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Coordination:	J. Oyarzabal[1]	joseoyar@labein.es
Authors:	J. Jimeno[1]	jjimeno@labein.es
	Deina. Agnostos[2]	dagnostos@anco.gr
	Dr. Gunter Arnold [3]	garnold@iset.uni-kassel.de
	Dipl. Phys. Alexander Berg [3]	aberg@iset.uni-kassel.de
	Elke Mustermann[4]	emustermann@mvv.de
	Tade Agnostos[5]	tagnostos@power.ece.ntua.gr
	Hans Mustermann[6]	hmustermann@siemens.de
	J.M. Yarza[7]	jm.yarza@ziv.es
		[1]LABEIN, [2]ANCO, [3]IWES, [4]MVVV, [5]NTUA, [6]Siemens, [7]ZIV

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1. Introduction

This document is basically divided in three parts, the first part analyses different aspects resulting from the integration of µGrids into electric power systems based on IEC 61850 ideas and components. This section is intended to provide the basic elements extracted from distribution automation and smart grids serving as general framework and then suggesting some system requirements and depicting alternative communication layouts.

The second part describes the application of the IEC 61850-7-420 data model to the effective control of DER Units and Controllable loads. The implementation details, source code configuration, embedded test or even module API are dismissed favouring the high level data structures. This implementation is used as shared and unique interface to Diesel units, a micro turbine and measuring units from the deployed agent based control system.

The communication protocol in use is XML-RPC –a downscaled and simplified version of SOAP- providing a clear, easy, reasonable and open source alternative over the MMS mapping included on the standard.

The next chapter focuses on the application of the IEC 61850-7-420 on concrete commercial inverter. The communication protocol applied is MMS as defined on the standard but a layered approach is used to interface the physical equipment.

2. Integration of µGrids in electric utility systems

2.1. Overview[1]

µGrid equipment, more specifically Distributed Resources (DR), will have increased impacts on distribution utilities, due not only to improvements in DR device technology, cost, and efficiency, but also to the rapid growth of the deregulated electricity marketplace. These deregulation forces have spurred interest in non-standard and dispersed sources of generation to meet increasingly competitive requirements for energy, ancillary services, and other energy services.

Distribution utilities will be a major player in deregulation as retail marketing becomes more widespread. DR devices will present not only technological headaches for incorporating these devices in the distribution system, but the operation and ownership of DR devices will also provide significant opportunities to distribution utilities, particularly if they can manage these resources effectively. This management requires communications between the distribution operations centers and the DR devices in the field, and entails the development of monitoring and control capabilities. In particular, the flow of information among all of the different stakeholders in the DR marketplace is crucial to the effective use of DR technology.

No single communications and control technology or strategy will be the best for all distribution utilities. Rather, a proliferation of choices exist which utilities will need to assess individually, based on their business goals, the mix and range of customers within their territory, the types of DR devices being installed, their power system characteristics and equipment, the availability of different public and private communications infrastructures, and their existing distribution automation capabilities.

2.2. Open Architecture for µGrid in Distribution Automation (DA) and Smart Grids[2]

At the time of integrating µGrids within the Distribution system, the main objectives include:

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[1] Source: http://xanthus-consulting.com/projects/distributed_energy_resources.htm
[2] Source: http://xanthus-consulting.com/projects/distributed_energy_resources.htm

1. Improve the strategic value of Distributed Energy Resources (DER) in electric utility system operations through contributions to the development of the needed utility communication infrastructure.
2. Create the ability to use DER as a valuable resource in distribution automation.
3. Develop DER device communication object models that enable strategic use of DER in distribution automation for functions such as routine energy supply, voltage regulation, power factor control, emergency power supply, disaster recovery operations, and harmonic suppression.
4. Enable flexible reconfiguration of distribution systems into islands or “microgrids” to aid in strategic and emergency system operations.
5. Enable the complementary interactive strategic use of new technologies being deployed in distribution system environments, such as DER and other power quality devices, and load management capabilities.
6. Determine other activities that are needed to integrate DER into the evolving communication infrastructure of future distribution systems.

So, main task to achieve these objectives are:

1. Refine the DER Communications Architecture
2. Refine the DER object models through coordination with object modelling efforts, including IEC efforts, the Common Information Model (CIM), and pilot implementations.
3. Verify the DER object models through individual and integrated testing in a laboratory and/or factory environment. This effort entails development efforts by vendors and participation by utilities and other interested parties.
4. Validate the DER object models integrated in actual DER equipment in the field.
5. Promulgate the DER object models through the standards processes of the IEEE and/or the IEC, by appropriate formatting of the DER object model documents, and subsequent editing of the documents to reflect IEC/IEEE comments.
6. Implement a program to encourage vendor adoption of the DER object models.

7. Develop Certification procedures and tools for validating vendor implementations of the DER object models.

2.3. International Data Object Models for Distributed Energy Resources (DER) (IEC 61850-7-420) [3]

There is a growing interest in implementing DER devices throughout the world. As the DER technology evolves, nations recognize the economic, social, and environmental benefits of integrating DER technology within their electric infrastructure. The manufacturers of DER devices are facing the age-old issues of what communication standards and protocols to provide to their customers for monitoring and controlling DER devices, in particular when they are interconnected with the electric utility system. In the past, DER manufacturers developed their own proprietary communication technology. However, as utilities and other energy service providers start to manage DER devices which are interconnected with the utility power system, they are finding that coping with these different communication technologies present major technical difficulties, implementation costs, and maintenance costs. Therefore, utilities, DER manufacturers, and the customers they serve are increasingly interested in having one international standard that would define the communication and control interfaces for all DER devices. Such standards, along with associated guidelines and uniform procedures would simplify implementation, reduce installation costs, reduce maintenance costs, and improve reliability of power system operations.

At the same time, the object modelling technology has developed within the last few years to become well-established as the most effective method for managing information exchanges. In particular, the UCA object models for the exchange of information within substations (UCA-SA) have moved through the standardization process, and are now formally designated as the IEC61850 International Standard. Many of the components of this standard can be reused for object models of other types of devices. Some new components are also needed, but these follow standard rules for defining new components, thus making them compatible with the existing IEC 61850 standards.

[3] Source: http://xanthus-consulting.com/projects/distributed_energy_resources.htm

The Electric Power Research Institute (EPRI) and its partners have undertaken the challenge of developing initial object models using the documented approach of the Utility Communications Architecture (UCA) and now the IEC 61850 series of standards. As these DER object models are developed, they are being coordinated with the overall IEC 61850 standards through a new working group, IEC TC57 WG17 *“Communication Systems for Distributed Energy Resources (DER).*” The work is also being coordinated with the definition of information and communication system requirements for DER in IEEE by IEEE 1547.3.

These data object models are data with standardized names and standardized formats for exchanging data between different equipment or systems. Standard object models, combined with standard service models (methods for sending the data, e.g. report-by-exception, periodic, control commands) and standard protocols (the bits and bytes actually send over the communication channel), permit different systems to interact with minimal customization and greater interoperability. The combination of object model, service model, and protocol profiles can be termed the “information model”.

These DER information models are based on open-system language, semantics, services, protocols, and architecture, which have been standardized by IEC 61850, but they include some extensions to IEC 61850. All these models are described in part 7-420, and they basically address only “Nouns”, making use of the IEC 61850 constructs of Logical Devices, Logical Nodes, Data Objects, Common Data Classes, Common Attributes and Standard Data types. Part 7-420 covers:

- General DER Management
- Photovoltaic systems
- Fuel cells
- Diesel generation
- Combined heat and power

Wind power is handled separately by IEC 61400-25 standard, and currently status of this part is Final Draft International Standard (FDIS). From the perspective of MicroGrids, we still can miss some other technologies, like flywheels for instance.

In order to ensure the standardization process is simplified, these DER information models are compatible with IEC 61850, IEC61970 (CIM), IEC60870-5 (telecontrol protocol, which also formed the base for DNP), and IEC60870-6 (ICCP/TASE.2) standards.

The object models in this draft document are ready for trial use by vendors in order to provide feedback and updates.

The interrelationship between IEC TC57 modelling standards is illustrated in Figure 2-1.This illustration shows as horizontal layers the three components to an information exchange model for retrieving data from the field, namely, the communication protocol profiles, the service models, and the object models. Above these layers is the information model of utility-specific data, termed the Common Information Model (CIM), as well as all the applications and databases needed in utility operations. Vertically, different areas are shown: substation automation, DER, distribution automation, customer services, generation (including large hydro plants), etc. Although this document addresses only the IEC 61850 object models, additional modelling efforts will be needed for DER (and other domain areas) in the CIM/CFL areas.

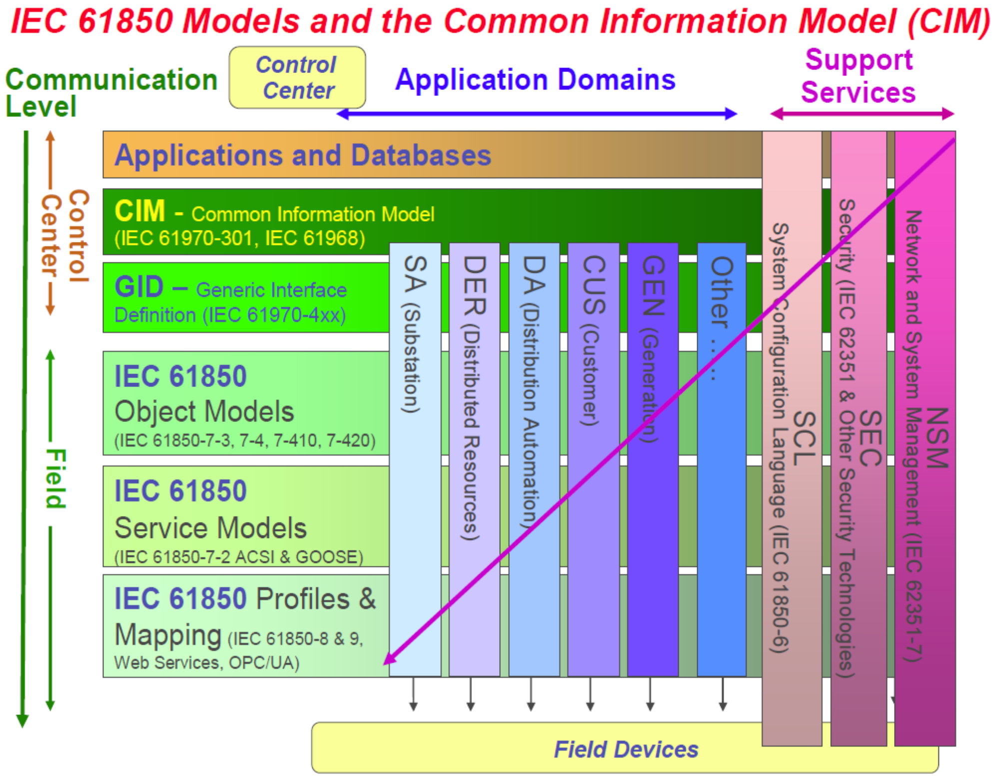

Figure 2-1: IEC 61850 Modelling and Connections with Other IEC TC57 Models

2.4. Communication in Distribution Power Systems

Trends for the future indicate that communication moves down to the customers:

- Decentralized energy management
- Metering services
- Distribution automation

Besides, common data models and services based on IEC 61850 provide important features:

- Plug and play
- Interoperability
- Uniform engineering
- Equal security

MicroGrids' penetration, distribution automation and smart grids are pushing towards an active distribution system with flexible communication for RTUs, smart meters, protections and control devices. And communication architectures should take advantage of all technologies available, like radio, Ethernet, power line carrier and services like GSM, GPRS or ISDN.

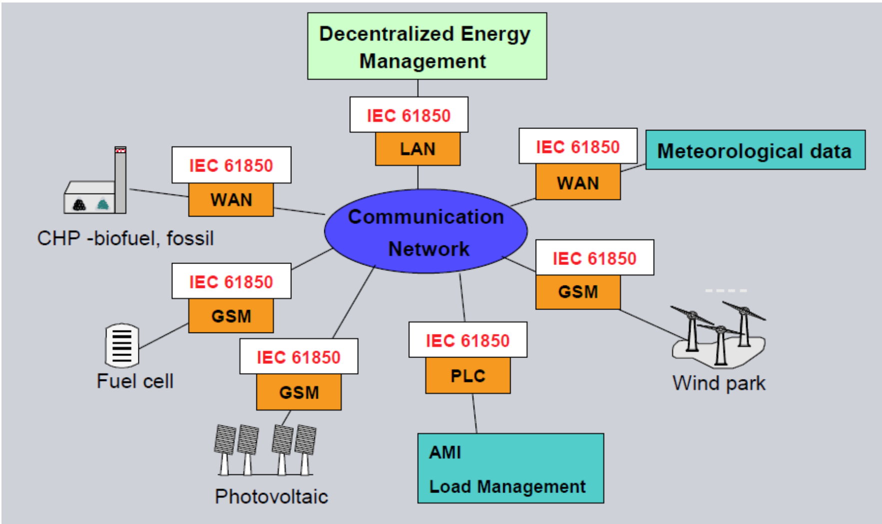

Figure 2-2: Integration of communication means and protocols

This means that it will be necessary to develop new mappings of IEC 61850 to be able to make use of existing infrastructure different from Ethernet, the one adopted by IEC 61850 for substations.

But, why the need of DER communication? In the future, if the DERs get an amplified quota of the supply task, they have to be tied also more into the management of the distributive networks. For example:

- Tension and reactive support
- Net restoration after disturbances
- Reduction of losses and overloads

2.5. Benefits of Using IEC 61850-7-420

Benefits of using an international standard that defines the communication and control interfaces for all DER devices, and develops DER object models, are basically:

- Simplify DER implementation

- Reduce DER installation and maintenance costs
- Encourage and facilitate more widespread use of DER
- Improve the strategic value of DER in electric utility distribution system operations
- Create the ability to use DER as a valuable resource in future automation systems, developing communication object models that enable strategic use of DER in Distribution Automation for functions such as routine energy supply, voltage regulation, power factor control, emergency power supply, etc
- Enable flexible reconfiguration of distribution systems into intentional islands (MicroGrids) to aid in strategic and emergency system operations
- Enable the complementary strategic use of new technologies being deployed in distribution system environments, such as DER, sag correction and other power quality improvement devices, and load management capabilities
- Improve reliability and economics of power system operations

Other advantages derived from the standard itself are:

- One consistent data model
- No conversion of data necessary, therefore no lost of information
- Easy maintenance of data models
- Share the interoperability of communication based on IEC 61850
- Seamless integration into the station automation and the power control system
- Using the industrial approved technologies
- Saving time and cost for: Implementation, Maintenance, Enhancement and Training

2.6. Communication Requirements for DER

In principle, DER may require the exchange of the same data objects like it is common inside a substation. The content of data objects for communication will depend on the importance of the DER.

And regarding latency requirements, these could be lower than in the case of substations:

- Control with return information: 2 s
- Set points (P,Q): 2 s
- Alarms: 1 s
- Status information: 5 s
- Meterings: 2 s
- Measurements: 2 s
- Parameter setting:10 s
- Fault record:1 minute

2.7. Reliable Ethernet LAN Deployment in Electrical Substations

Nowadays, deployment of IEC 61850 systems is based on Ethernet networks. In fact, the sole part of standard that specifies how to map in real the IEC 61850 abstract models is part 8-1. This part specifies the mapping over Ethernet, making use of MMS protocol.

So, at this time, it's important to analyze reliability of Ethernet networks and the most suitable architectures.

2.7.1. Main aspects affecting reliability in Ethernet network design

When designing an Ethernet network for an electrical substation, there are two questions that the designer shall try to answer first:

- How can I design a network that is less prone to service loss? There are some aspects that must be taken into account, such as equipment selection, interface technology suitability for the environment, or network topology. A brief discussion follows on the preferred network topologies.
- Once a problem arises (link fault, equipment breakout), what kind of mechanisms shall I use to limit the impact on the network and get it back to operation in the shortest possible time? Here the availability of backups plays a key role. Some details are provided for active versus passive backups.

2.7.1.1. Ethernet Network Topology and its Impact on Resilience

The topology of an Ethernet LAN network plays a key role in the reliability of the overall system. The network designer can choose from a number of topologies. Any of them imply a trade-off between cost of implementation, ease of maintenance, number of networking equipment needed and system fault tolerance.

There are many possible topologies. Some of them (cascaded bus or simple star) are not inherently fault tolerant, and therefore they are not included in the discussion. More robust topologies are described and the probability of network failure for each case is analyzed.

Simple star with redundant trunk links

In this structure, all the switches providing communications access to the IEDs are connected to a single central backbone switch, located in the substation's main building. The connection from each of the remote switches to the central switch is redundant, to avoid connectivity losses due to a single link failure.

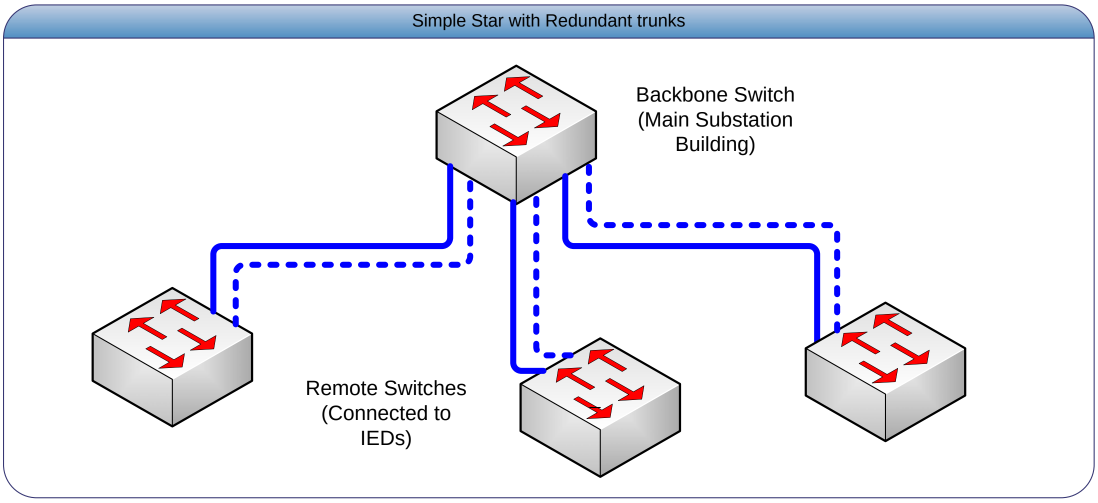

Figure 2-3: Ethernet network topology: Simple star

The main advantage of this structure is the low cost of installation. This topology is best in terms of latency, because two IEDs are always at the same distance (two hops).

The main drawback consists on the single point of failure represented by the backbone switch, whose failure would put the entire network out of service. Thus a logical improvement would be to eliminate this single point of failure, as in a double star.

Double star with redundant trunk links

In this topology, remote switches are connected to two different backbone switches, which in turn share a trunk connection linking them. If any of the backbone switches fails, the network can still work with full functionality.

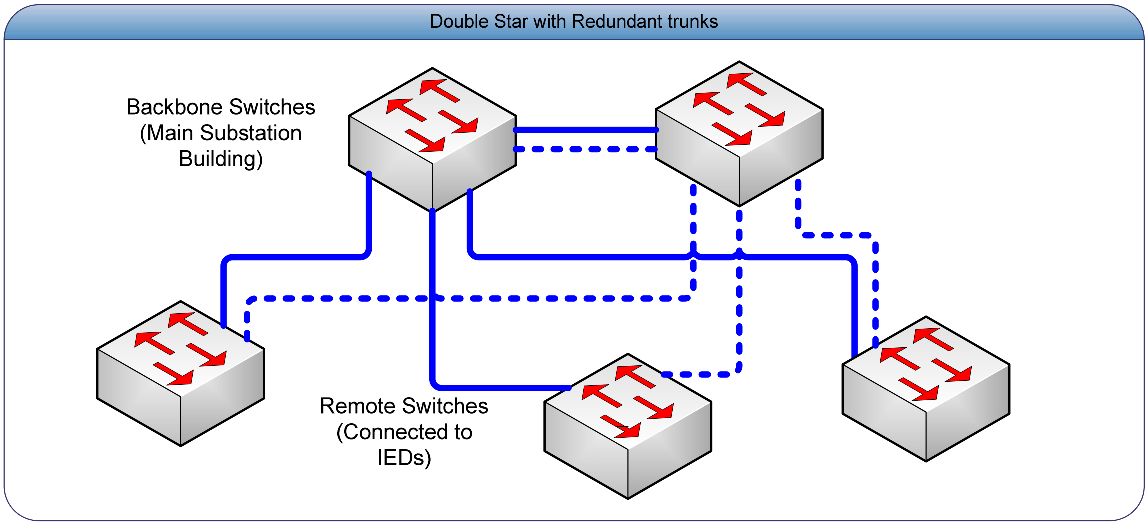

Figure 2-4: Ethernet network topology: Double star

Empirical calculations [Ref-1] show that this topology brings a 40% reduction in the probability of loss of connectivity, compared with a single star.

The main drawback is the increased expense in communications equipment, and the deployment of optical fiber links, which in this case cannot share the same ditches. It also can result in poorer latency values, because the traffic may have three hops between IEDs.

