedances, distances, nominal powers, etc.);
- **Bridge Model:** it is the connection schema for all other schemas. In this data model every relation among Measure & Control, Management and Network are described.

In Figure 0-1 the overall database architecture with the relations among schemas is represented. The Management Model is not directly connected to other schemas. In fact it is used only to manage the algorithms installed in the SAU which in turn exchange data with other schemas.

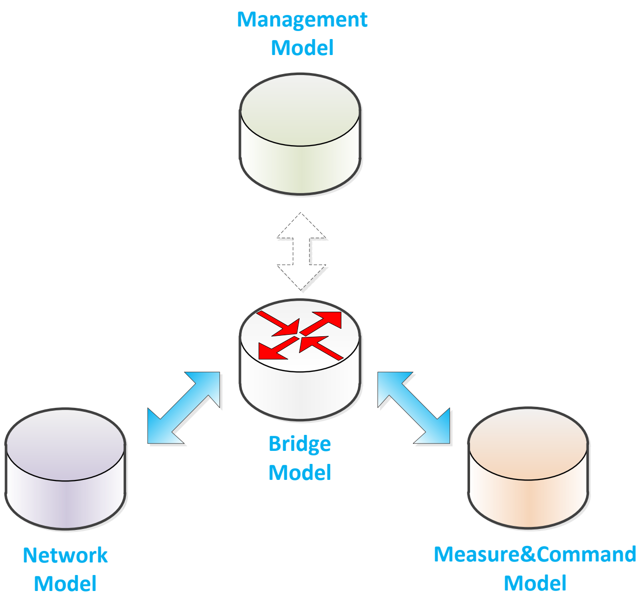

Figure 0-1: Relations among SAU Database schemas

Measure & Command Model

The Measure & Control model has been defined starting from IEC61850 Data model. The model, which is mainly composed by physical device, logical device, logical node, data object and data attribute, has been expanded with a set of entities used to collect real-time and historical data retrieved from the field and with a set of information to parameterize the communications interface to each physical device (such as IP addresses, TCP ports, users and passwords, etc.). A group of tables has been defined specifically to model forecast profiles.

Management Model

In the IDE4L SAU more than one algorithm type and more than one instance of the same algorithm type can be executed at the same time. In particular, a group of algorithms are running during the life of the SAU in order to perform several calculations (state estimation, state forecast, power control, etc.). Most of them have a strong interaction with the others and they must be synchronized and controlled in order to obtain the expected result.

This section reports the description of the data model designed to manage the algorithms parameterization and synchronization. However it must be clear that the data model allows the management of the algorithms execution but it cannot perform the control so that a specific execution function (i.e. a finite state machine) should be included in each algorithm implementation.

Figure 0-2 describes an example of automaton that could be used to control the internal status of a simple SAU algorithm. The events which mark the transitions should come from updates of database rows or from timers.

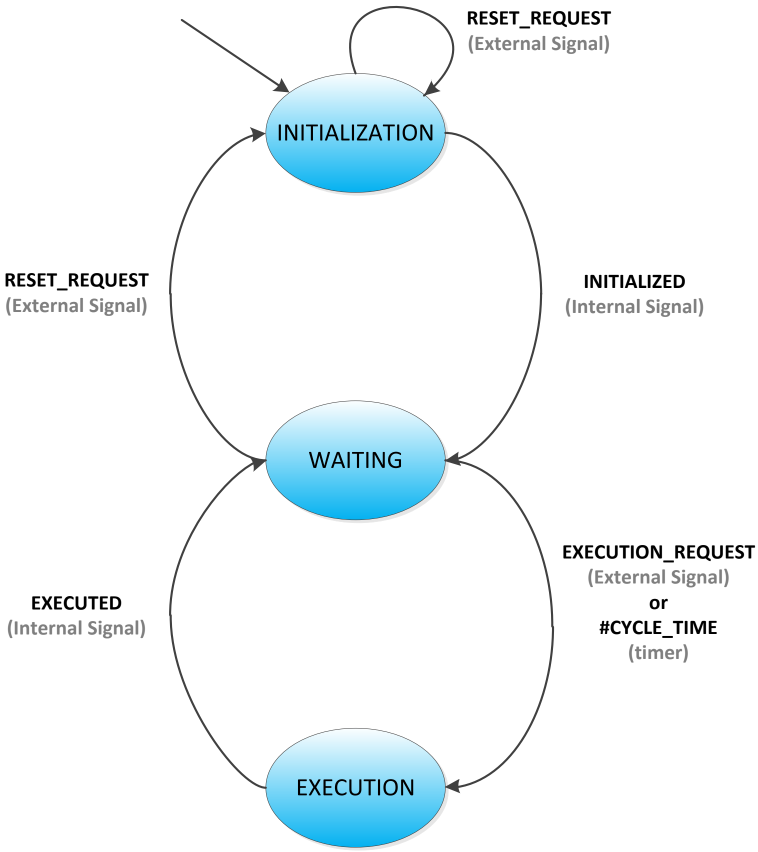

Figure 0-2: Finite state machine to control the internal status of a SAU algorithm

Network Model

Network topology model is based on IEC CIM model, version "iec61970cim17v05_iec61968cim12v09_iec62325cim03v02".

The schema has been designed starting from the previous version proposed in the Smart Domo Grid project. Major changes with respect the older database version are related to the model for PV plants, and in general to simplify the old schema.

IEC 61970-301 reports "All CIM attributes are implicitly optional in the sense that profiles using the CIM may eliminate any attributes." So in principle, most of fields in CIM Network Topology tables are allowed to be "Null" so that applications and algorithms which must interact with the database can give Null or Non-Null values to these optional columns based on their own needs.