Simple ringed star

This case is similar to the simple star, but instead having all the remote switches redundantly linked to the backbone switch, they form a ring among them. As a result of this, any link may fail without affecting network performance. And in case of switch failure, the rest of the network would be able to continue in operation.

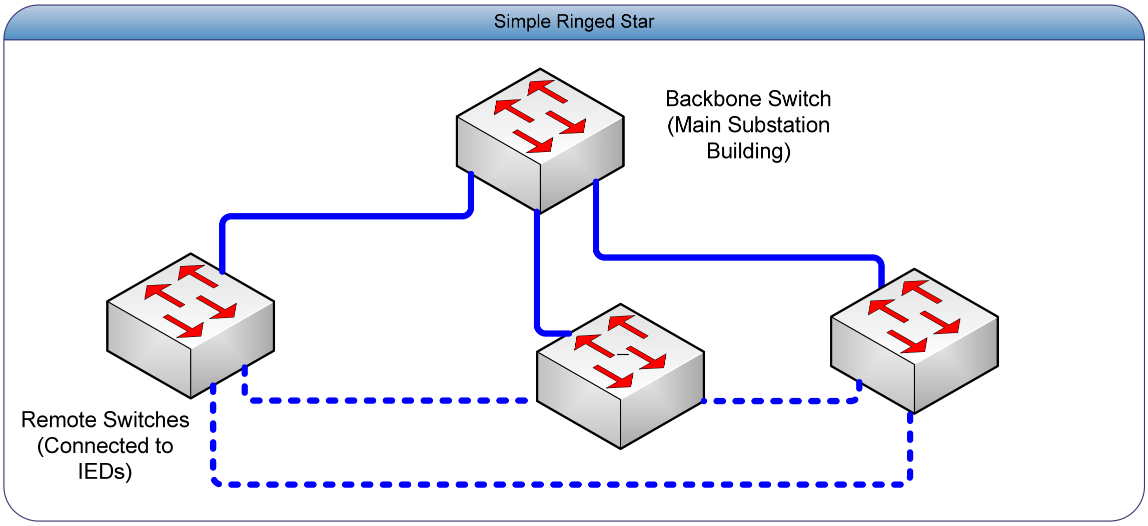

Figure 2-5: Ethernet network topology: Single ringed star

Previous work [Ref-1] tells us that this architecture has a similar availability level as the double star, without the extra cost of the redundant backbone switch. However, as usually installation costs account for a significant amount of system cost, careful calculations should be made or each installation, because linking remote switches may imply extra digging.

Note that the star-portion of the system provides us the latency advantage related with this structure, as ring topologies have poor latency performance.

Link Fault Recovery

Whenever a link fails in one of the previously discussed topologies, the Ethernet network must have the ability to establish an alternative path to transport the data previously carried by the fallen link. There are two standard approaches to solve this issue, which pursue the same goal but have different philosophies: active versus passive backup.

Active Backup (Link Aggregation Protocol)

In an active backup network, both redundant links are configured as a logical entity (channel). This is performed by means of the Link Aggregation Control Protocol (LACP, IEEE 802.3ad [Ref-2]). In this scheme both switches sharing the redundant links must support this feature. The networking equipment identifies the links as active, and balance the traffic load in them as long as the links are active. These links can be aggregated in any number, but all of them being part of an aggregation must start and end in the same switches.

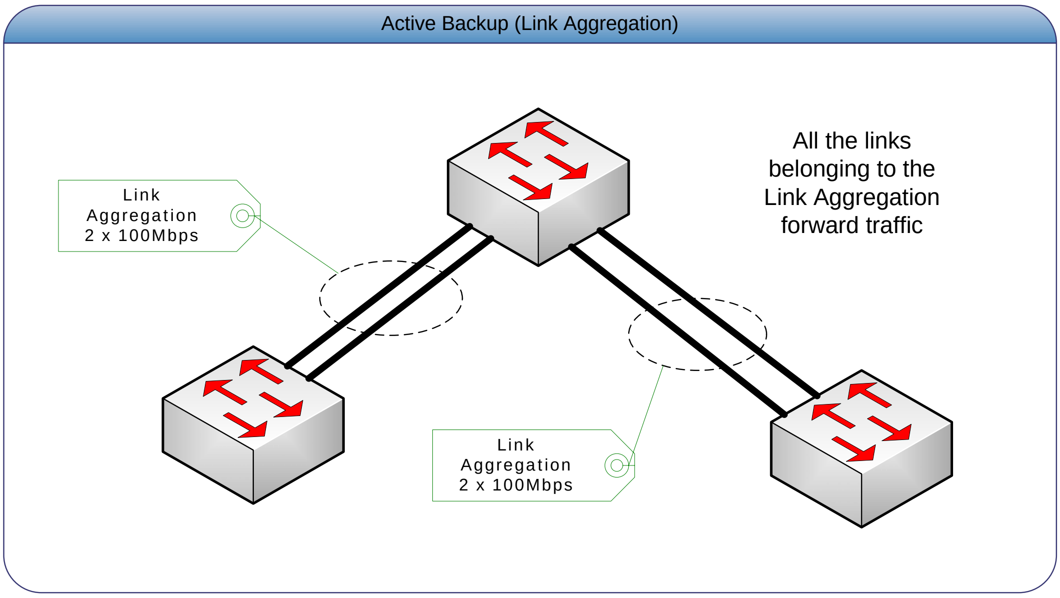

Figure 2-6: Ethernet network topology: Active backup

If one of the links fails, the traffic will be diverted via the remaining active links, with no loss of functionality. The main benefit of this approach is that all the deployed infrastructure is used, so the network can handle a bigger throughput. Its main drawback is that after a fault there will be no loss of traffic only if the remaining active links have enough bandwidth to carry all the traffic, because if not the total traffic will exceed the capacity of the active link. This issue may be handled via traffic prioritisation.

However in a zero-traffic-loss oriented system, the use of active backup poses no special benefit as excess capacity must be readily available for the system to be resilient.

<u>Passive backup (Spanning Tree Protocol)</u>

In a passive backup system, only one of the links carries the traffic, and the other ones remain as alternate routes just in case the active link fails. The Spanning Tree Protocol (IEEE 802.1D-2004 [Ref-2]) manages the active link designation and maintenance process. The silent links carry only STP-related frames.

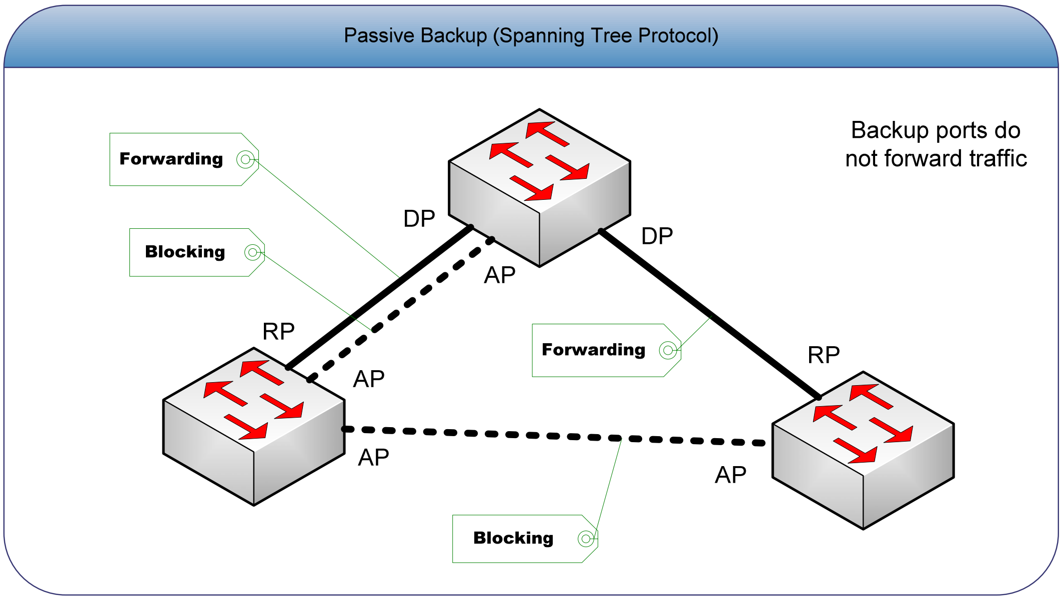

Figure 2-7: Ethernet network topology: Pasive backup

For the passive backup the redundant links must not start and end in the same switches. With this approach the impact of a single link fault does not affect the adjacent coupled link, as in active backup, but it may impact and reconfigure the whole network. Thus careful protocol parametrization of the devices is needed in order to establish preferred link routes and avoid widespread reconfigurations due to local topology changes.

Former versions of the STP protocol led to slow recovery times in meshed networks (usually in the order of tens of seconds), mainly because the state machine of the protocol often communicated processes with timeout mechanisms. The latest version of the standard (2004) includes a new asynchronous signal notification scheme in the protocol state machine which allows faster implementations. Currently fully standard implementations such as the one embedded in µSysCom's 3SWT switch family allow recovery times in the order of milliseconds.

Measurements performed in ring topologies by µSysCom show that the recovery time may be approximated by the formula:

$$Tr < 5 + 3*(N-1) \text{ milliseconds}$$

Where Tr is the recovery time in milliseconds and N is the number of switches in a ring. In a meshed topology the recovery time depends linearly with the number on links involved in the reconfiguration. This backup scheme is being widely adopted in the utility industry.

2.7.1.2. IEC61850 functional requirements for Ethernet networks

The IEC61850 standard defines the systems and communication networks to use in electrical substation automation. This standard specifies every aspect related with communications between IEDs.

Ethernet is the network technology chosen by IEC61850 [Ref-4]. It has some clear advantages, such as maturity, low cost, robustness and, potentially, performance in terms of capacity and low latency. These two functional requirements are discussed in the following paragraphs.

Ethernet Capacity (Bandwidth)

Currently deployed Ethernet links have 100Mbps or 1Gbps capacities. Even though this may seem a lot coming from a serial-communications and dial-up connection systems perspective, the IEC61850 defined the special goose messages with traffic prioritisation in mind. In this way, traffic with different levels of priority, will coexist in the same physical network. This will not have any practical effect on the network until the links approach nearly-full level of utilization.

In any case, no matter the low bandwidth usage an Ethernet link may have in a current IEC61850 system, new control and monitoring applications will evolve that will pose a heavier traffic burden on the network. For this reason it is of capital importance that in substation networks currently deployed in substations:

Enough free bandwidth is allotted for future network traffic growth, no matter the present level of utilization [Ref-5].

Traffic management feature support are enforced in communications equipment (QoS, traffic prioritization), to ensure that in a scenario of future, traffic intensive applications, high importance traffic (GOOSE, control applications) can be prioritized over low priority background traffic.

Ethernet Latency

IEC61850 specifies that the maximum transfer time of a message in a network must not exceed a certain time depending on its priority. For instance, type I messages (trigger, etc) require a total transmission time below 3 milliseconds.

The transmission time must be divided among the emitting IED processing time (t_a), the network transmission time (t_b), and the receiving IED processing time (t_c), as shown in the following figure:

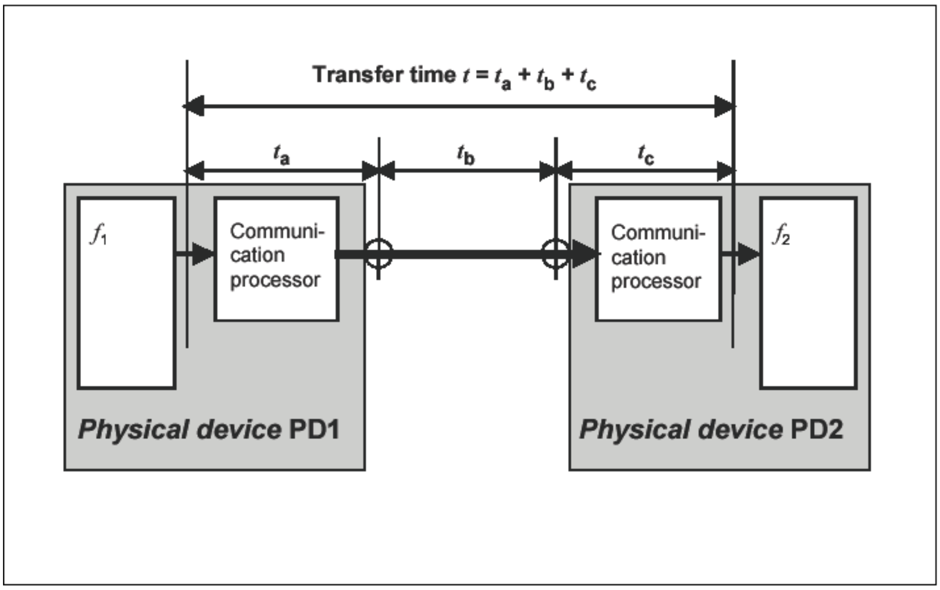

Figure 2-8: Ethernet network latency for IED communication

IEC61850 specifies t_a and t_c to be less than 40% of the total transfer time. Thus t_b must be below 20% of the total time, for the worst case less than 600 microseconds, including propagation times and latencies included by networking equipment.

A GOOSE frame with 64 byte size occupies 6.7 microseconds of the wire in a 100Mbps link, and 67 microseconds in a 10Mbps link. Thus lower than 100Mbps link do not seem appropriate to handle IEC61850 traffic, since the total transfer time would be exceeded in a few Ethernet link hops using store and forward devices.

On the other hand, latency in networking equipment (switches) depends heavily on link capacity utilization. Latency for the same frame may skyrocket from 3 microseconds (typical measured latency for a non-congested link) to more than 500 microseconds (congested link with frame loss and no traffic prioritisation).

2.7.1.3. Conclusion

An Ethernet local area network aimed at an electrical substation environment shall be conceived having in mind certain aspects that affect dramatically the robustness and reliability of the network, namely:

- Network topology shall be chosen carefully for optimal network resilience.
- Detailed link and equipment backup policies shall be compared and accordingly implemented throughout the network.
- Traffic prioritisation is a subject to think about in Ethernet networks designed to comply IEC61850, and it is mandatory whenever the Ethernet links may have peaks of utilization above 50% of their capacity.
- Special care should be paid to network capacity planning and scalability, since new applications will emerge and future traffic growth will affect critical operation traffic, unless some spare capacity is previously provisioned.

2.7.2. DER Integration into the Power System Information Infrastructure

The demand for DER systems which are interconnected with the distribution power systems is increasing greatly. Although distribution power systems are and will continue to be the most impacted by DER, transmission and the management of generation operations are also impacted.

As a result, for greater efficiency and reliability of the power system, automation of the distribution systems is becoming a major requirement. And the challenge is the implementation of an information infrastructure to meet requirements of this distribution automation as new remote control functions, modified distribution configurations, increasingly intelligent protection systems, and the use of significantly more telecommunication and information technologies.

It's possible to take advantage of IEC 61850 object models for DER to approach automation objectives, since a standardized communications interface for DER devices permit the interoperability between different systems from different vendors.

DER systems involve the following aspects:

- Management of the interconnection between the DER units and the power systems they connect to.
- Monitoring and controlling the DER units as producers of electrical energy.
- Monitoring and controlling the individual generators, excitation systems, and inverters/converters.
- Monitoring and controlling the energy conversion systems (reciprocating engines, fuel cells, photovoltaic (PV), and combined heat & power (CHP)).
- Monitoring and controlling the auxiliary systems (interval meters, fuel systems, and batteries).
- Monitoring the physical characteristics of equipment (temperature, pressure, heat, vibration…).

These information requirements for DER systems denote the interactions involving Distributed Energy Resources in Power system Operations. These IEC 61850 DER object models do not address market operations.

2.7.3. Chances of Integrating DER systems into the Power System

The number and type of Distributed Energy Resources systems interconnected to power systems has sharply increased worldwide. Besides, there is a great diversity of ownership and operators: utilities, customers, and independent energy service providers. But finally, utilities have to manage their power system operations efficiently and reliably.

All agents involved are exploring new methods for safely, reliably, and effectively implementing and interconnecting DER systems. At the same time, utilities are trying to reduce their operational costs without jeopardizing the security of the power system. Therefore, DER technologies are increasingly being evaluated, and the operational requirements for interconnecting these DER systems are being assessed.

But DER systems can have very different operational characteristics:

- Exclusively driven by their energy source, such as wind and solar energy.
- With more control capability, but constrained by emission limits or availability limits.

- Many need to balance the production of electrical energy with other requirements, such as heating buildings for CHP units.
- With great variability that requires a balancing mechanism with alternate energy sources. For instance, wind farms can use part of the inconstant wind power electrical energy to charge batteries.
- Some of the services and capacities that DER devices can provide utilities are:
- Generation capacity to offset load within a customer site, to support local load on a distribution feeder, and/or to provide energy within a substation. DER owners can be paid for this generation.
- Load following over short time frames or to neutralize the large non-conforming loads of the DER owner, with the benefit for utilities of an improved power quality on the feeder connected to this load.
- Power supply balancing in case of DER units whose energy source can be variable. Wind farms and solar systems can lean on batteries and pumped storage to fill valleys and maintain a more constant power supply.
- Peak shaving during peak load times scheduling, manually or remotely controlling DER devices to turn on or provide more power.
- Operating or “spinning” reserve, provided by DER devices which are on-line or have a short start-up and synchronization time. This operating reserve could come in small increments and could be scheduled by utilities to avoid starting up much larger units.
- Emergency backup generation provided by the same DER devices taking part in the operating reserve.
- Voltage support provided by many DER devices located along the feeders. This would permit the feeder voltage at the distribution substation to have a wider range for the load tap changer, reducing feeder voltage at the substation during peak loads, and vice versa during low loads.
- Var support provided by some DER devices, in place of capacitor banks with similar benefits as for voltage support.
- Intentional islanding, allowing some distribution feeders with significant amounts of available DER energy to become self-supporting islands in case of black-out.

- Green power, using the renewables (wind, solar, etc.) that cause less pollution than the traditional power plants.
- Reduce construction of utility facilities, decreasing the investments in other case required. Because DER devices can provide peak shaving, and support voltage and vars on the feeder, and the costs associated with installing, interconnecting, and operating these smaller DERs are significantly offset.
- DER products for sale. Utilities could provide DER devices for sale, and operation and maintenance services for DER as well, using the knowledge of the company and its equipment for installing, testing, monitoring and controlling.

2.7.4. DER Monitoring and Control Models

Probably the main challenge of installing DER devices is the interconnection of the DER systems to distribution systems, which were not designed for two-way power flows. Besides, deregulation process in the energy market makes situation more complicated.

In any case, the key to exploit DER efficaciously will be a suitable exchange of critical and relevant information. The lack of remote monitoring and control the DER devices in real-time, utilities will be blind and inefficient in using these DER resources.

- DER Stakeholders are the roles that different people or companies play in relation to each other with respect to the DER systems, both from a power system operational point of view and in the deregulated electricity marketplace. The requirements of information these stakeholders have, determine the communication systems they need and the flow of information as well.
- Sometimes, the same person or company may play two different roles at one time. Main roles are:
- DER Owners: They benefit from using their DER either for serving their own load or from providing ancillary services or energy capacity in return for a remuneration to be agreed.
- Marketers or Energy Services Providers (ESP): They buy DER owners the energy they produce and other services (e.g. ancillary services) they can provide to serve their customer loads. Marketers will bargain with the owners over the type of services, the schedule and the price.

- Distribution System Operators (DSO): They are in charge of operating the distribution system and, generally, are responsible for the maintenance and emergency activities on the power system. Additionally, they have to carry out DER schedules in their area of influence, monitor the DER systems, and guarantee that all DER units have tripped off in an emergency.
- DER Operators: They are responsible for turning the DER systems on and off during normal operations, according to the needs of the DER Owners for their own use, as well as to the requirements of any contractual DER schedule. The DER Operators may be a person pushing a button on the DER device, or an automated controller with a scheduler, or DSO with a remote control capacity. In any case, all DER devices will have safety systems to turn off or prevent from turning on when the conditions are risky for the device to operate.
- Distribution System Maintenance: They are the field people in charge of the distribution system maintenance, and generally, they work for the DSO. And with regard to DER devices, they have to guarantee that these DERs don't connect to the power system when they must not.
- DER Device Maintenance: These people have to ensure that the DER system and their security stoppage system are operating properly.
- DER System: The DER system itself must provide real-time data on its condition when queried, and respond to local and/or remote control commands, as well as protective relaying commands.
- Distribution Power System Protection: This system is made up of the distribution power system protection devices, which guarantee the protection of the whole distribution system when faced wrong operations of DER equipments.
- Telecommunications Maintenance: Under utility control or responsibility of a third party, it ensures the reliability and availability of the telecommunications system.

Illustrated in Figure 2-9, it's obvious that communications for DER plants involve not only local communications between DER units and the plant management system, but also between the DER plant and the utility and the operators who manage both the plant and the individual DER units.