The CIM network topology tables are depicted in Figure ?? "CIM-network-topology-diagram". They are used for storing static features of network. In most cases, each table corresponds to one CIM class, with each column representing one CIM attribute. The exception is *cim_powertransformerend*, *cim_perlengthsequenceimpedance* and *cim_synchronousmachine*, which combine two or three CIM classes into one table.

Many CIM classes involved in this schema inherit from CIM class ConductingEquipment. They represent physical parts of the AC power system that can carry current, including BusbarSection, Junction, Switch, PowerTransformer, ACLineSegment, SynchronousMachine and EnergyConsumer. Other classes such as Terminal and ConnectivityNode do not correspond to any physical equipment, but they play important role for presenting/deducing network topology, and indicating the placement of measurement points. CIM class Measurement represents measurement point; whereas classes Setpoint and Command indicate the control/command point.

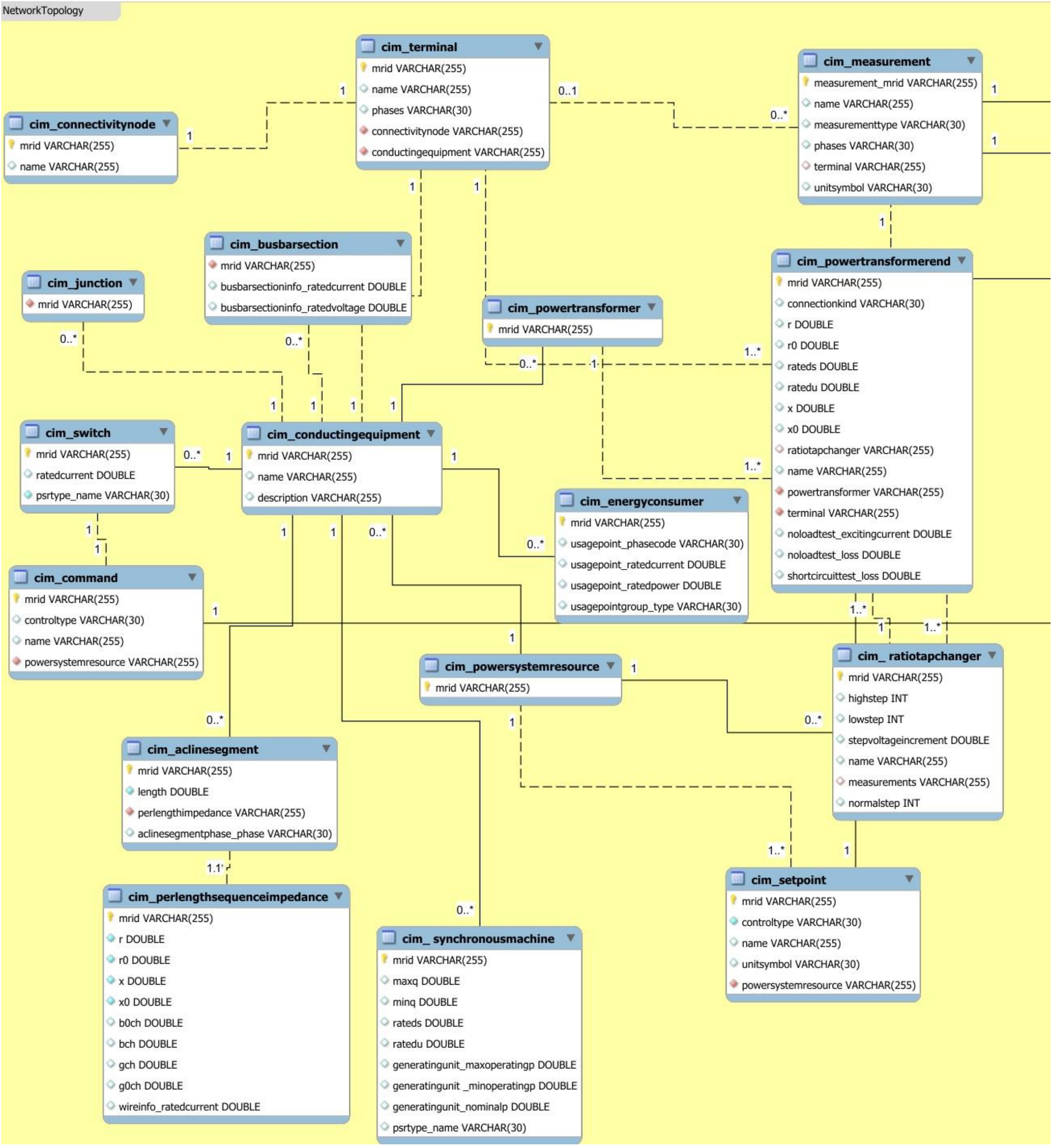

Figure ??. CIM network topology diagram.

Bridge Model

Bridge model groups a set of tables used to map runtime and historical measures and commands exchanged with field devices (IEDs, actuators, etc.) with their instances in the Network topology. In particular four different tables have been defined to map discrete or analog measures and commands with their positions in the network topology among Measure & Command model and Network model.

7.5 Applications

List of applications to be implemented

Application = Algorithm on single actor (NOT use case, includes many actors)

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APPENDIX

A1 Detailed use cases

Use case detailed template

Description of the Use Case

General

Name of Use Case

ID	Domain see Annex A Selection List	Name of Use Case	Level of Depth Cluster, High Level Use Case, Detailed Use Case

Version Management

Changes / Version	Date	Name Author(s) or Committee	Domain Expert	Area of Expertise / Domain / Role	Title	Approval Status draft, for comments, for voting, final
			Primary			
			Additional			
			Additional			

Basic Information to Use Case

Source(s) / Literature	Link	Conditions (limitations) of Use

Relation to Higher Level Use Case	
Cluster	Higher Level Use Case

Maturity of Use Case – in business operation, realized in demonstration project, , realised in R&D, in preparation, visionary
Prioritisation

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Generic, Regional or National Relation
View - Technical / Business
Further Keywords for Classification

Scope and Objectives of Use Case

Scope and Objectives of Function

Narrative of Use Case

Narrative of Use Case
Short description – max 3 sentences
Complete description

Actors: People, Systems, Applications, Databases, the Power System, and Other Stakeholders

Actor Name see Annex A Selection List	Actor Type see Annex A Selection List	Actor Description see Annex A Selection List	Further information specific to this Use Case

Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	Impact of Issue on Use Case	Reference – law, standard, others

Preconditions, Assumptions, Post condition, Events

Actor/System/Information/Contract	Triggering Event	Pre-conditions	Assumption

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Referenced Standards and / or Standardization Committees (if available)

Relevant Standardization Committees	Standards supporting the Use Case	Standard Status

General Remarks

General Remarks

Drawing or Diagram of Use Case

Drawing or Diagram of Use Case – recommended “context diagram” and “sequence diagram” in UML

Step by Step Analysis of Use Case

S.No	Primary Actor	Triggering Event	Pre-Condition	Post-Condition

Steps – Normal Sequence

Scenario Name :						
Step No.	Eve nt	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Technical Require-ments ID
1						

Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name :						
Step	Eve	Description of	Information	Information	Information Exchanged	Technical Require-

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No.	nt	Process/Activity	Producer	Receiver		ments ID
1						

A2 Standards

The main objectives of the control centers are managing, controlling and protecting distribution power networks. In deliverable D3.1, the architecture of a Control Center able to support smart features has been defined. Furthermore, the main functionalities have been analyzed, resulting a list of modules needed to implement the Control Center: monitoring module, forecasting module, state estimation module, power and voltage control module, simulation module, supervision module and control module, and the integration with other systems is also taken into account. Some standards are needed in order to support the aforementioned architecture. In this chapter, the commonly used standards are reviewed.

A2.1 TCP/IP family

It is a set of network protocols, normally named TCP/IP family as a reference of the two most important ones, the first ones to be defined and the most used.

- TCP: Transmission Control Protocol
- IP: Internet Protocol

There are more than one hundred protocols; some of them are highlighted:

- ARP: Address Resolution Protocol
- FTP: File Transfer Protocol
- HTTP: HyperText Transfer Protocol, used to web access
- POP: Post Office Protocol, used for e-mail
- SMTP: Simple Mail Transfer Protocol, used for e-mail
- Telnet: Teletype Network, to access remote equipment

The correspondence between TCP/IP protocols and OSI model is shown in the following figure:

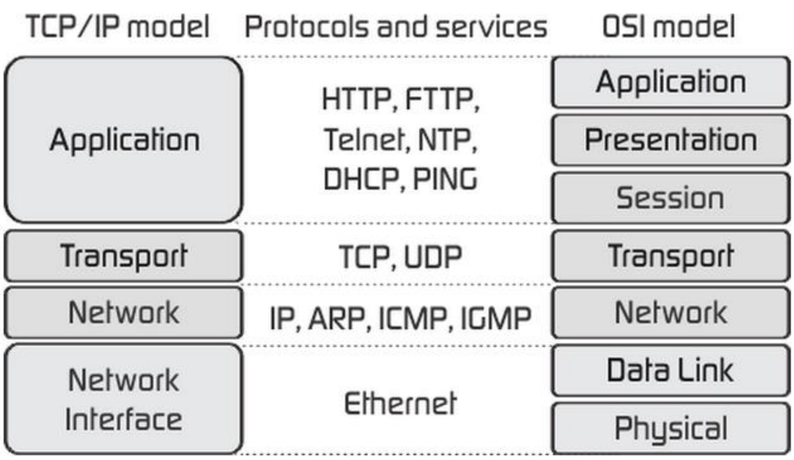

Fig. 5: Correspondence between TCP/IP and OSI models

TCP/IP protocols have a high reliability, and they are suitable for large and medium-sized networks.

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A2.2 Distribution automaton

IEC 61850

"Communication networks and systems for power utility automation" (IEC 61850) is a standard for the design of power station automation, and it is a part of the International Electrotechnical Commission Technical Committee 57 (TC57), whose main parts covers the system management, communication requirements for functions and devices, basic communication structure for substation and feeder equipment, or configuration language for communication in electrical substations related to IEDs.
It is not conceived for a specific voltage level; instead, it can be applicable to all kind of installations (generation consumption, substations) of all sizes and voltage levels. It provides interoperability between the functions to be performed in a substation although residing in devices from different vendors, with the same Functional and operational requirements.

This standard is used for information exchanges, defining which information can be interchanged, and how can it be interchanged.