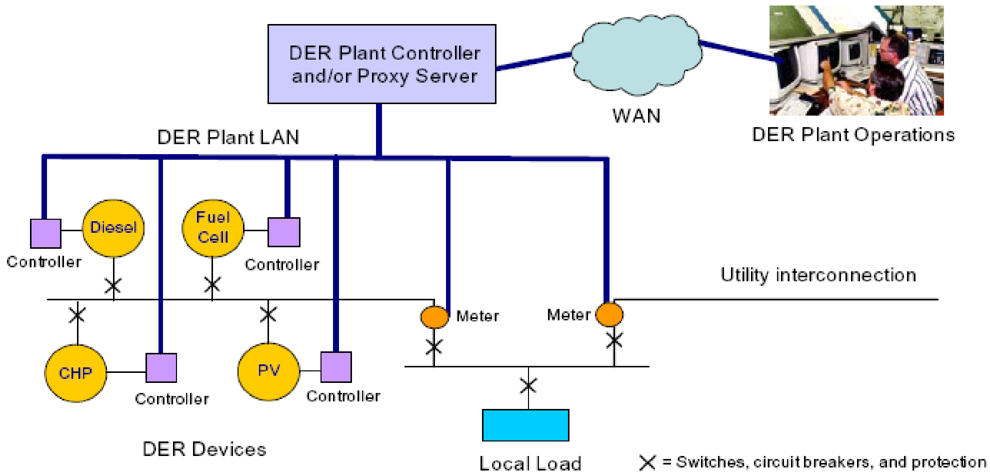

Figure 2-9: Possible DER plant communications

Part IEC 61850-7-420, as was indicated previously, covers basically next topics:

- General DER Management
- Photovoltaic systems
- Fuel cells
- Diesel generation
- Combined heat and power

Next figures, extracted from standard draft, show generic diagrams for each of these technologies with main Logical Nodes modelling their functionalities.

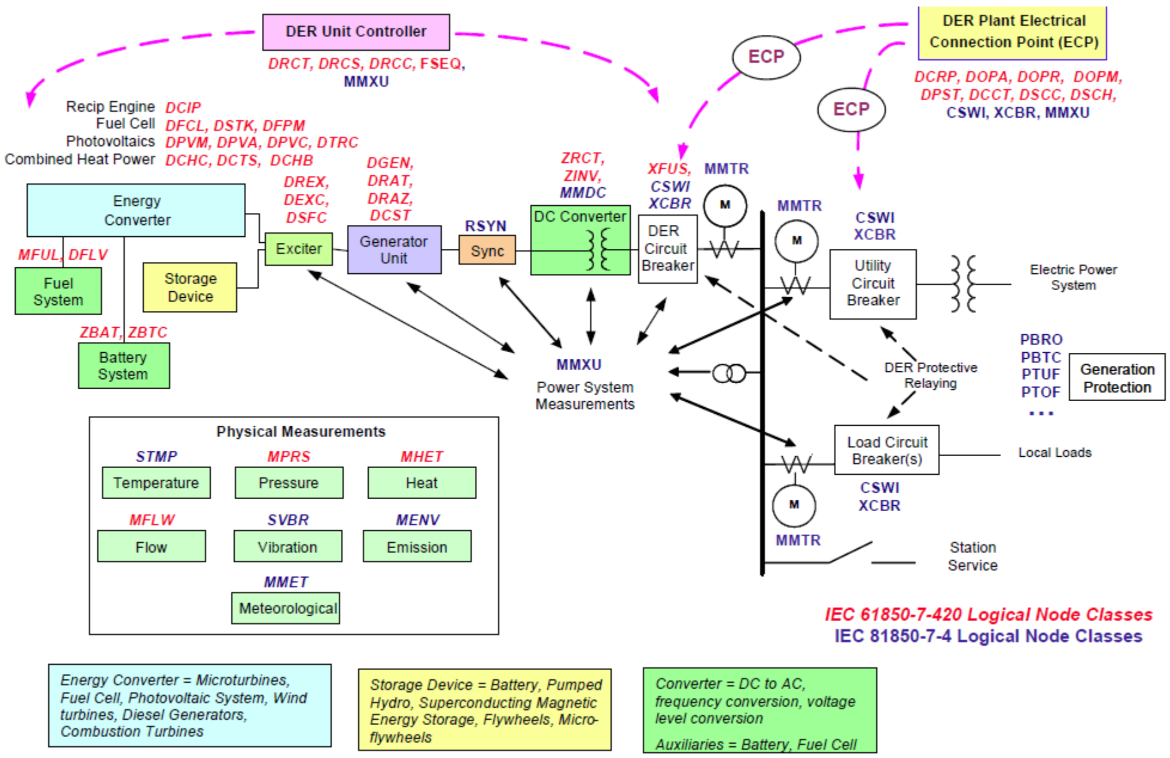

Figure 2-10: IEC 61850-7-420 Overview of LD & LN

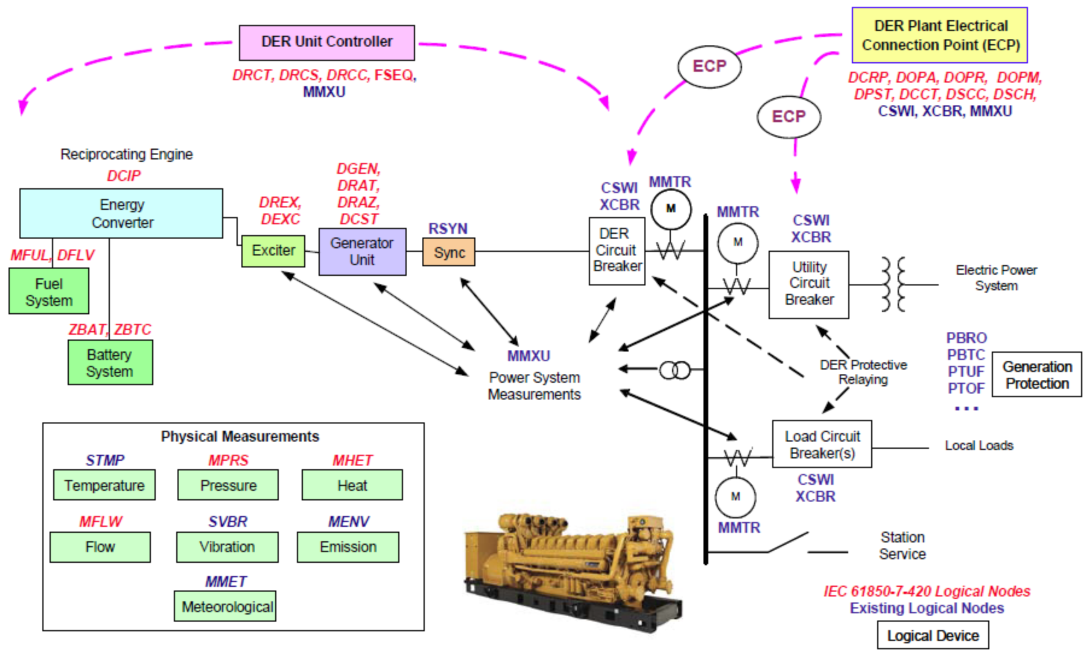

Figure 2-11: IEC 61850-7-420 Reciprocating engine LD & LN

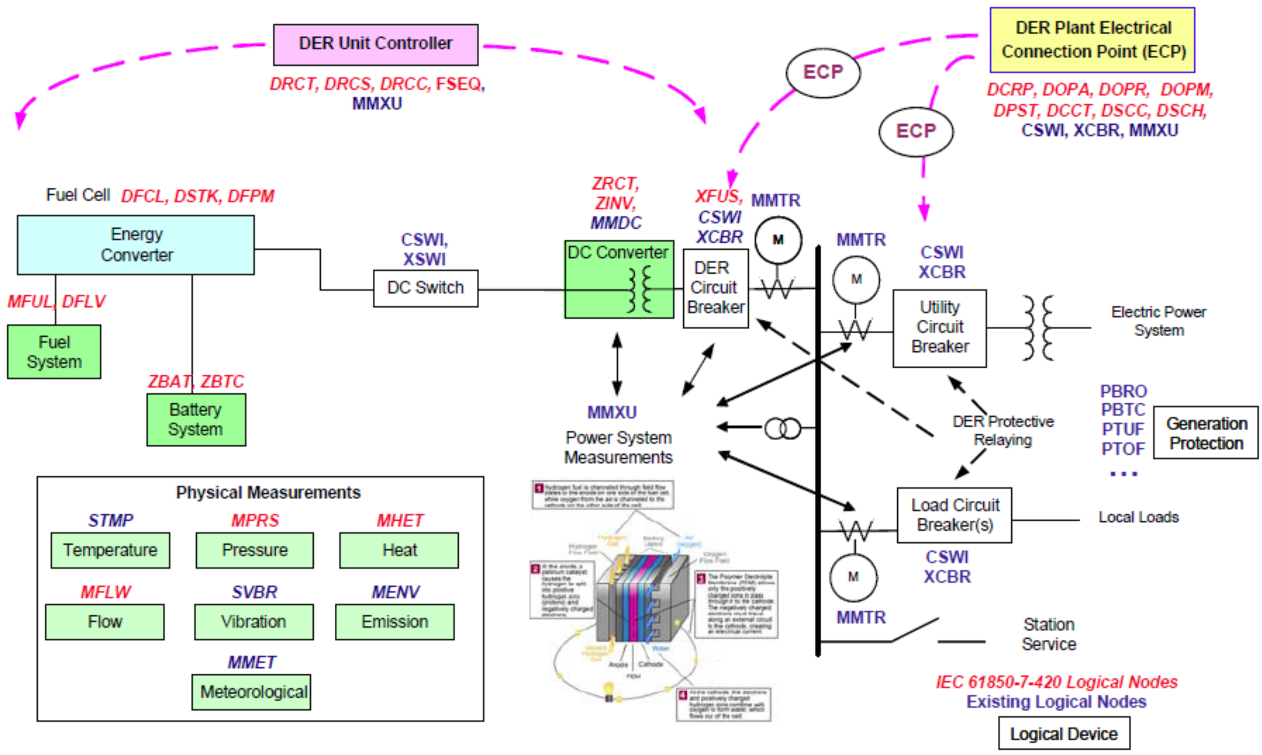

Figure 2-12: IEC 61850-7-420 Fuel Cell engine LD & LN

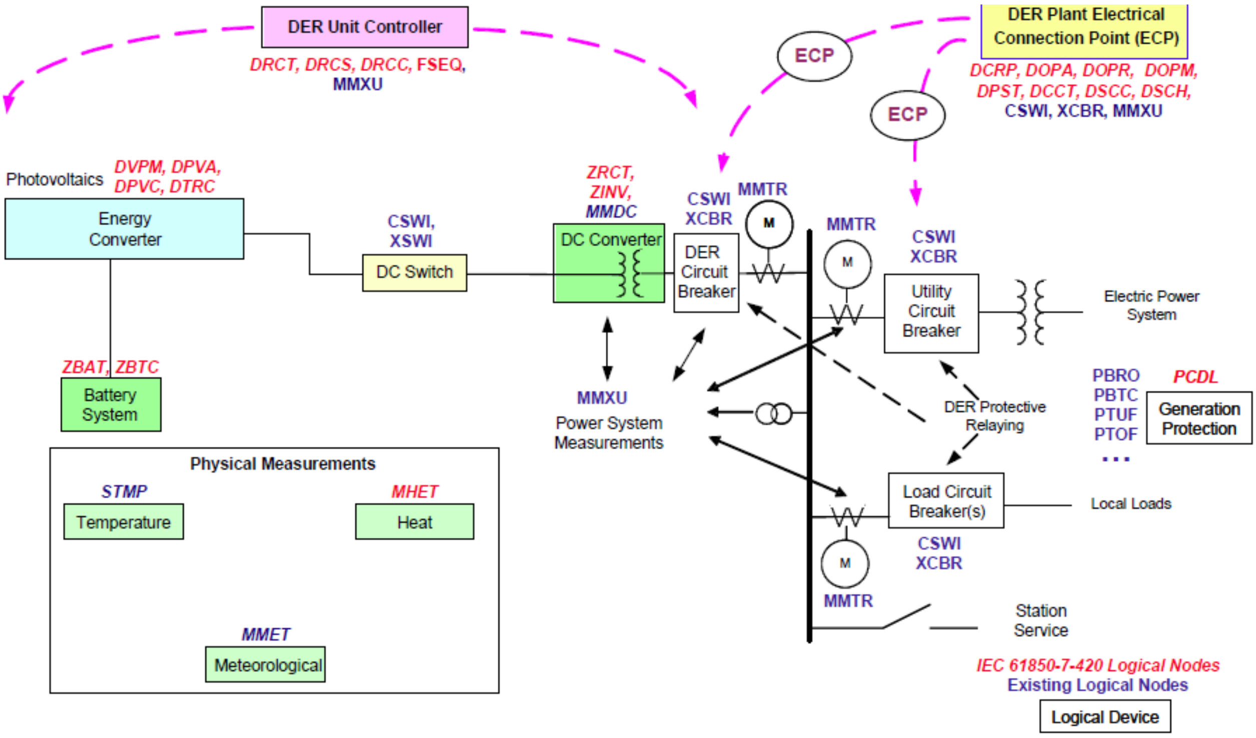

Figure 2-13: IEC 61850-7-420 Photovoltaics LD & LN

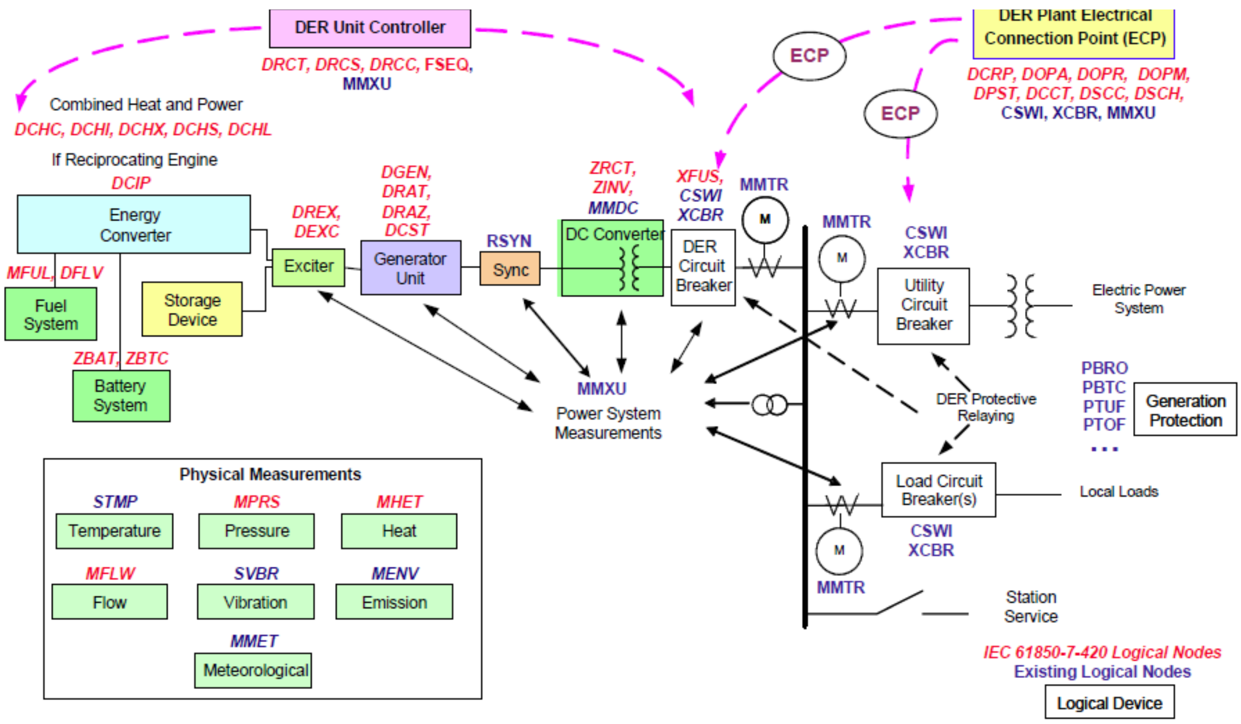

Figure 2-14: IEC 61850-7-420 CHP system LD & LN

2.7.5. Next Steps

- First step will be to finalize IEC 61850-7-420, something that is expected to happen in 2009.
- It's still unclear and under discussion if mapping should be MMS-based or WEB services based. Or perhaps, both, depending upon requirements.
- It's still necessary to undertake models of additional DER types, like:
  - Energy storage
  - Plug-in electric vehicles
  - Biomass?
  - …
- It must be determined what DER aspects should be modelled in CIM:
  - Distribution power system configurations with DER
  - Distribution Management Systems

- And regarding Conformance testing requirements, more pilot implementations should be developed to acquire more experience. And also interoperability testing procedures are needed to guarantee the principle of interoperability on the same way is done with IEDs for substations.

3. IEC 61850-7-420 over XML-RPC for µGrid control

µGrids are composed of generation and consumption devices that must be controlled by a centralized or decentralized MicroGrid Management System. Nowadays, those devices that form part of a MicroGrid have their own communications protocol as given by the specific manufacturer; this implies that applications used for monitor & control these devices must implement each specific communication protocols making the development of this control software complex, time consuming and difficult to extend for new equipment.

The most promising standardization effort for DER communications is the IEC 61850 which specifies the following items among others:

- Data models for DER devices (part 4-704) and substations.
- Services for accessing the functions provided by the devices.
- Specific low level communications mapping.

The range of devices to be controlled is wide: diesel generators, gas turbines, inverters, meters, load banks, switches, batteries etc. each one having their own legacy communication systems. The purpose of the software, called CSDER (Communication Services for DER), is to offer the way to translate these proprietary communication protocols to a form of the IEC 61850 based protocol.

This chapter describes the software developed for the local control of distributed energy resources based partly in IEC 61850 specifications detailing an implementation of the required services, data models and a communication mapping. This software module acts as a gateway between the proprietary protocols of DER devices and offers a standardized way to access the functionality of the DER devices. The gateway software can be used by different applications such as Energy Management Systems (EMS), or any kind of control and monitoring software.

The IEC 61850-7-420 based software description is divided into four main parts:

- <u>Requirements</u>: shows the functional and technical requirements that the software must fulfil.

- Design: describes the software architecture and development tools.

The Table 3-I shows how the described software implements the different parts of the IEC 61850 standard:

Table 3-I: IEC 61850 implementation summary

IEC 61850 – Communication networks and systems in substations		Implementation
61850-1	Introduction and Overview	
61850-2	Glossary	
61850-3	General Requirements	
61850-4	System and Project management	
61850-5	Communication Requirements for Functions and Device Models	
61850-6	Substation automation system configuration language	Not implemented, anyway, the software contains configuration files which make it completely configurable regarding the data model and communications mapping layers.
61850-7-1	Principles and Models	
61850-7-2	Abstract Communication Service Interface	Basic services are implemented that allow obtaining the description of the model, obtaining data and operating the device.
61850-7-3	Common data classes	The needed CDC-s for modelling required functions for generators, loads and measurement devices are implemented.
61850-7-4	Compatible logical node classes and data classes	The needed LN-s and CDA-s for modelling required functions for generators, loads and measurement devices are implemented.
61850-8-1	Mapping to MMS and ISO/IEC 8802-3	An alternative implementation of the low level communications using XML-RPC is used.
61850-9-1	Sampled values over serial unidirectional multidrop point to point link	Not implemented.
61850-9-2	Sampled values over ISO/IEC 8802-3	Not implemented.
61850-10	Conformance Testing	

This section describes in detail why and how the different parts of the standard have been implemented.

3.1. Requirements

Requirements are divided into functional and technical requirements; the first ones describe what functionality is to be offered by the application while the latter deals with hardware and platform environment issues.

In any case the software has been designed to make easy and straightforward its extension in order to implement new functions.

3.1.1. Functional requirements

From the point of view of a MicroGrid Management System, the idea is to hide all particularities and complexities of the devices in the MicroGrid, that is, to handle in a homogeneous and similar way any type of devices, such as:

- Generators
- Loads
- Storage Systems
- Measurement devices
- Switching devices

The implementation developed deals with generators, loads and measurement devices, anyway, the software design makes easy to implement new types of devices (storage systems and switching devices) with minimum effort.

For each of these types of devices two aspects have been identified: Device Monitoring and Device Control. This way, each type of device will offer to higher level control systems common measurement and control parameters. The implementation is not intended for protection devices or systems that require real time monitoring and reaction times (order of milliseconds); the focus of the implementation is to represent an interface to Management System in charge of the coordination and optimization of the MicroGrid, together with SCADA like systems for the man machine interface (MMI).

3.1.1.1. Device monitoring

The application must be able to obtain the relevant parameters from the monitored device. The data retrieved form such device will differ depending on the device: active power, reactive power, status of switches, frequency, voltage, etc.

On the other hand, the software must also provide the IEC 61850 services able to serve monitoring data for remote systems.

As consequence, data monitoring requirements will depend on the specific device and should hide any irrelevant (i.e. internal) data.

Data monitoring requirements for loads

The Table 3-II shows the data to be monitored in case the device to be controlled is a load with the capability to be switched on and off.

Table 3-II: Data monitoring requirements for on/off loads.

Data	Update Rate	Description
Active Power rating	Once, when the application starts	Active power rating of the load
Reactive Power rating	Once, when the application starts	Reactive Power rating of the load
Output Active Power	≤ 1 sec.	Measured Active Power consumed by the load
Output Reactive Power	≤ 1 sec.	Measured Reactive Power consumed by the load
Status	≤ 1 sec.	Connection status (ON/OFF) for each controlled load.