The standard is divided in several sections:

- IEC 61850-1: Introduction and overview
- IEC 61850-2: Glossary
- IEC 61850-3: General requirements
- IEC 61850-4: System and project management
- IEC 61850-5: Communication requirements for functions and device models
- IEC 61850-6: Configuration language for communication in electrical substations related to IEDs
- IEC 61850-7: Basic communication structure for substation and feeder equipment
- IEC 61850-7-1: Principles and models
- IEC 61850-7-2: Abstract communication service interface (ACSI)
- IEC 61850-7-3: Common Data Classes
- IEC 61850-7-4: Compatible logical node classes and data classes
- IEC 61850-7-10: Requirements for web-based and structured access to the IEC 61850 information models
- Specific communication service mapping (SCSM)
    - IEC 61850-8-1: Mappings to MMS (ISO/IEC 9506-1 and ISO/IEC 9506-2)
    - IEC 61850-9-2: Sampled values over ISO/IEC 8802-3
    - IEC 61850-10: Conformance testing

The standard can be divided in three main blocks:

- Data models – IEC 61850-6, IEC 61850-7-3, IEC 61850-7-4
- "Cold" data interchange models: files coded in description/configuration language SCL (System Configuration Language) – IEC 61850-6
- "Hot" data interchange models – IEC 61850-7-2, IEC 61850-8-1, IEC 61850-9-2

These models, all in the scope of software and information management, are conceptually different and independent. However, they have strong synergies that allow a coexistence between them.

Data model

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It is the kernel of the standard IEC 61850. It consists of a formal, non ambiguous and structured representation of the information that can be interchanged, allowing the procedure to be automated.

The exchange of information can happen between two or more agents such as:

- IED
- Control Center
- IED Configuration tools
- Operative applications (DMS…)
- Strategic applications
- Human operators

It is based on reusable predefined blocks, having a hierarchical structure.

“Cold” data interchange model

It is based on plane text files coded in SCL (a particularization of XML). This file describes a data structure which is a particularization of the model, and can be applied to an IED or a complete substation. They contain the structure of the data, but not the current field values, and they are not supposed to be exchanged during operation, nor to be used in real-time applications.

“Hot” data interchange models

They are used in real-time functionalities, with three independent application level protocols:

- Client/server communications with a Control Center located inside or outside the substation (“vertical” communications)
- Fast event-oriented communications between equal elements (“horizontal” communications)
- Sampled values

The protocol stack is the following one:

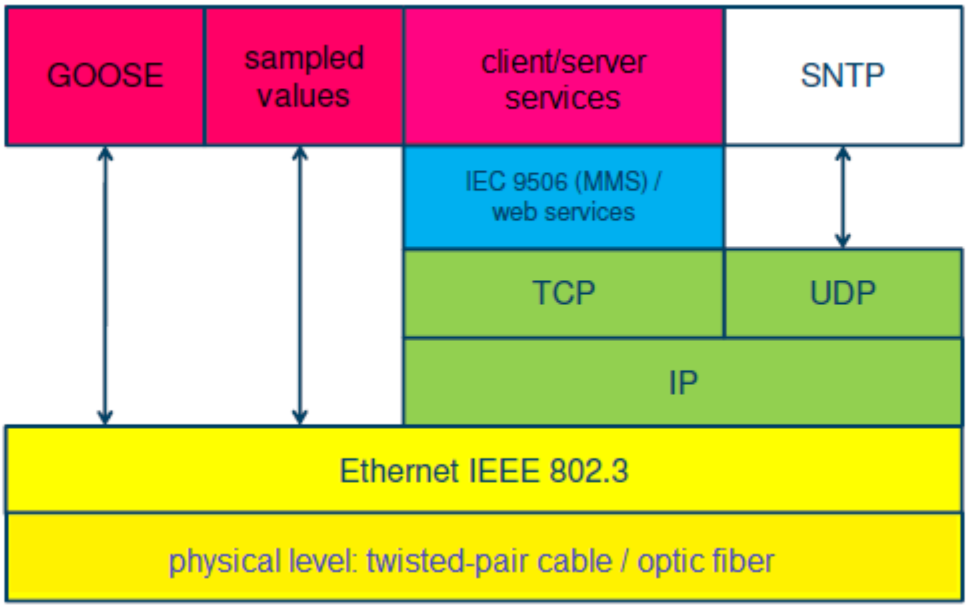

Fig. 1 IEC 61850 protocol stack

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IEC 61850 standard offers flexibility and great functionality by implement Object Oriented model and fast GOOSE messages between IEDs. It also possibility to achieve less than one microsecond accuracy with the distributed clocks through Ethernet by GPS system and IEEE 1588 standard.

IEC 60870-5-101

It is an international standard for telecontrol, teleprotection and communications, commonly used in electric power systems. It was released at the beginning of 1990 by the IEC.

Table 0-A Increase of IEC 60870-5 [2]

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004
Nª IEC 870-5-SAS	6	26	46	88	124	160	200	235	270

This protocol was widely found in the energy sector, and it is still used nowadays. It is based on the EPA architecture (Enhanced Performance Architecture), defining only the physical, link and application layers of the OSI model. IEC 60870-5 protocol is based on a three-layer Enhanced Performance Architecture (EPA) reference model for efficient implementation within RTUs, meters, relays, and other IEDs.

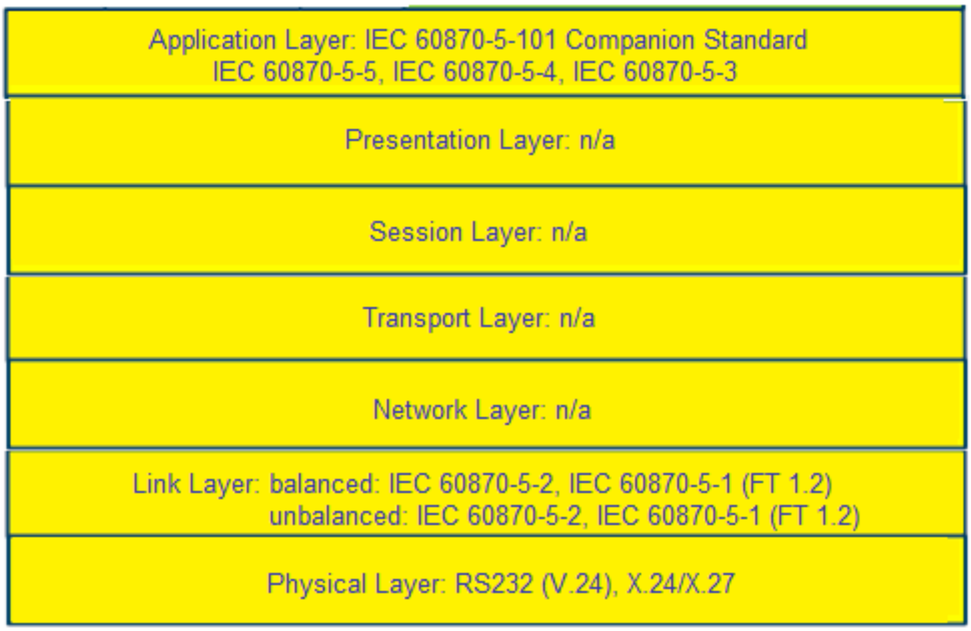

Fig.2: IEC 60870-5-101 Protocol stack

IEC 60870-5-101 is mainly used with relatively slow transmission media on the asynchronous V.24 interface. The standard baud rates are up to 9600 bit/s, but higher ones (<115200 bit/s) are currently used.

The standard is divided in several sections:

IEC 60870-5-1 defines different transmission frame formats, although IEC 60870-5-101 only uses the FT1.2 format and provides structures that are also directly applicable to the interface between RTUs and IEDs.

- IEC 60870-5-2 defines the Data link layer transmission mode
- IEC 60870-5-3 defines the basic application data structure

- IEC 60870-5-4 definition and coding of Information Elements
- IEC 60870-5-5 defines basic application layer functions
- IEC TS 60870-5-601 defines "Conformance Test Cases" for IEC 60870-5-101

The original standard is open in some issues, so there are different implementations for the same devices, being usually incompatible among them. As a consequence, some Utilities have developed their own version of the standard, carrying out the risk of incompatibilities.

IEC 60870-5-104

IEC60870-5-104 protocol is an international standard released in 2000. It is an extension of 101 version, having an application layer based on IEC 60870-5-101, and with some changes in transport, network, link and physical layer.

Its main characteristics are:

- Enabling communication between control center and substations via TCP/IP network. TCP protocol is used for connection-oriented secure data transmission.
- Some functions available in IEC 60870-5-101 are not available in IEC 60870-5-104, such as short time stamps (3-byte format).
- In practice, both protocols are often combined, using the IEC 60870-5-101 application layer and the IEC 60870-5-104 transport layer.
- The standard defines an interoperability list, to ensure interoperability between devices.

The main advantage of IEC 60870-5-104 is that it enables the communication via a standard network (TCP/IP network), allowing a simultaneous data transmission between different devices and services. However, it does not solve problems like the definition of communication with redundant systems or networks, and data encryption (with the use of the internet).

The main argument for using Standard IEC 60870-5 is reduction of maintenance costs due to reduced maintenance of secondary side devices. However, presented a limited interoperability and it is a local solution.

A2.3 Metering standards

In the literature, several protocols have been proposed for an efficient communication of SMs (Smart Meters), like DLMS/COSEM and IEC 61850 [Feuerhahn2011]. Nevertheless, the most promising standard is nowadays DLMS/COSEM, which has been already used by different suppliers.

COmpanion Specification for Energy Metering (COSEM) [IEC 62056-6-2] is a specific object-oriented model for the Electronic Energy (EE) meters communication interfaces, providing a complete view of their available functionalities directly through the interfaces.

Device Language Message Specification (DLMS) [IEC 62056-5-3] defines an application layer that does not depend on the lower layer. It has been developed with the aim to provide an interoperable environment in which to exchange metering data/information.

DLMS/COSEM is a standard that uses COSEM to define the EE meters interfaces and DLMS for the data exchange between different devices. More specifically:

- The interface model provides only a functional description via building block, without describing the specific aspects of its implementation;
- The communication protocol defines the data access and transport.

The DLMS/COSEM standard is divided in three blocks:

- Modeling of both the device interfaces and the rules for the data identification;
- Messaging: mapping of the interface model on the messages;
- Transporting: message transport through the communication layer.

The DLMS/COSEM standard defines a client-server communication scheme: the MDC periodically polls the SM for data acquisition. This communication scheme has severe scalability issue in a system which should be able to provide information for monitoring and control of the distribution grid. For this reason, recently DLMS/COSEM has introduced the event notification and Push mechanisms, which can be used to send notification of events to the MDC of to trigger the transmission of messages without the direct request of the MDC. This approach is similar to the Report service defined by the IEC 61850 [Feuerhahn2011]. Nevertheless, at the moment few meters on the market supports these modes of operation because of their recent introduction in the standard.

PRIME Alliance STG-DC 3.0

PRIME Alliance is a group of Utilities, meter and semi-conductor chipset manufacturers, IT, service and consultant companies, research organisms and other smart grid industry related companies, which stands for an interoperable standard for Advanced Meter Management and Smart Grid.