The type of loads whose consumption can be reduced under some demand side management scheme (either by shifting either by curtailment) is not considered at this stage.

Data monitoring requirements for generators

The Table 3-III shows the data to be monitored in case the device to be controlled is a generator. Note that not all the parameters described here are applicable to all generators, this list covers all parameters that are considered significant for generators but not all of them can be implemented in certain generators.

Table 3-III: Data monitoring requirements for generators

Data	Update Rate	Description
Output Active Power	≤ 1 sec.	Measured Active Power injected by the generator
Output Reactive Power	≤ 1 sec.	Measured Reactive Power injected by the generator
Frequency at injection point	≤ 1 sec.	Measured Frequency at generator's connection point
Voltage at injection point	≤ 1 sec.	Measured Voltage at generator's connection point
Maximum Active Power	Once, when the application starts	Maximum Active Power that the generator can produce
Minimum Active Power	Once, when the application starts	Minimum Active Power that the generator can produce
Maximum Reactive Power	Once, when the application starts	Maximum Reactive Power that the generator can produce
Minimum Reactive Power	Once, when the application starts	Minimum Reactive Power that the generator can produce
Maximum Frequency	≤ 1 sec.	The maximum frequency in the P-F droop corresponds to the minimum active power.
Minimum Frequency	≤ 1 sec.	The minimum frequency in the P-F droop corresponds to the maximum active power.

Data	Update Rate	Description
Maximum Voltage	≤ 1 sec.	The maximum voltage in the Q-V droop corresponds to the minimum reactive power.
Minimum Voltage	≤ 1 sec.	The minimum voltage in the Q-V droop corresponds to the maximum reactive power.
Status (started/stopped)	≤ 1 sec.	Indicates if the generator is started and connected to the network
Droops Status	≤ 1 sec.	Indicates whether P-F and Q-V droops are active or not
Operating Mode	≤ 1 sec.	Indicates the operating mode of the generator: Voltage source: the generator acts as a master in the network setting the voltage and frequency Current source: the generator acts as slave following the network voltage and frequency

<u>Data monitoring requirements for measurement devices</u>

The Table 3-IV shows the data to be monitored in case the device to be controlled is a measurement device.

Table 3-IV: Data monitoring requirements for measurement devices

Data	Update Rate	Description
Active Power flow	≤ 1 sec.	Measured Active Power flow
Reactive Power flow	≤ 1 sec.	Measured Reactive Power flow
Frequency	≤ 1 sec.	Frequency at measurement point
Voltage	≤ 1 sec.	Voltage at measurement point

3.1.1.2. Device control

The software must provide the necessary IEC 61850 services that allow performing control actions over the devices. The application should hide the complexity of the control actions, for example: in case the device needs some kind of starting sequence, the application will perform that sequence of actions on its own when it is requested to start the device.

The control actions will vary depending on the specific device that it is being controlled, some examples could be: start/stop a generator, set points for power production, connect/disconnect loads etc.

<u>Control requirements for loads</u>

The application must provide the following control actions for loads:

Table 3-V: Control requirements for on/off loads

Control action	Description

Control action	Description
Connect	Connect and disconnect the load from the network

As said before, loads whose power can be reduced under DSM schemes are not considered for this implementation.

Control requirements for generators

The application must provide the following control actions for generators:

Table 3-VI: Control requirements for generators

Control action	Description
Active Power Set Point	Sets the desired active power output of the generator
Reactive Power Set Point	Sets the desired reactive power output of the generator
Maximum Frequency	Sets the desired frequency at maximum active power in the P-F droop
Minimum Frequency	Sets the desired frequency at minimum active power in the P-F droop
Maximum Voltage	Sets the desired voltage at maximum reactive power in the Q-V droop
Minimum Voltage	Sets the desired voltage at minimum reactive power in the Q-V droop
Start and Stop the generator	Starts and connects the generator to the network leaving it ready to inject power Stops the generator
Activate and Deactivate droops	Activates and deactivates P-F and Q-V droops
Set operating Mode	Sets the operating mode of the device to Voltage Source or Current Source

Control requirements for measurement devices

No control requirements are applicable for measurement devices.

3.1.2. Technical requirements

The following table summarises the technical requirements to be fulfilled by CSDER software:

Table 3-VII: Technical requirements

Concept	Requirements
Operating System	Windows and Linux environments should be supported.
Hardware	PC based hardware platforms.
Proprietary communications with devices	The software should be flexible and easily adaptable to legacy and process bus protocol communications, such as ModBus, proprietary protocols etc.
IEC 61850 communications	Control applications should access the services offered by the software using standardised internet protocols.

It must be noted that currently IEC 61850 uses MMS (Manufacturing Message Specification) as lower level communication protocol, MMS is a closed protocol used mainly in industrial applications. Nowadays internet technologies are widely used and easily accessible, so an internet based protocol could be more suited for a domain where open, well known internet protocols, are easy to implement using already existing tools.

3.2. Design

This section describes the software architecture and design details used for implementing the IEC 61850 based communications gateway.

The JAVA programming language has been chosen for the development of the software because of its portability, object oriented model and wide use by the open source community. The software architecture is specified in terms of UML (Unified Modelling Language). The concrete details about packages and classes used for implementing the software are described.

As previously introduced, the main objective of the software is to provide a modular and extensible architecture, so the addition of new devices with their different models and communications protocols can be made easily and without effort.

3.2.1. Software high level architecture

The software has been organized into different components or modules. The distinct modules are related among them through the use of interfaces and some shared classes for fast and easy substitution, extension or modification of any of the modules without affecting the remaining modules.

The software implementation is based on IEC 61850 specifications. The *IEC 61850 – Communication networks and systems in substations* standardises communication services and protocols for the management of substations. It specifies the services, data models, and protocols that an IEC 61850 system must provide. An extension of the standard (part 7-420) specifically defines the data model for different DER plants.

CSDER software is not a strict implementation of the standard; the standard is only used as a base in order to develop controllers and to analyse the validity of the standard for MicroGrid applications. Taking into account the focus of the implementation, it has been considered that there is no need for the complexity that imposes the implementation of the whole standard.

The Figure 3-1shows the modules described in following sections:

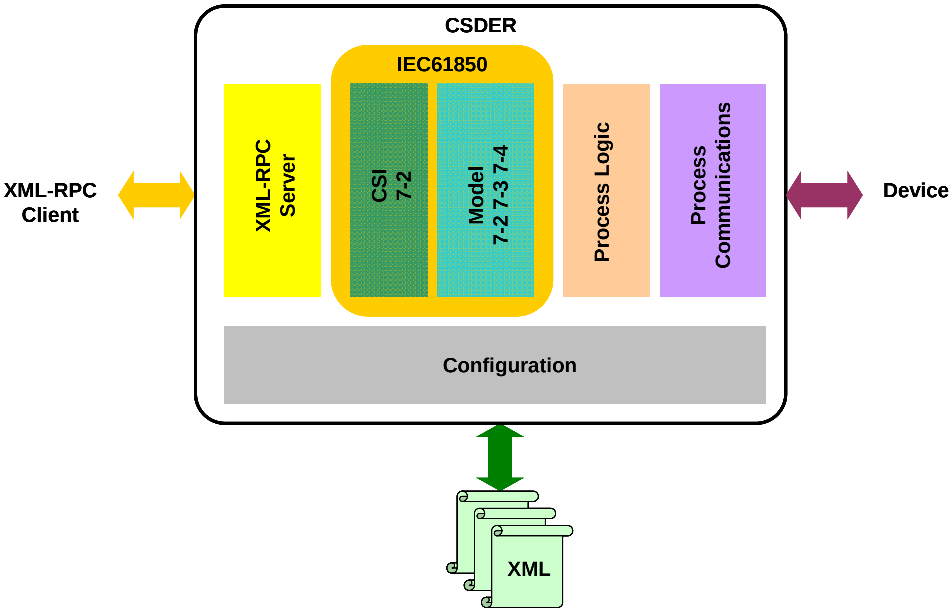

Figure 3-1: High level software architecture

3.2.2. Main component

The main module includes the root classes that creates and launches the application. The principal class is *Main* that starts the sequence in order to configure, initialise and start the other modules and has the procedure for stopping in a clean way the application. A class named *ServerCnf* holds the configuration parameters for the application.

The *Module* interface must be implemented by all the modules and defines the methods that allow the *Main* class to start and stop any module.

The *Registry* class is used to store all instances of the created modules and provides references to other module instances.

The Figure 3-2 class diagram shows the classes and packages inside the main package:

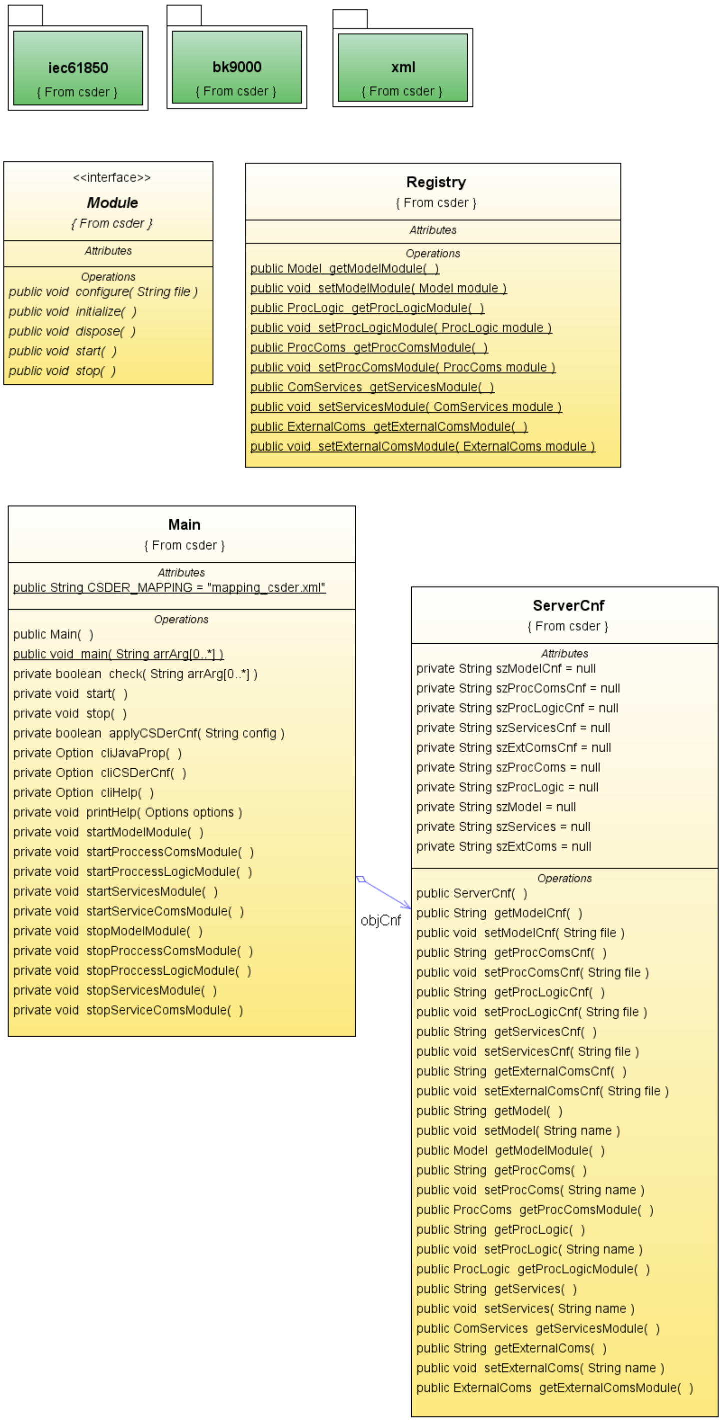

Figure 3-2: Main package class diagram

3.2.3. Data model module

The data model module implements IEC 61850 data model as specified in parts 7-3, 7-4 and 7-420. It contains all the information modelling the controlled device.

The implementation is complete in the sense that all the attributes for the implemented elements (LN-s, CDC-s and CDA-s) have been deployed as specified by the standard, but not all of the elements have been implemented (out of the scope for the software specification). The model could be extended in the future with more IEC 61850 elements as needed by the controllers and without affecting the other modules in the software.

When implementing the model, the standard provides a large set of elements with their corresponding attributes for implementing in detail different generation technologies, components of those generation devices etc. In any case, the standard also models the devices at a higher level, without entering into the detail of each generation technology and parts. According to the software requirements and after analysing available model elements it has been considered that these high level models for the generation devices are enough to meet the needs of the deployed MicroGrid Management System.

The root model package has *ModelImp* class implementing *Model* and *Module* allowing other modules to interact with it (see Figure 3-3). *LN*, *CDC* and *CDA* packages contain the different classes holding model information.

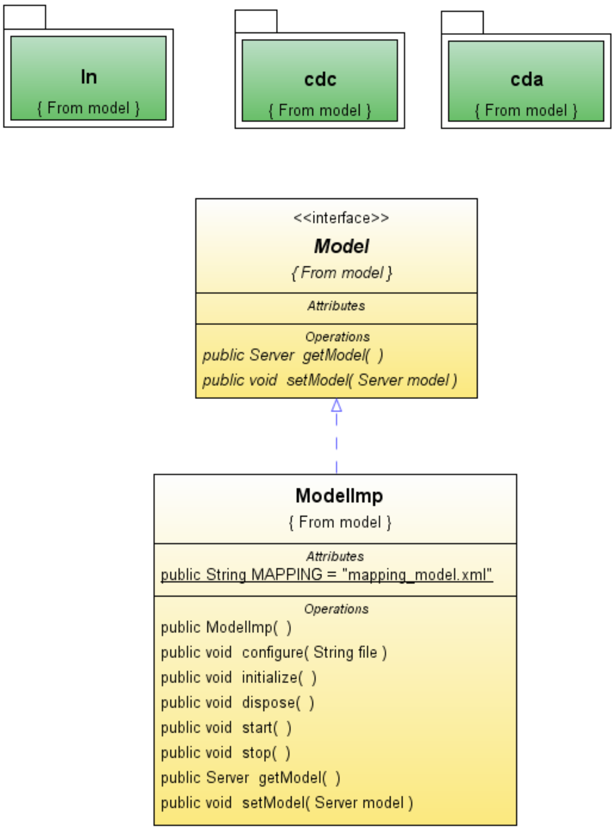

Figure 3-3: Model package class diagram

The data model is organized in a tree hierarchy where the top class is *Server*, and represents information offered by an IEC 61850 server.

A *Server* has one *LPHD* class holding server information and several *LD* classes representing a logical view of the devices being modelled. Each *LD* is described by a *LLN0* class, and each atomic function in a *LD* is modelled as a *LN*. Figure 3-4 shows the class diagram with the data model hierarchy.

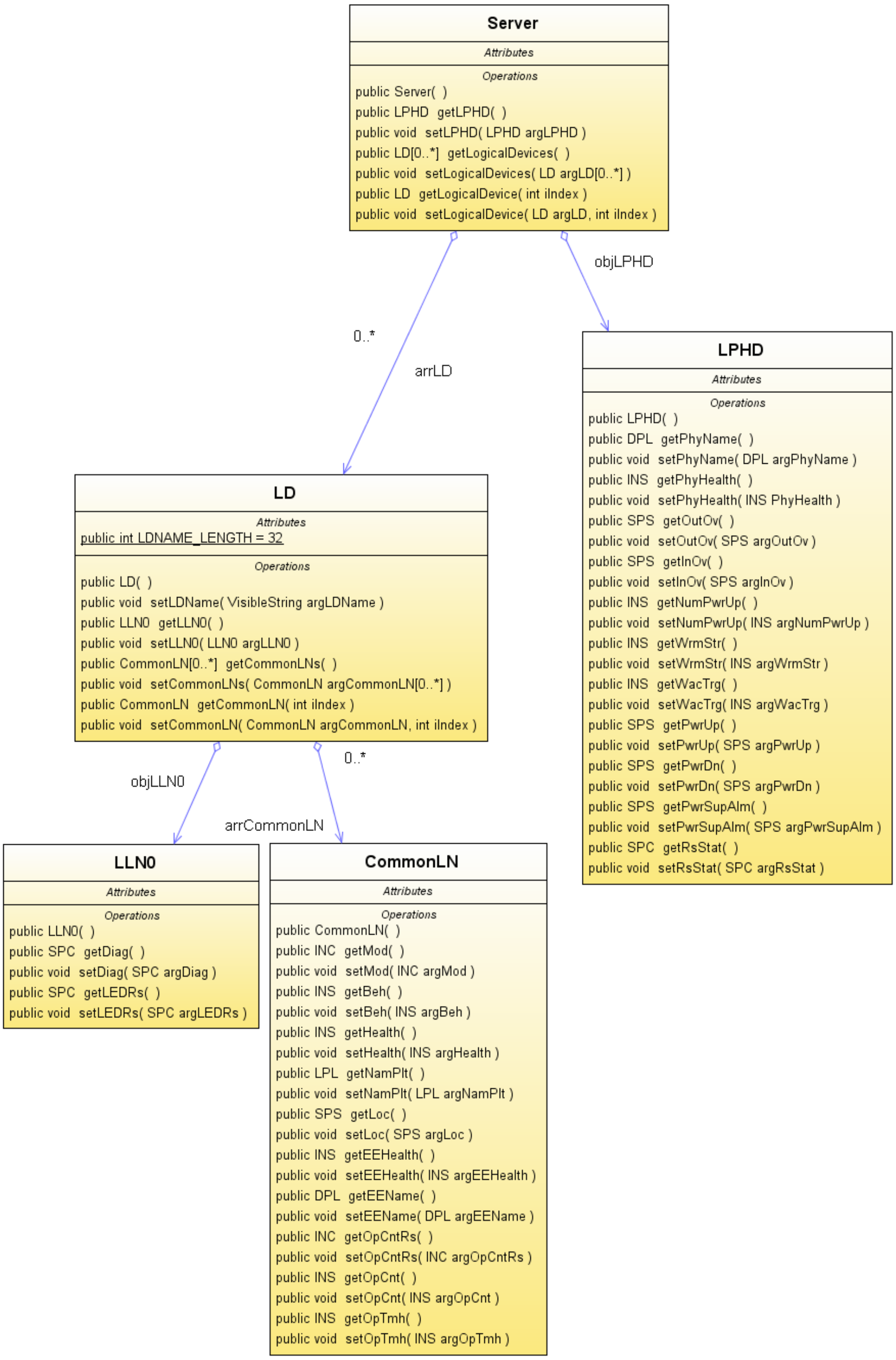

Figure 3-4: Data model hierarchy class diagram

3.2.3.1. Logical Nodes

The *LN* package contains the different logical nodes holding information about the features a device can have; at this moment *LN*-s for generators, loads and measurement devices have been implemented.

The following LN-s are considered:

- LLN0: Contains information about the Logical Device
- DCLO: Logical node for modelling controllable loads
- MMXU: Holds measurement data
- DGEN: Models DER generator operations
- DRAT: Holds information about DER generator basic ratings
- DCST: Contains the information for modelling costs associated to generator operations
- DRCT: DER unit controller characteristics, including type of DER etc.

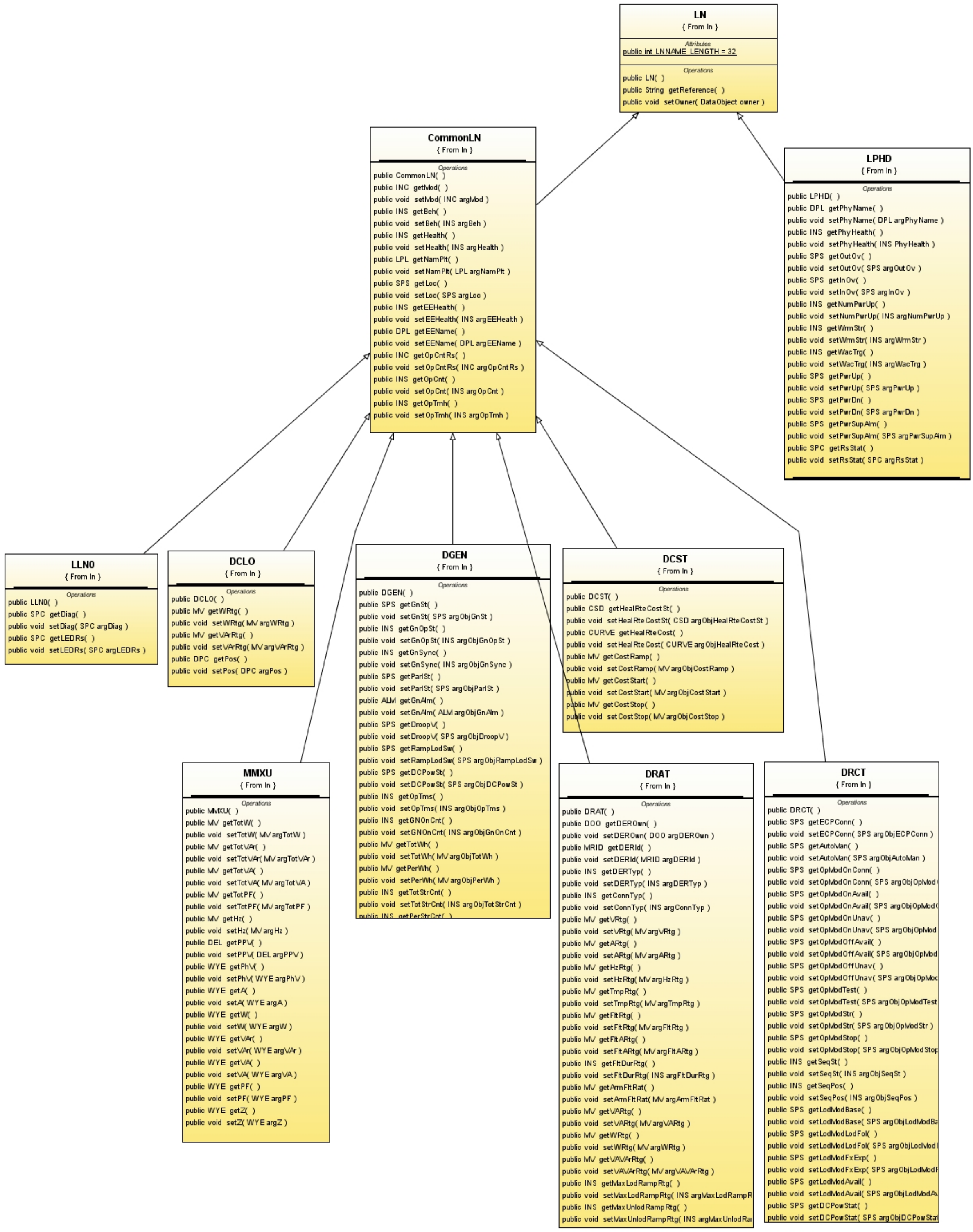

Figure 3-5: LN inheritance view in a class diagram

Two different aspects should be highlighted regarding the design of the implementation for generators and loads:

Logical Node for controllable loads

The IEC 61850 standard does not consider any model for loads; in order to overcome this issue, a new *DCLO* (Distributed Controllable Load) LN has been created. This LN models loads that can be switched on and off by the control system. The design of the *DCLO* LN is based on the rules for LN extension according to IEC 61850. In fact, all attributes have been created by analysing similar attributes in other already available LN-s according to their function.

DCLO extends *CommonLN* class which holds all the attributes common to all LN-s.

Table 3-VIII: DCLO Logical Node

DCLO		
Attribute	**Type**	**Description**
WRtg	MV	Load active power rating
VArRtg	MV	Load reactive power rating
Pos	DPC	Controllable position of the load, it is used to control the ON and OFF status of the load.

Logical Nodes for generators

Regarding the modelling of generators, the way to handle P-F droops and Q-V droops is somehow confusing and it is not a clear way to implement it, so the following approach has been taken.

Four parameters are needed to define each of the droops, in case the P-F droop:

- Pmax: Maximum active power provided by the generator.
- Pmin: Minimum active power provided by the generator.
- Frmax: Maximum frequency in the droop as corresponds to the frequency at Pmin.
- Frmin: Minimum frequency in the droop as corresponds to the frequency at Pmax.

Another possibility could be to consider the following parameters for defining the droop:

- Pmax: Maximum active power provided by the generator.
- Pmin: Minimum active power provided by the generator.

- Fr droop: The frequency droop in watts per hertz. It represents the droop curve slope.
- Fr offset: Frequency offset gives the frequency axis value for the point at the mid point of the droop.

It seems that the standard could be able to provide the elements to model P-Fr droops as explained in the second case (using Fr offset and Fr droop) while there it seems no model for Q-V droop. In any case, as it is not a clear how P-F droop is to be modelled because not all needed elements are in the same LN, and their meaning is confusing, the first workarround has been taken, that is, new attributes have been implemented in DRAT logical node (Frmax and Frmin / Vmax and Vmin) for modelling all droops, P-F & Q-V in a clear, uniform and easy way.

3.2.3.2. Common Data Classes

The *CDC* package holds classes representing types of attributes in LN-s. This information is divided into description, status, control and measurement data. In this case the CDC-s specified in the standard are enough for complying with the requirements.

The Figure 3-6 depicts some of the implemented CDC-s, the complete list includes: ALM, ASG, CMV, CSD, CURVE, DEL, DOO, DPC, DPL, HMV, INC, INS, LPL, MRID, MV, SPC, SPS and WYE.

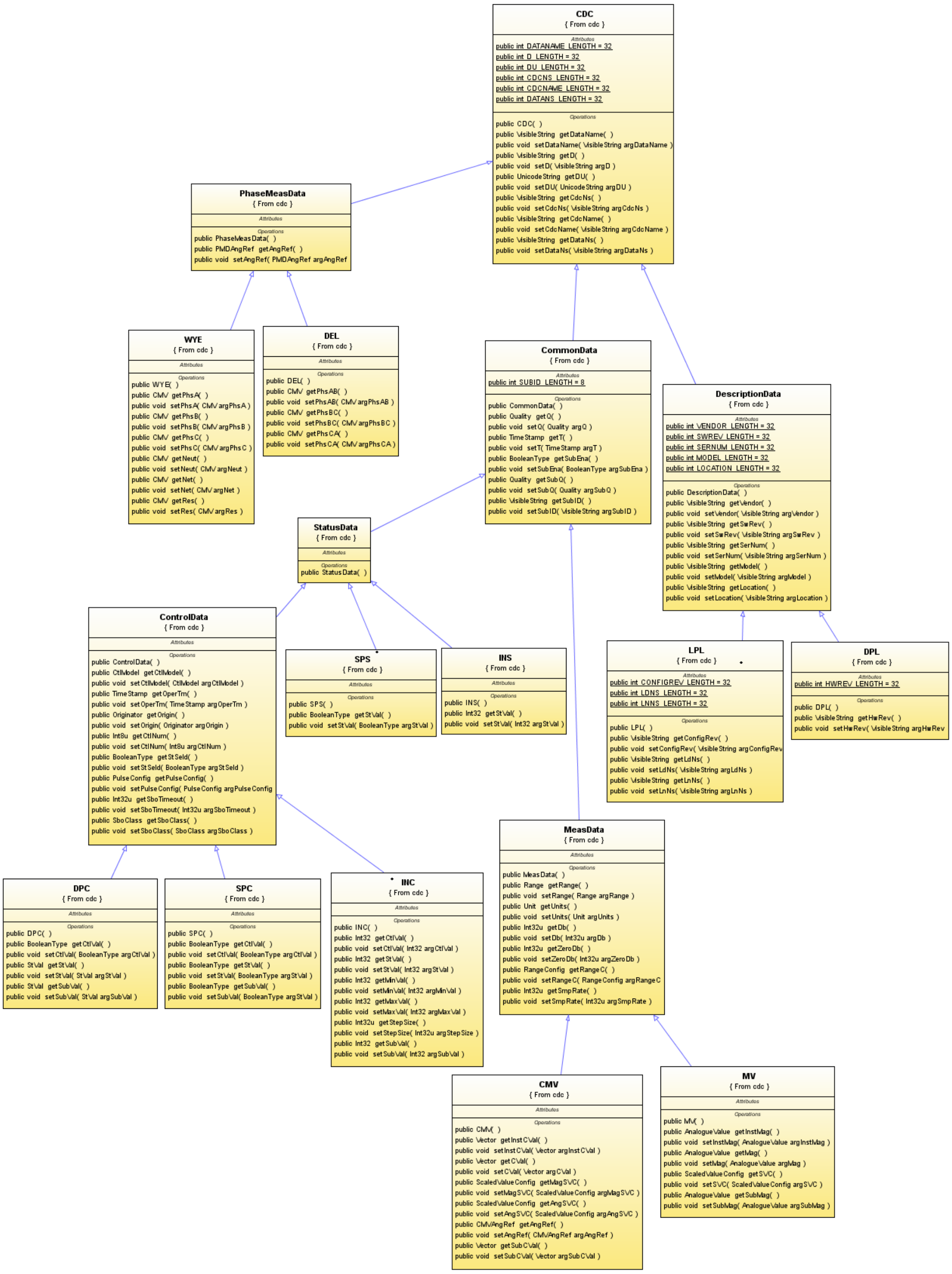

Figure 3-6: CDC class diagram

3.2.3.3. Common Data Attributes

Finally, at the end of the model hierarchy, *CDA* classes represent attribute types for *CDC* attributes. *CDA*-s can be complex containing other *CDA*-s or simple representing numbers, strings, enumerations, time and quality concepts.

CDA classes extend from java's *Observable* class; this allows the Communication Service Interface and Process Logic modules to subscribe to changes in required *CDA*-s and to be notified whenever a change in the value of a *CDA* occurs. The process part of the software (the one communicating with the device) is aware of any changes in the model produced by the external services part (the one communicating with IEC 61850 clients) acting accordingly and vice versa.

As with CDC-s, no new CDA elements are required to meet the needs of modelling the different generators, loads ans measurement devices.

Figure 3-7, Figure 3-8 and Figure 3-9 describe class diagrams with *CDA* classes.

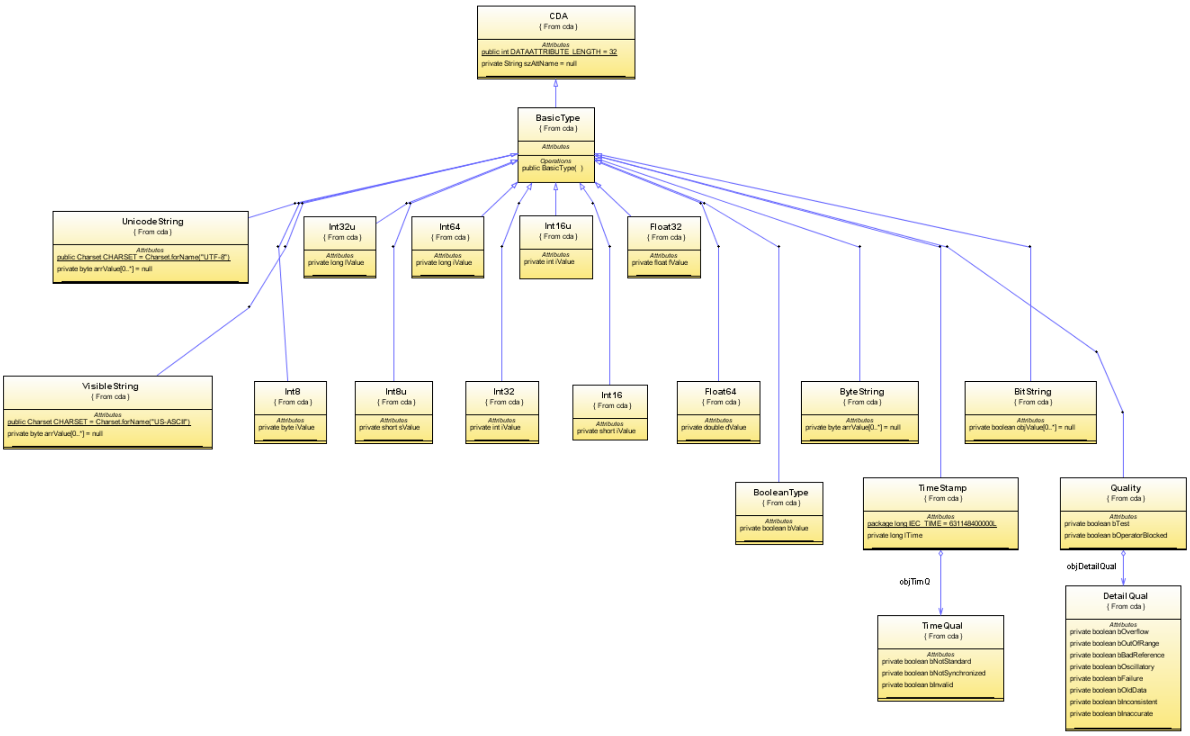

Figure 3-7: Basic CDA class diagram

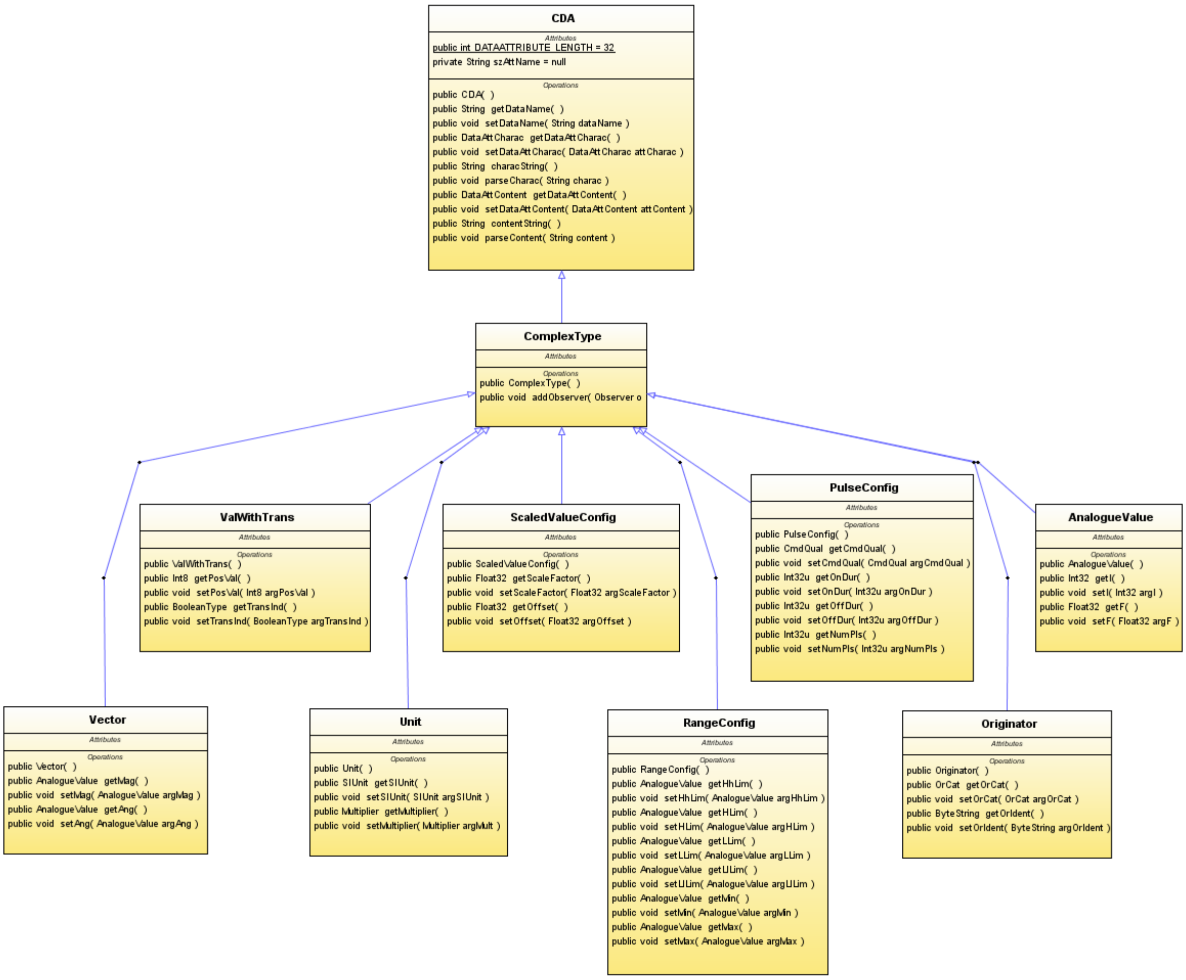

Figure 3-8: Complex CDA class diagram

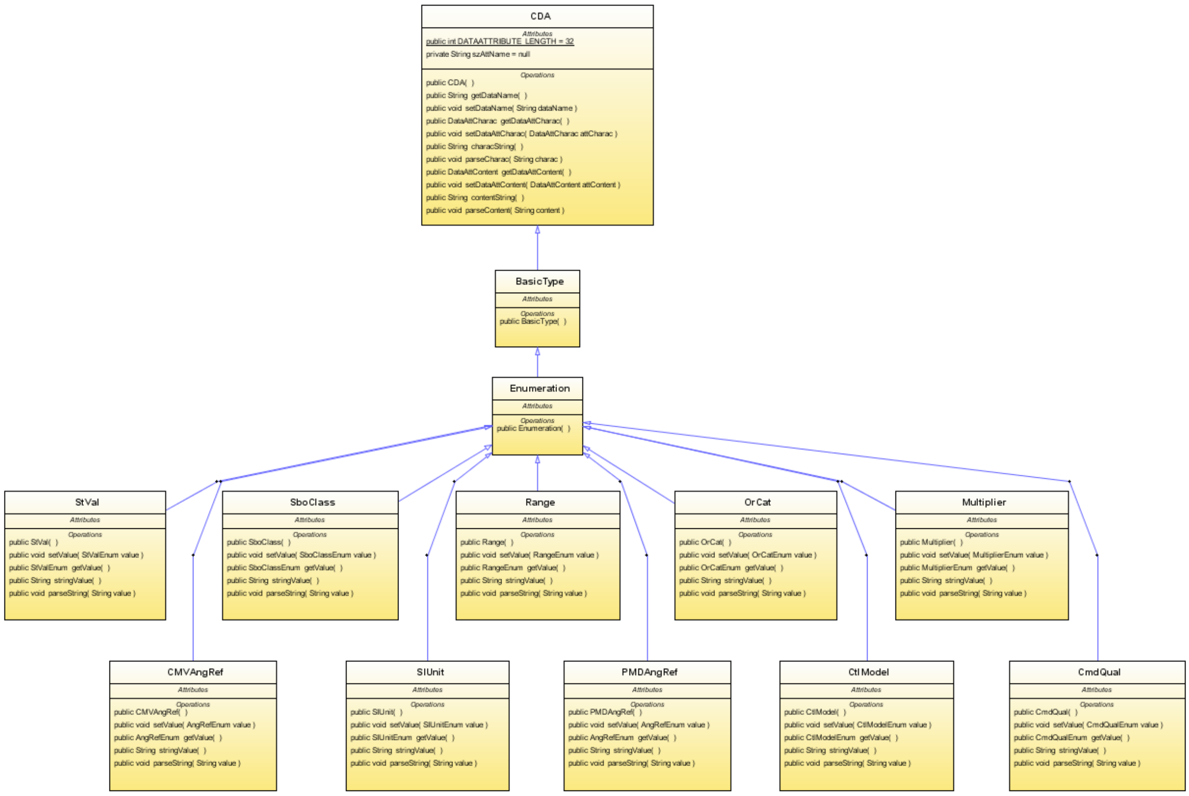

Figure 3-9: Enumeration CDA class diagram

3.2.4. Communication Services Interface module

The Communication Services Interface module implements some of the services specified in part 7-2 of IEC 61850. This module allows IEC 61850 clients to access the information held in the model. It provides services to get data from the model, set data into the model, make control actions over the device and obtain the model structure. The CSI module never interacts directly with the device, this way the same code can be reused for different type of controllers.

The *ComServicesImp* implements *ComServices* and *Module* interfaces allowing, through the methods specified on those interfaces, the interaction by other components with this module. The different classes owned by *ComServicesImp* implement the services offered by the CSDER software according to IEC 61850. The Figure 3-10 below describes the classes in CSI module.

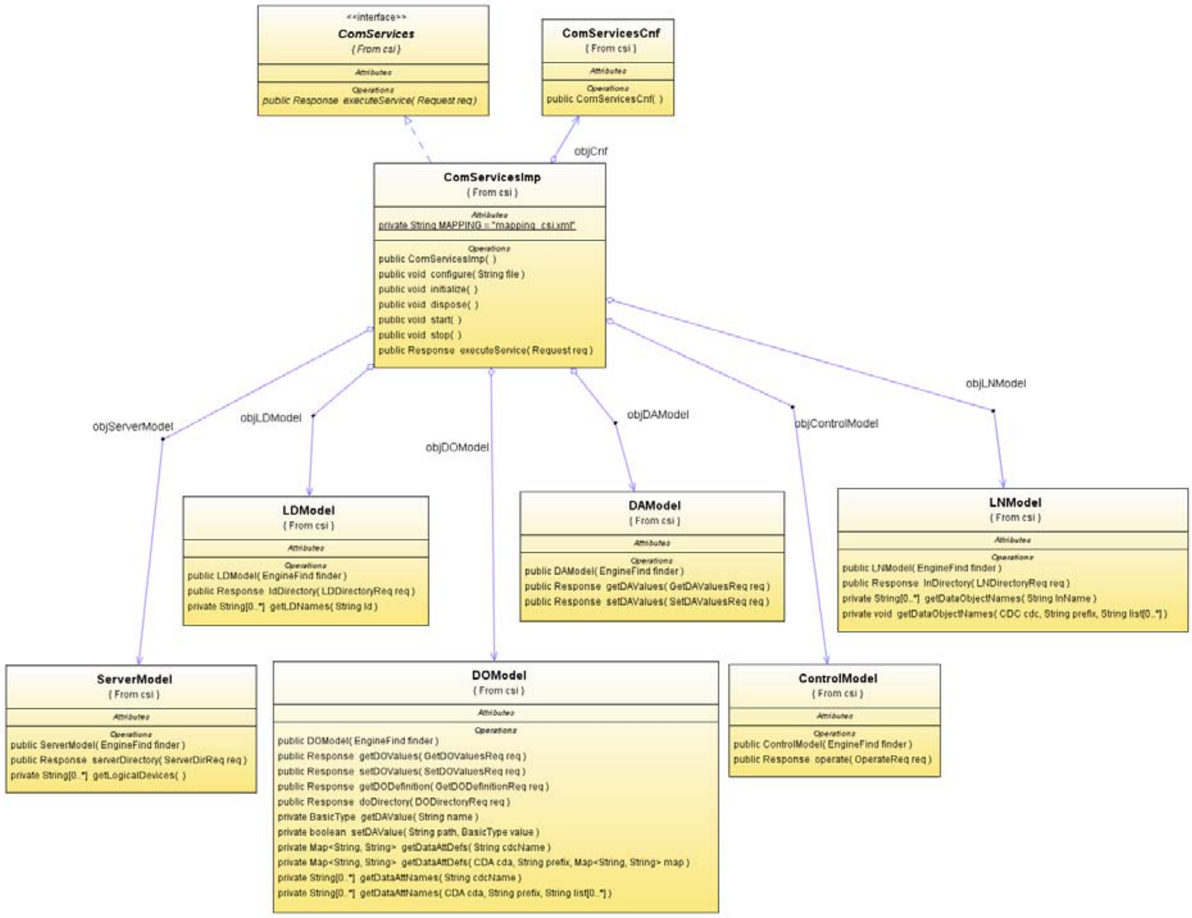

Figure 3-10: CSI class diagram

The implemented services are shown in Table 3-IX: Implemented services; these services are a subset of all specified services in the standard.

Table 3-IX: Implemented services

Classification	Name	Description	Observations
Server Model	Server Directory	Returns a list of the element identifiers contained in the server.	This service does not support FILE nor CLIENT_ASSOCIATION element types, only LOGICAL_DEVICE type is supported.
Logical Device Model	Logical Device Directory	Returns the list of Logical Node identifiers contained in a certain Logical Device.	
Logical Node Model	Logical Node Directory	Returns the list with element identifiers held by a certain Logical Node.	Only DATA_OBJECT element types (CDC instances) are supported, DATA_SET, REPORT_CONTROL, LOG_CONTROL, LOG, GOOSE_CONTROL and SAMPLED_MEASURED _VALUE_CONTROL types are not supported.

Data Object Model	Data Object Directory	Returns a list of CDA instance identifiers belonging to a certain CDC.	When a CDA instance has another nested CDA instance the full identifier (path) is returned.
	Data Object Definition	Returns a list of CDA instance types belonging to a certain CDC.	When a CDA instance has another nested CDA instance the type of the most nested CDA is returned.
	Get Data Object Values	Returns a list of CDA instance values corresponding to the specified list of CDA identifiers.	In case of nested CDA instances, the most nested CDA-s values must be asked.
	Set Data Object Values	Sets a list of CDA instance values corresponding to the specified list of CDA identifiers.	In case of nested CDA instances, the most nested CDA-s values must be set.
Data Attribute Model	Get Data Attribute Values	Returns the value of the specified CDA instance.	In case of nested CDA instances, the most nested CDA-s values must be asked.
	Set Data Attribute Values	Sets the value of the specified CDA instance.	In case of nested CDA instances, the most nested CDA-s values must be set.
Control Model	Operate	Makes the requested operation on the device.	Test, Interlock and Synchrocheck options are not supported. Select Before Operate With Normal Security, Direct Control With Normal Security and Select Before Operate With Normal Security modes are not supported, only Direct Control With Normal Security is supported. Time Activated Operate mode is not supported. Control operations are only allowed over DPC, SPC and INC instances.

3.2.5. Specific Communication Services Mapping module

This module defines how external applications can access the services in the CSI module. IEC 61850 sets MMS and ISO/IEC 8802-3 as the communication protocols for interacting with servers. MMS is used in industrial applications and it is not possible to obtain free, open implementation of it, therefore It has been discarded the use of the protocols specified in the standard and implemented XML-RPC[4] protocol as a widely used protocol in internet, with several open source tools and API-s supporting it. Anyway the modular design of the software permits swapping from one implementation to another in case it is considered more useful.

[4] Without entering into details and broadly speaking, XML-RPC is some kind of lightweight version of SOAP(protocol used for web services and other web based applications).

The *XmlRpcServerImp* class implements *ExternalComs* and *Module* interfaces adding the interoperability with the other modules present in the software. *XmlRpcServerImp* class launches an XML-RPC server that listens to client requests; each attached handler performs the required mappings to relate the XML-RPC services and argument types into IEC 61850 services and types and returns the corresponding results, mapping again those result types to XML-RPC types.

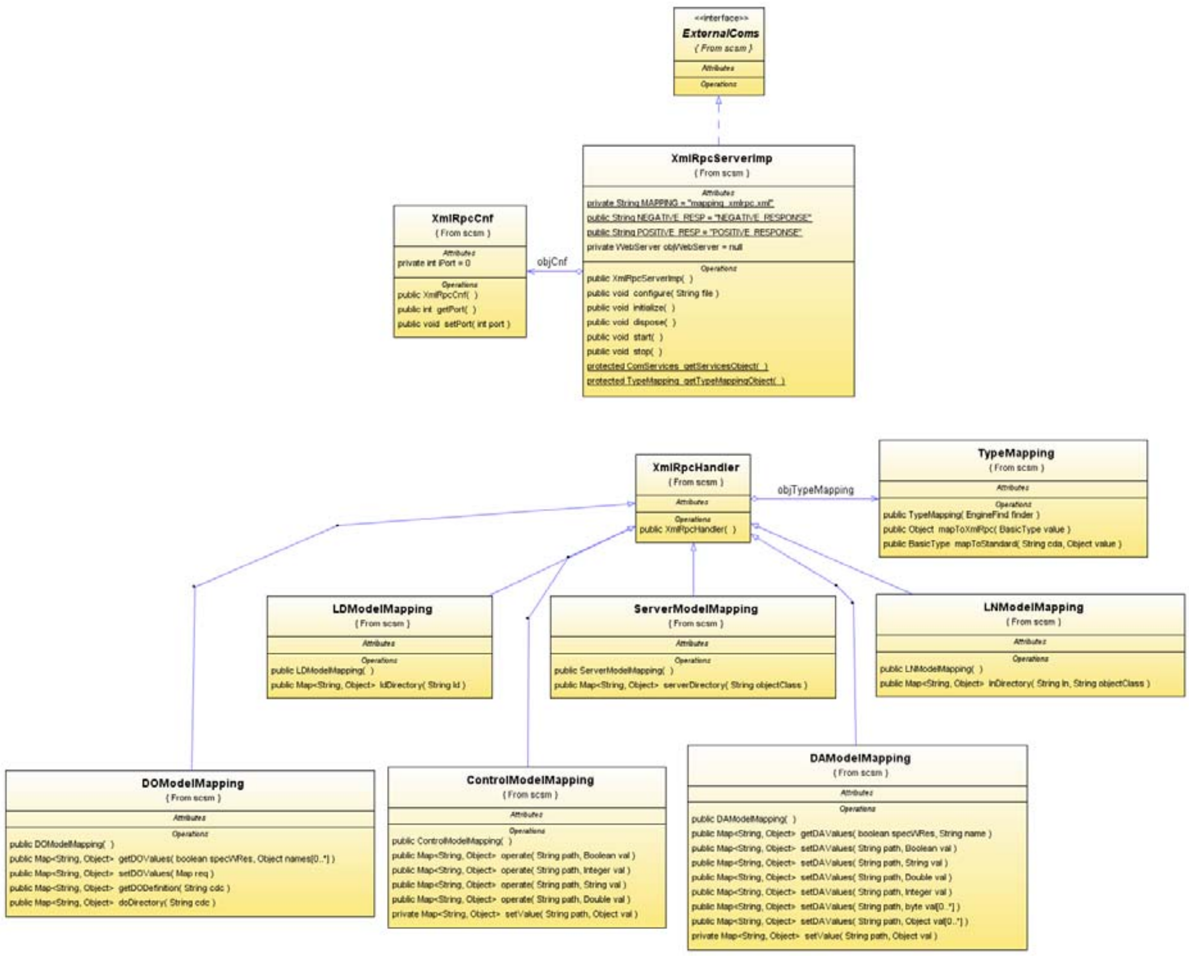

Figure 3-11: SCSM module class diagram

Note that, even if the services mapping module allows providing the complete set of options for the implemented services, the services implementation module may not support all of them (see section 3.2.4) and may return a failure response.

The XML-RPC server exposes the services as specified in the following tables:

Table 3-X: Server Directory service XML-RPC description

	ServerModel.serverDirectory		
	Xml-rpc type	**Java type**	**Description**
Input	string	String	Element type to be asked for. Possible values are: “LOGICAL_DEVICE”, “FILE”, “CLIENT_ASSOCIATION”
Output	struct	java.util. Map	Map with two entries: key=”POSITIVE_RESPONSE” value=String[] key=”NEGATIVE_RESPONSE” value=String In case the service execution was successful an array of strings containing all object identifiers is returned, otherwise an error response is returned.

Table 3-XI: Logical Device Directory service XML-RPC description

	LDModel.ldDirectory		
	Xml-rpc type	**Java type**	**Description**
Input	string	String	Identifier of the LD instance for which the information is requested
Output	struct	java.util. Map	Map with two entries: key=”POSITIVE_RESPONSE” value=String[] key=”NEGATIVE_RESPONSE” value=String In case the service execution was successful an array of strings containing all LN instances identifiers is returned, otherwise an error response is returned.

Table 3-XII: Logical Node Directory service XML-RPC description

	LNModel.lnDirectory		
	Xml-rpc type	**Java type**	**Description**
Input	string	String	Identifier of the LN for which the information is requested.
	string	String	Element type to be asked for. .Possible values are: “DATA_OBJECT”, “REPORT_CONTROL”, “LOG_CONTROL”, “LOG”, “GOOSE_CONTROL”, “SAMPLED_MEASURED_VALUE_CONTROL”
Output	struct	java.util. Map	Map with two entries: key=”POSITIVE_RESPONSE” value=String[] key=”NEGATIVE_RESPONSE” value=String In case the service execution was successful an array of strings containing all object identifiers is returned, otherwise an error response is returned.

Table 3-XIII: Data Object Directory service XML-RPC description

DOModel.doDirectory

	Xml-rpc type	Java type	Description
Input	string	String	Identifier of the CDC instance for which the information is requested.
Output	struct	java.util. Map	Map with two entries: key="POSITIVE_RESPONSE" value=String[] key="NEGATIVE_RESPONSE" value=String In case the service execution was successful an array of strings containing all CDC instances identifiers is returned, otherwise an error response is returned.

Table 3-XIV: Get Data Object Definition service XML-RPC description

	DOModel.getDODefiniton		
	Xml-rpc type	**Java type**	**Description**
Input	string	String	Identifier of the CDC instance for which the information is requested.
Output	struct	java.util. Map	Map with two entries: key="POSITIVE_RESPONSE" value=java.util.Map<String, String> key="NEGATIVE_RESPONSE" value=String In case the service execution was successful a Map containing CDA instances identifiers as keys and their corresponding definitions as values are returned, otherwise an error response is returned.

Table 3-XV: Get Data Object Values service XML-RPC description

	DOModel.getDOValues		
	Xml-rpc type	**Java type**	**Description**
Input	boolean	Boolean	Represents IEC 61850's SpecificationWithResult parameter. Indicates whether the list of object identifiers shall be returned with a positive response.
	array	String[]	Array of CDA identifiers for which values are wanted. Note that most nested CDA-s are required.
Output	struct	java.util. Map	Map with two entries: key="POSITIVE_RESPONSE" value=java.util.Map<String, Object> key="NEGATIVE_RESPONSE" value=String In case the service execution was successful a Map containing CDA instances identifiers as keys and their corresponding values as values are returned (see Table 3-XX for value types mapping), otherwise an error response is returned.

Table 3-XVI: Set Data Object Values service XML-RPC description

DOModel.setDOValues

	Xml-rpc type	Java type	Description
Input	struct	java.util.Map	Map containing CDA identifiers as keys and the values to be set as values (see Table 3-XX for value types mapping).
Output	struct	java.util.Map	Map with two entries: key="POSITIVE_RESPONSE" value=String key="NEGATIVE_RESPONSE" value=String In case the service execution was successful a string indication successfulness is returned otherwise an error response is returned.

Table 3-XVII: Get Data Attribute Values service XML-RPC description

	DAModel.getDAValues		
	Xml-rpc type	**Java type**	**Description**
Input	boolean	Boolean	Represents IEC 61850's SpecificationWithResult parameter. Indicates whether the list of object identifiers shall be returned with a positive response.
	string	String	CDA identifier for which value is wanted. Note that most nested CDA-s are required.
Output	struct	java.util. Map	Map with two entries: key="POSITIVE_RESPONSE" value=java.util.Map<String, Object> key="NEGATIVE_RESPONSE" value=String In case the service execution was successful a Map containing the CDA instance identifier as key and its corresponding value is returned (see Table 3-XX for value types mapping), otherwise an error response is returned.

Table 3-XVIII: Set Data Attribute Values service XML-RPC description

	DAModel.setDAValues		
	Xml-rpc type	**Java type**	**Description**
Input	string	String	CDA identifier for which the value is going to be set.
	Int/ boolean/ string/ double/ base64/ array	Integer/ Boolean/ String/ Double/ byte[]/ String[]	Value to be set (see Table 3-XX for value types mapping).
Output	struct	java.util.Map	Map with two entries: key="POSITIVE_RESPONSE" value=String key="NEGATIVE_RESPONSE" value=String In case the service execution was successful string indication successfulness is returned otherwise an error response is returned.

Table 3-XIX: Operate service XML-RPC description

	ControlModel.operate		
	Xml-rpc type	**Java type**	**Description**
Input	string	String	Control CDA identifier for which the value is going to be set.
	Int/Boolean/ string/double	Integer/ Boolean/ String/ Double	Value to be set, depends on the control CDA to access (see Table 3-XX for value types mapping).
	array	String[]	Array of string objects where the first object indicates the time since 1.1.1990, the second object indicates the time class (MILLIS, HUNDRED_MILLIS, TEN_MICROS) and the third indicates time quality as a sequence of three bits (Not-Standard, Not-Synchronized, Invalid).
	boolean	Boolean	Test status, indicates if the information is caused by normal operation or by test.
	boolean	Boolean	Indicates if the server should perform synchrocheck check before operation or not.
	boolean	Boolean	Indicates if the server should perform interlock check before operation or not.
Output	struct	java.util.Map	Map with two entries: key=”POSITIVE_RESPONSE” value=String key=”NEGATIVE_RESPONSE” value=String key=”Name” value=String key=”TIMESTAMP” value=String[] key=”TEST” value=Boolean A positive response contains a successful message, while a negative response contains a failure message. Following negative responses are allowed: “not-supported, “blocked-by-switching-hierarchy”, “blocked-by-event”, “blocked-by-interlocking”, “blocked-by-setpoint-command”, “target-exists”, “parameter-error”, “time-limit-over”, “address-error”, “hardware-error”, “1-of-n-control”, “system-crash”, “step-limit”, “command-already-in-execution”, “plausibility-error”, “blocked-by-synchrocheck”, “debounce-active”, “abortion”, “parameter-charge-in-execution”, “CB-alarm”. The name parameter indicates the identifier of the control object. Timestamp is the time stamp when the client requested the control operation. Test indicates if the information is caused by normal operation or by test.

Finally, the Table 3-XIX shows how CDA values are mapped from IEC 61850 types to XML-RPC types and vice versa:

Table 3-XX: Value types mapping

IEC 61850 type	XML-RPC type	IEC 61850 type	XML-RPC type	IEC 61850 type	XML-RPC type
Int8	int	Float32	double	Quality	String
Int16	int	Float64	double	Timestamp	array
Int32	int	Boolean	boolean	Enumeration	string

IEC 61850 type	XML-RPC type	IEC 61850 type	XML-RPC type	IEC 61850 type	XML-RPC type
Int64	int	UnicodeString	string		
Int8u	int	VisibleString	string		
Int16u	int	BitString	string		
Int32u	int	ByteString	base64		

BitString objects are mapped to strings containing a sequence of "1" and "0" characters.

Quality objects are mapped as strings containing a sequence of "1" and "0" with the following structure:

- validity (0-1): "00" -> GOOD, "01" -> INVALID, "10" -> QUESTIONABLE
- detailQual (2-9): Overflow (bit 2 = 1), OutOfRange (bit 3 = 1), BadReference (bit 4 = 1), Oscillatory (bit 5 = 1), Failure(bit 6 = 1), OldData (bit 7 = 1), Inconsistent (bit 8 = 1), Inaccurate (bit 9 = 1)
- source (10): "0" -> PROCESS, "1" -> SUBSTITUTED
- test (11): "0" -> NORMAL, "1" -> TEST
- operatorBlocked (12): "0" -> NORMAL, "1" -> OPERATOR_BLOCKED

Timestamp objects are mapped as string arrays with the following structure:

- The first object indicates the time since 1.1.1970.
- The second object indicates the time class (MILLIS, HUNDRED_MILLIS, TEN_MICROS)
- The third indicates time quality as a sequence of three bits (Not-Standard, Not-Synchronized, Invalid).

3.2.6. Process Logic module

The process logic module is specific to the device being controlled, so it is impossible to give a detailed description of the functions performed by it. In general terms this module would have to support different tasks:

1. Polling: The polling task consists on asking the device being controlled for measurement and status parameters and filling the corresponding model elements with this information. The polling period for updating information about the device must be fast enough to meet the requirements (one second or less). In case there is

not a direct mapping between the elements in the standard model and the proprietary model of the device, the Process Logic module would be in charge of translating it by making the corresponding operations according to the standard model. This could be a simple task such as translating scales or numerical representations to more complex operations such as merging two different parameters to obtain the required one.

2. Control: The control task registers to the control parameters in the model using Java's observable/observed mechanism so when one of those parameters changes the control task is automatically notified and performs the required control actions. As in the Polling task the mapping of the standard control actions may not be direct to respective control commands in the device; so the control task would be in charge of performing the corresponding control actions that are specific to the device and mapping the control action according to the standard. For example switching on a generator could imply a sequence of control actions such as starting the engine and then connecting to the network etc.

Specific process logic module classes must implement the *ProcLogic* and *Module* interfaces allowing other modules to interact with the process logic module. The package also contains a *ProcLogicCnf* class holding configuration parameters.

Figure 3-12 shows an example of a process logic implementation for a specific load bank:

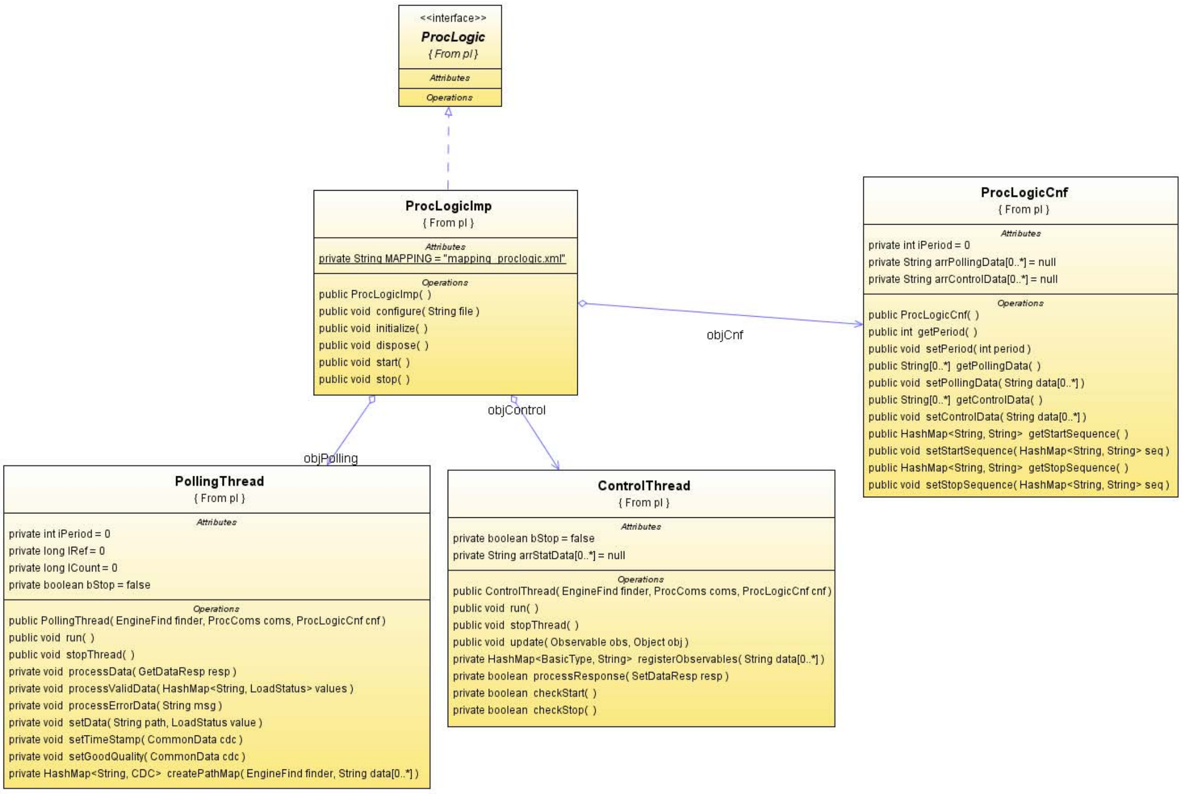

Figure 3-12: Process Logic module class diagram

3.2.7. Process Communications module

This module is also specific for the controlled device, and is intended to map Process Logic messages to the specific communication protocol used by the device. As with the process logic module it is not possible to describe beforehand in detail this module since it depends on the protocol used by the specific device.

Figure 3-13 shows an example of an implementation of the process communication module for a load bank communicating through ModBus TCP protocol:

Figure 3-13: Process communication module class diagram

3.2.8. Configuration component

The configuration module uses *Castor* (an XML/Java serializer & deserializer) in order to configure each module with configuration parameters specified in XML files. This module has *XmlBinder* class able to unmarshall Xml files into Java objects that are used by the different modules as configuration parameters' storage.

Figure 3-14 shows the class diagram of the configuration component.

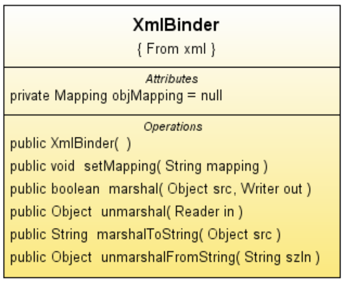

Figure 3-14: Configuration component class diagram

Next sections describe the different configuration parameters available for each module.

3.2.8.1. Configuration for Model module

The configuration file for the model module holds an XML representation of the complete model of the device to be controlled. The configuration file contains all the information that when unmarshalled creates the model objects. It consists on the complete hierarchy of Server, LN-s, CDC-s and CDA-s describeing the specific model of the device.

3.2.8.2. Configuration for Communication Services Interface module

No configuration is needed for this module.

3.2.8.3. Configuration for Specific Communication Services Mapping module

Contains the following configuration parameters:

Table 3-XXI: SCSM configuration parameters

Parameter	Description
port	Port where the XML-RPC server will be listening for client requests.

3.2.8.4. Configuration for Process Logic module

The configuration file for the process logic module will be specific to the implementation and device requirements; anyway the provided mechanism permits including as many configuration parameters as needed.

3.2.8.5. Configuration for Process Communications module

Same as the process logic module this module is also specific for the device being implemented.

3.2.8.6. Configuration for main application

The configuration for the main application provides the way to specify the different implementation classes executed for a certain device together with their configuration files.

Application main configuration parameters are described in Table 3-XXII.

Table 3-XXII: Main application configuration parameters

Parameter	Description
model-cnf	Configuration file path for the model module.
model	Class implementing the model module.
proc-coms-cnf	Configuration file path for the process communications module.
proc-coms	Class implementing the process communications module.
proc-logic-cnf	Configuration file path for the process logic module.
proc-logic	Class implementing the process logic module.
services-cnf	Configuration file path for the communication services interface module.
services	Class implementing the communication services interface module.
external-coms-cnf	Configuration file path for the specific communication services mapping module.
external-coms	Class implementing the specific communication services mapping module

3.3. Conclusions

The chapter 3 describes the requirements and design for implementing IEC 61850 based protocol gateways used for monitoring and controlling the devices in a MicroGrid.

The design has been focused on providing a modular, extensible and portable software suitable for a domain where a wide range of equipment must be controlled, each one with its own proprietary communications protocols and functions.

For this purpose, models for generation, load and measurement equipments have been developed from a high level perspective, hiding the complexity of specific generation, load and measurement technologies but providing a set of services enough for matching the needs of a MicroGrid Energy Management System.

During the design and implementation phases some issues have been detected regarding the IEC 61850 model:

- There is no model for controllable loads, so a new DCLO logical node has been created to model this kind of loads.

- Generators' P-F and Q-V droops have been redefined in order to include then within the model in an easy and clean way.

Regarding the Specific Communication Service Mapping, an XML-RPC protocol implementation is proposed. This implementation is an open and internet based protocol which allows easily developing client applications and deploying them into already existing internet based networks.

Finally, the work done in this task has been used to implement the protocol gateway software deployed for the monitoring and control of Labein's Microgrid in "WPF - Demonstration on laboratory Microgrids", task TF2. This control system is then applied for implementing and installing a secondary frequency control in charge of restoring scheduled export/import power during the grid connected mode and recovering statutory frequency values at islanded mode ("WPB Development of Alternative Control Strategies (hierarchical vs. distributed)" task TB3, TB5 and TB6)

4. IEC 61850-7-420 over MMS for µGrid control

This chapter describes the implementation of the latest communication standard for DER equipment (IEC 61850-7-420) and the MMS service for the bidirectional battery inverter “Sunny Island”.

First, an overview of the communication structure and details about the different hardware and software components are presented. Then, a summary of results, development and experimental issues, especially software and integration aspects are reported.

4.1. Design

4.1.1. Structure and components for IEC 61850 communication

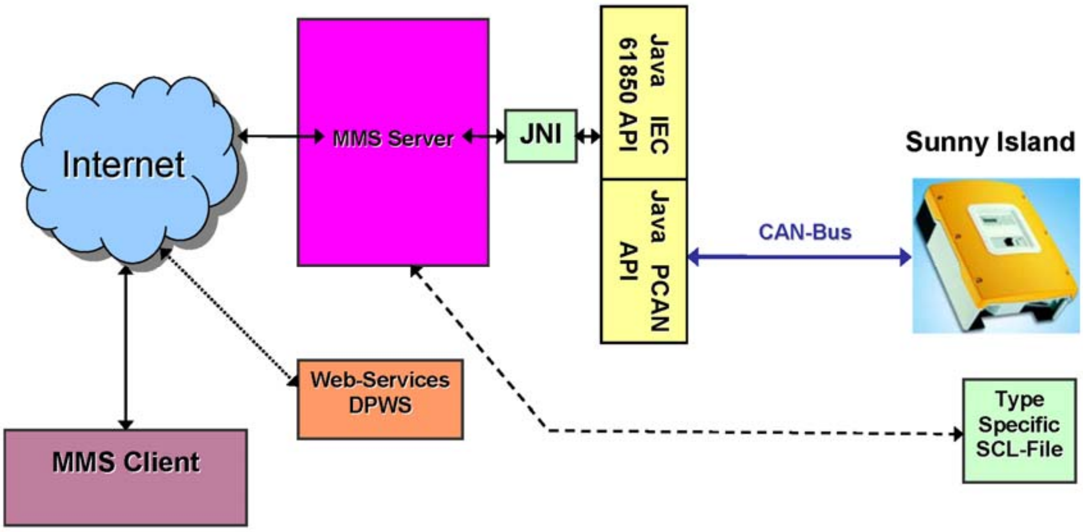

Figure 4-1: Applied Structure and components for IEC 61850 communication

In order to control a Sunny Island using IEC61850 MMS-service a method for establishing the communication link between these two devices was developed. Figure 4-1 gives an overview of the communication structure and shows the different hardware and software components. The microgrid equipment *Sunny Island* is physically connected to the “MMS-Server” computer with a serial/USB adapter using a proprietary (SMA Solar Technology AG) CAN-Bus protocol. Different new developed software components (based on Java PCAN, Java IEC 61850, Java Native Interface) are the “virtual” interface between the CAN-Bus protocol and the IEC 61850 “world”.

If the MMS-Server software gets requests from an MMS-Client they will be forwarded to the device and its reply will be passed back to the MMS- Client.

The whole experimental setup is located at DeMoTec, a large laboratory of Fraunhofer IWES and the University of Kassel.

The different hardware and software components, which are used for the IEC 61850 communication, according to Figure 4-1, will be explained in detail.

4.1.2. Sunny Island

A Sunny Island 5048 is a bidirectional battery inverter for off-grid systems from SMA Solar Technology AG. It can be used for setting up an isolated AC microgrid in different system configurations. Figure 4-2 shows the components, which can be integrated into a Sunny Island system. The Windy Boys and the Sunny Boys operate like current sources. They convert DC to AC power and they are connected to the Sunny Island on the AC1 side which is the island grid. The public grid is the connection AC2. On the DC side batteries, PV modules or DC loads can be connected.

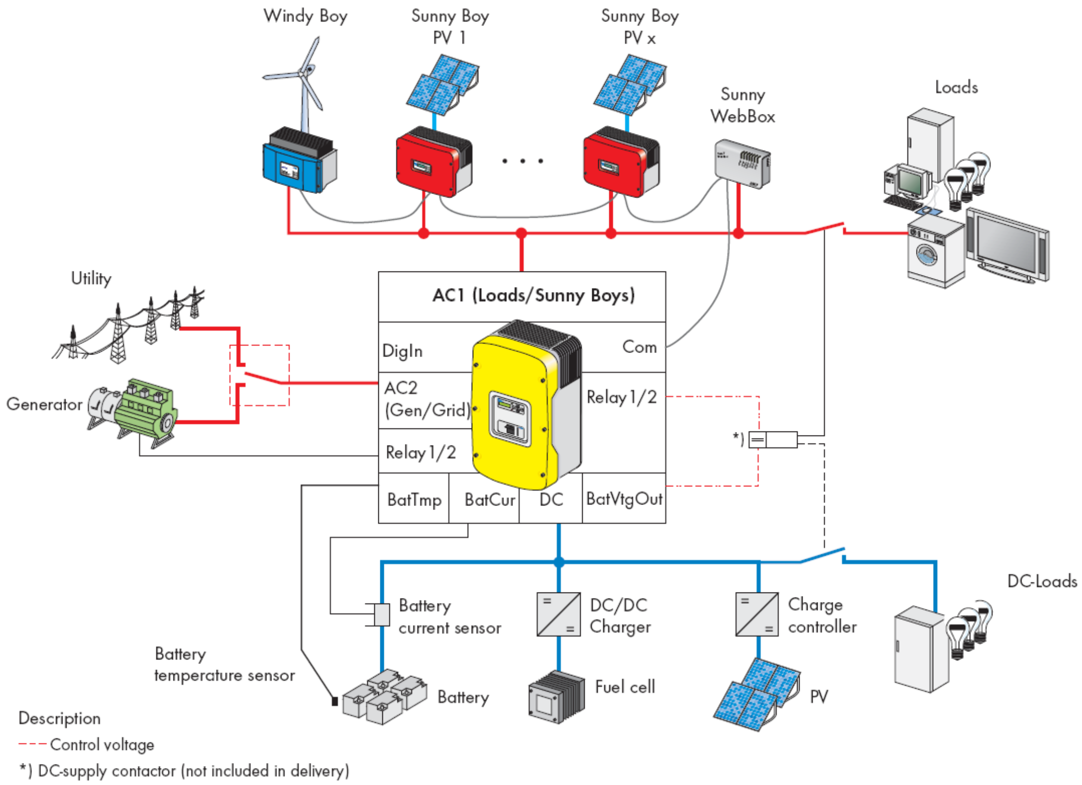

Figure 4-2: Sunny Island Microgrid and connection possibilities for distributed MG components

Sunny Island can be used as grid forming unit for setting up an isolated AC-microgrid. Although Sunny Island could be synchronised to the public AC-grid, it does not need the public grid for supply of AC loads, connected to the Sunny Island-microgrid. Battery banks coupled to its DC-interface will be charged with the energy from grid-feeding units connected to the Sunny Island AC-microgrid or discharged if the electricity production within the AC-microgrid is less than the power consumption.

The parallel operation of up to four devices on a single phase of a battery or three devices on a three-phase system enables the Sunny Island 5048 to set up stand-alone power supply systems with outputs ranging from 3 kW to 26 kW. Thanks to its sophisticated generator management it can control connected diesel generators in a particularly gentle and fuel-saving manner.

The Sunny Island 5048 monitors the set voltage and frequency limits on the grid and generator. If there limits are not observed it disconnects from the external source without interruption and changes to stand-alone grid operation. The Sunny Island 5048 also has an integrated anti-islanding process in order to prevent unintended islanding on the public grid.

If this process is triggered the system also completely changes to stand-alone mode without interruption.

Figure 4-3: Test setup with three Sunny Islands located at DeMoTec lab of Fraunhofer IWES in Kassel.

Several analogue as well as binary process and setpoint variables of Sunny Island are available via its CAN-Bus interface, and thus could be transferred via the IEC 61850 communication. The Table 4-I lists a set of important variables, which have been implemented in the IEC61850 communication:

Table 4-I: Sunny island considered parameters & variables

Type[5]	Data Type & Length	Name	Variable Description
AMV	S16, 2 Byte	ExtPwrAt	Active power consumption from public grid

[5] Listed type are associated to the proprietary Sunny Island CAN bus protocol:
- AMV Analogue Measure value
- AS Analogue Setpoint value
- BC Binary Control
- BS Binary Status

Type[5]	Data Type & Length	Name	Variable Description
AMV	S16, 2 Byte	ExtPwrRt	Reactive power consumption from public grid
AMV	S16, 2 Byte	InvPwrAt	Active power supply to Sunny Island Microgrid
AMV	S16, 2 Byte	InvPwrRt	Active power supply to Sunny Island Microgrid
AMV	S16, 2 Byte	InvVtg	Phase to neutral voltage of Sunny Island Microgrid
AMV	S16, 2 Byte	InvFrq	Power frequency of Sunny Island Microgrid
AMV	S16, 2 Byte	BatTmp	Battery temperature
AMV	S16, 2 Byte	BatSOC	Battery State-of-charge
BS	1 Bit	GdOn	Connected to public grid
BS	1 Bit	ExtVfOk	Voltage and Frequency of public grid are in valid range
BS	1 Bit	Run	SI in operation
BS	1 Bit	Error	SI is faulted
AS	S16, 2 Byte	FedinCurAt	Setpoint for Active Current feed-in to public grid
AS	S16, 2 Byte	FedinCurRt	Setpoint for Reactive Current feed-in to public grid
AS	U16, 2 Byte	InvVtgNom	Nominal phase to neutral voltage of Sunny Island Microgrid
AS	U16, 2 Byte	InvFrqNom	Nominal power frequency of Sunny Island Microgrid
AS	U16, 2 Byte	BatChrgVtg	Nominal battery charging voltage
BC	1 Bit	ManStr	Start or Stop of Sunny Island
BC	1 Bit	GdManStr	Deny/Allow automatic Grid Synchronisation
BC	1 Bit	CurAtEna	Disable/Enable manual Active Current Setpoint
BC	1 Bit	CurRtEna	Disable/Enable manual Reactive Current Setpoint
BC	1 Bit	ManChrgSel	Start or Stop of manual Battery Charging Operation

4.1.3. PCAN-USB-Adapter

As already mentioned, the Sunny Island device is physically connected to the computer, which behaves as MMS server via CAN bus connection and the PCAN- USB Adapter.

This adapter allows the connection of a CAN bus to an USB interface of an IBM compatible PC. With the help of this adapter any PC can be linked to a High-speed CAN (HS-CAN).

The main properties of this adapter are listed:

- Connection of a High-speed CAN (CAN specifications 2.0A and 2.0B) to a PC
- Use of any USB port at the PC (USB 1.1, compatible with USB 2.0)
- Power supply via USB connection
- CAN transfer rate up to 1 MBit/s
- Galvanic isolation at CAN connection up to 500 V (PCAN-USB ISO only)

- Support for operating systems Windows (98 SE, ME, 2000 SP4, XP) and Linux

4.1.4. IEC 61850 and IEC 61850-7-420

IEC 61850 is a relatively new standard for the design of electrical substation automation and it mainly defines the following aspects:

- general conditions for substations
- most important information for hardware
- information for protection, guard, control and measuring
- digital connection for primary data
- configuration language

The abstract data models defined in IEC61850 can be mapped to a number of protocols. Current mappings in the standard are to MMS (Manufacturing Message Specification), GOOSE, SMV, and soon to Web Services. These protocols can run over TCP/IP networks and/or substation LANs using high speed switched Ethernet to obtain the necessary response times of < 4ms for protective relaying. Within the standard all conditions for automation are fulfilled. That affects the communication structure and the strictly object-related data model.

IEC 61850-7-420 is the part of IEC 61850 covering communication with distributed energy resources (DER) and microgrid equipment. Thereto the following description concentrates on the modelling and implementation of the Sunny Island device based on IEC 61850-7-420.

Figure 4-4 illustrates one example for modelling of a PV based system according to IEC 61850-7-420 and its Logical Nodes associated with one configuration of a photovoltaic system although actual implementations may vary, depending on the system requirements. The next chapter describes the necessary logical nodes for modelling of Sunny Island in details.

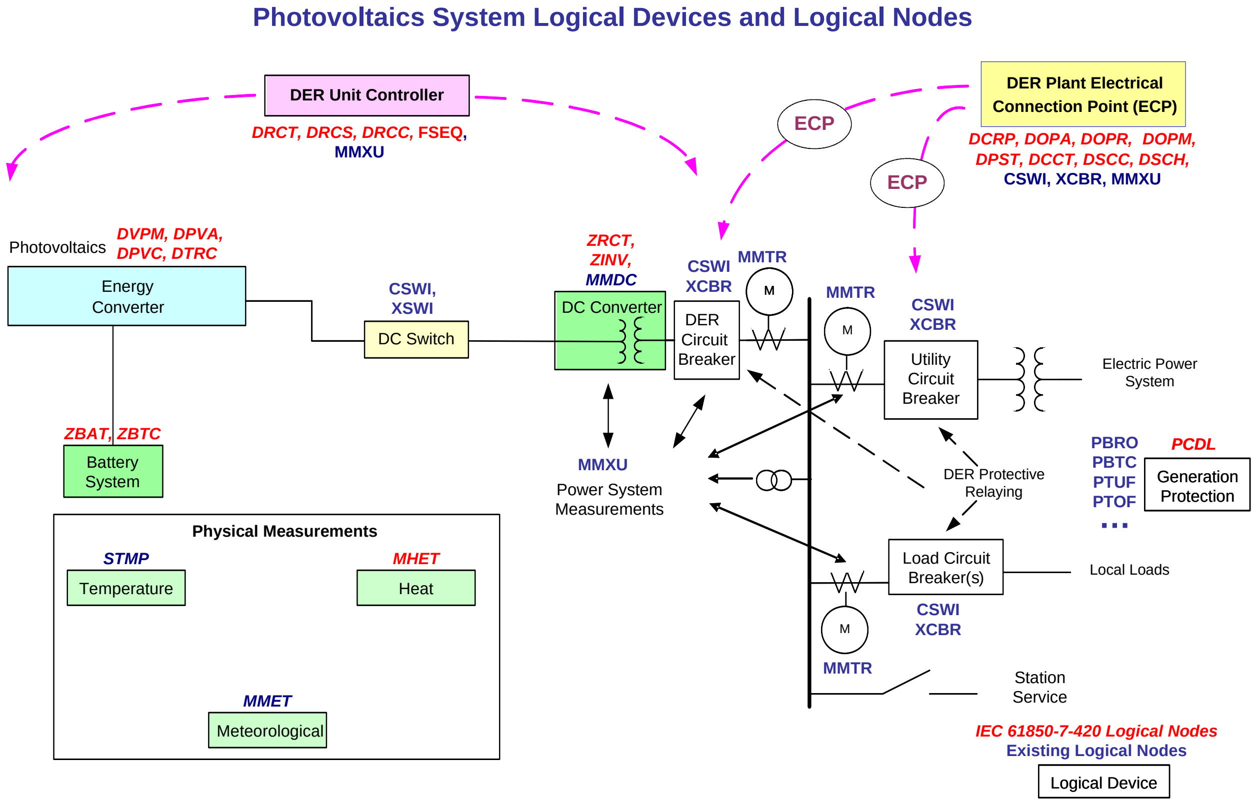

Figure 4-4: Example of Logical Nodes associated with a photovoltaic system. The existing Logical Nodes (blue) are from IEC 61850-7-4, the red ones from the new IEC 61850-7-420

4.1.5. Logical nodes at the Sunny Island

In the experiment three Sunny Island were used to set up a three-phase system. One was configured as Master device (Phase A), the others as Slave devices (Slave 1 = Phase B, Slave 2 = Phase C).

Figure 4-5 shows the modelling of the “Sunny Island” cluster with the used logical nodes according to IEC 61850-7-420 and IEC 61850-7-4:

- ZBAT (1x) (batteries for energy storage)
- ZBTC (1x) (battery charger for energy storage)
- DRCC (3x for three phases) (DER supervisor controller with control actions),
- DRCS (1x) (DER supervisor controller status information)

- ZINV (6x) (DC to AC conversion: functions for the control and monitoring of the inverter)
- MMXU (2x) (Electrical measurement at the AC1 and the AC2 output)

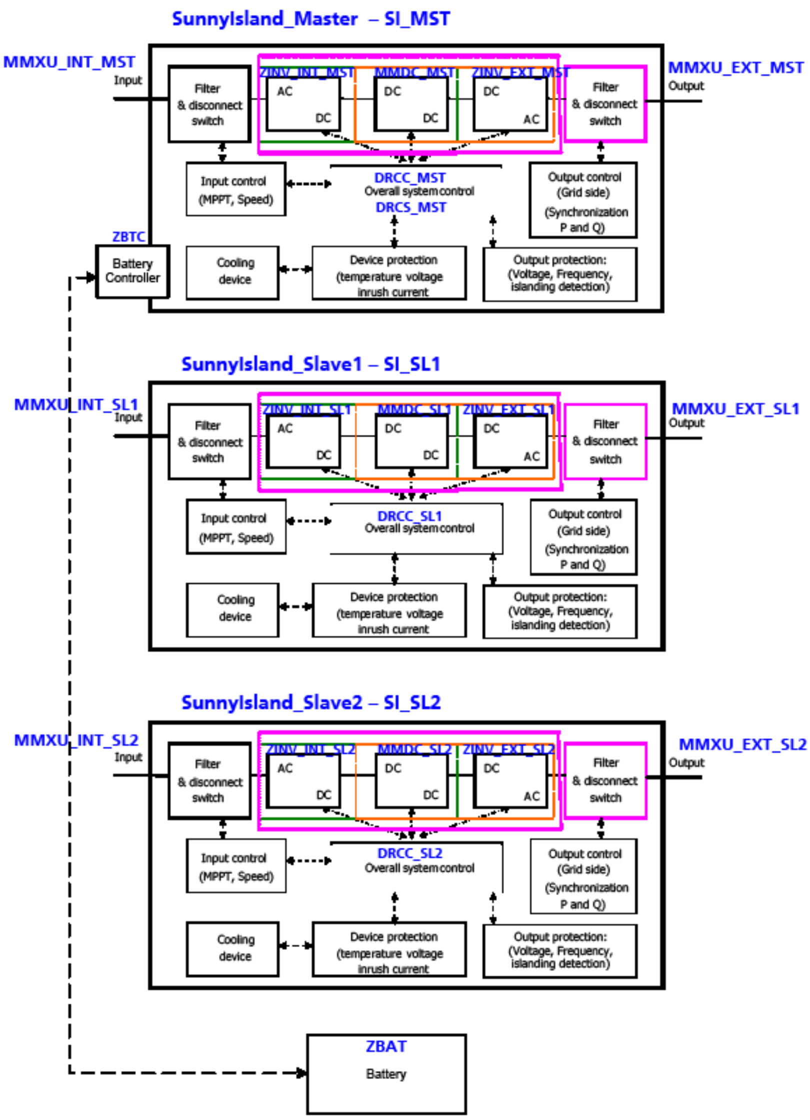

Figure 4-5: Logical Nodes of the Sunny Island

The output on the left side of Figure 4-5 is connected to AC1 i.e. the Sunny Island microgrid, the right output with the public grid.

In the next tables, the existing as well as new data objects, its data classes and selected data attributes, which are necessary for implementation of Sunny Island process, status and setpoint values according to Figure 4-5 are presented in detail.

Table 4-II: DER supervisory control DRCC

Data class	Data attribute	Data object[6]	Description
SPC	stVal	GnStrMan	manual start of generator
SPC	stVal	GdSyncAllow	grid operation blocked/free
SPC	stVal	GnGdConAllow	Signal for Enable / Disable grid/generator connection
SPC	stVal	DERStr	Start DER unit
SPC	stVal	DERStop	Stop DER unit
SPC	stVal	FltAck	Fault clearing
SPC	stVal	Rly1Op	On/Off Relay 1
SPC	stVal	Rly2Op	On/Off Relay 2

Table 4-III: DER controller status DRCS

Data class	Data attribute	Data object[7]	Description
INS	d	ErrCode	error message
SPS	stVal	Rly1	On/Off Relay 1
SPS	stVal	Rly2	On/Off Relay 2
SPS	stVal	GnRn	Feedback signal Generator in operation
SPS	stVal	AutoGn	Generator request
SPS	stVal	AutoLodExt	Load shedding 1 request
SPS	stVal	AutoLodSoc	Load shedding 1 request
SPS	stVal	Tm1	Timer 1 request
SPS	stVal	Tm2	request by Timer 2 active
SPS	stVal	ExtVfOk	grid/generator voltage/frequency in valid range
SPS	stVal	GdOn	grid connected
SPS	stVal	Run	In operation
SPS	stVal	MccAutoLod	Load shedding request in multi cluster mode
SPS	stVal	Chp	CHP request
SPS	stVal	ChpAdd	Add. CHP request

Table 4-IV: Measurement MMXU

Data class	Data attribute	Data object[8]	Description
WYE	phsA.cVal.mag	W	active power Phase A
WYE	phsB.cVal.mag	W	active power Phase B

[6] New objects are coded in blue colour.
[7] New objects are coded in blue colour.
[8] New objects are coded in blue colour.

Data class	Data attribute	Data object[8]	Description
WYE	phsC.cVal.mag	W	active power Phase C
WYE	phsA.cVal.mag	VAr	reactive power Phase A
WYE	phsB.cVal.mag	VAr	reactive power Phase B
WYE	phsC.cVal.mag	VAr	reactive power Phase C
WYE	phsA.cVal.mag	PhV	Voltage (Phase A-N)
WYE	phsB.cVal.mag	PhV	Voltage (Phase B-N)
WYE	phsC.cVal.mag	PhV	Voltage (Phase C-N)
MV	mag	Hz	frequency

Table 4-V: Battery systems ZBAT

Data class	Data attribute	Data object[9]	Description
SPC	stVal	BatSt	Equalisation charging
MV	mag	Vol	battery voltage
MV	mag	Amp	battery current
MV	mag	InBatTmp	battery temperature
MV	mag	BatSOC	battery SOC
INS	stVal	Health	battery SOH
SPS	stVal	BatFan	Fan Battery room
SPS	stVal	AcdCir	Battery acid recirculation
SPS	stVal	MccBatFan	Fan Battery room in multi cluster mode

Table 4-VI: Battery charger ZBTC

Data class	Data attribute	Data object[10]	Description
ASG	setMag	ChaVSet	Nom. Charging voltage
ASG	minVal	ChaVSet	Min. Charging voltage
ASG	maxVal	ChaVSet	Max. Charging voltage
ASG	setMag	SOCSet	Nom. Battery State of charge (SOC)
ASG	minVal	SOCSet	Min. SOC
ASG	maxVal	SOCSet	Max. SOC
ENG	setVal	BatChaTyp	Battery charging mode
ENG	setVal	BatChaSt	Battery charging mode status

[9] New objects are coded in blue colour.
[10] New objects are coded in blue colour.

Table 4-VII: Inverter ZINV

Data class	Data attribute	Data object[11]	Description
ENG	setVal	ACTyp	inverter type
ASG	setMag	OutWSet	output power setpoint
ASG	setMag	OutCurAtSet	active current setpoint
ASG	minVal	OutCurAtSet	Min. active current
ASG	maxVal	OutCurAtSet	Max. active current
ASG	setMag	OutCurRtSet	reactive current
ASG	minVal	OutCurRtSet	Min. reactive current
ASG	maxVal	OutCurRtSet	Max. reactive current
ASG	setMag	OutHzSet	rated frequency setpoint
ASG	minVal	OutHzSet	Min. rated frequency
ASG	maxVal	OutHzSet	Max. rated frequency
ASG	setMag	OutVSet	rated voltage setpoint
ASG	minVal	OutVSet	Min. voltage
ASG	maxVal	OutVSet	Max. voltage
SPC	stVal	OutCurAtManEna	manual rated active current
SPC	stVal	OutCurRtManEna	manual rated reactive current
SPC	stVal	ChaVManEna	manual rated charge voltage
SPC	stVal	EquChrgeManEna	Manual Equalisation charge
SPC	stVal	GnStrManEna	manual start of generator
SPC	stVal	GdStrManEna	manual grid operation
SPC	stVal	SetVtgFrqManEna	manual voltage/frequency setpoint
SPC	stVal	GnGdConEna	Enable manual Grid connection
ENG	SetVal	InvOpSt (replace Stdby)	state of operation

4.1.6. IEC 61850-MMS service

As already mentioned before, in this project the MMS service of IEC 61850 was used for data transmission. Manufacturing Message Specification (MMS) is an international standard (ISO 9506) dealing with messaging system for transferring real time process data and supervisory control information between networked devices and/or computer applications.

[11] New objects are coded in blue colour.

The standard Manufacturing Messaging Specification (MMS) is useful for object oriented exchange of data in the production sector and is used for coupling of automation systems.

Important properties of MMS are:

- General usability in different applications. So-called 'Companion Standards' contain detailed specifications for certain device types (NC, robots, etc.), but they are based only on general MMS-services.
- Defined objects (variables, programmes, events, etc.) and their services
- More traffic data by suitable grid physics
- Low costs because of usage of standard components from the bureau environment (network cards, routers, address distribution)

This standard is the base for transmission protocols IEC 61850 and IEC 60870-6.

Figure 4-6 shows the graphical user interface (Project Explorer) of the used MMS client “SISCO AXS4-MMS” with the information object of the Sunny Island cluster and its logical nodes. In this screenshot the logical node “MMXU_INT” as well as the path to the data object, which represents the Phase A to neutral voltage of the Sunny Island microgrid is displayed.

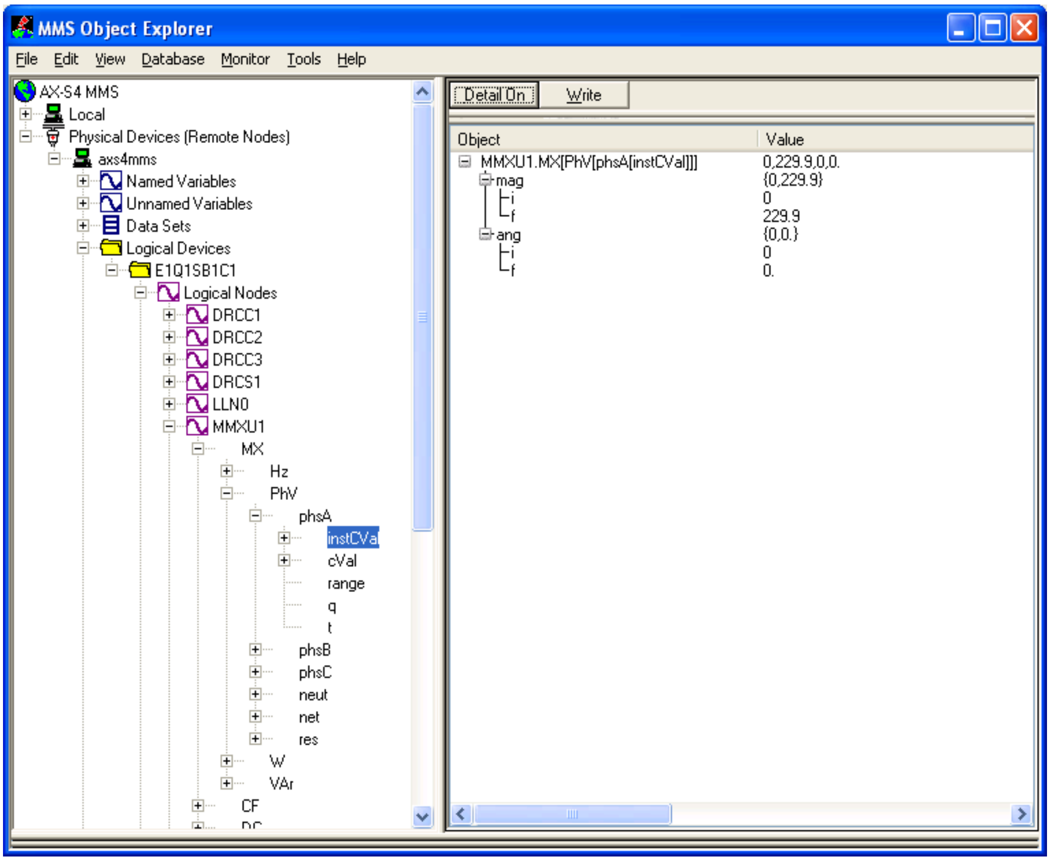

Figure 4-6: MMS interface with logical nodes

4.1.7. Integration in OGEMA framework

The whole setup is embedded in the OGEMA framework which was developed by Fraunhofer IWES ([Ref-14]). Figure 4-7 shows its Graphical User Interface with different values from the experiment: system Status, SoC (state of charge), temperature, voltage and current.

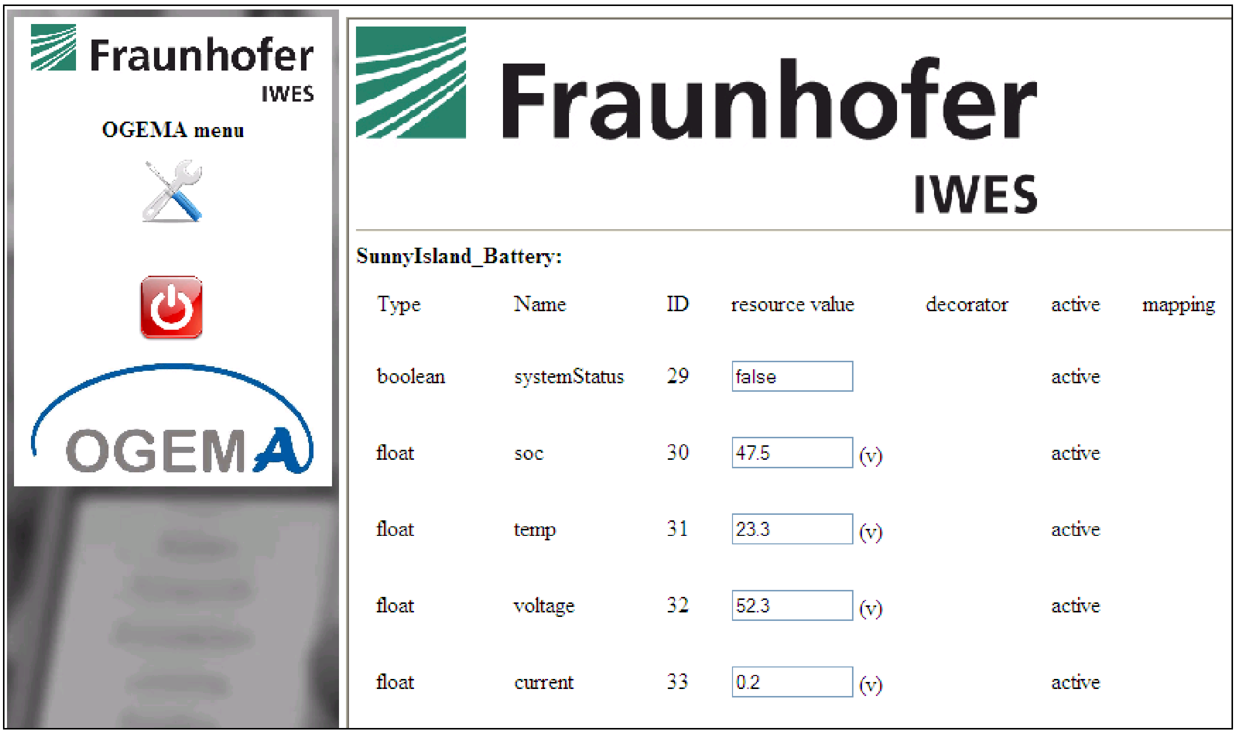

Figure 4-7: Values from OGEMA framework

4.2. Conclusions

An IEC 61850 based communication to Microgrid equipment has been successfully developed, implemented and tested:

- The communication standard for DER equipment (IEC 61850-7-420) is applied for a bidirectional battery inverter, which is an important Microgrid device managing, for instance storage systems.
- The data object definition from the IEC61850-7-420 logical nodes was not complete as to model the Sunny Island device and, as consequence, the model had to be extended.
- The modelling of the device and its implementation into a device specific SCL-file requests a deep knowledge of the device functionalities and is therefore a non-trivial task.
- It was proved that a secure and reliable communication with IEC 61850-7-420 standard using MMS service for control, monitoring and diagnosis of DER equipment is possible and feasible.

- The layered approach and configured setup no time delay between request and reception of values could be noticed but intensive testing have not been conducted.
- In future characterized by an IEC61850 based communication, the response with a larger number of devices should be assessed.

5. References

[Ref-1] Arzuaga, T., Cadenas, A., Arzuaga, A, "*Fiabilidad de las redes LAN en las Subestaciones Eléctricas*", XII ERIAC 2007.

[Ref-2] IEEE 802.3ad, "Link Aggregation Control Protocol Specification", IEEE, 2000

[Ref-3] IEEE 802.1D-2004, "Spanning Tree Protocol Specification", IEEE, 2004

[Ref-4] IEC61850-5, "Communications Networks and Systems in Substations. Part 5: Communication Requirements for Functions and Device Models", IEC, 2003

[Ref-5] Seifert, R. "The Switch Book", J. Wiley & Sons, 2000

[Ref-6] "IEC 61850: Communication networks and systems in substations", IEC TC 57.

[Ref-7] "IEC 61850 part 7-420: DER Logical Nodes", IEC TC 57.

[Ref-8] D. Nestle, C. Bendel, J. Ringelstein, K. Schwarz, "Data models for the integration of the low voltage level into grid communication and control using decentralised decision" Oldenburg, June 2007.

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[Ref-10] K. Schwarz, "IEC 61850, IEC 61400-25 and IEC 61970: Information models and information exchange for electric power systems", DistribuTech, 10/2004.

[Ref-11] X. Qiu, W. Wimmer, "Applying object-orientation and component technology to architecture design of power system monitoring" International Symposium on Component-Based Software Engineering, 2000.

[Ref-12] http://en.wikipedia.org/wiki/IEC_61850

[Ref-13] SMA Solar Technology AG: Sunny Island 5048 - Installation & Instruction Manual

[Ref-14] David Nestle: Concept of the Open Gateway Energy Management Alliance, http://www.ogemalliance.org/files/OGEMA-Alliance.pdf, 2009

6. Web Sites

[www-1] http://www.iec.ch/
International Electrotechnical Commission – IEC

[www-2] http://www.epri.com/
Communication Standards for future integration of DER

[www-3] http://www.offis.de/
Workshop Standardisation for DER

[www-4] http://www.ogemalliance.org/
OGEMA web site.

7. Glossary

Term	Stands for	Notes
AC	Alternating Current	
API	Application Programming Interface	
CAN	Controller Area Network	
CDA	Common Data Attributes	IEC 61850 terminology
CDC	Common Data Classes	IEC 61850 terminology
CHP	Combined Heat & Power	
CIM	Common Information Model	IEC standard 61970-301
CIS	Component Interface Specification	IEC 61970 component
DA	Distribution Automation	EPRI IntelliGrid terminology
DC	Direct Current	
DER	Distributed Energy Resources	
DG	Distributed Generation	
DMS	Distribution Management System	
DNP3	Distributed Network Protocol v3	(see http://www.dnp.org/)
DO	Data Object	IEC 61850 terminology
DSM	Demand Side Management	
DSO	Distribution System Operator	
DR	Distributed Resources	
ECP	Electrical Connection Point	
EMS	Energy Management Systems	
EPRI	Electrical Power Research Institute	(see http//www.epri.com/)
EPS	Electrical Power System	
ESP	Energy Service Provider	
FDIS	Final Draft International Standard	Internal code for an official standard state (see http://www.iec.ch)
HV	High Voltage	
GOOSE	Generic Object Oriented Substation Event	UCA definition for relay-relay messages
GPRS	General Packet Radio Service	Mobile phone communication protocol.
GSM	Global System for Mobile Communications	Mobile phone communication protocol.
GSSE	Generic Substation Status Event	Same as GOOSE in IEC 61850 terms
ICCP	Inter Control Centre Communication	IEC 60870 component
IEC	International Electrotechnical Commission	(see http://www.iec.ch/)
IED	Intelligent Electronic Device	
IEEE	Institute of Electrical and Electronics Engineers	
ISDN	Integrated Services Digital Network	Digital telephone or telecommunications network designed to carry voice, data, images, video…
ISO	International Organization for Standardization	(see http://www.iso.org/)
LACP	Link Aggregation Control Protocol	Ethernet network backup design.
LAN	Local Area Network	
LD	Logical Device	IEC 61850 terminology
LN	Logical Node	IEC 61850 terminology
LV	Low Voltage	

Term	Stands for	Notes
MMI	Man Machine Interface	I
MMS	Manufacturer Message Specification	ISO Standard 9506-1, 9506-2
MV	Medium Voltage	
OGEMA	Open Gateway Energy Management Alliance	
PV	Photovoltaic	
RDF	Resource Description Framework	(see http://www.w3c.org/)
RTU	Remote Terminal Unit	
SCADA	Supervisory Control And Data Acquisition	
SCL	Substation Configuration Language	IEC 61850 terminology
SoC	State of Charge	Term for battery loading
STP	Spanning Tree Protocol	Ethernet network backup design.
TASE	Telecontrol Application Service Element	IEC 60870 component
TCP/IP	Transmission Control Protocol / Internet Protocol	(see http://www.ietf.org/)
UCA	Utility Communications Architecture	(see http://www.ucausersgroup.org/)
UCA-SA	UCA Substation Automation	(see http://www.ucausersgroup.org/)
UML	Unified Modelling Language	(see http://www.uml.org/)
USB	Universal Serial Bus	
XML	eXtensible Mark-up Language	(see http://www.w3c.org/)
XML-RPC	XML Remote Procedure Call	
WAN	Wide Area Network	

8. Annexes