The alliance was established in 2009 with 8 founding companies, and the first interoperable system was installed in 2010. In 2011, two Spanish DSOs (Iberdrola and Gas Natural Fenosa) started to use the standard, followed by EDP in Portugal, in 2012. The deployments continued in Australia, Poland, Argentina, Brazil, Lebanon and Romania, having a total of 5 million meters deployed in 2014. In 2015, the version 1.4 of the specification is released.

PRIME represents a public, open and non-proprietary telecommunication architecture to offer secure and reliable communications from smart meters to control centers, enabling the real-time capabilities demanded by smart grid applications. Its main goal is to offer a set of standards which allow for a full interoperability among equipment and systems from different providers.

The reference model of protocol layers used in PRIME specification is shown in the figure [1]:

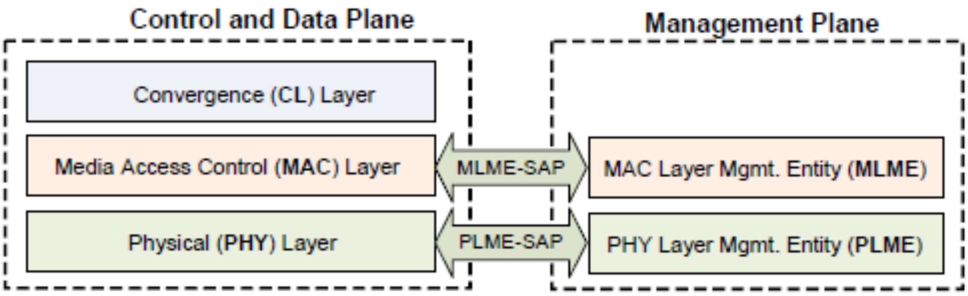

Fig. 3: Reference model of protocol layers used in PRIME

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The Convergence Layer function is to classify the traffic, associating it with its proper MAC connection. It maps any kind of traffic to be properly included in MPDUs. The Media Access Control Layer provides functionalities such as system access, bandwidth allocation, connection establishment/maintenance and topology resolution. The Physical Layer transmits and receives MPDUs between neighbor nodes using OFDM. This type of modulation adapts easily in the presence of frequency selective channels, it is robust to impulsive noise, and it achieves high spectral efficiencies with simple transceiver implementations. The Physical Layer employs a flexible coding scheme, and it also adapts its data rate to channel and noise conditions by the MAC.

DLMS/COSEM

DLMS/COSEM is a common language for Automatic Meter Reading – or more general, Demand Side Management –:

- DLMS (Device Language Message Specification) defines a generalized concept for abstract modeling of communication entities – application layer protocol.
- COSEM (COmpanion Specification for Energy Metering) sets the rules, based on existing standards, for data exchange with energy meters – data model.
- Communication profiles

DLMS/COSEM provides an object model, an identification system for all metering data, a messaging method to communicate with the model and to convert the data into a series of bytes, and a transporting method to carry the data between the metering equipment and the data collection system. It is continuously evolving to meet new requirements. Utilities, manufacturers and system providers conforms the DLMS User Association, and they are in charge of developing and maintaining the specification, offering standardization, developing conformance tests and supporting users.

Its characteristics are:

- Evolutive: the COSEM model, the DLMS services and the communication profiles can be extended independently.
- Flexible: the standard elements can be freely combined to tailor the system to the target application.
- Interoperable: the object model, features implemented, standard identifiers and data types ensure interoperability among products from different providers.
- Secure end-to-end: advanced security features based on tested cryptographic standards ensure end-to-end security between systems and meters.
- Efficient: its characteristics ensure low overhead and efficient data exchange.

There are several standards describing DLMS/COSEM:

- IEC 62056 for electricity metering
- EN 13757 for gas, water, heat metering
- IEC 61334 for Distribution automation
- IEC 61361 for user requirements

In the case of electricity metering, the standard IEC 62056 has different parts:

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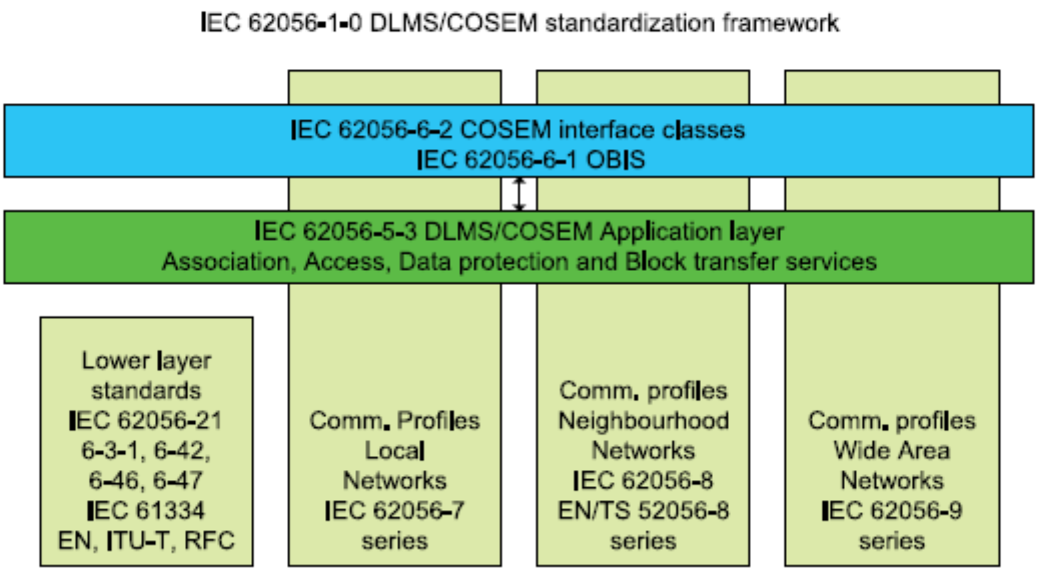

Fig. 4: IEC 62056 standard

- IEC 62056-1-0:2014, Smart metering standardization framework (pre-release)
- IEC 62056-21:2002, Direct local data exchange (3rd edition of IEC 61107) describes how to use COSEM over a local port (optical or current loop)
- IEC 62056-3-1:2013, Use of local area networks on twisted pair with carrier signalling
- IEC 62056-41:1988, Data exchange using wide area networks: Public switched telephone network (PSTN) with LINK+ protocol
- IEC 62056-42:2002, Physical layer services and procedures for connection-oriented asynchronous data exchange
- IEC 62056-46:2007, Data link layer using HDLC protocol
- IEC 62056-47:2006, COSEM transport layers for IPv4 networks
- IEC 62056-51:1998, Application layer protocols
- IEC 62056-52:1998, Communication protocols management distribution line message specification (DLMS) server
- IEC 62056-5-3:2013, DLMS/COSEM Application layer
- IEC 62056-6-1:2013, Object identification system (OBIS)
- IEC 62056-6-2:2013, COSEM Interface classes
- IEC 62056-7-6:2013, The 3-layer, connection-oriented HDLC based communication profile
- IEC 62056-8-3:2013, Communication profile for PLC S-FSK neighborhood networks
- IEC 62056-9-7:2013, Communication profile for TCP-UDP/IP networks

Table 2 shows a comparison of various qualitative features of DLMS and IEC61850 protocols [3]

	DLMS	IEC61850
Load Profile	✓	✓
Clock Synchronization	✓	✓

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Push Metering Data	✗	✗
Interface Object Model	✓	✓
Security Mechanisms	✓	✗

Table 0-B. DLMS and IEC61850 Comparison

Main conclusion of Table 2 is that the performance of DLMS and IEC 61850 is quite similar and there are not important differences.

A2.4 Standards related to PMUs

IEEE C37.118

The standard defines synchronized phasor measurements used in electric power systems and provides a method to quantify measurements and tests to be sure that the measurements conform to the definition. It also defines the Total Vector Error (TVE) limits for measurement accuracy as well as a data communications protocol, including message formats for communicating this data in a real-time system. The standard is defined in 2 section of .1 and .2.

The .1 section of the standard includes methods for evaluating a PMU measurement and requirements for steady-state, dynamic operating conditions and frequency measurement. TVE or "total vector error" compares both magnitude and phase of the PMU phasor estimate with the theoretical phasor equivalent signal for the same instant of time [Martin2010].

The .2 section of the standard expands the communication method to include higher order collection and extends the data reporting characteristics. Also indications of data quality is included. PMU identification is added to all messages. The structure is extended to enable data transmission from a phasor data concentrator (PDC) which included data from several PMUs. Data types and classes are identified. Since network communication is becoming more common, mapping into higher order protocols is described. The underlying data communication protocol is left to users, and several industry standard methods have been developed that support this standard.

IEC 61850-90-5

IEC 61850-90-5 is a protocol for transmitting digital state and time synchronized power measurement over wide area networks enabling implementation of wide area measurement and protection and control (WAMPAC) systems based on the IEC 61850 protocols commonly used in substation automation [Falk2012].

In contrast to IEEE C37.118 Standard, the 90-5 has developed the specification so that it will support remote controls, configuration methods, communication mapping and operation. It is also considering the broader perspective of new uses that have not been implemented as well as the problem areas that also exist.

IEC 61850-90-5 has normative references to IEEE C37.118.1 as the method for measuring synchrophasors. The scope of 61850-90-5 is:

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- Enhance the 61850 object model for proper representation of synchrophasors
- Provide a routable and secure protocol that can transmit either GOOSE or Sampled Value using those IEC 61850 Application Protocol Data Units (ADPUs)
- Provide migration capability from the C37.118, and its typical deployment architecture, to that of IEC 61850-90-5

Other standards relevant to PMUs

There are some type of standards that are not specific for PMUs functionality, operation and communication, but are relevant since they make a treatment of real operability of PMU devices considering practical aspects from the functionality, that need to be considered when dealing with PMU devices. In particular it can be of interest to mention, the test system described by NIST that describes the testability of PMU devices with some standard pattern. Also the description of some standard algorithms that are used for data compression. They are not directly addressable by the before mentioned standards related to PMU but are under consideration under practical situations.

C 37.242-2013

The C37.242-2013 – IEEE Guide for Synchronization, Calibration, Testing, and Installation of Phasor Measurement Units (PMUs) for Power System Protection and Control. Such a collection of information aims to provide guidance for synchronization, calibration, testing, and installation of phasor measurement units (PMUs) addressing particularly the following topics:

(a) Considerations for the installation of PMU devices based on application requirements and typical substation electrical bus configurations;

(b) Techniques focusing on the overall accuracy and availability of the time synchronization system;

(c) Test and calibration procedures for PMUs for laboratory and field applications;

(d) Communications testing for connecting PMUs to other devices including Phasor Data Concentrators (PDCs).

In addition to the before mentioned IEEE Guide, in North America, there are some efforts being done in order to define testability environment for PMU.

NIST test system for PMUs

In addition to standards describing the functionality and limits for the PMU devices, it is of interest to make reference to the testability of such PMUS according to some normative. In particular the National Institute of Standards and Technology (NIST) PMU test system makes traceable magnitude and phase calibration for AC signals under steady-state and dynamic conditions. Also, calibrated are the frequency and rate of change of frequency measurements made by the PMUs.

The following picture shows the block diagram of the proposed NIST PMU test system [Tang2012], where The signals from the GPS clock used by the NIST test system are the 1 pulse per second (1 PPS) signal used to synchronize the start of the signal generation and the signal sampling ensuring that the generation and sampling rate signals are synchronized to the clock reference signal.

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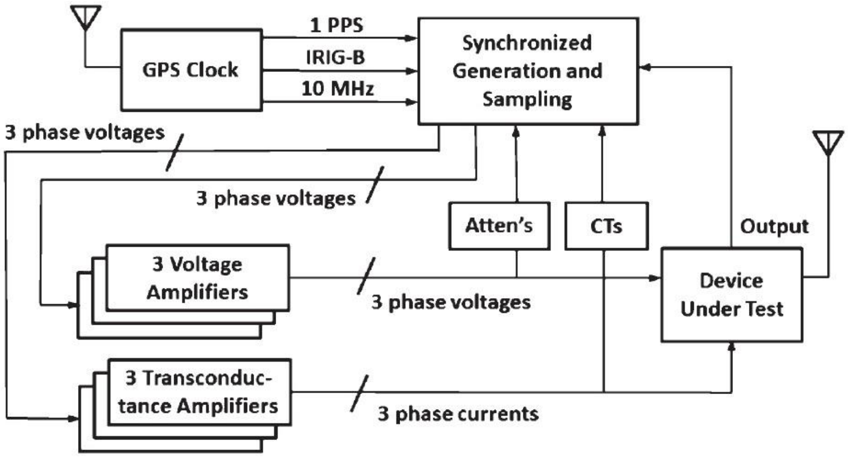

Figure 3.3.1.1. *NIST PMU test system.*

The NIST PMU test system is calibrated using calibrated test input signals. The method uses signals synchronized with UTC and with constant magnitude. The NIST test system algorithms are used to estimate the magnitude and absolute phase angle of the signals. The test must be in accordance with the specificaiotn made by C37.118.1-2011.

Standards for data compression for PMU information:

The standard C37.118 provides information on how to connect PMU equipment, for example via Ethernet, and how the data is being transmitted. Data packets commonly include: a timestamp, frequency, frequency rate of change, three phase voltage and three phase currents. The voltage and current data can be represented by real and imaginary components or as a magnitude and phase. Additional digital or analog channels can be defined depending on the measurement system. The PMU data is synchronized using GPS and is capable of providing measurement updates at a rate of 50/60 Hz.

A great amount of information is then transmitted from the PMUs that me allocated in a Wide Measurement Area, so in order to avoid the usage of storage resources, the data must be compressed. A PMU measuring at 60 Hz would produce 257 MB of frequency, voltage and current data in a day. If we were to assume that current data would compress at an equivalent rate as the voltage data. Using compression this data could be reduced to about 98 MB. The timestamp data and status data are highly compressible since very little information is contained in these fields. An interesting work has been done in [Top2013] that reports testing results for different standard algorithms. In particular five compression formats are reported: gzip, bzip2, 7-zip, szip, and szip.

- Gzip is the oldest algorithm and is based on the Lempel-Ziv 77 algorithm [Ziv1977].
- The bzip2 compressor uses the Burrows-Wheeler algorithm [Burrows1994].
- The 7-zip algorithm utilizes the Lempel-Ziv-Markov algorithm [Pavlov]
- Finally, the szip algorithm is targeted at scientific data and uses the extended-rice algorithm [Schindler]

A2.5 CIM standards

CIM, or Common Information Model, is a set of standards developed by Electric Power Research Institute (EPRI), and now maintained by International Electrotechnical Commission (IEC). CIM standardizes the messages/files exchanged between systems by providing a common vocabulary (or semantics) and message/file schemas. It aims to facilitate information exchange and system integration in the power system operations and planning domain.

IEC 61970-301 standard [12] defines a semantic model that describes the components of a power system at an electrical level and the relationships between each component. IEC 61968-11 standard [13] extends this model to cover other aspects of power system software data exchange such as asset tracking, work scheduling and customer billing. It gives more focuses on distribution management. IEC 62325-301 [14] extends the model further, to cover the data exchange between participants in electricity markets. Currently, CIM model has three primary uses. The first is to facilitate the exchange of power system network data between organizations such as TSOs. For instance, ENTSO-E has defined a profile to allow different TSOs within Europe exchange network data using CIM model. The second use is to allow the exchange of data between applications within an organization using, e.g., Enterprise Integration technologies such as SOA (Service-Oriented Architecture) and Web services. The third is to exchange market data between organizations.

The definition of CIM model uses UML (Unified Modeling Language) notation. It can be encoded in a variety of format, including XML, RDF (Resource Description Framework) and Database Schema.

CIM standards are continuously evolving. IEC TC 57 WG (working group) 13 is working on IEC 61970 series of standards, WG 14 focuses on IEC 61968 series, whereas WG 16 is developing IEC 62325 standards. Besides, WG 19 is seeking the harmonization of CIM and IEC 61850 data model.

A3 List of attached files

Detailed use cases:

Data exchange table (Table 6.2.1):

Enterprise Architect model of IDE4L architecture:

IEC 61850 Logical Node and CIM class tables of monitoring, control and business use cases (Tables 7.1, 7.2 and 7.3):

Database scheme of Substation Automation Unit:

SQL script to implement the database: