INTERNSHIP REPORT

USE OF IEC 61850 FOR LOW VOLTAGE MICROGRIDS POWER CONTROL

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Preface

From the 1st of November, 2012 until the 28th February, 2013 I did an internship at Alliander, a giant energy distribution company which covers large areas in the Netherlands. Alliander core business involves distributing gas and electricity to a huge amount of customers which is about nearly a third of the Netherland's population. This internship project is a part of my 2 year master program which I conduct at University of Twente, the Netherlands.

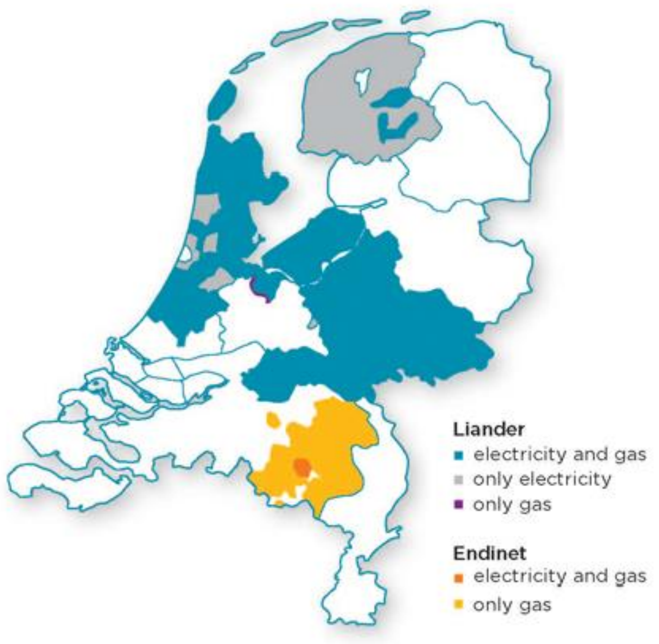

Figure 0.1 Alliander electricity and gas distribution grid [14]

The assignment that I conducted for my internship is about the use of the well-known IEC 61850 standard for control of the Low Voltage (LV) Microgrids. The main content of the project is to use the standardized data format and syntax in the standard to model the smart electrical equipment in order to design an IEC 61850 communication network for Microgrids power control. This topic is also very well-suited to my major and also brought me to a very new and interesting area of using communication technologies in electricity network. Through the assignment, I not only gained a lot of major knowledge but more importantly, I also had a great chance to sharpen my skills in a professional working environment. Not less important than the communication technologies that I have learnt is the communication skills that I have been trained and practiced through giving presentations, discussing with the supervisors, some experts in the field and other staffs within and outside the company.

Acknowledgement

I am very appreciated to Mr. Frans Campfens, my supervisor at Alliander who gave me very in-time valuable instructions and brought me to knowledgeable experts like Mr. Marco Janssen, president and CEO at UTInnovative, who gave me extensive guidance regarding many practical issues. I also would like to express my gratitude to Dr. ir. G. Karagiannis for his permission to be my academic supervisor and more importantly for his enthusiastic encouragements and precious instructions during my internship period. He gave me in-time feedbacks on my research and helped to organize an interesting presentation in which I could present my ideas and achievements to other professors and researchers of the faculty.

Throughout the internship, I have also learnt many things about the Dutch culture whose benefits are far beyond what I could learn in a normal project. In short, I would like to thank Alliander and University of Twente, Internship Office for introducing me to this great opportunity in which I have developed myself both academically, professionally and socially.

Dung Nguyen

Abstract

This report explains the basic description of the IEC 61850 protocol stack, the definition of Smart Grid, Microgrids and Low Voltage (LV) Microgrids. The report focuses on explaining the feasibility of extending the application of IEC 61850 which was designed for substation automation, to control the energy usage of LV Microgrids. To fulfill this objective, the report will describe in detail the method of modeling the intelligent electrical devices based on the defined rules and syntax in IEC 61850, and the way of using the IEC 61850 abstract services to exchange those data for power control of a LV Microgrid. Moreover, a communication network topology along with a Use case will be defined in order to illustrate the possibility of using IEC 61850 to control the power consumption/generation of a typical LV Microgrid.

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Acronyms

ASN-1	Abstract Syntax Notation Number One
BRCB	BUFFERED-REPORT-CONTROL-BLOCK
CT	Current Transformer
DER	Distributed Energy Resource
EPRI	Electric Power Research Institute
ES	Electric Vehicle
EV	Energy Storage
GOOSE	Generic Object Oriented Substation Events
GSE	Generic Substation Event
GSSE	Generic Substation State Event
HCMC	Home Control and Management Center
HI	Hybrid Inverter
HMI	Human Machine Interface
ICMP	Internet Control Message Protocol
IEC	International Electrotechnical Committee
IED	Intelligent Electronics Device
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
LN	Logical Node
LV	Low Voltage
MMS	Manufacturing Message Specification
MV	Medium Voltage
OSI	Open System Interconnection
PUAS	Power Utility Automation System

PV panel	Photovoltaic panel
RCMC	Regional Control and Management Center
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SG3	Smart Grid Strategy Group
SNTP	Simple Network Time Protocol
SOE	Sequence of Event
TC57	Technical Committee 57
TCP	Transmission Control Protocol
UCA	Utility Communication Architecture
UDP	User Datagram Protocol
URCB	UNBUFFERED-REPORT-CONTROL-BLOCK
VT	Voltage Transformer

Chapter 1

Introduction

Many believe that there is a need for the current power grid to undergo a profound change to evolve into a more modern grid. The current one-way power distribution infrastructure has existed for several decades and cannot cope with the emerging challenges nowadays, for examples, the penetration of distributed energy resources (DERs), electric vehicles (EVs), the need for higher resiliency against failures, better security and protection, etc. This modernized grid – often termed as "Smart Grid", "IntelliGrid", "GridWise", etc. [23, 24] – is considered the future of the electricity grid with the integration of advanced information communication technologies (ICT) in order to efficiently deliver sustainable, economic and secure electricity supplies [23].

In fact, communication networks have been in existence for several decades along with the power grid for monitoring and protection control, but the network architecture has not changed much since the first day [26]. Power utilities still do not have much insight into distribution network, where nearly 90% of all power problems come from [25].

In the distribution network, the low-voltage (LV) part (less than 1kV) is a challenge for the control and management of the power grid as it involves the participation of households with their various private assets, such as household appliances, DERs, storages, EVs. A household may form a cluster known as "microgrid" which includes the local generators, storages, loads and control. These microgrids may be integrated into a larger grid when power and information exchange among them are available [25].

IEC 61850 emerges as the promising protocol for the future smart grid. It was designed to ensure interoperability of the communication between Intelligent Electronic Devices (IEDs) in substation automation systems. An IED is the microprocessor based device that performs several protective, control, and similar functions. The main idea of IEC 61850 to break down the functions of IEDs into core functions called Logical Nodes (LNs). Several logical nodes can be grouped into a Logical Device (LD) which provides communication access point of IEDs. By standardizing the common information model for each LN and the associated services, IEC 61850 provides the interoperability among IEDs of different manufacturers in substation automation systems.

IEC 61850 has been extended outside the scope of substation automation systems to cover DERs, EVs, and the communication to control centre. Therefore it can potentially be applied to the power control and asset management of LV microgrids, where private assets like DERs, EVs are present.

Power control functions are important in LV microgrids as the systems perform the modulation of the equipment energy consumptions/generations. Power control within LV microgrids also supports Demand Response for dynamic load operation. On the other hand, asset management involves the tasks of the system to obtain an overall status of the equipment participating in the microgrid, such as the list of devices within the scope and their capabilities, the health monitoring of the devices and alarm handling.

1.1 Problem statement and research objectives

1.1.1 Problem statement

As briefly described above, IEC 61850 was originally designed for communication within substation automation systems and later was developed to support communication to DER and to control centre with the objective of solving the interoperability problem caused by the co-existence of multiple proprietary communication protocols. However, in the struggle of transforming the traditional centralized grid to distributed smart gird, the energy consumers also play a not-less-important role than the energy producers. According to European Technology Platform definition of smart grid [15] – the future electricity grid, smart grid should *"allow consumers to play a part in optimizing the operation of the system"*. Nevertheless in the area of communication in home automation systems and LV microgrids, there are still many different protocols for control and management of the smart appliances; therefore, interoperability is still a serious problem to be solved.

1.1.2 Research objectives

Based on the observation that IEC 61850 has great flexibility and extensibility, the main research objective of this assignment is to **use IEC61850 for Low voltage Microgrids power control**. The goal is to apply the concepts of IEC 61850 to a different domain, the LV microgrids, to perform power control of both energy consumption devices, e.g. smart household electrical appliances, and Distributed Energy Resources – DERs including the energy generators and energy storage. A good power control algorithm will help to utilize the available energy resources efficiently.

The main objective above can be decomposed to 3 smaller objectives:

- ***Objective 1:*** Designing a communication network topology in LV Microgrids.
- ***Objective 2:*** Modelling LV Microgrids electrical components
- ***Objective 3:*** Applying IEC 61850 services for power control in LV Microgrids

A well-designed network topology is required for seamless communication between various kinds of smart electrical components in a typical microgrid such as the Regional/Home control and management centre, the controllable Distributed Energy Resources (DER) including PV panel, wind turbine, energy storage, electric vehicle…and the smart household appliances.

To allow those devices communicate with each other using IEC61850 protocol, those devices needs to be modelled as IEC61850 data objects. Moreover, the data objects which defined in a standardized way also allow interoperable actions between different equipment inside a microgrid. Because the initial scope of IEC61580 is only for communications inside substation automation systems, many data objects needed for smart appliances have not been defined yet and modelling those devices is an important task in this project.

Finally, when the network topology and data objects of the equipment are available, the IEC61850 services will be applied to perform all the power control functions such as getting device information, changing the operating set-points to reduce the power consumption, etc. To illustrate how those services can be applied for these tasks, a Use case will firstly be defined to explain the capability of the IEC61850 protocol to support power control in LV microgrids.

1.2 Report structure

The report is organized as follows. Chapter 2 introduces a technical description about the related concepts i.e. IEC61850 standard, smart gird and microgrids. Chapter 3 describes the processes of designing a communication network topology and modelling the LV Microgrid electrical components in order to accomplish the objective 1 and 2. Chapter 4 defines a specific Use case to demonstrate the usage of these IEC 61850 data models and services for power control in LV Microgrids. This chapter is aimed to achieve objective 4 of the research. The conclusion and future work is given in Chapter 5.

Chapters 2 and 3 in both the Internship reports of T.G. Pham and A.D. Nguyen are the same, since they have been developed and written by both authors of these two reports. The reason of this is that the students worked during their Internship on solving issues focussing on similar research areas, and where the first part of their research activity was identical.

Chapter 2

Technical descriptions

This chapter describes the concept and architecture of IEC 61850, as well as the motivation of transforming the conventional centralized electricity grid to a distributed intelligent electricity grid of the future, which is named Smart Grid. An important part of the Smart Grid to achieve large-scale automation of the Smart Grid is called Microgrids, is also explained in this chapter. This chapter is based largely on the official documents of the international standard IEC 61850 [1, 8] and a document of the Smart Grid Strategy Group – SG3 which is about the roadmap of Smart Grid [12].

This chapter is organized as follows: Section 2.1 describes the IEC 61850 standards. Section 2.2 explains the concept of Smart Grid and the origin of Smart Grid designing decision. Section 2.3 gives a description about LV Microgrids and the structure of a LV Microgrid. Finally Section 2.4 summarizes all the technical descriptions provided in this chapter.

2.1 Description of IEC 61850

2.1.1 Scope of IEC 61850

IEC 61850 was initially designed for communication in substation automation systems by the Institute of Electrical and Electronics Engineers – IEEE/Electric Power Research Institute – EPRI Utility Communication Architecture (UCA) and the working group "Substation Control and Protection Interfaces" in the International Electrotechnical Committee (IEC) Technical Committee (TC) 57. The development of advanced and powerful microprocessors some years ago supported the possibility for building Power Utility Automation System (PUAS) [1]; and consequently several Intelligent Electronics Devices (IEDs) was created each of which supported proprietary communication protocol from its manufacturer. Nevertheless, the co-existing of various proprietary communication protocols also led to the big challenge of interoperability, and therefore required investment for complicated and costly protocol converter when used IEDs from different vendors [1].

IEC 61850 was created to solve that interoperability problem by defining standard semantics, abstract communication services which can be mapped to different protocols, configuration descriptions and engineering processes [1]. From the original scope of supporting communications in substation automation systems, IEC 61850 standard has been extended to support communications from control centers to Distributed Energy Resources (DER) and communication between substations and control center as well as feeder automation domain [1].

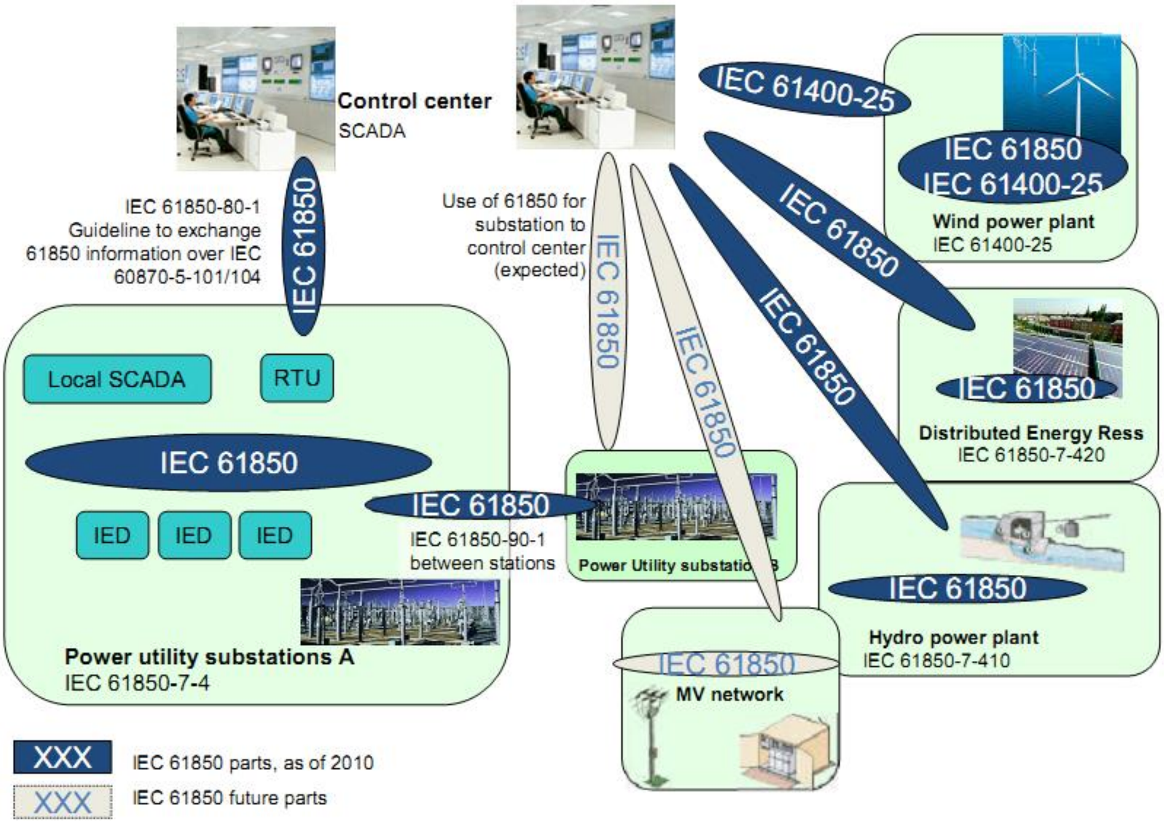

Figure 2.1 – Scope of application of IEC 61850, copied from [1]

Figure 2.1 represents the scope of the standard with updates about the possible extensions for more domains. It shows that at the moment, IEC 61850 protocols can be used to support communications inside substations and from control centers (SCADA – Supervisory Control and Data Acquisition) to the Remote Terminal Units – RTUs and DERs. The standard is going to be extended to support communications between Control centers and Power Utility substation as well as to the Medium Voltage – MV networks.

2.1.2 Standardization approach

IEC 61850 provides a huge variety of communication functions which allows telecontrol, teleprotection, supervision and monitoring different IEDs in an electric power system. The standardization approach of IEC 61850 series as mentioned in IEC 61850-part 1 [1] is to combine the strength of three methods:

- ***Functional decomposition***: is used to understand the logical relationship between components of a distributed function which will be decomposed and represented as Logical Nodes (LNs)

- ***Data flow modeling***: is used to understand the communication interfaces that must support the exchange of information between distributed functional components and the functional performance requirements.
- ***Information modeling***: is used to define the abstract syntax and semantics of the information exchanged

In short, IEC 61850 decomposes and standardizes the functions as logical nodes, classified the communication interfaces between different functional levels, and models the information exchange in term of data objects, data attributes and abstract communication services.

2.1.3 Content of the IEC 61850 series

IEC 61850 consists of many parts which explain the standard step-by-step from general information such as the introduction and overview in part 1, the glossary in part 2, the general requirements in part 3, system and project management in part 4, to the communication requirements and specifications in part 5, part 6 and part 7-1 to 7-4.

As IEC 61850 is a standardized abstract method for communications and integration between multi-vendor IEDs, it is needed to be mapped to specific protocols to support different functional requirements for protection, supervision and control, and monitoring. Therefore, parts 8-1, 9-1, 9-2 of the standard define the specific communication mapping of IEC 61850 protocols to different communication profiles.

Additionally, the standard also defines the guidelines of using the logical nodes to model the functions of substation automation systems (part 7-500), hydro power plants (part 7-510) and distributed energy resources (part 7-520).

As the standard is still in development, it is going to cover more areas such as power inverters for DER systems (part 90-7), electric mobility (part 90-8), energy storage (part 90-9), and DER scheduling (part 90-10) (See Figure 2.2 for the overall structure of IEC 61850 standard).

In short the basis rule of setting the numbers to documents in IEC 61850 is [1]:

- 7-4xx documents are normative definition of domain specific name spaces
- 7-5xx documents are informative application guidelines of the 7-x documents, i.e. providing guidance on how to model application functions based on part 7-x.
- 8-x documents are normative definitions of the ACSI mapping (except communication services related to sample values)
- 9-x documents are normative definitions of the ACSI mapping dedicated to communication services related to sample values
- 80-x documents are additional informative Technical Specifications related to communication mapping
- 90-x are additional informative Technical Reports for further enhancement/extensions of the IEC 61850 domains

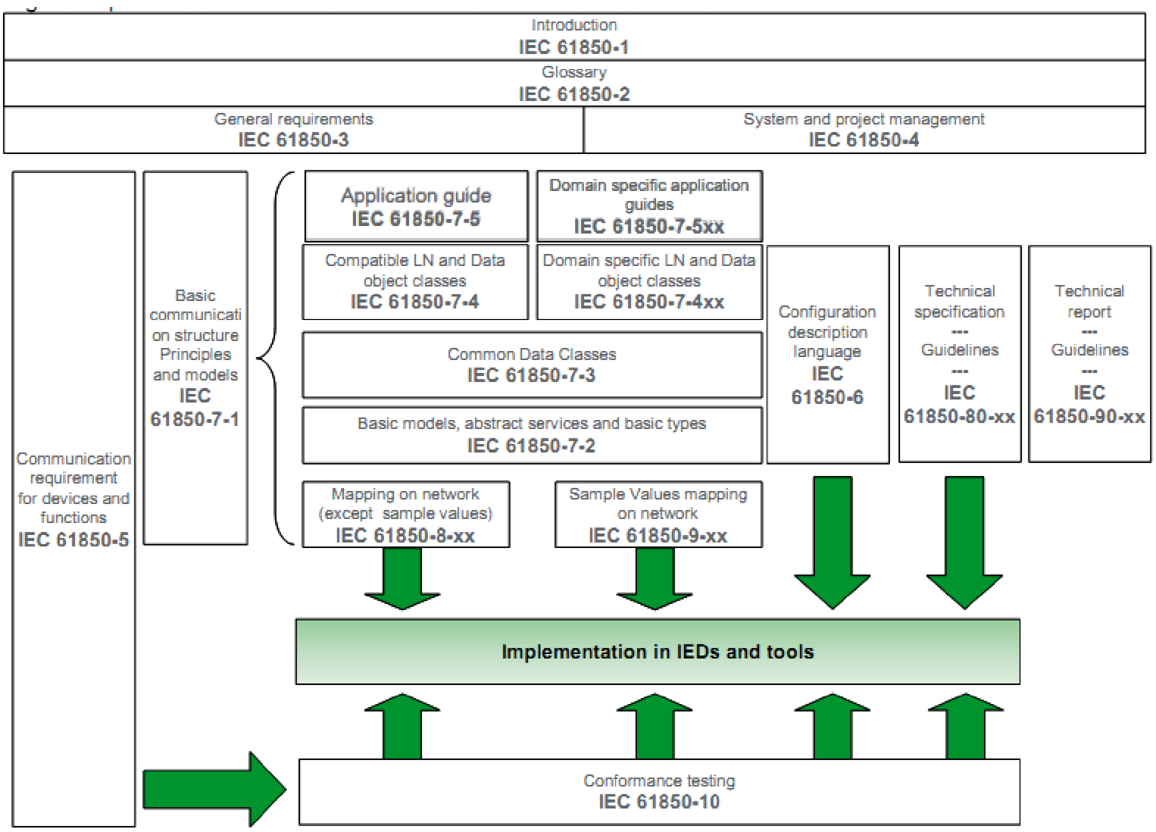

Figure 2.2 – Links between IEC 61850 parts, copied from [1]

2.1.4 Extensibility of IEC 61850

A significant advantage of IEC 61850 is its extensibility characteristic obtained by making the communication independent from the application by specifying a set of abstract services and objects as illustrated in Figure 2.3. This allows the user to design different applications without relying on specific protocols. As a consequence, the data objects defined in IEC 61850 could be applied into diversity of communication solutions without having modifications to the models.

This advantage is the source of motivation for me to propose this extension of IEC 61850 with the aim to support communications between control center and smart appliances and DERs which has not yet been mentioned in the scope of the standard. They method of using IEC 61850 data models and abstract services to control LV microgrids will be described in detail in the next chapter 3 and 4.

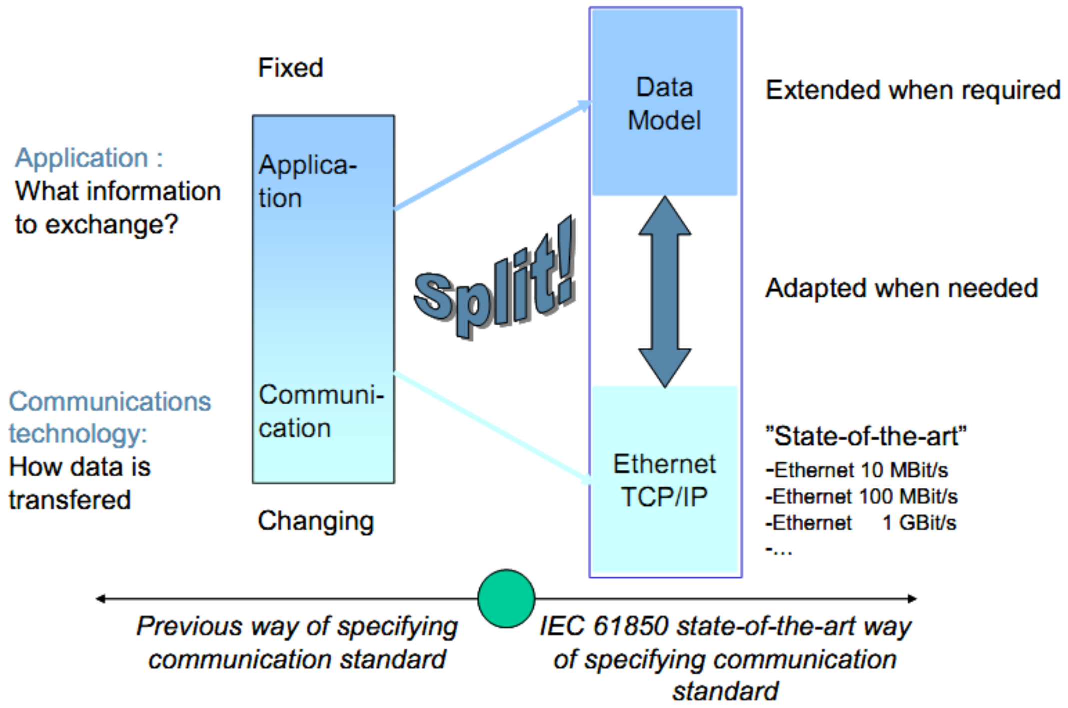

Figure 2.3 – IEC 61850 specifying approach, copied from [1]

2.1.5 IEC 61850 data modeling principle

IEC 61850 data modeling helps to guarantee interoperability between multi-vendor IEDs running IEC 61850 since all the data are modeled following standardized syntax and format in an object-oriented method.

There are two main levels of modeling [1]:

- The breakdown of a real device (physical device) into logical devices.
- The breakdown of logical device into logical nodes, data objects and attributes.

Logical device is the first level of breaking down the functions supported by a physical device i.e. an IED. A logical device usually represents a group of typical automation, protection or other functions [1]. The Logical Device hosts communication access point of IEDs and related communications services and provides information about the physical devices they use as host (nameplate and health) or about external devices that are controlled by the logical device (external equipment nameplate and health).

Logical nodes are the smallest entities decomposed from the application functions and are used to exchange information. It supports the free allocation of those entities on dedicated devices (IEDs). It is illustrated in Figure 2.4.

Based on its functionality, a logical node contains a list of data with dedicated data attributes which have a well-structured semantic.

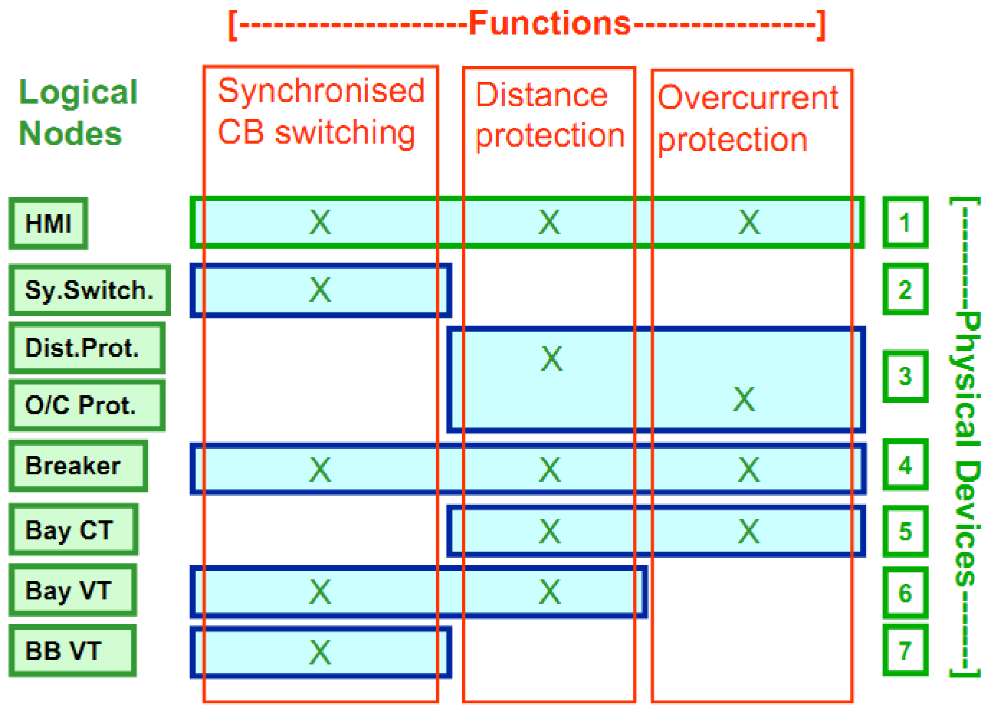

Figure 2.4 – Relationship between functions, logical nodes and physical nodes, copied from [1]

Figure 2.4 illustrates the decomposition of an application functions to multiple logical nodes which represent the smallest entities used to exchange information. It also represents the allocation of logical nodes to physical devices. For example the Distance protection function can be decomposed to six different logical nodes which are the Human Machine Interface (HMI) to represent the data to user, the Distance Protection and Overcurrent protection logical nodes – Dist.Prot. and O/C Prot. to perform protection functions , the breaker to open/close the short circuit and the Bay Current Transformer (CT) and Voltage Transformer (VT) to provide measurement data for problem identification. These logical nodes can be placed on individual devices such as logical node HMI on physical device station computer (physical device 1), logical node breaker on Bay control unit (physical device 4), and two logical nodes Bay CT and Bay VT on current and voltage transformer respectively. Or more than one logical node can be allocated in the same physical device such as the Distance protection and Overcurrent protection logical nodes were allocated on the same physical device – Distance protection unit with integrated overcurrent function physical device.

Many definitions of the typical logical nodes for substation automation systems can be found in IEC 61850-7-4 [6] and further details about the data attributes are explained in IEC 61850-7-3 [5].

2.1.6 IEC 61850 communication services

Besides standardizing the data formats in an object-oriented manner, IEC 61850 also defines a set of abstract services for exchanging information among components of a Power Utility Automation System. These services are described in detail in part 7-2 of the standard [4]

The categories of services are as follows [1]:

- retrieving the self-description of a device,
- fast and reliable peer-to-peer exchange of status information (tripping or blocking of functions or devices),
- reporting of any set of data (data attributes), Sequence of Event SoE – cyclic and event triggered,
- logging and retrieving of any set of data (data attributes) – cyclic and event,
- substitution,
- handling and setting of parameter setting groups,
- transmission of sampled values from sensors,
- time synchronization,
- file transfer,
- control devices (operate service),
- Online configuration

The complete Abstract Communication Service Interface – ACSI services are shown in table 2.1. The description of these classes is referred to [4]

Table 2.1 – ACSI classes, copied from [4]

GenServer model GetServerDirectory **Association model** Associate Abort Release **GenLogicalDeviceClass model** GetLogicalDeviceDirectory **GenLogicalNodeClass model** GetLogicalNodeDirectory GetAllDataValues **GenDataObjectClass model** GetDataValues SetDataValues GetDataDirectory GetDataDefinition	**LOG-CONTROL-BLOCK model:** GetLCBValues SetLCBValues QueryLogByTime QueryLogAfter GetLogStatusValues **Generic substation event model – GSE** GOOSE SendGOOSEMessage GetGoReference GetGOOSEElementNumber GetGoCBValues SetGoCBValues **Transmission of sampled values model** **MULTICAST-SAMPLE-VALUE-CONTROL-BLOCK:** SendMSVMessage GetMSVCBValues

<u>DATA-SET model</u> GetDataSetValues SetDataSetValues CreateDataSet DeleteDataSet GetDataSetDirectory **<u>SETTING-GROUP-CONTROL-BLOCK model</u>** SelectActiveSG SelectEditSG SetSGValues ConfirmEditSGValues GetSGValues GetSGCBValues **<u>REPORT-CONTROL-BLOCK and LOG-CONTROL-</u>** **<u>BLOCK model</u>** **BUFFERED-REPORT-CONTROL-BLOCK:** Report GetBRCBValues SetBRCBValues **UNBUFFERED-REPORT-CONTROL-BLOCK:** Report GetURCBValues SetURCBValues	SetMSVCBValues **UNICAST-SAMPLE-VALUE-CONTROL-BLOCK:** SendUSVMessage GetUSVCBValues SetUSVCBValues **<u>Control model</u>** Select SelectWithValue Cancel Operate CommandTermination TimeActivatedOperate **<u>Time and time synchronization</u>** TimeSynchronization **<u>FILE transfer model</u>** GetFile SetFile DeleteFile GetFileAttributeValues

- **Data Set** – permit grouping of data objects and data attributes
- **Substitution** – support replacement of a process value by another value
- **Setting group control** – defines how to switch from one set of setting values to another one and how to edit setting groups
- **Report control** and **logging** – defines conditions for generating report and log. There are two classes of report control: **BUFFERED-REPORT-CONTROL-BLOCK (BRCB)** and **UNBUFFERED-REPORT-CONTROL-BLOCK (URCB)**. For **BRCB** the internal events that trigger the report will be buffered so that I will not be lost due to transport flow control constraints or loss of connection. For **URCB** internal events issues immediate sending of reports on a "best effort" basis i.e. if no association exits, or if the transport data flow is not fast enough, events may be lost.
- **Control blocks for generic substation event (GSE)** – supports a fast and reliable system-wide distribution of input or output data values; peer-to-peer exchange of IED binary status information, for example, a trip signal.
- **Control block for transmission of sampled values** – fast and cyclic transfer of samples, for example, of instrument transformers.
- **Control** – describes the services to control, for example, a device.

- **Time and time synchronization** – provides the time base for the device and system
- **File system** – defines the exchange of large data blocks such as programs.

For implementation, the abstract services could be mapped on different protocol profiles; the selection of an appropriate mapping depends on the functional and performance requirements and will be described in the next section.

2.1.7 Specific communication service mapping

As stated above, the mappings of the services to different protocol profiles are based on the functional and performance requirements. Due to the different requirements for transfer time of difference functions inside substations, IEC 61850 classifies the messages exchanged between the IEDs to six performance classes as follows [4]:

- Type 1 (Fast messages)
- Type 1A (Trip)
- Type 2 (Medium speed messages)
- Type 3 (Low speed messages)
- Type 4 (Raw data messages)
- Type 5 (File transfer functions)
- Type 6 (Time synchronisation messages)

The required transfer times rely upon the requirements of the functions, for example, the "trip" message to open the circuit breaker for protection must be very fast (~3 ms) to prevent damage to the system; however, the transfer time for file transfer functions to transfer a large amount of data does not have to be time-critical (1000 – 10,000 ms).

Figure 2.5 provides the mapping of these messages to different communication profiles. Messages of type 1, 1A, and type 4 which are time-critical are mapped directly on Ethernet. Messages of type 2, 3 and 5 which are used for automation, auto-control functions, transmission of event records, reading and changing set-points…etc. are mapped to MMS and TCP/IP or OSI communication profiles. It is because these messages require message oriented services [2, 4] which the Manufacturing Message Specification – MMS provides. MMS services and protocol can operate over the full OSI and TCP/IP compliant communication profiles [4]. This is also the only protocol that easily supports the complex naming and services models of IEC 61850 [19]. This protocol also includes the exchange of real-time data, indications, control operations, and report notifications. This mapping of ACSI to MMS defines how the concepts, objects, and services of the ACSI are to be implemented using MMS concepts, objects, and services. This mapping allows interoperability across functions implemented by different manufacturers [4].

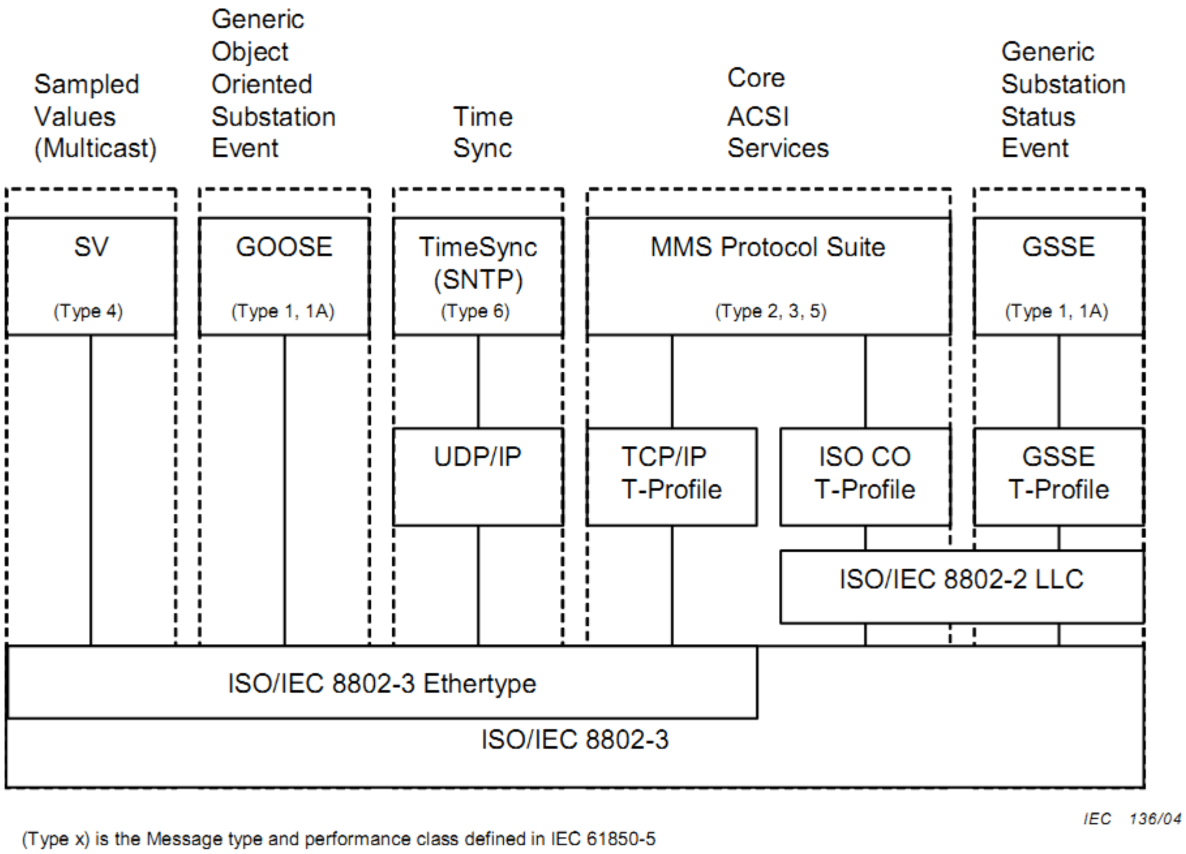

Figure 2.5 – Overview of IEC 61850 functionality and profiles, copied from [4]

2.1.7.1 Manufacturing message specification – MMS

MMS is a client/server communication model. MMS defines the difference between the entity that establishes the application association and the entity that accepts the application association. The entity that establishes the association is called the client and the one that accepts the association is the server.

In client/server model, the client is able to request for the data at any point of time when the association is valid. The messages exchanged follow a request/response mechanism.

MMS also supports the report services. For the report services, instances of report control blocks which include the values of the data object to be reported to the client, are configured in the server at configuration time. The server can restrict access to an instance of a report control block to one or more clients.

The report will be triggered based on the configured triggered conditions which represented by the attribute **TrgOp**. Some typical trigger options for report generation are **data-change** which relates to the change in a value of DataAttribute representing the process-related value of the data object; **quality-change** which relates to a change in the quality value of a DataAttribute; and **data-update** which relates to a freeze event in a value of a DataAttribute representing a freeze value of the data object (for example, frozen counters) or to an event triggered by updating the value of a DataAttribute [4].

The **data-update** triggered condition can be used to provide periodic report generation with the statistics values that may be calculated or updated periodically.

In MMS, the triggered conditions are encoded as a PACKET_LIST with the data-type bit-string which represents an ordered set of values defined when the type is used.

- Bit 0 reserved
- Bit 1 data-change
- Bit 2 quality-change
- Bit 3 data-update
- Bit 4 integrity
- Bit 5 general-interrogation

The Application profile of MMS can be mapped onto the TCP-IP T-Profile or OSI T-Profile. Table 2.2 represents the A-profile of MMS

Table 2.2 – Service and protocols for client/server communication A-Profile, copied from [8]

OSI model layer	Specification			m/o
	Name	Service specification	Protocol specification	
Application	Manufacturing Message Specification	ISO 9506-1:2003	ISO 9506-2:2003	m
	Association Control Service Element	ISO/IEC 8649:1996	ISO/IEC 8650:1996	m
Presentation	Connection Oriented Presentation	ISO/IEC 8822:1994	ISO/IEC 8823-1:1994	m
	Abstract Syntax	ISO/IEC 8824-1:1999	ISO/IEC 8825-1	m
Session	Connection Oriented Session	ISO/IEC 8326:1996	ISO/IEC 8327-1:1997	m

The TCP/IP T-profile is represented in Table 2.3

Table 2.3 – TCP/IP T-profile, copied from [8]

OSI Model Layer	Specification			m/o
	Name	Service specification	Protocol specification	
Communication	Requirement for internet host	RFC 1122		m
Transport	ISO Transport on top of TCP	RFC 1006		m
	Internet Control Message Protocol (ICMP)	RFC 792		m
	Transmission Control Protocol (TCP)	RFC 793		m
Network	Internet Protocol	RFC 791		m
	An Ethernet Address Resolution Protocol (ARP)	RFC 826		m
Link Redundancy	Parallel Redundancy Protocol and High Availability Seamless Ring	IEC 62439-3		o
DataLink	Standard for the transmission of IP datagrams over Ethernet networks	RFC 894		m
	Carrier Sense Multiple Access with collision detection (CSMA/CD)	ISO/IEC 8802-3:2001		m
Physical (option 1)	10Base-T/100Base-T	ISO/IEC 8802-3:2001		c1
	Interface connector and contact assignments for ISDN Basic Access Interface. [a]	ISO/IEC 8877:1992		
Physical (option 2)	Fibre optic transmission system 100Base-FX	ISO/IEC 8802-3:2001		c1
	Basic Optical Fibre Connector. [b]	IEC 60874-10-1, IEC 60874-10-2 and IEC 60874-10-3		
[a] This is the specification for the 10BaseT connector.				
[b] This is the specification for the ST connector.				
c1 It is recommended to implement at least one of the two Physical interfaces. Additional or future technologies may be used.				

2.1.7.2 GOOSE services communication profile

The Generic Object Oriented Substation Events – GOOSE provides fast and reliable system-wide distribution of data, based on a publisher-subscriber mechanism (Generic Substation Event – GSE management). GOOSE is one of the two control classes within the GSE control model (the other is Generic Substation State Events – GSSE).

GOOSE uses Data-set to group the data to be published. The use of Data-set allows grouping many different data and data attributes. Table 2.2 shows the application profile (A-profile) of GSE/GOOSE services:

Table 2.4 – Service and protocols for GSE management and GOOSE communication A-profile, copied from [8]

OSI model layer	Specification			m/o
	Name	Service specification	Protocol specification	
Application	GSE/GOOSE protocol	See Annex A		m
Presentation	Abstract Syntax	NULL		m
Session				

Instead of mapping onto the OSI TCP/IP profile like MMS, GOOSE is mapped directly to Ethernet. The transport profile (T-profile) for GSE/GOOSE can be found in table 2.3

Table 2.5 – GOOSE/GSE T-profile, copied from [8]

OSI model layer	Specification			m/o
	Name	Service specification	Protocol specification	
Transport				
Network				
Link Redundancy	Parallel Redundancy Protocol and High Availability Seamless Ring	IEC 62439-3		o
DataLink	Priority Tagging/ VLAN	IEEE 802.1Q		m
	Carrier Sense Multiple Access with collision detection (CSMA/CD).	ISO/IEC 8802-3:2001		m
Physical (option 1)	10Base-T/100Base-T	ISO/IEC 8802-3:2001		c1
	Interface connector and contact assignments for ISDN Basic Access Interface. [a]	ISO/IEC 8877:1992		
Physical (option 2)	Fibre optic transmission system 100Base-FX	ISO/IEC 8802-3:2001		c1
	Basic Optical Fibre Connector. [b]	IEC 60874-10-1, IEC 60874-10-2 and IEC 60874-10-3		

[a] This is the specification for the 10BaseT connector.

[b] This is the specification for the ST connector.

c1 It is recommended to implement at least one of the two physical interfaces. Additional or future technologies may be used.

GOOSE provides an efficient method of simultaneously delivery of the same generic substation event information to more than one physical device through the use of multicast. GOOSE messages contain information that allows the receiving device to know that a status has changed and the time of the last status change [8]. The event that causes the server to invoke a **SendGooseMessage** service is a local application issue as defined in 7-2.

2.1.7.3 Sampled Value

Sampled Value or Samples of Measured Values (SMV) is the protocol for transmission of analog measurement from the current and voltage transformers.

Sampled value messages are exchanged in a peer-to-peer publisher/subscriber mechanism like GOOSE messages. However GOOSE is multicast while SMV can be unicast or multicast.

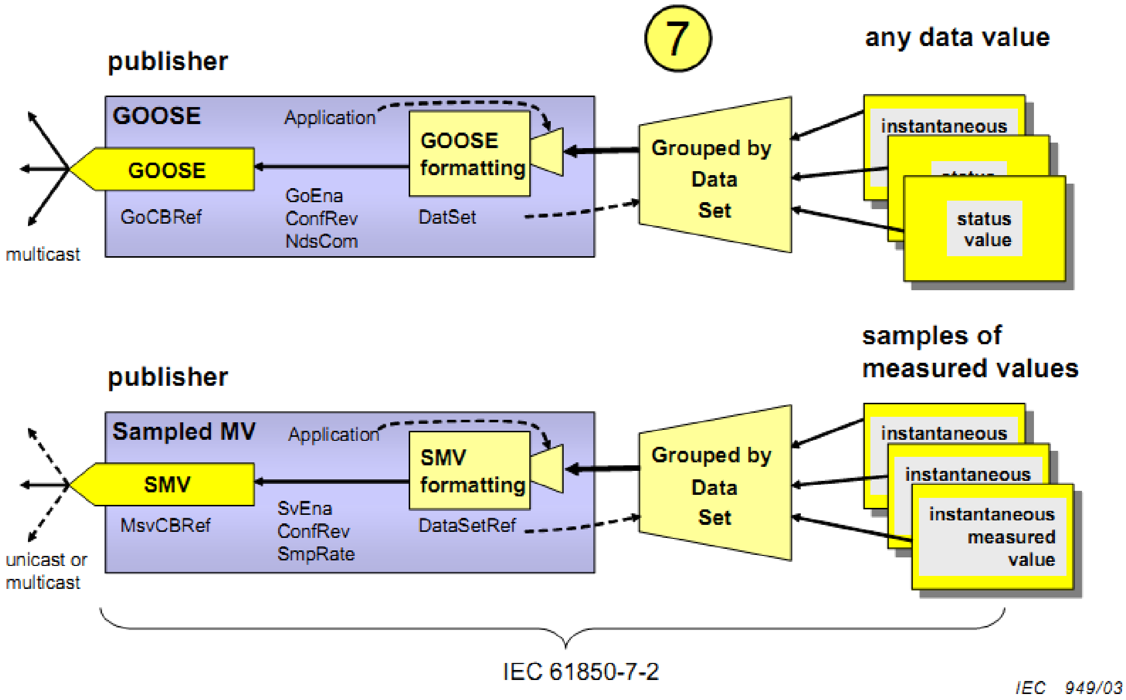

Figure 2.6 – peer-to-peer data value publishing model, copied from [4]

The transmission of sampled value is controlled by the **MULTICAST-SAMPLE-VALUE-CONTROL-BLOCK – MSVCB** if multicast is used; and by the **UNICAST-SAMPLE-VALUE-CONTROL-BLOCK – USVCB** if unicast is used.

The transmission rate of the sampled value can be altered by configuring the Data Attribute **SmpMod** which specifies the definition of units of samples i.e. unit of samples per nominal period, samples per second or seconds per sample; and the **SmpRate** which specifies the sample rate with the definition of units of sample defined by **SmpMod.**

Basically SMV can be mapped to Ethernet with different configurations as defined in part 9-1 [20] and part 9-2 [21] of the IEC 61850 series.

Part 9-1 maps the Sampled Value to a fixed link with pre-configure Data-set. Figure 2.8 presents the communication profile defined in part 9-1

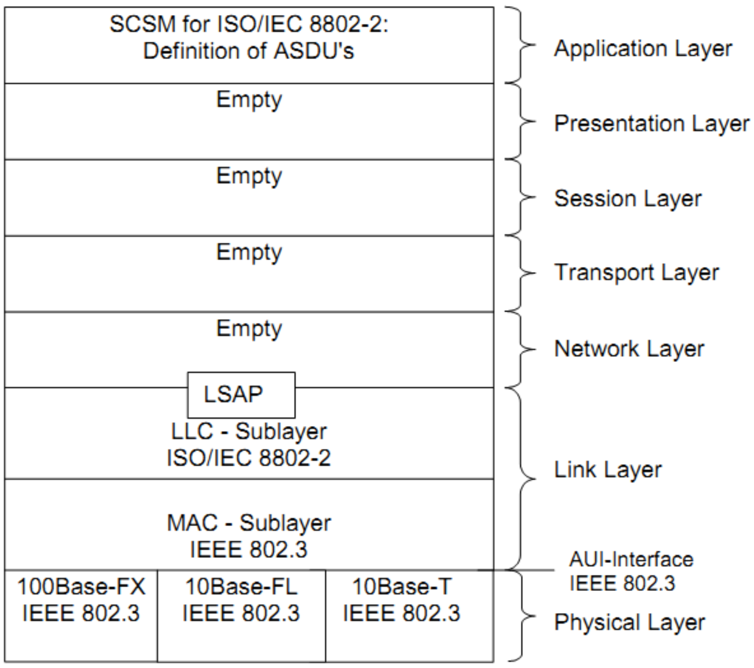

Figure 2.7 – SMV mapped to serial unidirectional multidrop point to point link, copied from [20]

Part 9-2 provides a more flexible implementation of SMV data transfer by allowing a user-configurable Data-set in which the data values of various sizes and types can be integrated together.

2.1.7.4 Generic Substation State Events – GSSE

This control model is similar to GOOSE. However, the GSSE only supports a fixed structure of status data to be published; meanwhile the data for the GOOSE message is configurable by applying data sets referencing any data [4].

2.1.7.5 Time Sync

The time synchronization model must provide accurate time to all IEDs in a power utility system for data time stamping with various ranges of accuracy, e.g. millisecond range for reporting, logging and control and microsecond range for sample values [4].

Time synchronization protocol used by IEC 61850 to provide synchronization between IEDs is Simple Network Time Protocol – SNTP.

Table 2.4 shows the application profile of the Time Sync service

Table 2.6 – Time Sync A-Profile, copied from [8]

OSI model layer	Specification			m/o
	Name	**Service specification**	**Protocol specification**	
Application	Simple Network Time Protocol	RFC 2030		m
Presentation				
Session				

The transport layer uses the Internet Control Message Protocol (ICMP) and User Datagram Protocol (UDP) over IP and Ethernet.

2.2 Smart Grid and Microgrids

Traditionally, the electricity grid was built as a centralized control network with the unidirectional power flow from the massive electricity generation like hydro/thermal power plants via the transmission grids and distribution grids to the customers [15]. In the past, this centralized control network was suitable with the clear separation between customers who were almost pure consumers and the massive power plants which generated all electricity for both domestic and industrial demands.

However, the traditional energy resources such as gas, oil and coal are non-renewable. The massive electricity production has led to a global decline of gas, oil and other natural resources. The rapid development of many developing countries alongside with the population explosion led to the severe energy shortages in the late of 20^{th} century. More importantly, using these energy resources has led to seriously negative effects on human like including CO_2 pollution, global warming, climate change and etc. For example, the climate change caused more than 36 million of displacement and evacuation in 2008 according to United Nations Office for the Coordination of Humanitarian Affairs and the Internal Displace ment Monitoring Centre [16]

As it was vital to find new energy resources for a sustainable future, many renewable energy resources have been explored during the last few decades including the wind turbine, Photovoltaic panel, heat pump…leading to a great transformation of the electricity grid from unidirectional power flow with centralized control network to bi-directional power flow with distributed control centers.

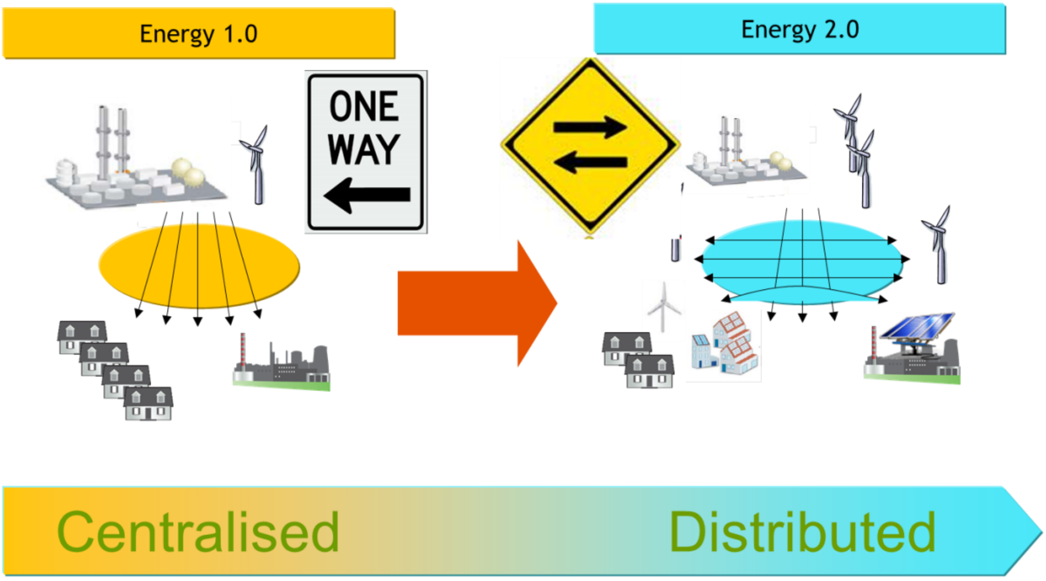

Figure 2.8 – Transformation from traditional to future electricity grid, copied from [14]

Figure 2.8 illustrates the transform from a traditional electricity grid to an intelligent electricity grid. The traditional grid shown in the figure only requires the one-way communication due to the unidirectional energy flow from the centralized power plants to the consumers. However, with the rapid growth of the Distributed Energy Resources – DERs such as wind farms, solar panels, the contribution of those distributed generations is remarkable. Additionally, it is desired to utilize these resources which provide many advantages such as renewable and environment-friendly nature. However using these resources also introduces new issues such as voltage stabilizing, energy balancing, pricing and so on. These problems require the creation of a bidirectional communication network to support automation, supervision and control, and monitoring functions. Therefore, the second generation of the electricity grid is being designed with a new communication infrastructure to support the two-way communications between all the active intelligent components within the grid and to the control centers.

2.2.1 Smart Grid

According to European Technology Platform Smart Grid, the definition of Smart grid is [15]:

A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.

Smart grid consists of the smart elements from customer / prosumer such as smart consumption which enable demand response or home automation systems, building automation systems, to bulk generation with increased use of power electronics and power grid (Transmission and Distribution) including substation automation systems, power monitoring system, energy management system, asset management system and condition monitoring, distribution automation and protection [15]. Figure 2.9 provides an overall architecture of the Smart grid with the participation of many elements from the energy generation, the transmission/distribution networks to the customers with the services and managements from the markets, operations and service provider.

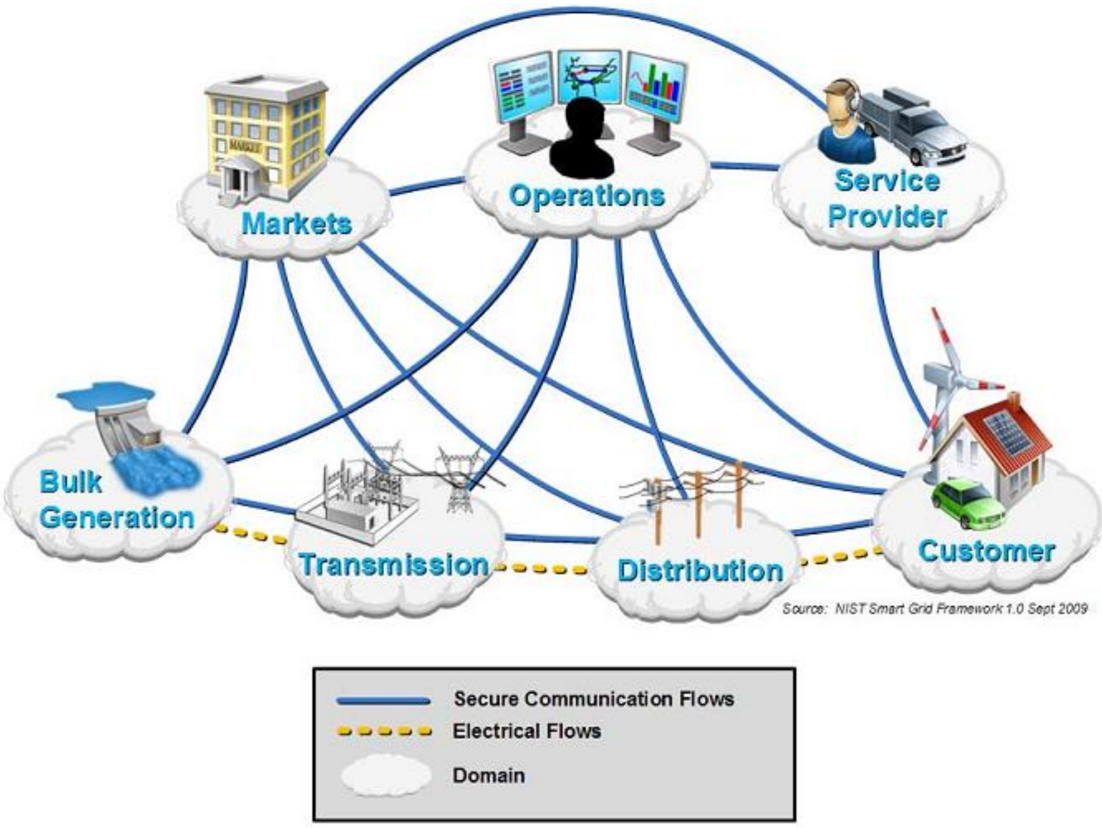

Figure 2.9 – Conceptual model of smart grid, copied from [15]

In short, the key idea of smart grid is the use of more and more intelligent controllable devices with high level of interoperability to build a sustainable, economic and secure electricity network.

2.2.2 LV Microgrids

LV Microgrids " describe the concepts of managing energy supply and demand using an isolated grid that can island or connect to the utility's distribution Smart Grid" [17]. Therefore, LV Microgrids are crucial part in order to achieve an overall Smart Grid with the participation of consumers.

From the above definition of LV Microgrids, we can decompose the three main parts of a LV Microgrid as: **energy supply**, **load** and the **control** part for managing the energy supply and demand. It is illustrated in Figure 2.10.

An important objective of building LV Microgrids is to create self-contained cells with use of distributed energy resources in order to help assure energy supply in distribution grids even when the transmission grid has a blackout [12]

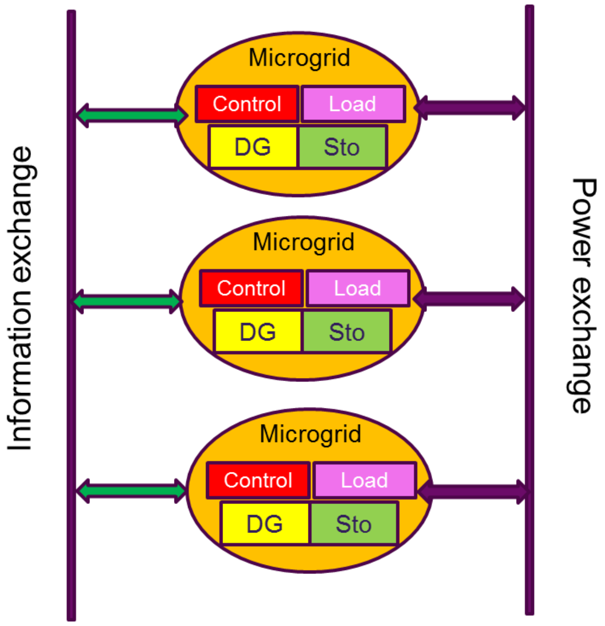

Figure 2.10 – Microgrids architecture, copied from [18]

In order to fulfill that objective, the control algorithm and protocols for Microgrids control and management are very important. Basically, there are two elements for control and management: the energy generators and the household appliances which consume energy. The design of the algorithm and protocol should be able to provide best energy efficiency, resilience to failures.

However, in addition to the energy-related issues, another very important aspect to be considered is the privacy and convenience for the customers. Therefore, the function like access control has to be taken into consideration.

2.3 Summary

This chapter provided an overall picture of IEC 61850 standard including the scope of the standard, data models, abstract services, communication protocols and communication profiles mapping. These theories will be applied to achieve the objectives of the research in chapter 3 and chapter 4. Moreover, descriptions of the Smart Grid and Microgrids were also described in this chapter. This background information will help to clarify the new possibly-applied domain of IEC 61850 proposed by this research.

Chapter 3

IEC 61850 network designing and data modeling for microgrids components

Chapter 3 describes the communication network designing and data modeling processes which are the two important research tasks in order to allow power control of Microgrids through using IEC 61850 data models and services. As being emphasized above, the current covering areas of IEC 61580 include communications in substation automation systems, between substations and to DERs. Therefore, for LV microgrids power control, before using the IEC 61850 services to control the smart electrical devices, we have to model those devices as IEC 61850 data models and design a network topology to support seamless communication between those devices. In addition, although IEC 61850 facilitates modeling a lot by giving many object models for common functions like measurement, metering, monitoring…etc., there are still some missing pieces for building a diversity of functions for household appliances like tuning the temperature of an electric heater or refrigerator. This chapter explains how to model new devices and new functions as IEC 61850 models.

3.1 Communication network designing

In this part, a simple but typical communication network will be designed to allow the communication between different actors in a Microgrid which support the use of IEC 61850 data models and services for power control.

3.1.1 Microgrids power diagram

Normally, a LV Microgrid consists of three building blocks: the DERs including energy distributed generators like PV panel and energy storage, and the electrical loads which consumes energy. A LV Microgrid can operate in islanding mode or grid connected mode. The latter is chosen for this research. A typical LV Microgrid can be illustrated in figure 3.1.

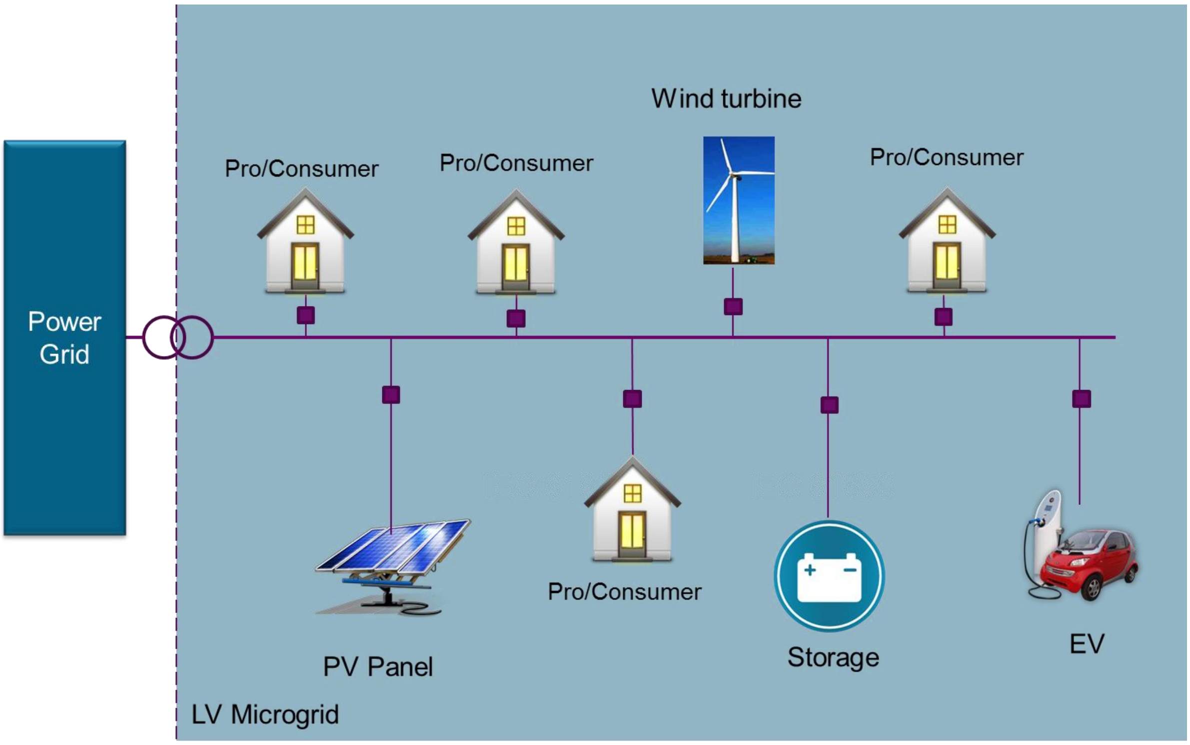

Figure 3.1 – LV microgrids diagram

Figure 3.1 illustrates a typical LV Microgrid which consists of the Smart houses and the public Distributed Energy Resources (DERs). In this case, the components of the LV Microgrid can be classified to three types: energy consumers, energy generators and energy storages. The energy consumers are the household electrical appliances inside the houses. The energy generators are the public Low voltage DERs such as wind turbine or PV panel and private DERs in the Smart houses. The energy storages are controllable battery systems used to store the energy for urgent situations or other future plans. A special component is the Electric vehicle (EV) which can be seen as both the energy consumer and energy storage.

3.1.2 Communication network topology for LV Microgrids power control

According to the current version of IEC 61850, the underlying communication network infrastructure standardized is Ethernet. Therefore, we need to build an Ethernet-based communication network to connect all the equipment. Within this research, a network topology was designed for that purpose.

This network was designed as a hierarchical topology in which each Smart house was represented as a subnet and these subnets together created kind of field area network. The control part of the Microgrid here was the Regional Control and Management Center (RCMC) which was also connected to the field area network. Figure 3.2 presents the communication network topology designed for LV Microgrid control and management.

Physically, the each subnet and RCMC should connect to an Ethernet switch to establish so-called point-to-point links between RCMC and each subnet.

There could also be some public DERs, EV that should be managed by the RCMC and therefore, they should have an Ethernet connection with RCMC through connecting to the Ethernet switch.

Other important functionality is protection which is handled by the protection device and the Circuit breaker (modeled by the XCBR logical node). However, because the messages for protection need to be very fast, they are handled by another protocol (GOOSE) instead of the protocol for control purpose (MMS) as explained in chapter 2.

Because the scope of this research is about power control in LV Microgrids, the protection part is not analyzed. The protection device and circuit breaker in the following figure is just for illustration of a typical LC Microgrid with both control and protection functions.

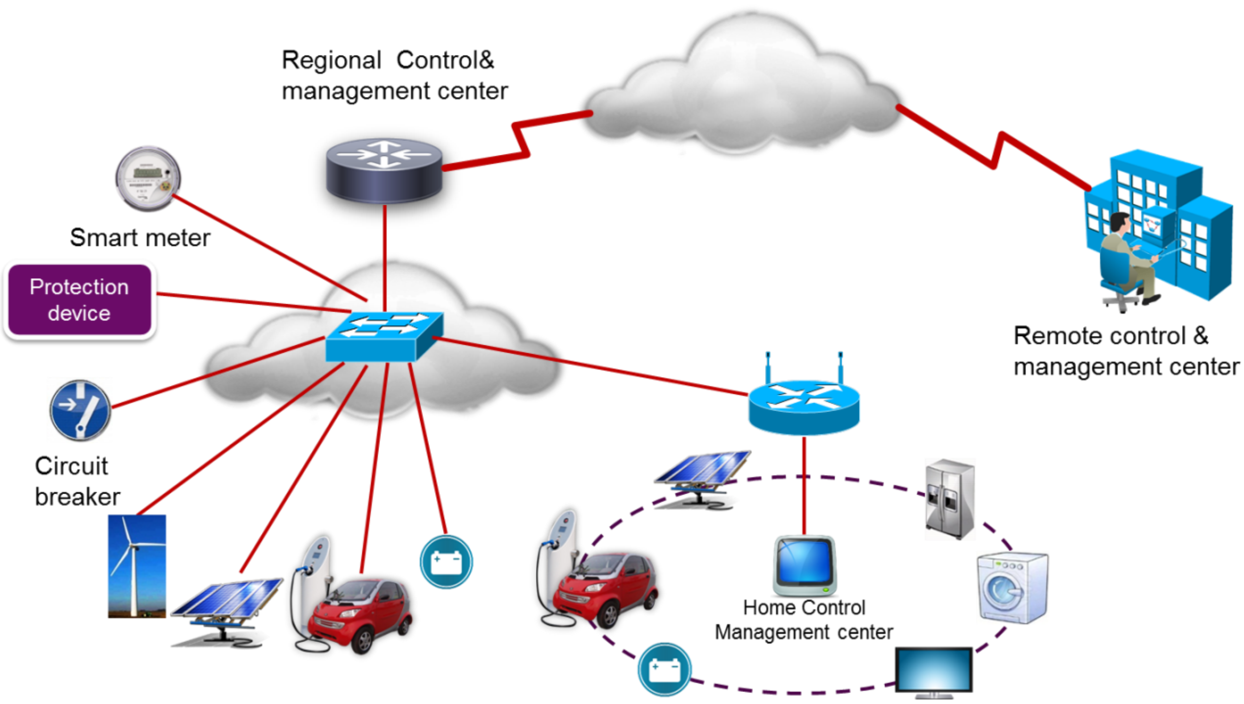

Figure 3.2 – Communication network topology for LV Microgrids power control

As we can see in Figure 3.2 inside a smart home, there is a Home Control and Management Center (HCMC) which is in charge of controlling all DERs and smart household appliances inside the house. HCMC can handle the Demand Response sent from RCMC to manage the energy consumption/production of the house. HCMC can control the household appliances to moderate their energy consumption and the DERs to modify their power production ability.

RCMC is capable of monitoring and managing all HCMCs if it is permitted by the houses' owners to efficiently utilize the available energy of the grid.

3.2 IEC 61850 data modeling

The main idea of IEC 61850 is to breakdown a physical device into logical devices, each of which will be further broken down into logical nodes, data objects, and data attributes [1].

The Logical Device hosts communication access point of IEDs and related communication services, and is hosted by a single IED. However, there's no rule on how to arrange Logical Devices into a physical device which brings a great flexibility to the user.

Logical Nodes are the smallest entities which are decomposed from the application functions. Logical nodes are the building blocks of the standard since they represent the smallest functions of the device. Because the scope of this project is very different with the original scope of IEC 61850, many new functions could appear which require to be modeled. This section will describe how to model a new function as IEC 61850 logical nodes.

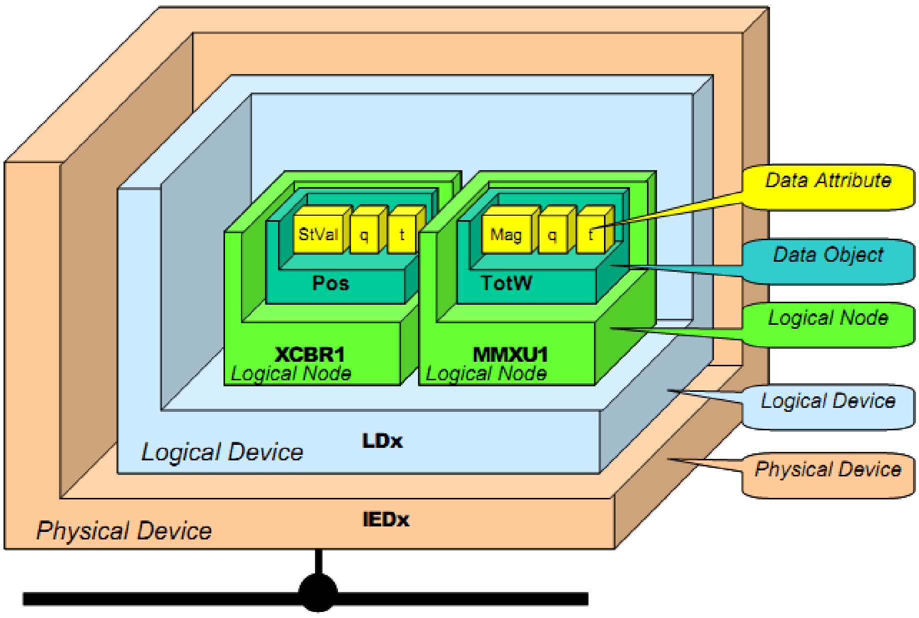

Figure 3.3 – IEC 61850 data modeling, copied from [1]

Figure 3.3 illustrates the principle of IEC 61850 data modeling. In this case, physical device IEDx is composed of a logical device LDx in which there are two different logical nodes **XCBR** and **MMXU**. XCBR1 and MMXU1 are the instances of the logical node class XCBR and MMXU which represent the circuit breaker and the measurement unit respectively.

Each logical node is composed of many data objects. For example in this situation, logical node XCBR1 contains the data object **Pos** which represents the position of the circuit breaker. This data object consists of many data attributes among which are **StVal** attribute for setting the position of the breaker to open or close, **q** attribute stands for quality of the data and **t** stands for time of operating the function.

3.2.1 Extension rule for logical nodes

The rules for extending or creating new logical nodes classes are defined in IEC 61850 part 7-1 [3]

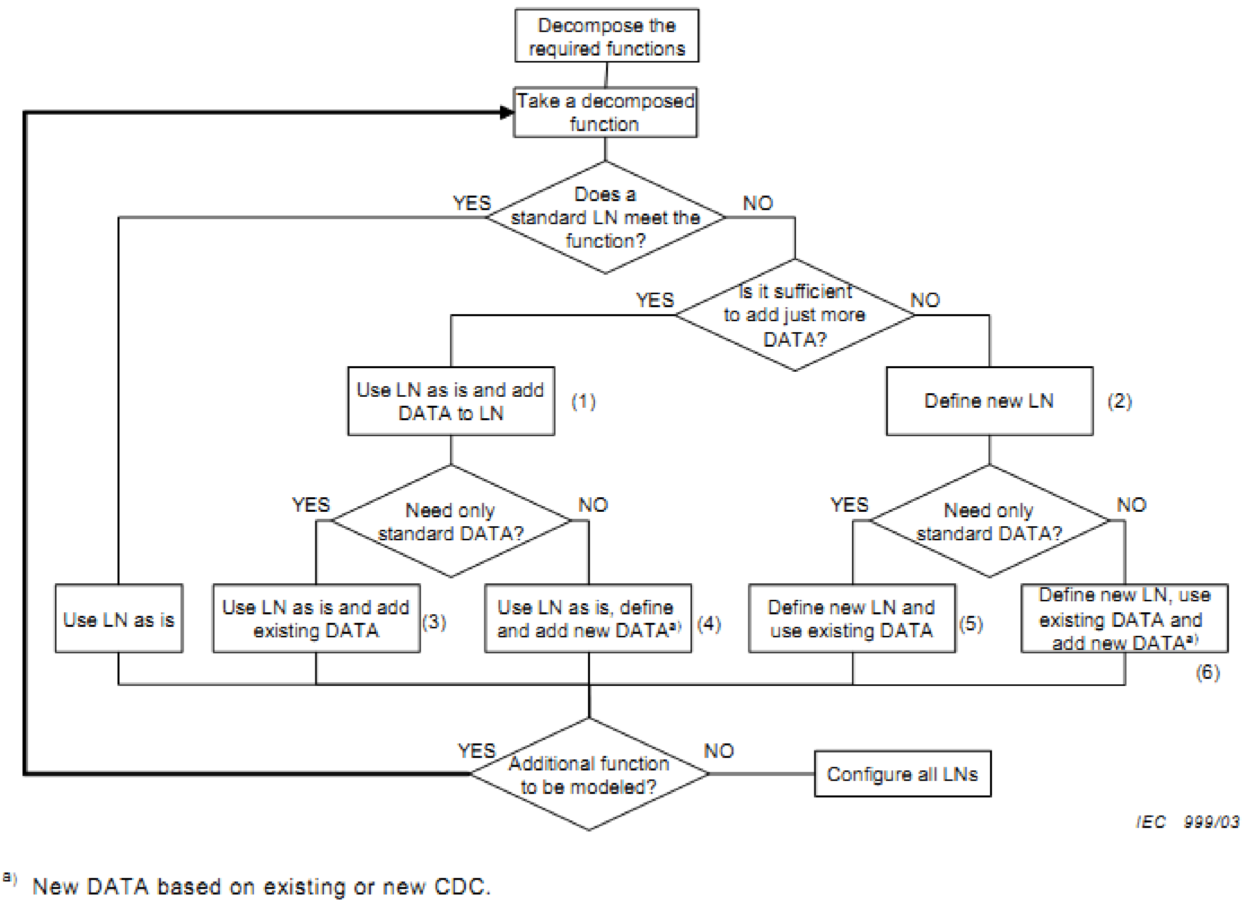

Figure 3.4 – Basic extension rules diagram, copied from [3]

The rules modeled in Figure 3.4 can be briefly summarized as follows [3]:

- If there is any Logical Nodes Class which fits the function to be modeled, an instance of this logical node shall be used with all its mandatory data (M).
- If there are dedicated versions of this function with the same basic data different instances of this Logical Node Class shall be used.
- If there are no Logical Nodes Classes which fit to the function to be modeled, a new logical node shall be created according to the rules for new Logical Nodes.

3.2.2 IEC 61850 data modeling for Microgrids components

There are 3 types of equipment to be modeled in a typical LV Microgrid:

- Distributed energy resources (DER): Photovoltaic – PV panel, electric vehicle, energy storage…
- Smart household appliances: LCD TV, electric heater, refrigerator…
- Control and management centers: Regional/Home control and management center.

3.2.2.1 Distributed energy resources

Following the extension rule for logical nodes above, we mostly utilize the existing logical nodes defined in the standard part 7-420 [7], the draft technical reports part 90-7 [9] and part 90-8 [10] for modeling the DERs. Additionally, the object models for wind turbine can be found in series IEC 61400-25: "Communications for monitoring and control of wind power plants". In Figure 3.5, we can see that many existing logical nodes defined for substation automation systems were applied for DERs, and also many new logical nodes were defined to represent the new functions of DERs.

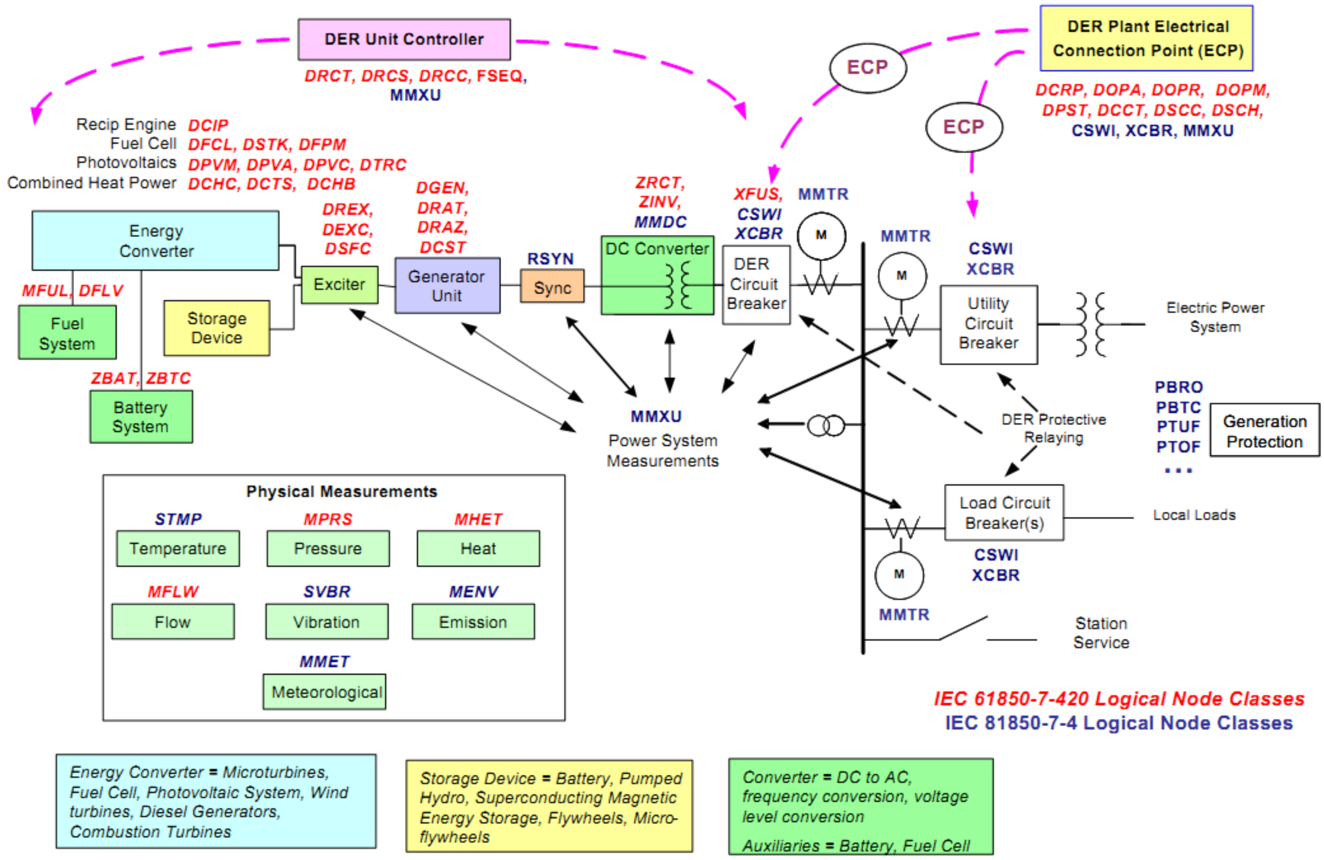

Figure 3.5 – Conceptual organization of DER logical devices and logical nodes, copied from [7]

Because there is no strict rule on the arrangement of logical devices on physical device, it is not necessary to implement all of the logical nodes in this figure to a DER. Actually, depends on the specific locations and application requirements of the DER, only respective logical nodes should be added.

For simplification, only the PV panel is used as the distributed generator and the energy storage is the battery which also connects to the PV through a hybrid inverter for charging purpose in the houses. The Hybrid Inverter allows the reverse flow of power from the PV and energy storage to the grid in case of emergency or in response to the Demand Response l issued by RCMC to prevent peak loads.

3.2.2.2 Smart household appliances

As the household appliances are the new devices to be modeled within IEC 61850, the first step of modeling should be identifying their features. There are hundreds of different household appliances; therefore, we only take into account the appliances that consume much energy. Table 3.1 summarizes the typical energy-consuming appliances and their significant characteristics to be modeled.

Table 3.1 – Smart household appliances and their typical characteristics

Household Electric Appliances	Television	Electric cooker	Cooker Hood	Microwave	Electric Stove	Dishwasher	Refrigerator	Washing machine	Clothes Dryer	Bread maker	Coffeemaker	Air conditioner	Fan	Electric heater	Dishwasher	Electric water heater	Printer	Kettle	Lighting system
Properties																			
On/Off	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Voltage	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Current	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Frequency	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Energy consumption	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Product information (serial number, manufacturer…)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Temperature		X		X	X		X		X	X		X		X		X		X	
Speed													X						
Energy modulation		X		X	X		X	X	X			X	X	X		X			X

Regarding the appliances parameters listed above, the basic functions required for control and management of household appliances are:

- switching ON/OFF the equipment,

- monitoring the device statuses,
- measuring/monitoring the energy-related parameters (current, voltage, frequency, energy consumption),
- monitoring other parameters (e.g. temperature),
- moderating the energy consumption by alternating the operation modes of the devices,

Firstly, IEC 61850 provides the two logical nodes **MMXN** and **MMTN** for measurement and monitoring of single-phase voltage, current, frequency and energy consumption [6]. Therefore, we should utilize these logical nodes to model the energy self-measuring and monitoring functions of the household appliances.

Secondly, for monitoring the devices in term of physical/product information, IEC 61850 defines the logical node **LPHD** [6] consisting of the physical information of the equipment which is mandatory for all IEDs. Therefore, with the Get and Report services it is possible to get this information.

Similarly, for monitoring other operational parameters such as temperature, pressure, heat…of the devices, IEC 61850 also provisions the corresponding logical nodes **STMP, MPRS, MHET**… [7].

Although there are many logical nodes existing in the standard that are applicable, some functions for household appliances control have naturally not been defined due to the difference in scope between substation automation systems and home automation systems. Energy moderation is the most important function to be modeled for power control but it is not included in the standard. Therefore, a new general logical node for all smart appliances named ***ZAPL*** was defined as table 3.2

Table 3.2 – ZAPL class

ZAPL class				
Data Object Name	**Common Data Class**	**Explanation**	**T**	**M/O/C**
LNName		Shall be inherited from Logical-Node Class (see IEC 61850-7-2)		
Data Objects				
EEHealth	ENS	External equipment health		O
EEName	DPL	External equipment name plate		O
OpTmh	INS	Operation time		O
Status				
Oper	SPS	Operation status of the appliance		M
OperMod	ENS	Operating mode: 1-Autonomous; 2-Schedule; 3-Manual		M
Controls				
OperCtl	SPC	Start/Stop the appliance		M
AutoManCtl	ENC	Sets operation mode to Autonomous, Schedule or Manual		M
Schedule	ARY	The schedule for the lighting system		O
Settings				
LoadSpt	ASG	Set load target %		O

This logical node allows retrieving information about the operation status of the corresponding appliance such as the operation status and operating mode i.e. the appliance is working autonomously or following a schedule or being manually controlled by the user.

This is important as it brings the user highest privilege to control his or her appliances. If the users do not want disruption caused by the telecontrol functions from HCMC, they can simply switch the appliance to manual mode.

More importantly, this logical node represents the energy modulation function which is indispensible to control the energy consumption of the appliances. By setting the load target set-point, HCMC or the users can modulate the energy consumption of the appliances.

The function turning ON/OFF the device is also modeled in ***ZAPL*** logical node since it is a basic and mandatory function for all devices.

Though through setting the load target, HCMC can control the energy consumption of all smart appliances, another way to tune the energy consumption of a device is to directly change its operational threshold like changing the speed of a fan or temperature of a heater or refrigerator.

There is a logical node called **STMP** defined in IEC 61850-7-4 for temperature supervision, and it is convenient to utilize this logical node and add more data objects to support the temperature modulation function. Table 3.3 shows the extension of the existing logical node STMP to support the function of temperature modulation.

Table 3.3 – Extension to STMP class, based on [6]

STMP class				
Data Object Name	**Common Data Class**	**Explanation**	**T**	**M/O/C**
LNName		The name shall be composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2 clause 19		
Data Objects				
EEHealth	ENS	External equipment health		O
EEName	DPL	External equipment name plate		O
Measured Values				
Tmp	MV	Temperature		O
Status information				
Alm	SPS	Temperature alarm level reached		O
Trip	SPS	Temperature trip level reached		O
Settings				
TmpAlmSpt A	ASG	Temperature alarm level set-point		O
TmpTrSpt	ASG	Temperature trip level set-point		
TmpSpt*	**ASG**	**Temperature set-point**		**O**

* New data attribute added to the standard STMP for setting the temperature

A temperature set-point was added to **STMP** class to control the temperature. Therefore, an instance of the **STMP** class with **TmpSpt** allows tuning the energy consumption of a heater or refrigerator by changing its output temperature.

3.2.2.3 Control and management center

Within the scope of this research, communications in smart home systems and Demand Response are the main concentrations.

For control in smart home systems, HCMC can apply IEC 61850 services for all control behaviors with the logical nodes in smart appliances. Therefore, it is not needed to define a logical node for HCMC for control purpose.

For Demand Response, it is necessary to model the data and function of HCMC that RCMC can access and perform the function to set the threshold for energy consumption of the house in particular peak demand periods. For this purpose, a new logical node ***ZHCM*** was defined in table 3.4.

Table 3.4 – ZHCM class

ZHCM class				
Data Object Name	**Common Data Class**	**Explanation**	**T**	**M/O/C**
LNName		Shall be inherited from Logical-Node Class (see IEC 61850-7-2)		
Data Objects				
EEHealth	ENS	External equipment health		O
EEName	DPL	External equipment name plate		O
OpTmh	INS	Operation time		O
Status				
Oper	SPS	Operation status of the Home control and management center		M
OperMod	ENS	Operating mode Value – Explanation 1 – Autonomous 2 – Controllable		M
Settings				
MaxWh	ASG	Set-point of maximum energy consumption		O

In this logical node, there is a data object **OperMod** representing the operating mode of HCMC. If HCMC is configured to be controllable, RCMC can use the data object **MaxWh** to change the allowed maximum energy consumption of the house.

If there is no error and the control function succeeds, HCMC will then control the in-home DERs and appliances to reduce the energy consumption in response to the Demand response signal sent from RCMC.

3.3 Summary

This chapter fulfilled the two first objectives of the research: Objective 1 – Designing a communication network topology for power control in LV Microgrids; and Objective 2 – Modeling LV Microgrids electrical components for power control.

In section 3.1, a communications network topology was designed to allow the information transmissions among the LV Microgrid. Due to the current version of IEC 61850 that standardizes Ethernet as the layer 2 protocol, this network was built over Ethernet. However, it is also possible for future research to define mapping to other underlying network protocols for transmitting the IEC 61850 information such as wireless or cellular networks.

Section 3.2 gave a further details about IEC 61850 data modeling principles which were mentioned in chapter 2. More importantly, this section described how to use those principles in practice by modeling the LV microgrid electrical components with IEC 61850 data objects. This section also defined some new logical nodes to represent the very important power controls functions i.e. ZAPL and ZHCM logical nodes. However, it is crucial to realize that this research has utilized many existing logical nodes defined in IEC 61850 documents to model different components in a very different area with the substation automation systems. This shows the great possibility of extending the scope of IEC 61850 to other area in order to provide interoperability to the future Smart Grid.

Chapter 4

Applying IEC 61850 data models and services for Microgrids power control

Chapter 3 has fulfilled the two first objectives of the research which are designing a communication network topology for power control in LV Microgrids, and Modeling LV Microgrids electrical components for power control. However, these two objectives are just the two preparation steps to achieve the main goal of the research which is applying the IEC 61850 data models and services for LV Microgrids power control. Therefore, this chapter will continue to achieve the research goal by using the communication network topology and object models defined in chapter 3 to control the power consumption/generation of both the energy consumption devices – the smart household appliances, and the distributed energy resources.

Firstly, in section 4.1, a Use case for LV Microgrids power controls focusing on controlling the power consumption/generation of the smart appliances and DERs inside the households is defined. There are plenty of algorithms designed for controlling the power generation and consumption of a LV Microgrid. However, this research does not focus on algorithm designing. Therefore, the algorithm provided within this Use case may not contain all the possible functions for controlling the energy usages within a LV Microgrid. Instead, the role of this Use Case is to illustrate how we can use the IEC 61850 data models and services to perform power control functions of a typical LV Microgrid. This Use case contains almost the typical control behaviors for a LV Microgrid; therefore, it can be used to explain the use of almost IEC 61850 services for control functions.

In particular, this is a typical Use case in which the Home Control and Management Center (HCMC) can control the energy consumption of the smart house by controlling electricity consumption of the smart appliances and electricity generation of the Distributed Energy Resources (DERs). It also brings conveniences to the user by allowing the user to choose between various lifestyle control modes, based on which the HCMC will automatically control the smart appliances to use the energy most intelligently. This Use Case is developed from [11] with some modifications to allow mapping to IEC 61850.

IEC 61850 part 7-2 defined the abstract communication services to allow access to the data objects in the Logical nodes to perform the desired functions. However, the document mostly provided the definition and syntax of the services without clear examples of how to use these services to access to the data objects, data attributes in specific logical nodes to perform some functions. In this chapter, many specific examples will be described in order to explain how to use the logical nodes and abstract services to perform control functions. This is also a contribution of this research besides the main goal of successfully applying the IEC 61850 protocols in a totally different domain with substation automation – LV Microgrid power control.

Additionally, the Use Case defined in this part also applies an important feature, Demand Response or Load Management, to dynamically manage customer consumption of electricity in response to the supply conditions. In this Use case, Demand Response is used mostly for prevention of the peak load. RCMC can control the energy consumption of a smart house by sending the Demand Response signal to the HCMC which will set the maximum energy consumption set-point of the Smart house.

Demand Response was mentioned in many standards including the document of Smart Grid Strategic Group – SG3 about the roadmap of the Smart Grid [12]; however, it has not been mentioned in IEC 61850 documents. Within this chapter, IEC 61850 protocols will be used to perform Demand Response. Although in this Use case, Demand Response is only used to prevent the peak loads, it is possible to implement near real-time energy management to achieve energy balance at all times. This can be done by using the proxy which allows RCMC to directly control the PV panel, Energy storage and even the smart appliances. However, this implementation may raise the problem with users' privacy. Hence, it requires further research and investigation on the possibility of applying this method. The use of proxy is mentioned in chapter 5.

With the goal described above, this chapter is organized to step-by-step analyze the capability of the IEC 61850 protocols to be applied on LV Microgrids power control domain. It explains how to use the existing services in the standard to perform various kinds of control functions to efficiently manage the energy consumption and generation devices of a typical LV Microgrid.

The structure of the chapter is as follows: Section 4.1 provides the definition of the LV Microgrid power control Use Case including the power control algorithms and the messages exchanged between different components. Section 4.2 describes in detail how these algorithms can be achieved and how the messages can be exchanged using the IEC 61850 services. The newly-defined logical nodes in chapter 3 will be used here to explain how IEC 61850 services are used to access and exchange the data contained in logical nodes to perform the dedicated functions.

4.1 LV Microgrids power control use case

The scope of this Use Case is about control of equipment within a LV Microgird such as PV panels, Electric vehicles, energy storage and smart household appliances.

The objective of this Use Case is to construct a robust and interoperable LV Microgird in order to achieve energy efficiency through defining a smart algorithm to control all the DERs as well as the smart household appliances. The algorithm to control the renewable energy resources and the smart appliances will be described within this Use case. Then the information exchange between the devices will be specified in order to facilitate the interpretation into IEC 61850 data structures and services.

4.1.1 Description of the Use Case

This Use Case can be divided into three scenarios of scheduling, smart appliances control and energy consumption control by Demand Response Signal.

In the first scenario, the Home Control and Management Center decides the daily optimal scheduling of the distributed energy generator (the PV panel). At the beginning of the day (a pre-configure point of time), RCMC will send a report about the weather forecast information to HCMC for forecasting the output of the DER (PV panel) and the demand of the day. The weather forecast information combines with the historical demand usage information helps HCMC to choose the most suited schedule for the DER. There are pre-defined schedules for the DERs which were pre-configured in the Hybrid Inverter and HCMC can activate a schedule by sending a control command to the Hybrid Inverter.

In the second scenario, based on the pre-configured lifestyle control mode, the HCMC can control all the controllable appliances to use the energy most efficiently.

The Distributed Energy Resources installed in a smart house are the PV panel, the Energy Storage (battery) and the Electric Vehicle. The PV panel and the ES are connected and controlled by the Hybrid Inverter. Therefore, to control the PV and ES, the HCMC sends control commands to the Hybrid Inverter.

The typical smart appliances to be controlled are:

- Electric heaters in each room
- A refrigerator.
- The lighting systems.
- Fans.
- Dummy load system to simulate other appliances in a typical house.

In the third scenario, if HCMC is in controllable mode, RCMC can reduce the smart house's energy consumption during peak demand periods by setting a lower value for the maximum energy consumption of the house through the HCMC. If the setting service by the RCMC is successful, the HCMC will control the DERs to produce more power and reduce the smart appliances consuming electricity to decrease the energy consumption of the house under the maximum energy consumption set-point and relieve the Microgrid from peak demand loads.

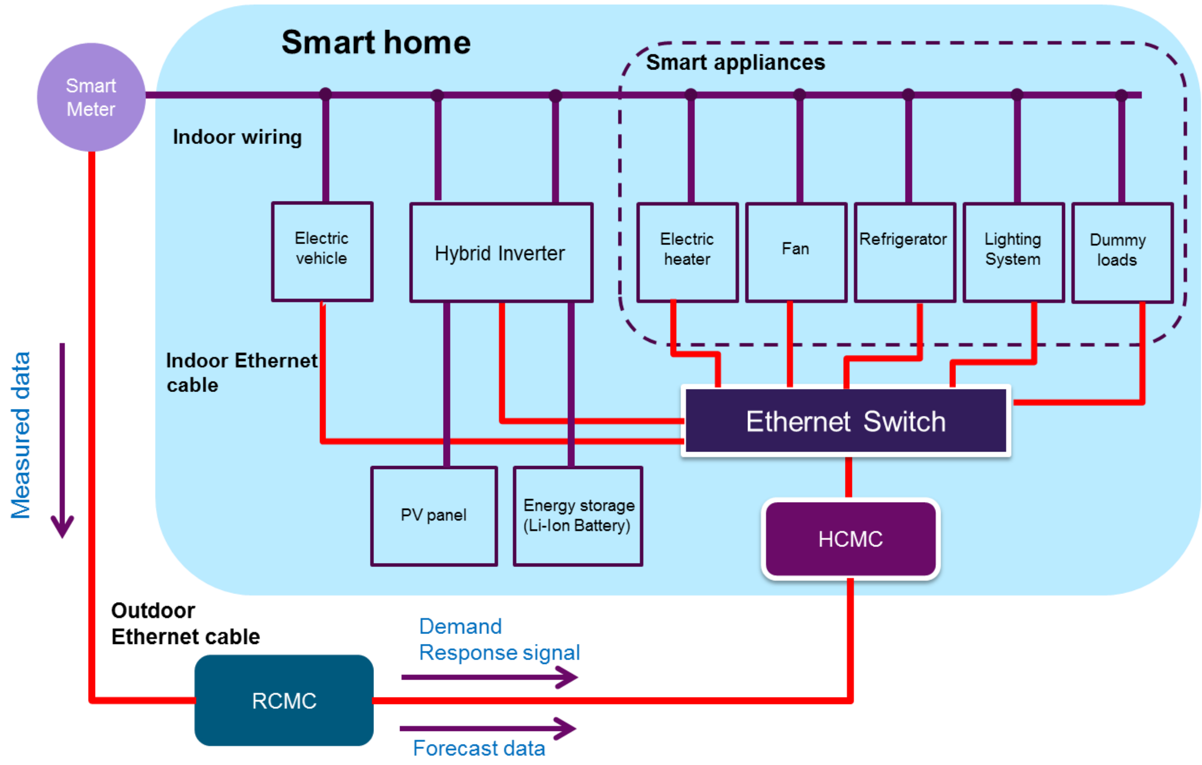

Figure 4.1 – Micrograds equipment control Use Case, based on [11]

Figure 4.1 can be considered a zoom into the communication network topology presented in Figure 3.2 of chapter 3. It focuses on the communication network inside the Smart home and the connection between RCMC and HCMC. For simplicity the connection between the RCMC and HCMC is presented as a point-to-point link. The Demand Response signal is initiated by RCMC and is sent to HCMC through that connection. The Demand Response signal is issued based on the measurement data sent from the Smart Meter to RCMC.

PV panel and Energy Storage are connected to the communication network through a microprocessor-based Hybrid Inverter (HI) with remote control function integrated. With this design, the Energy Storage which is the rechargeable battery system can store the power generated by the PV panel in normal case and release that energy in emergency or in response to the Demand Response signal.

4.1.2 Actor Role

These actors represent the communication exchange actors in the network. These actors will exchange data through sending and receiving a lot of messages that contain the information objects defined in table 4.2. Brief descriptions of all actors are provided in table 4.1

Table 4.1 – Actor type

Grouping (Community)		***Group Description***
Actor Name	***Actor Type***	***Actor Description***
Home Control & Management Center	Subsystem	HCMC is in charge of controlling all the equipment inside a house including the DERs and Smart Appliances
PV panel	Subsystem	Photovoltaic Panel for power generation from the solar energy
Electrical Storage (ES)	Subsystem	Energy Storage system consists of Li-Ion battery. Charge/Discharge and ES power is controlled by the Hybrid Controller
Electric vehicle (EV)	Subsystem	The plug-in electric vehicle which uses rechargeable battery can deliver electricity to the grid in respond to peak load demand
Hybrid Inverter (HI)	Subsystem	Hybrid Inverter is controllable inverter which handles PV generation and ES charge/discharge functions simultaneously
Smart appliances	Device	The smart appliances are all the household electrical appliances that can be controlled by the HCMC.
Smart Meter	Device	The intelligent electricity metering device which provides information about the energy-related parameter to the RCMC
Regional Control and Management Center (RCMC)	System	The Regional Control and Management Center acts as a microgrid control and management center which manages all the utility's DERs and the HCs within the Microgrids

4.1.3 Information exchanged

This section describes the information objects used by different actors defined in the previous section to control the energy consumption of the smart house. In the next section 4.2, these information objects will be mapped to IEC 61850 data objects.

The information objects that will be exchanged for performing power control functions in the network are summarized in table 4.2.

Table 4.2 – Information object exchanged

Information Object Name	***Information Object Description***
Weather forecast information request	Request for weather information such as temperature, humidity, daylight duration…
Weather forecast information response	Response with weather forecast information
HI status request	Request for hybrid status which consists of the status of the connected PV panel and Energy storage (battery) including for example the output of the PV, State of charge of the ES…
HI status response	Response with HT status information
Past demand and output record data	Information about the demand and output of the smart house on the previous day
Electricity demand forecast data	Forecast information about the electricity needed for the coming day
PV output forecast	Forecast information about the electricity generated by the PV panel for the coming day
DER schedule request	Activate the chosen schedule for DER operation which is decided by HCMC based on the weather forecast information and the past demand and output data.
DER schedule response	Indicates that the DER schedule request succeeded or failed
Appliances control request	Application control command for controlling the smart appliances like turning ON/OFF a device, setting an operational parameter, moderating energy consumption.
Appliances control request	Response to the application control command indicating if the command succeeded or failed
Demand Response Signal (DRS) request	Command to reduce the energy consumption of the smart house sent from RCMC to HCMC
Demand Response	Information to indicate if the DRS request command succeeded or failed

Signal (DRS) response	
PV output increase request	Setting the maximum output set-point of the PV to a higher value to allow the PV to generate more power
PV output increase response	Indicates that the request of increasing PV output succeeded or failed
ES discharge mode request	Switching the ES to discharge mode to become a supply equipment and consequently reduce the energy consuming from the grid
ES discharge mode request	Indicates that the ES discharge mode request succeeded or failed
EV status request	Request for electric vehicle status including the State of Charge
EV status response	Response with EV status information
EV discharge mode request	Switching the EV to discharge mode to become a supply equipment and therefore reduce the energy consuming from the grid
EV discharge mode request	Indicates that the EV discharge mode request succeeded or failed
Measured data report	Voltage, current, energy consumption of the smart house

The information specified in table 4.2 will be used by the actors defined in table 4.1 to perform the control functions of LV Microgrid smart electrical components.

4.1.4 Step by step analysis of function

4.1.4.1 Step to implement function – Scenario 1

The steps to perform the functions in scenarios 1 in which HCMC will retrieve the weather forecast information and past data to decide working schedules for the DERs, is shown in table 4.3.

Table 4.3 – Step to implement function – scenario 1

#	Primary Actor	Name of Process/ Activity	Description of Process/ Activity	Information Producer	Information Receiver	Name of Information Exchanged	Notes
1.1.1	HCMC	Weather forecast information request	HCMC requires weather forecast information from RCMC	HCMC	RCMC	Weather forecast information request	
1.1.2	RCMC	Weather forecast information response	RCMC replies the HCMC's request with the weather forecast information	RCMC	HCMC	Weather forecast information response	
1.2	HCMC	Acquisition of Past demand and output record data	HCMC acquires the Past demand and output record data from its database	HCMC	HCMC	Past demand and output record data	
1.3	HCMC	Electricity demand forecast	HCMC forecasts electricity demand based weather forecast and past electricity demand record data.	HCMC	HCMC	Electricity demand forecast data	

#	Primary Actor	Name of Process/ Activity	Description of Process/ Activity	Information Producer	Information Receiver	Name of Information Exchanged	Notes
1.4	HCMC	PV output forecast	HCMC forecasts the PV output based on the weather forecast information and the Past demand and output record data	HCMC	HCMC	PV output forecast	
1.5.1	HCMC	HI status request	HCMC requests for the power condition of the HI-connected PV and ES	HCMC	HI	HI status request	
1.5.2	Hybrid Inverter	HI status response	HI sends the power condition of the PV and ES to the HCMC	HI	HCMC	HI status response	
1.6.1	HCMC	DERs schedule activation	HCMC activates the appropriate schedule for the DER	HCMC	HI	DER schedule request	
1.6.2	HCMC	DERs schedule response	HI sends back a response to indicate if the activation succeeded or failed	HI	HCMC	DER schedule response	

4.1.4.2 Step to implement function – Scenario 2

In Scenario 2, HCMC controls the Smart appliances based on the pre-configured lifestyle mode decided by the user to use the energy in a most efficient way. These steps are shown in table 4.4.

Table 4.4 – Step to implement function – scenario 2

#	Primary Actor	Name of Process/ Activity	Description of Process/ Activity	Information Producer	Information Receiver	Name of Information Exchanged	Notes
2.1.1	HCMC	Sending of Appliances control command	HCMC controls the smart appliances for energy efficiency	HCMC	Smart Appliances	Appliances control command request	
2.1.2	Smart Appliances	Responding control command	Smart Appliances sends response indicating the result of the control command	Smart Appliances	HCMC	Appliances control command response	

4.1.4.3 Step to implement function – Scenario 3

Table 4.5 describes the steps of responding to the Demand Response in order to reduce the consumption of electricity of the Smart house.

Table 4.5 – Step to implement function – scenario 3

#	Primary Actor	Name of Process/ Activity	Description of Process/ Activity	Information Producer	Information Receiver	Name of Information Exchanged	Notes
3.1	Smart Meter	Sending measured data	Smart Meter sends measured data to the RCMC which contains information about the energy consumption of the Smart House	Smart Meter	RCMC	Measured Data report	
3.2.1	RCMC	Issuing Demand Response Signal request	RCMC decides to reduce the power consumption of the demand side, and then sends the Demand Response Signal request to HCMC	RCMC	HCMC	Demand Response Signal request	
3.2.2	RCMC	Responding DRS request	HCMC sends back a response to indicate whether the DRS request succeed or failed	HCMC	RCMC	Demand Response Signal response	
3.3.1	HCMC	HI status request	HCMC requests for the power condition of the HI-connected PV and ES	HCMC	HI	HI status request	

#	Primary Actor	Name of Process/ Activity	Description of Process/ Activity	Information Producer	Information Receiver	Name of Information Exchanged	Notes
3.3.2	Hybrid Inverter	HI status response	HI sends the power condition of the PV and ES to the HCMC	HI	HCMC	HI status response	
3.4.1	HCMC	PV output increase request	HCMC sends control command to increase the output of the PV	HCMC	HI	PV output increase request	
3.4.2	HI	PV output increase response	HI sends a response indicating if the control command succeeded or failed	HI	HCMC	PV output increase response	
3.5.1	HCMC	Activating ES discharge mode	HCMC switches the ES to discharge mode	HCMC	HI	ES discharge mode request	
3.5.2	HCMC	Responding to discharge mode request	ES sends a response indicating if the activation of discharge mode succeeded or failed	HI	HCMC	ES discharge mode response	
3.6.1	HCMC	HCMC collects the power condition of EV	HCMC checks the latest condition of the EV SOC	HCMC	EV	EV status request	If the EV is plugged-in

#	Primary Actor	Name of Process/ Activity	Description of Process/ Activity	Information Producer	Information Receiver	Name of Information Exchanged	Notes
3.6.2	EV	EV replies with the its power condition	EV replies the ES SOC request from the HCMC with the State of Charge information	EV	HCMC	EV status response	
3.7.1	HCMC	Activating EV discharge mode	HCMC switches the EV to discharge mode	HCMC	EV	EV discharge mode request	
3.7.2	HCMC	Responding to discharge mode request	EV sends a response indicating if the activation of discharge mode succeeded or failed	EV	HCMC	EV discharge mode response	
3.8.1	HCMC	Sending control command	HCMC reduces the energy consumption of the smart appliances	HCMC	Smart Appliances	Appliances control command request	
3.8.2	Smart Appliances	Responding control command	Smart Appliances sends response indicating the result of the control command	Smart Appliances	HCMC	Appliances control command response	

4.1.5 Message flow diagram

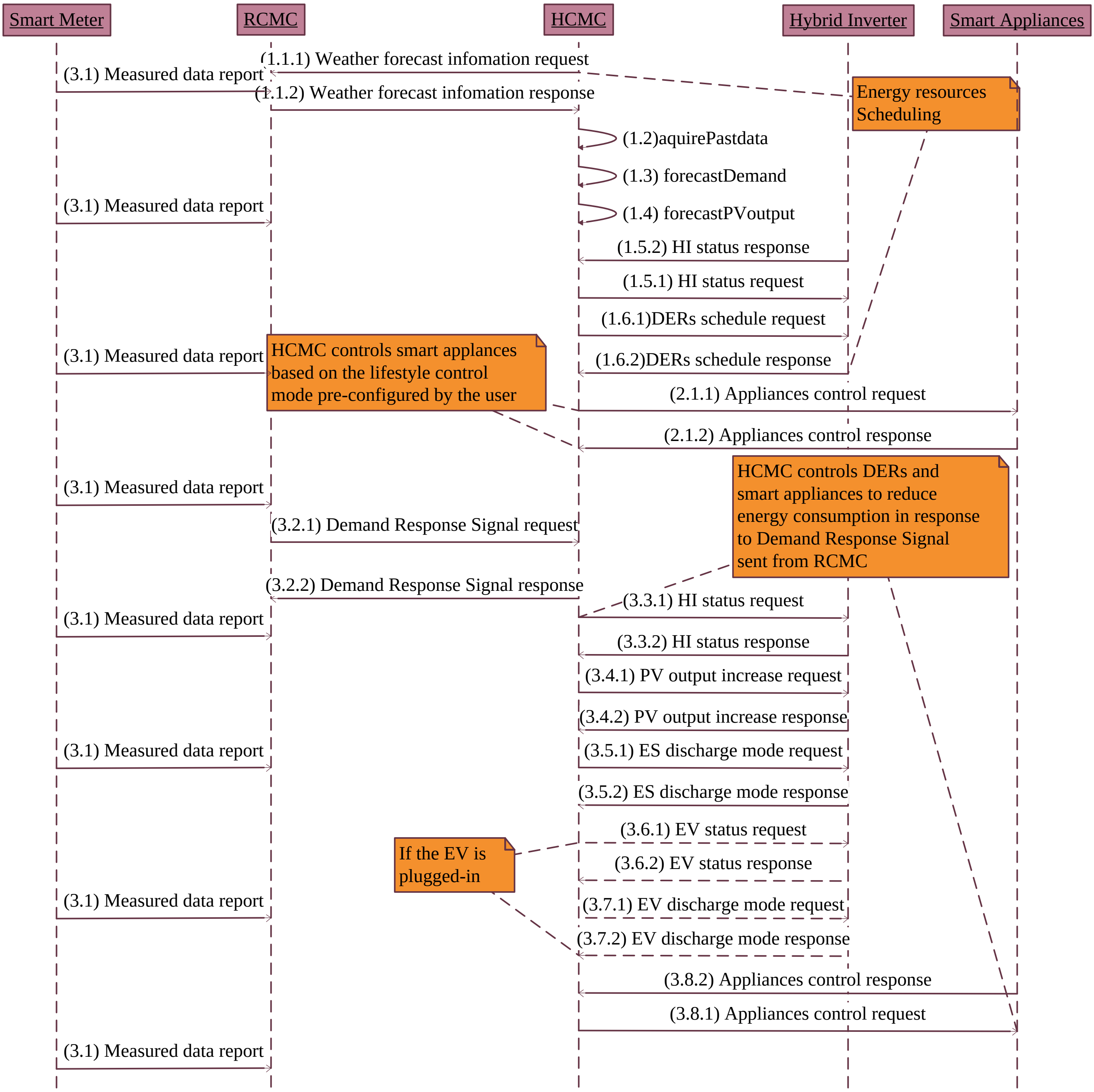

Figure 4.2 – Control messages flow diagram

Figure 4.2 illustrates the steps to implement the control functions described in section 4.1.4 in a message flow diagram. These actors and messages were defined in section 4.1.2 and 4.1.3 respectively.

4.2 IEC 61850 data models and services for microgrids power control

This part explains in detail how to use the IEC 61850 logical nodes and abstract services to perform the power control functions. In IEC 61850, the logical nodes are the containers of the data required to perform functions. The services are the methods that can be used to access to the data to acquire existing data values, to add new data objects or to change data object values. Therefore, the combinations of the logical nodes data models and services are used to perform the control functions.

Chapter 2 – Technical descriptions, section 2.1.6 introduced the abstract services provided by IEC 61850 part 7-2. Chapter 3 explained in detail the data modeling process, modeled the smart appliances and DERs, and defined new logical nodes to represent some control functionalities in a LV Microgrid.

In this section, the abstract services mentioned in chapter 2 are used with the object models and logical nodes defined in chapter 3 to achieve the goal of the research – applying the IEC 61850 for LV Microgrids power control. The following sections 4.2.1, 4.2.2, and 4.2.3 describe how to use the IEC 61850 data models and services to control LV microgrid electrical equipment with the goal of optimizing the energy usage.

4.2.1 Scenario 1 – scheduling

In this scenario, HCMC has to retrieve information from RCMC and Hybrid Inverter to decide a suitable schedule which will be activated for energy resources scheduling. IEC 61850-7-2 provides multiple services to retrieve data and to set different values for data objects, data attributes for control and management purpose. However, before performing these services, an application association has to be established.

An Application association can be considered an agreement between two parties in which the party that sends "associate" message will be the client and the other will be the server. In IEC 61850, the method of establishing an application association follows the **TWO-PARTY-APPLICATION-ASSOCIATION (TPAA)** class syntax defined in part IEC 61850-7-2 [4]

Figure 4.3 illustrate the syntax to establish an application association. The client that wants to establish the association will issue an "Associate" message. The entity that received the message might accept or decline the association by sending a response+ or response-. In case the receiver accepts the establishment, it becomes the server. From this point of time the client can request for the data from the server. After finishing the message transmission, the client can terminate the association by sending the "Release" message.

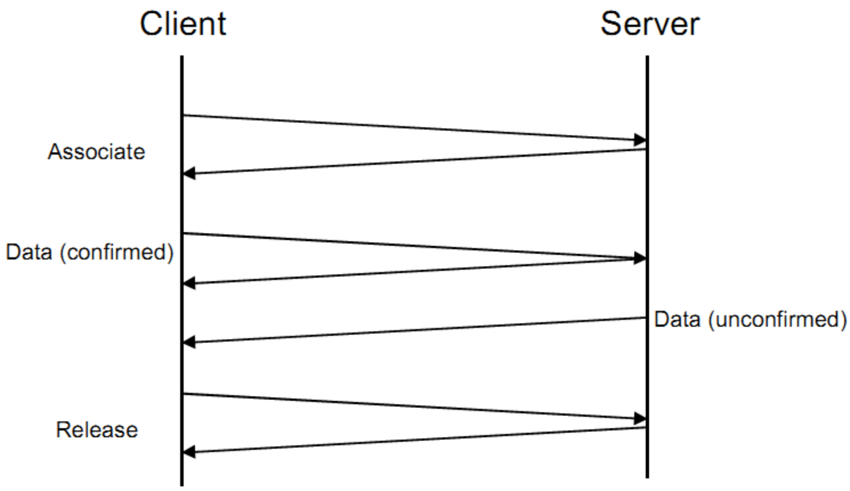

Figure 4.3 – TWO-PARTY-APPLICATION-ASSOCIATION (TPAA) class syntax, copied from [4]

In the first scenario, only the existing logical nodes in IEC 61850 documents are used. The method of using these logical nodes will be explained the next sections.

4.2.1.1 Weather forecast information exchange

In IEC 61850, the information required to perform a function is stored in the logical node in multiple data objects.

IEC 61850-7-2 provides different services to retrieve a single data object value within a logical node (**GetDataValues** service in **GenDataObjectClass**), or all data object values of a logical node (**GetAllDataValues** in **GenLogicalNodeClass**), or group of many data object values from a single logical node or from different logical nodes (**GetDataSetValues** in **DATA-SET** class).

For the weather forecast information, it is stored in a single logical node **MMET** in the Regional Control and Management Center. The **MMET** logical node as shown in table 4.4 contains many data objects which represent different meteorological information such as temperature, humidity, daylight duration…etc. These data objects are marked as **"O"** means they can be implemented or not depends on the user ("**O**" stands for Optional).

Table 4.6 – MMET logical node, copied from [6]

MMET class				
Data Object Name	**Common Data Class**	**Explanation**	**T**	**M/O/C**
LNName		The name shall be composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2 clause 19		
Data Objects				
Measured Values				
EnvTmp	MV	Ambient temperature		O
WetBlbTmp	MV	Wet bulb temperature		O
CloudCvr	MV	Cloud cover level		O
EnvHum	MV	Humidity		O
DewPt	MV	Dew point		O
DifInsol	MV	Diffuse insolation		O
DirInsol	MV	Direct normal insolation		O
DlDur	MV	Daylight Duration (time elapsed between sunrise and sunset)		O
HorInsol	MV	Total Horizontal Insolation		O
HorWdDir	MV	Horizontal Wind direction		O
HorWdSpd	MV	Average Horizontal Wind speed		O
VerWdDir	MV	Vertical Wind Direction		O
VerWdSpd	MV	Average Vertical Wind speed		O
WdGustSpd	MV	Max Wind gust speed		O
EnvPres	MV	Barometric pressure		O
RnFll	MV	Rainfall		O
SnwDen	MV	Density of snowfall		O
SnwTmp	MV	Temperature of snowfall		O
SnwCvr	MV	Snowcover		O
SnwFll	MV	Snowfall		O
SnwEq	MV	Water equivalent of snowfall		O

With the services provided in IEC 61850-7-2, there are 3 possible options in which HCMC can use different services to retrieve the weather forecast information

4.2.1.1.1 HCMC use GetDataValues service in GenDataObjectClass to retrieve individual data object value

This option is suitable when HCMC only needs a single value among a lot of different meteorological information (e.g. only temperature or only daylight duration).

This solution suits the situation when the network is bandwidth-limited. Even though at the current time, the Layer 2 network standardized in IEC 61850 is Ethernet which is broadband network, IEC 61850 can also be mapped on other narrow bandwidth network like Zigbee for home application network. In this case, this solution is a good choice as it helps to reduce the bandwidth consumption.

The **GetDataValues** parameter table can be found in the Annex.

An example of using the **GetDataValue** is HCMC uses **GetDataValues** service to retrieve the ambient temperature **EnvTmp** from logical node **MMET** of the RCMC.

In this scenario, the **EnvTmp** should represent the average ambient temperature of the day and is calculated by the internal function of the **RCMC.EnvTmp** (instantiated from the CDC **MV – Measured value)** is composed of the data attribute **mag** (of type **AnalogueValue**) which represents the temperature. Figure 4.4 shows the **reference** for the **GetDataValues.request.**

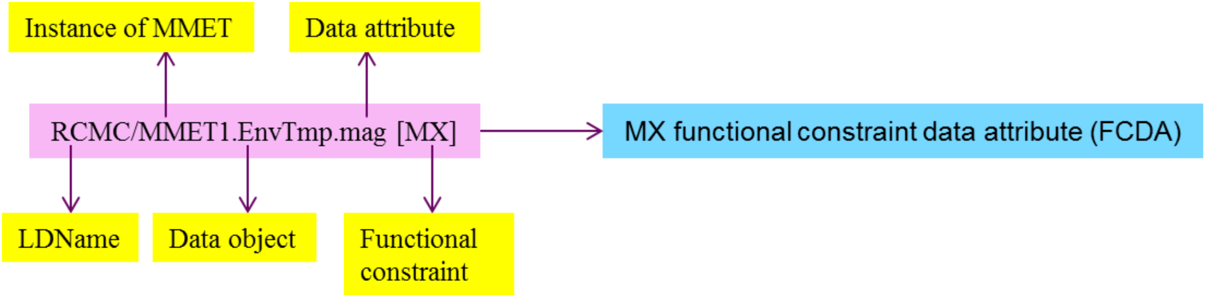

Figure 4.4 – Object reference with Functional constraint

If the service request succeeded, a **response+** with the average ambient temperature value will be returned.

In Figure 4.5, it is assumed that there's no application association established by HCMC between HCMC and RCMC. In this case, before sending the **GetDataValues.request** to retrieve information from RCMC, HCMC has to establish an application association following the **TWO-PARTY-APPLICATION-ASSOCIATION (TPAA)** class syntax as described above. This application association can be released after both parties finished exchanging information. However, it's not mandatory to terminate the association and keeping the association will help to eliminate delay and bandwidth consumption for exchanging the "associate" and "release" message every time HCMC needs to get data from RCMC. Therefore in the figure, the "release" message arrows are dash-typed means that the messages are optional.

The "Abort" service can also be used to abruptly disconnect a specific application association between the HCMC and RCMC and details about all of those services can be found in [4].

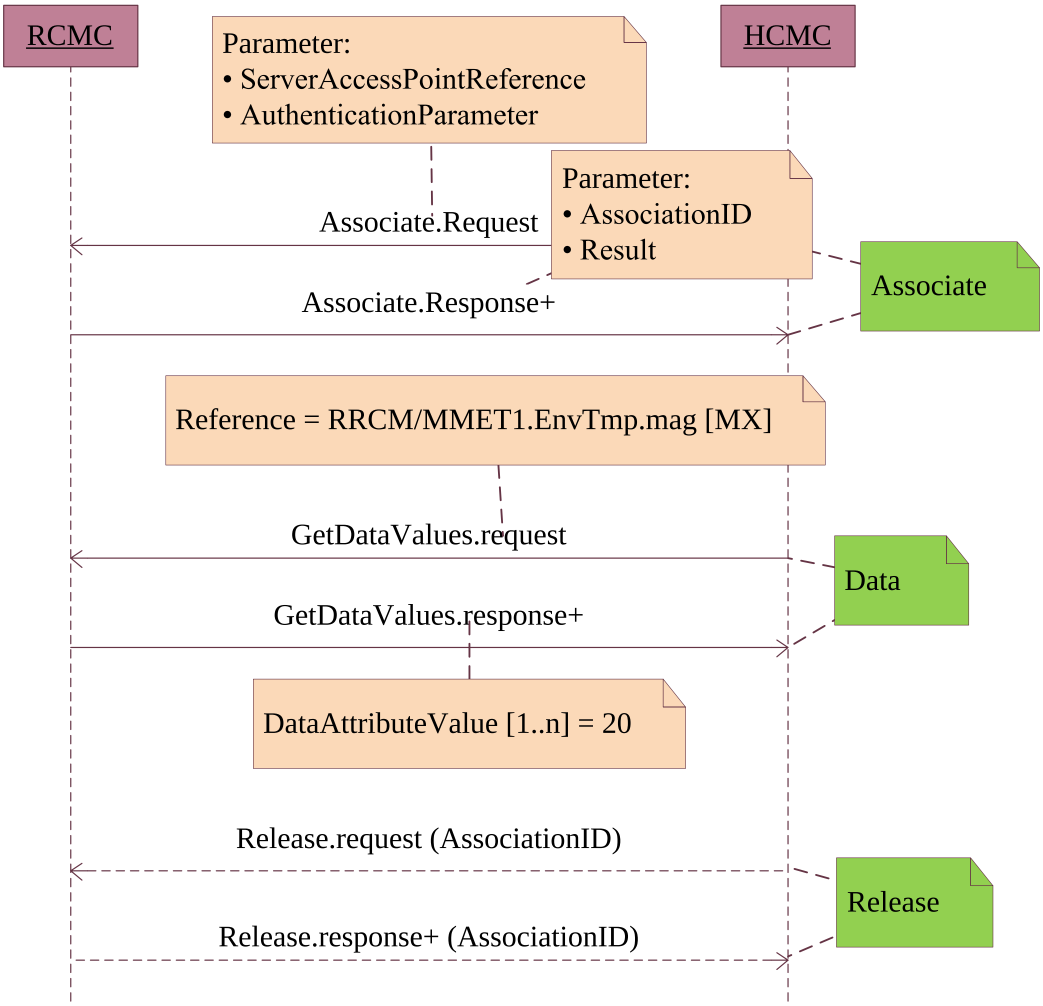

Figure 4.5 – HCMC uses GetDataValues service to get weather forecast information from RCMC

• **ServerAccessPointReference**	To identify the server with which the application association shall be established.
• **AuthenticationParameter**	if the **authenticationParameter** does not match a valid parameter, the service request shall be rejected
• **AssociationID**	to differentiate the application associations
• **Result**	Indicate whether the establishment is successful or not.

4.2.2.2.2 HCMC uses GetAllDataValues service in GenLogicalNodeClass to retrieve all data object values of an instance of LN MMET in RCMC

In this scenario, it is assumed that all the HCMCs of different Smart houses within the same region only need same information of weather forecast to predict the power demand of the day & output of the PV on that day in order to calculate the optimal schedule.

For simplification in this example, we assume that HCMCs only need information about the ambient temperature, humidity and daylight duration, and thus in RCMC, only the data object **EnvTmp**, **EnvHum**, **DlDur** which represent the ambient temperature, Humidity and Daylight duration respectively are needed.

Therefore, the instance **MMET1** of the logical node **MMET** in the RCMC will only contain the data objects **EnvTmp**, **EnvHum** and **DlDur.** The **GetAllDataValues** service enables the HCMC to retrieve all the information within a single request message. The **GetAllDataValues** service parameter can be found in the Annex.

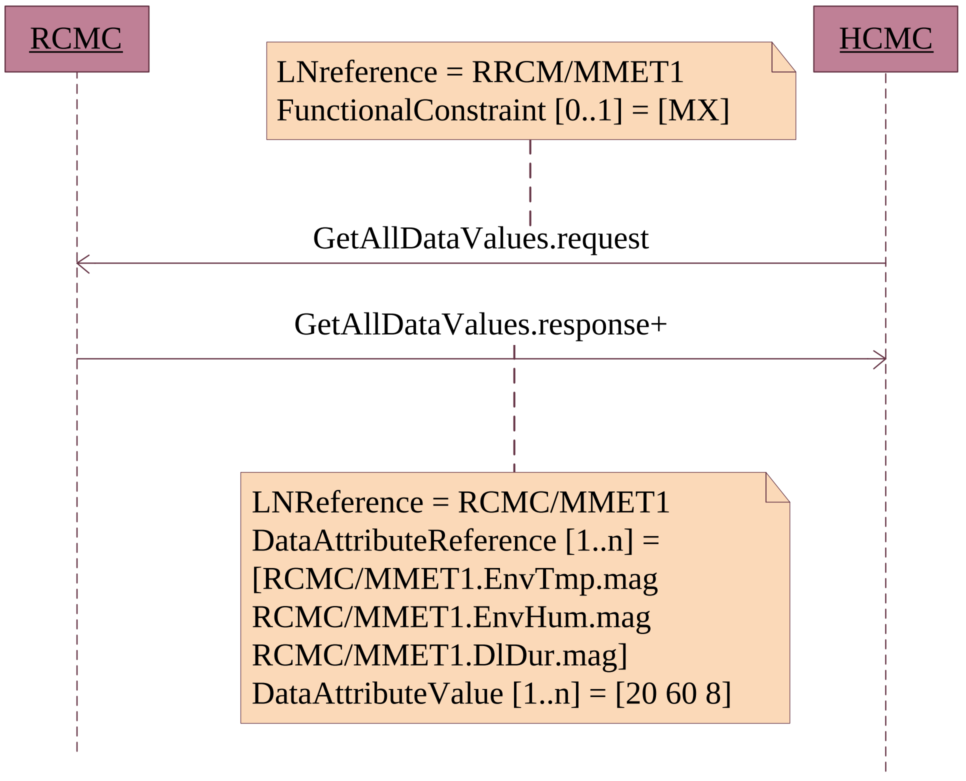

Figure 4.6 – HCMC uses GetAllDataValues service to get weather forecast information from RCMC

Figure 4.6 shows the message flow diagram when HCMC uses the **GetAllDataValues** service to retrieve the weather forecast information from RCMC. The **FunctionalConstraint MX** represents measurand information whose value may be read, substituted, reported, and logged but shall not be writeable [4]. The **FunctionalConstraint** (**FC**) is defined in *table 22 – Functional constraint value* in part IEC 61850-7-2 [4].

The returned values **[20 60 8]** represent the ambient temperature (20oC), humidity (60%) and daylight duration (8 hours) respectively.

In principle, the **FCD** is used, all the data attributes with the respective functional constraint will be returned in the **Response+** such as **q** (quality) and **t** (timestamp) which are mandatory. In the previous example, for simplification and illustration purpose, only part of the returned values is shown.

This **GetAllDataValues** service is well-suited when the HCMCs have the same configuration about creating schedule for energy resources. It also brings a convenience of getting all necessary data in a single request and required no pre-configuration like using Dataset. However, a shortcoming in comparison to the previous option is high bandwidth consumption. Therefore, this solution is more suitable for broadband network like Ethernet or wireless LAN such as IEEE 802.11g, 802.11n…etc.

4.2.2.2.3 HCMC uses GetDataSetValues in DATA-SET class to retrieve a group of data object values of an instance of LN MMET in RCMC

A **DATA-SET** is an ordered group of **ObjectReferences** of **DataObjects**, **SubDataObjects**, **DataAttributes**, and **SubDataAttributes** organized as a single collection for the convenience of the client.

The **GetDataSetValues** should be used by the HCMC to retrieve a group of weather forecast information provided by the RCMC.

It's very appropriate when RCMC provide a lot of different weather forecast information and each HCMC needs difference information as input for its algorithm to calculate the optimal schedule.

This option also allows great flexibility as it allows user to retrieve only information needed. However, it requires more effort for configuration the Dataset.

The **GetDataSetValues** parameter table can be found in the Annex

In the following example**,** HCMC uses **GetDataSetValues** service to retrieve the values of ambient temperature, humidity and daylight duration (**EnvTmp**, **EnvHum**, **DlDur)** which are the member of the Data-set **WeaInf**

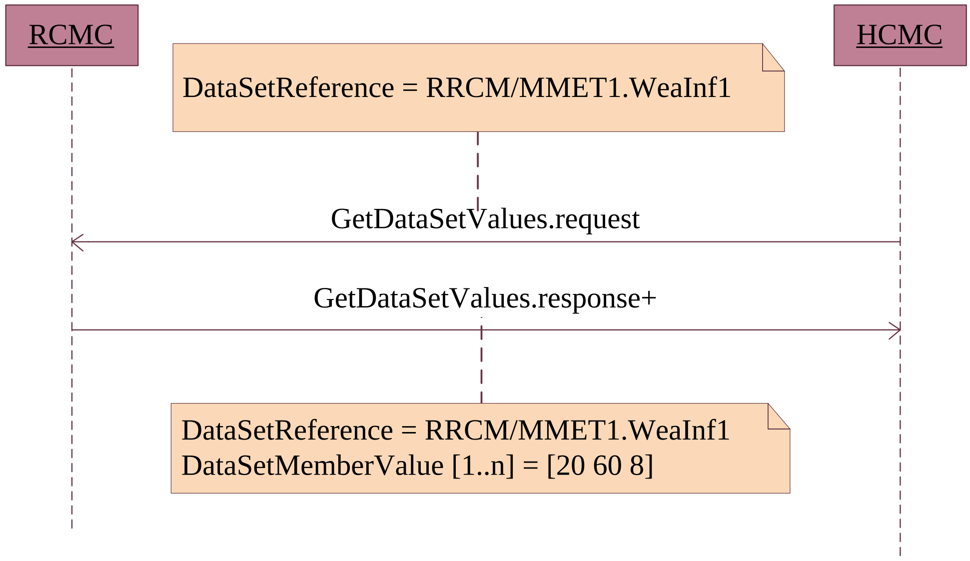

Figure 4.7 – HCMC uses GetDataSetValues service to get weather forecast information from RCMC

In Figure 4.7, HCMC sent a request using the GetDataSetValues service to retrieve the data values of the data objects of the Data-set **WeaInf** by specifying the reference of this Data-set. On receiving the request, RCMC responded with the value of all the Data set members which in this case are temperature, humidity and daylight duration (**EnvTmp**, **EnvHum**, **DlDur)**.

4.2.1.2 Hybrid Inverter information exchange

HCMC needs information about the power condition of the PV & ES which are connected to the Hybrid Inverter. In this use case, the Hybrid Inverter can be considered as a Hybrid Controller which controls both the PV & ES. It also stores the information about the power condition of the PV and ES. Hence, when HCMC needs information about the PV & ES, it will initiate a request message to the Hybrid Inverter.

For scheduling purpose, typically HCMC needs information about the connection status of the PV & ES and the State of Charge of the ES (Battery). Therefore, HCMC should use the **GetDataSetValues** service to retrieve this information from the Hybrid Controller. The Data-set that contains this information can be pre-defined as in Figure 4.8

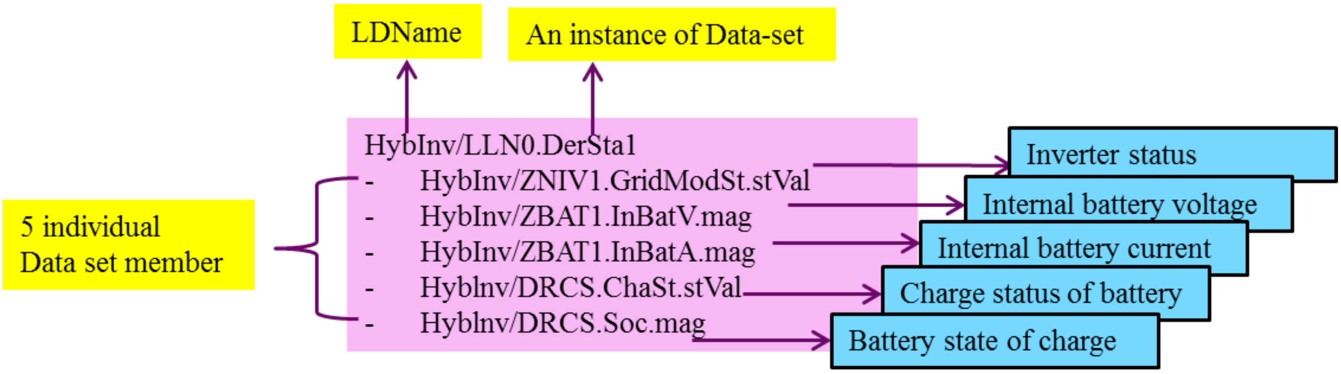

Figure 4.8 – Example of Hybrid inverter status information Data-set

With the **GetDataSetValues** service, HCMC can send only one request to the Hybrid Inverter to get back the information about the status of the PV and ES connected to the Hybrid Inverter. This function should be performed as illustrated in Figure 4.9.

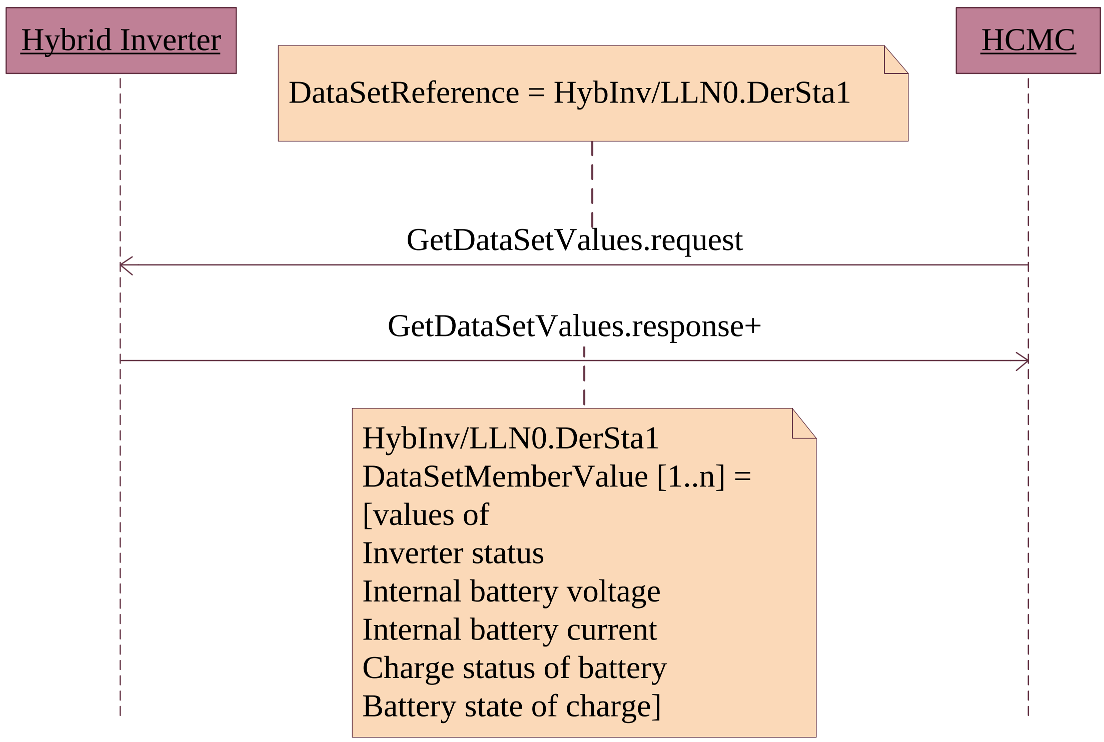

Figure 4.9 – HCMC uses GetDataSetValues service to get HI status information from HI

In Figure 4.9, HCMC used the **GetDataSetValues** services to retrieve the values of all Data-set member of the **DerSta1** which was defined in Figure 4.8

4.2.1.3 HCMC sends schedule to Hybrid Inverter

For the inverter-based DER systems, a single operational mode may not be suitable or efficient all the time. Therefore, the operational mode of the DERs should be changed due to specified time periods. Without schedules which the DERs can autonomously follow, HCMC needs to send many control commands per a few hours or even less. It may create negative impact on the bandwidth-limited communication systems. Hence, it is better to establish daily schedules which can be sent to the Hybrid Inverter at the beginning of a day so that the Hybrid Inverter will let the DERs autonomously switch the operational modes at a specific point of time. The schedules can also be established for several a few days or even for a week. However, in this use case we assume that the schedules will be calculated per day since the daily weather forecast information should be more accurate than the weekly one. IEC 61850-7-420 [7] defines the logical nodes **DSCH** for building a schedule.

Table 4.7 – DSCH class, copied from [7]

DSCH class				
Data name	**CDC**	**Explanation**	**T**	**M/O/C**
LNName		Shall be inherited from logical-node class (see IEC 61850-7-2)		
Data				
System logical node data				
		LN shall inherit all mandatory data from common logical node class		M
		Data from LLN0 may optionally be used		O
Status information				
SchdSt	INS	Indication that this schedule has been activated		M
Settings				
SchdId	ING	Non-zero identity of the schedule		M
SchdCat	ING	Category of schedule: Value – Explanation 0 – Not applicable / Unknown 1 – Regular 2 – Backup 3 – Emergency 4 – Maintenance 99 – Other		M
SchdTyp	ING	Type of schedule, identifying the operating mode under which the schedule will be used: Value – Explanation 0 – Not applicable / Unknown 1 – Energy 2 – Contingency reserve "spinning" 3 – Contingency reserve supplemental 4 – Emergency reserve 5 – Emission reserve 6 – Energy balancing 7 – Reactive power 8 – Black start 9 – Emergency islanding 99 – Other		M
SchdAbsTm	SCA	Array of energy targets for each schedule period using absolute time, starting at zero (UTC epoch)		C1
SchdRelTm	SCR	Array of energy targets for each schedule period using relative time offsets		C2

<table>
<tr><td>SchdVal</td><td>ING</td><td>Meaning of the val parameter in the SCA or SCR:<table><tr><th>Value</th><th>Explanation</th></tr><tr><td>0</td><td>Not applicable / Unknown</td></tr><tr><td>1</td><td>Active power</td></tr><tr><td>2</td><td>Reactive power</td></tr><tr><td>3</td><td>Power factor</td></tr><tr><td>4</td><td>Voltage</td></tr><tr><td>5</td><td>Price for active power</td></tr><tr><td>6</td><td>Price for reactive power</td></tr><tr><td>7</td><td>Heat</td></tr><tr><td>99</td><td>Other</td></tr></table></td><td></td><td></td></tr>
<tr><td colspan="5">Either C1 or C2 shall be used but not both</td></tr>
</table>

Multiple schedules can be pre-defined in the Hybrid Inverter. At each day, based on the received weather forecast information, demand and output data of the previous day, current lifestyle control mode, HCMC can decides which schedule should be activated.

The logical node **DSCC** defined in [7] is used to control the schedule

Table 4.8 – DSCC class, copied from [7]

DSCC class				
Data name	**CDC**	**Explanation**	**T**	**M/O/C**
LNName		Shall be inherited from logical-node class (see IEC 61850-7-2)		
Data				
System logical node data				
		LN shall inherit all mandatory data from common logical node class		M
		Data from LLN0 may optionally be used		O
Status information				
ActWSchdSt	INS	Indication of which energy schedule is active – schedule 0 indicates no schedule		M
ActAncSchdSt	INS	Indication of which ancillary services schedule is active – schedule 0 indicates no schedule		M
Controls				
ActWSchd	SPC	Activate specific energy schedule, using TimeActivatedOperate to establish start time for schedules using relative time and if start time is in the future. ctrVal: 0 = deactivate, 1 = activate		M
ActAncSchd	SPC	Activate specific ancillary services schedule, using TimeActivatedOperate to establish start time for schedules using relative time and if start time is in the future. ctrVal: 0 = deactivate, 1 = activate		M

Table 4.9 gives an example of an energy schedule is setup using DSCH logical node [13]

Table 4.9 – Example of DSCH schedule

DSCH			
Data object	**Data Attribute**	**Value**	**Explanation**
SchdID	stVal	1	Schedule ID – uniquely identify the schedule within an IED
SchdCat	stVal	1	Category of the schedule - regular
SchdTyp	stVal	1	Operational mode - energy
SchdAbsTm	numPts	24	24 hours – absolute time
	val	[0.2, 0.3, 0.5…]	Power for each hour
	time	[t0, t1, t2, …]	Start time of each hour
	valUnit	1	KW
SchdVal	stVal	1	Active power

This schedule defines the expected output of the PV panel. This schedule can be pre-configured at the Hybrid Inverter based on the historical data, user habit, weather condition…or can be dynamically created by the HCMC based on the specific weather forecast information for that day plus the historical data of the previous days.

For creation of the schedule, the service **CreateDataSet** and **SetDataSetValues** can be used.

In this use case, it's assumed that the schedules were pre-configured and the HCMC only choose to activate the most suitable one based on the currently receiving data.

In order to activate a schedule, the respective instance of the control schedule logical node **DSCC** should be activated by setting the data attribute **stVal** of the data object **ActWSchd** to TRUE for the energy schedule (for ancillary services schedule, the data attribute **stVal** of the data object **ActAncSchd** should be set).

The direct control with normal security model can be used for this purpose.

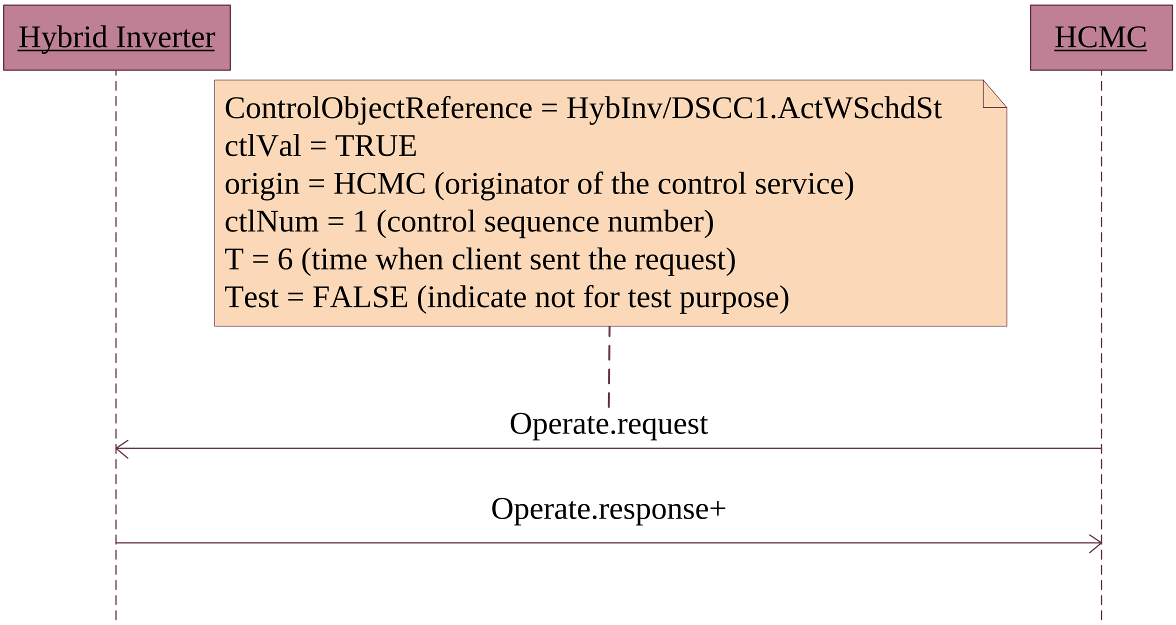

Figure 4.10 – HCMC uses Operate service to activate a schedule at HI

In Figure 4.10, the **Operate** service is used means that the schedule will be activated immediately. However, HCMC can use **TimeActivatedOperate** to establish the start time for this schedule using relative time and if the start time is in the future.

4.2.2 Scenario 2 – Appliances automatic control

In this scenario, the Home Control and Management Center can autonomously control all the smart appliances based on the rules pre-defined in the associated lifestyle control mode which pre-set by the user. Within the pre-defined lifestyle mode chosen by the user, the HCMC will control the appliances to use energy most efficiently.

In this use case, the basic control functions of the HCMC are basically switching ON/OFF any appliances and moderating the energy consumption of an appliance by tuning its operational parameters.

For this scenario, it is needed to use the new logical nodes that defined in chapter 3 for power control of the smart appliances. The new logical node has been defined for general control purpose of all smart appliances named ***ZALP***. This logical node provides the data object for switching ON/OFF a smart appliance as well as moderating its energy consumption by setting the load target (%).

This logical node also allows setting the operational mode of the appliance as **autonomous** in which the appliance can operate due to its internal algorithm; or schedule in which the appliance will follow a pre-defined schedule. If the manual mode is set, the HCMC will not be able to control the appliance. The load target is measured in percentage allows the HCMC to set the energy consumption of the appliance.

The data object **OperCtl** provides the ability to start/stop the appliance remotely by setting the corresponding data attribute **stVal** to TRUE/FALSE. Basically, the **Operate** service provided in **CONTROL** class and the **SetDataValues** service provided in the **GenDataObjectClass** can be used to start/stop the appliance and set the load target. The parameter of the **SetDataValues** service is defined in [7].

In the following example, the HCMC will use the IEC 61580 service model to turn off the TV and decrease the energy consumption of the lighting system by setting the load target.

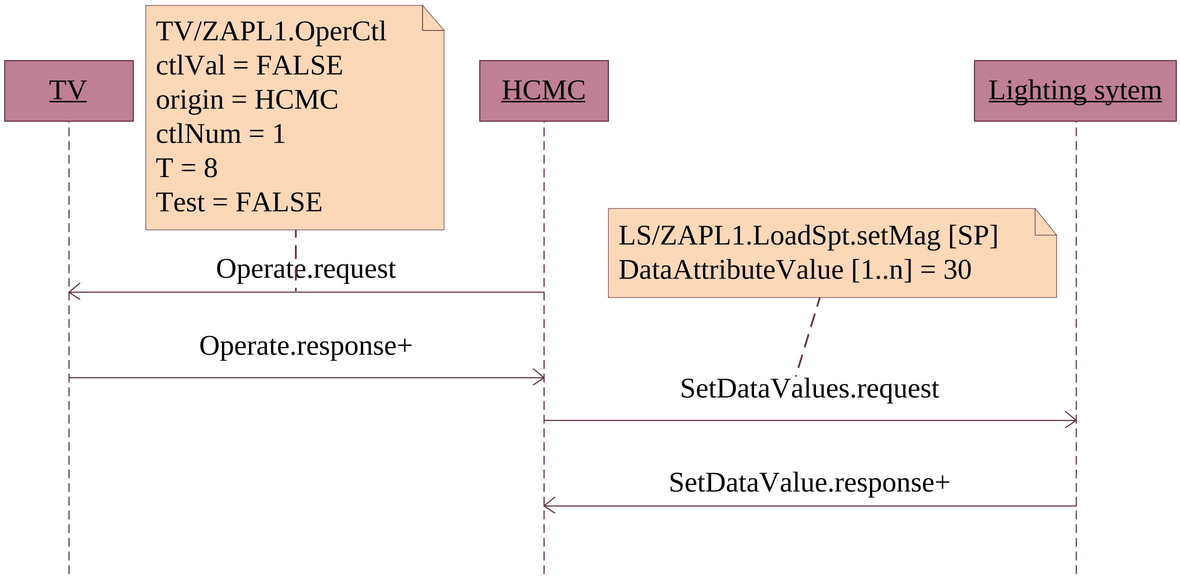

Figure 4.11 – HCMC controls smart appliances to reduce energy consumption

In Figure 4.11, HCMC turned off the TV by setting the data attribute **ctlVal = FALSE**. The parameter T = 8 indicates that the control command was issued at 8 o'clock. The **ControlObjectReference** = **TV/ZAPL1.OperCtl** indicates the **ObjectReference** of the controllable data object **OperCtl.**

The **Operate** service was implemented following the direct control with normal security model.

Similarly for the lighting system, the **reference = ZAPL1.LoadSpt.setMag [SP]** defined the **Functional Constraint Data (FCD)** and the Functional Constraint FC = SP means that the data attribute **setMag** represents a set-point information whose value may be controlled (control model) and read; and value controlled shall become effective immediately.

4.2.3 Scenario 3 – Demand response signal

The Demand Response (DR) Signal is sent from RCMC to the HCMC to suggest the HCMC to decrease the energy consumption in peak demand periods.

This control action requires the use of the new logical node ***ZHCM*** defined in chapter 3.

4.2.3.1 Metering information report from the Smart meter

The RCMC should have an overall picture about the energy consumption of the regional microgrid and the energy consumption of each Smart house. In order to obtain this information, the RCMC needs to connect to the Smart Meter located at each house and establish an application association to receive the metering information from the Smart Meter.

The metering function of the Smart Meter can be modeled as a MMTN logical node defined in IEC 61850-7-4 [6]

Table 4.10 – MMTN class, copied from [6]

MMTN class				
Data Object Name	**Common Data Class**	**Explanation**	**T**	**M/O/C**
LNName		The name shall be composed of the class name, the LN-Prefix and LN-Instance-ID according to IEC 61850-7-2 clause 19		
Data Objects				
Metered Values				
TotVAh	BCR	Net apparent energy since last reset		O
TotWh	BCR	Net Real energy since last reset		O
TotVArh	BCR	Net Reactive energy since last reset		O
SupWh	BCR	Real energy supply (default supply direction: energy flow towards busbar)		O
SupVArh	BCR	Reactive energy supply (default supply direction: energy flow towards busbar)		O
DmdWh	BCR	Real energy demand (default demand direction: energy flow from busbar away)		O
DmdVArh	BCR	Reactive energy demand (default demand direction: energy flow from busbar away)		O

The **report** service in **UNBUFFERED-REPORT-CONTROL-BLOCK (URCB)** class should be used by the Smart meter to send the metering information to the RCMC. Since this information is for controlling purpose only, the RCMC needs only the newest information from the Smart meter.

The **report** service includes the parameters in table 4.11

Table 4.11 – DSCC class, copied from [7]

ReportFormat		
Parameter name	**Parameter type**	**Explanation**
RptID	VISIBLE STRING65 [a]	Report identification
OptFlds	[a]	Optional fields to be included in the report
IF sequence-number = TRUE in optFlds		
SqNum	INT16U	Sequence number
SubSqNum	INT16U	Subsequence number
MoreSegmentsFollow	BOOLEAN	More report segments with the same sequence number follow
IF dat-set-name = TRUE in optFlds		
DatSet	ObjectReference [a]	Data set reference
If conf-revision = TRUE in optFlds		
ConfRev	INT32U	
Entry		
IF report-time-stamp = TRUE in optFlds		
TimeOfEntry	EntryTime	
EntryData [1..n]		
IF data-reference = TRUE in optFlds		
DataRef	ObjectReference	Respective DataAttrRef
Value	(*)	(*) type(s) depend on the definition of common data classes in IEC 61850-7-3
ReasonCode	ReasonForInclusion	If reason-for-inclusion (= TRUE) in optFlds. For the definition see 6.1.2.13.
[a] The type and value of this parameter shall be derived from the respective attribute of the **BRCB or URCB**.		

Figure **4.12** shows an example of a report sent from the Smart meter to the RCMC. This report has the sequence-number of 123 and the triggered option is Data-update means the report was triggered because the value of the **TotWh** which represents the total energy consumption was updated.

This allows the generation of periodic reports following the configuration of the **MMTN** data attributes **frPd** of the common data class **BCR**. More information can be found in IEC 61850-7-3 [22].

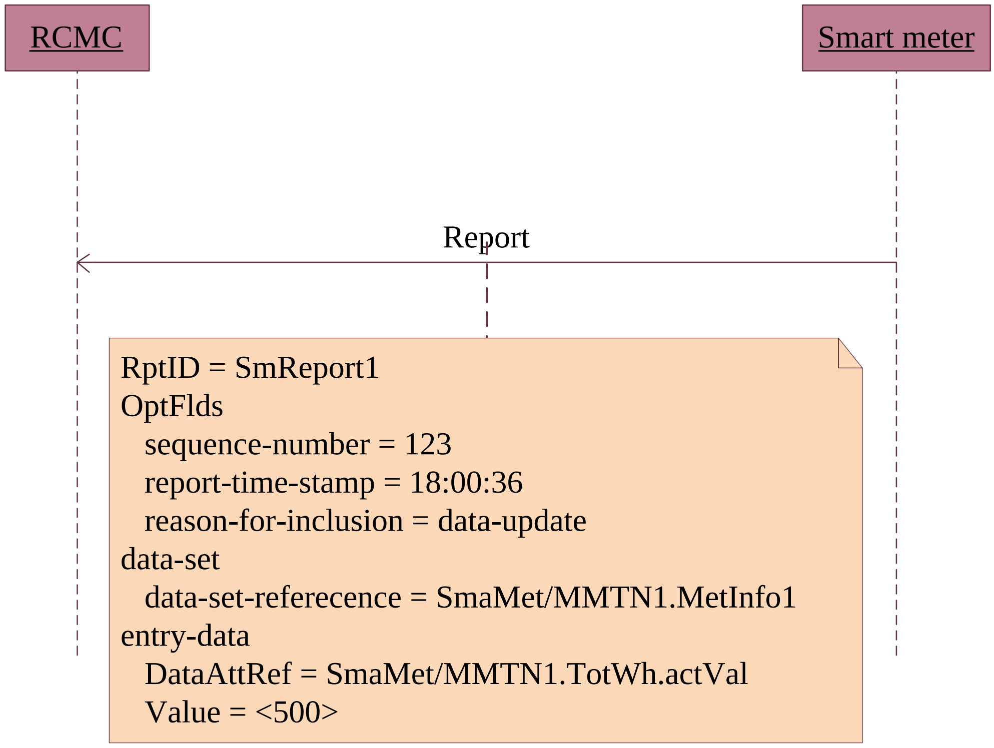

Figure 4.12 – Smart meter sends report with measured data to RCMC

4.2.3.2 Demand Response Signal issued by the RCMC

During peak demand periods, the RCMC calculates the amount of energy consumption expected to be reduced at each smart house based on the information about the current energy consumption of the smart houses.

In the HCMC, there should be a logical node composed of a controllable data object which represents the expected maximum energy consumption of the smart house. The owner of the smart house can configure the HCMC whether to allow remote control from the RCMC or not. If the owner gives control permission to the RCMC, the RCMC can control the energy consumption of the smart house by moderating this set-point. This logical node is **ZHCM** which is defined in chapter 2.

The **SetDataValues** service can be used by the RCMC to set the set-point of the maximum energy consumption of the smart house. An example is shown in Figure 4.13.

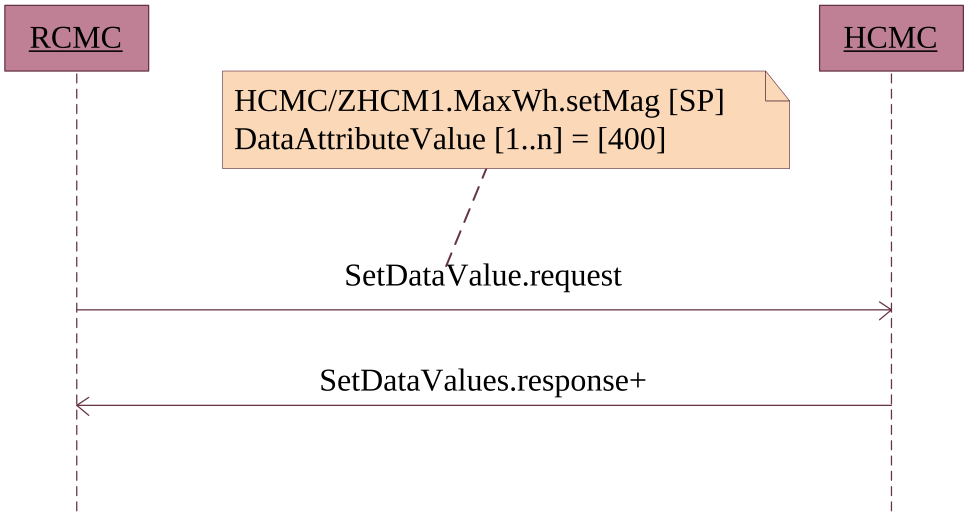

Figure 4.13 – RCMC sets the maximum energy consumption of the smart house

A returned **response+** indicates that the **SetDataValues** service was performed successfully. Otherwise, a **ServiceError** will return to inform the RCMC that there's a conflict or another problem so that the service was not successful. The specified **ServiceError** type can give the RCMC an idea about the problem.

Table 4.12 – ServiceError type definition, copied from [4]

ServiceError type definition			
Attribute name	**Attribute type**	**Value /value range/explanation**	**Used by**
ServiceError	ENUMERATED	instance-not-available | instance-in-use | access-violation | access-not-allowed-in-current-state | parameter-value-inappropriate parameter-value-inconsistent | class-not-supported | instance-locked-by-other-client | control-must-be-selected | type-conflict | failed-due-to-communications-constraint | failed-due-to-server-constraint | no-error	IEC 61850-7-2

4.2.3.3 HCMC control the DERs and smart appliances to reduce energy consumption from the grid

Once the RCMC successfully set the maximum energy consumption of the smart house to a lower value, the HCMC will control the DERs to produce more energy or using the redundant energy in the storage and/or decreasing the energy consumption by the appliances.

4.2.3.3.1 Increasing energy generation of the PV panel

It can be done by increasing the Output target watts set-point of the PV. The DER unit controller logical node **DRCT** should be implemented on the Hybrid Inverter for this purpose. The instance **DRCT1** represents the control logical node instance of the PV.

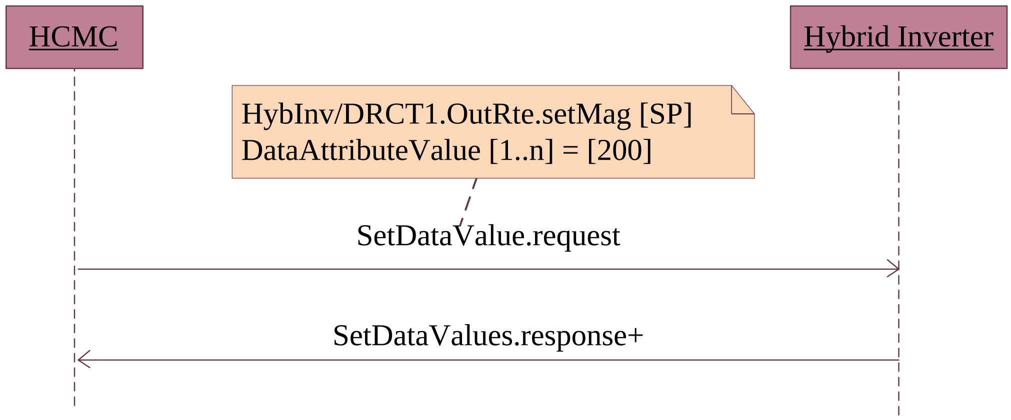

Figure 4.14 – HCMC increases the PV output

Figure 4.14 gives an example of HCMC using the SetDataValues service to set the maximum output **OutRte** of the PV panel by sending the request message to the Hybrid Inverter which can be considered the control module of the PV panel.

4.2.3.3.2 Set the Energy storage to discharge mode

Normally, the Energy storage (battery) will be set to charging mode in which it stores the energy produced from the PV for backup purpose. When there is a blackout in the transmission grid, this backup energy should be used to assure the operation of the most important appliances in the house. However, when the available energy in the grid is not enough or the transmission grid facing to problem due to peak demand request, the energy storage should also be set to discharge mode in order to release the grid from peak demand problem.

The HCMC has to issues command to set discharge rate by setting data object **OutWRte** of the instance **DRCT2** of logical node **DRCT** which represents ES, and then enable discharge rate by setting the data object **OpModExIm** of the logical node **DOPM** [7] [9]. This process is illustrated in Figure 4.15.

The value of the data object **OutWRte** decides if the battery is in charge or discharge mode. If the value is positive, the battery is discharging and vice versa.

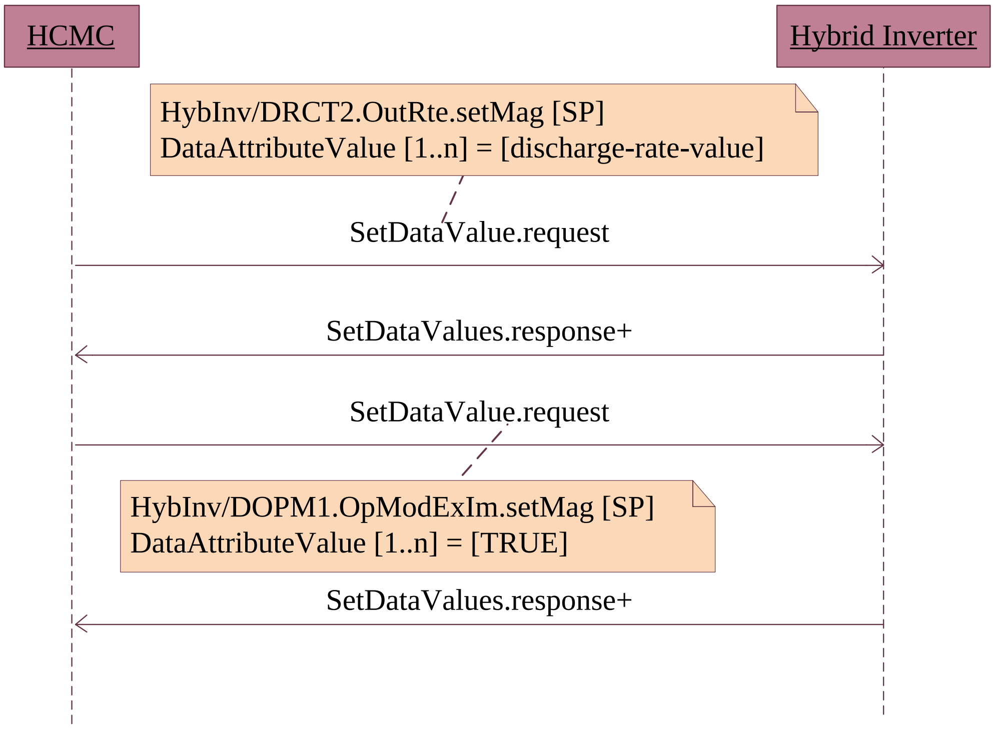

Figure 4.15 – HCMC sets the ES to discharge mode

4.2.3.3.3 Decreasing the energy consumption of the smart appliances

Another way to reduce the energy consumption of the house is to reduce the energy consumption of the appliances that are consuming much energy at this period. This can be done by modifying the energy set-point of the appliance.

For example, the HCMC can set the speed set-point of the Fan to a lower value in order to decrease the energy consumption of the Fan. Similarly, the temperature of the heater can also be decreased to reduce its energy consumption.

For other appliances, the new logical node ZHCM needed to be implemented in order to allow HCMC to control the energy consumption of those devices by setting the set-points.

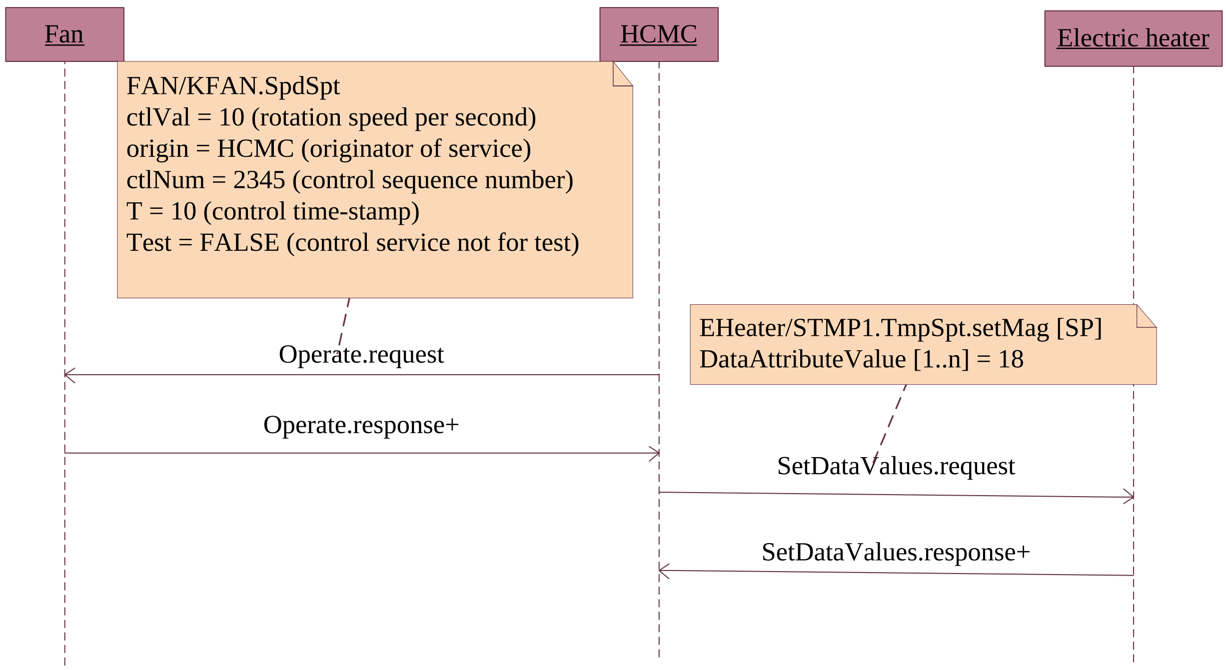

Figure 4.16 – HCMC control the Fan and Electric heater to reduce energy consumption

Figure 4.16 shows an example of smart appliances power control. HCMC can control the consumption of electricity of the Fan and the Electrical heater by setting their operating functions which are the speed and temperature respectively.

4.3 Mapping to MMS

The IEC 61850 protocols can be mapped to different communication profiles based on the performance requirements. The mapping principle was described in section 2.1.7 in detail.

For power control functions, the messages should be used are categorized in the type 2 (Medium speed messages), type 3 (Low speed messages) and type 5 (control command and file transfer) [2] because they are not needed to be time-critical. Figure 2.5 shows that these message types will be mapped to MMS.

Table 4.13 shows the mapping of IEC 61850 objects to the MMS objects and respective services.

Table 4.13 – MMS objects and services, copied from [8]

MMS OBJECT	IEC 61850 OBJECT	MMS SERVICES IN USE
Application Process VMD	Server	Initiate Conclude Abort Reject Cancel Identify[1]
Named Variable Objects	Logical Nodes and Data	Read Write InformationReport GetVariableAccessAttribute GetNameList
Named Variable List Objects	Data Sets	GetNamedVariableListAttributes GetNameList DefineNamedVariableList DeleteNamedVariableList GetNameList Read Write InformationReport
Journal Objects	Logs	ReadJournal InitializeJournal GetNameList
Domain Objects	Logical Devices	GetNameList GetDomainAttributes StoreDomainContents
Files	Files	FileOpen FileRead ObtainFile FileClose FileDirectory FileDelete
[1] Required by ISO 9506 for conformance.		

Mapping of IEC 61850-7-2 [4] and IEC 61850-7-3 [5] data attributes can also be found in IEC 61850-8-1 [8].

For example table 4.14 shows the mapping of **GetDataValues** service to MMS **Read** service

Table 4.14 – Mapping of GetDataValues service parameters, copied from [8]

GetDataValues parameters	MMS service or parameter	Constraint
Request	Read request service	
Reference	variableAccessSpecification	Maps to a 8-1VARSPEC
Response+	Read response service	
DataAttributeValue[1..n]	listOfAccessResult	
Response–	Read response service	
ServiceError	listOfAccessResult	See **Table 27**

To further clarify that mapping by specific example, Figure 4.5 which shows that HCMC uses the **GetDataValues** service to retrieve the temperature value from RCMC is reproduced to Figure 4.17 in which HCMC uses the **Read** service to get the temperature value from RCMC.

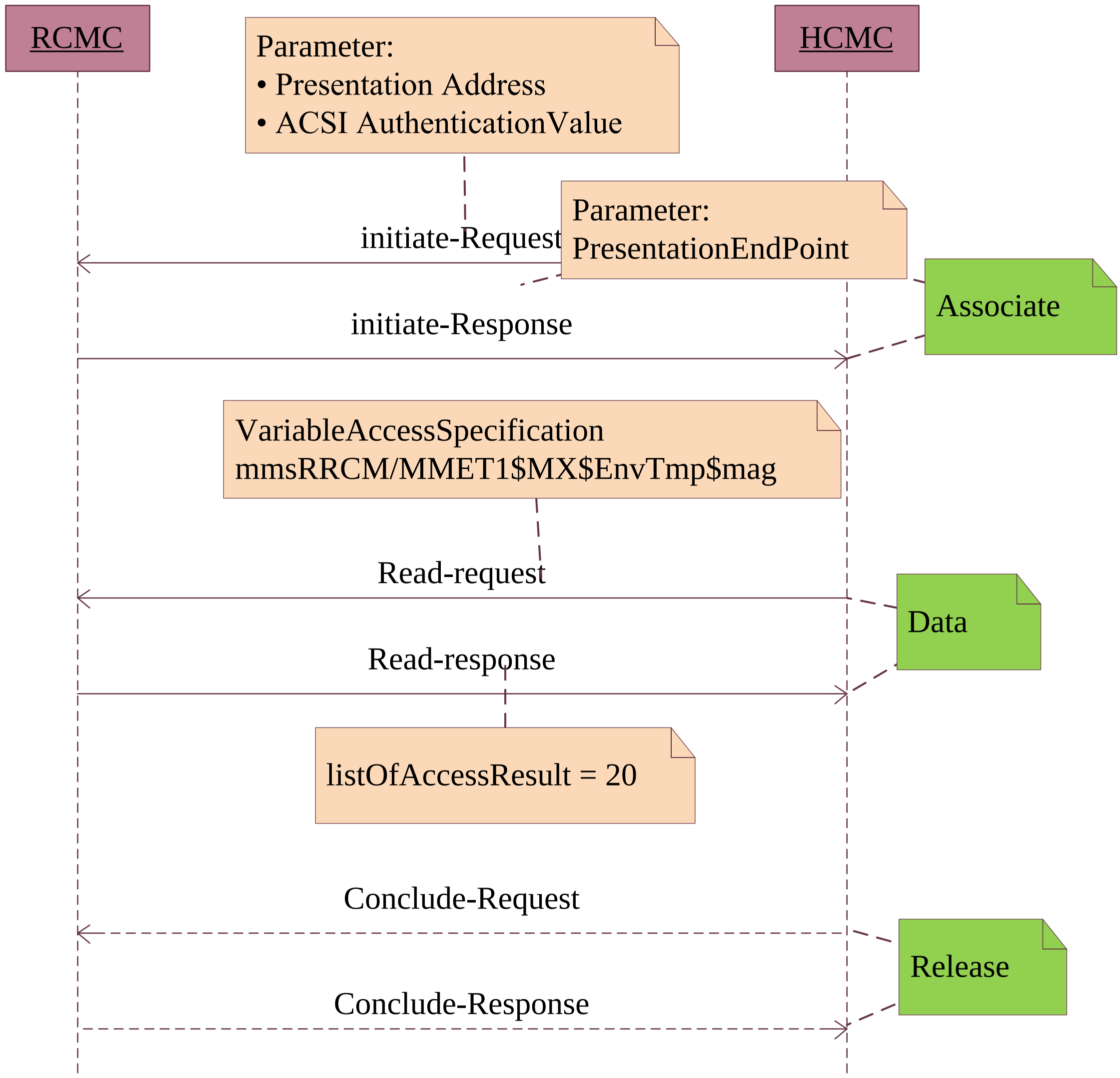

Figure 4.17 – HCMC uses Read service to get weather forecast information from RCMC

Figure 4.17 also maps the "**associate**" and "**release"** abstract services in IEC 61850 to establish a two-way application association to the "**initiate**" and "**conclude**" services in MMS.

4.4 Summary

This chapter presented a step-by-step analysis of using IEC 61850 data models and services to control the generation and consumption of electricity in a LV Microgrid. Firstly, a Use case with typical control behaviors and algorithms was defined applying the communication topology designed in chapter 3 to manage the energy usage of a LV Microgrid. Secondly, the IEC 61850 abstract services defined in IEC 61850-7-2 were applied to perform all the control functions. Many explicit examples were given in form of message flow diagrams to illustrate the way of using these abstract services to perform real control functions. For a specific control behavior i.e. retrieving data objects from logical nodes, the report showed various options which applied different services based on the characteristics of the underlying communication networks. This illustrated the flexible capability of IEC 61850 protocols for power control of LV Microgrids.

This chapter concluded with a specific example of how to map the IEC 61850 abstract services to a real protocol – MMS. It proved the possibility of implementing IEC 61850 for power control in LV Microgrid.

Chapter 5

Conclusion and Future work

IEC 61850 is an extensible protocol to support a growing demand in different domains. Initially it was designed for interoperability of different IEDs within Substation Automation Systems, and then was further extended to support object models for power plants, DER and inter-substation communication.

This report has shown a very new possible domain for IEC 61850 protocols, that is the LV Microgrid power control. Chapter 3 and chapter 4 provided clear evidences for that new proposal by applying IEC 61850 data object models and services to control various electrical devices inside a LV Microgrid with the objective of managing the consumption and generation of electricity in the network. The objectives of the research stated in chapter 1 were respectively achieved in chapter 3 with the design of communication network topologies and models of smart appliances and DERs with existing and new logical nodes, and chapter 4 with insightful analysis of applying the IEC 61850 abstract services to access to the data in logical nodes in order to perform a lot of different control functions.

IEC 61850 is a very complex standard with many documents. Chapter 2 of this report summarized the key contents of the standard to provide an overall picture of the standard scope, content and applications. With clear examples, this report helped to clarify the some parts of the standard which were written in a theoretical and abstract manner.

In short, the most important contribution of this research is showing the feasibility of applying IEC 61850 in the distribution-customer domain without significant changes to the protocols. The significant benefit is that it provides a solution for the interoperability problem in the customer domain when multiple protocols have been applying to perform similar control functions. IEC 61850 has been extending to cover both the High voltage and medium voltage networks; therefore, it will be advantageous to use the protocols for the Low voltage network in order to eliminate the requirement for the complex protocol converters.

Beside the technical aspect proposed in this report, one important issue that should be taken into consideration when designing a microgrid is the users' privacy. Even though it is a social issue, it must be considered carefully since the users have the right to decide whether or not to share their personal information. All of the social problems regarding control and management of microgrids require further study and long-term research to balance the utilization of technical advances and the human right of privacy.

For future work, there should be more use cased defined for different purposes such as voltage stabilization, microgrid islanding, etc. to see whether IEC 61850 can be used to support these use cases. New logical nodes for smart appliances should be defined also since there are hundreds of different electrical household appliances many of which have complex functions.

The Demand Response feature can be improved by giving the Regional Control and Management Center direct access and control of the DERs. It can be done by using the "proxy" defined in IEC 61850. Proxies are special devices that mirror logical devices located in other IEC 61850 physical devices. Figure 5.1 shows how multiple devices are mapped to one physical device. The logical device LD1 is copied from physical device PHD "A" to the physical device PHD "D". PHD "D" is a proxy. Similarly, logical device LD5 and LD6 of physical device PHD "B" are also mirrored to PHD "D". Therefore the information objects of physical device A and B, or more precisely of logical devices LD1, LD5 and LD6 are available in physical device D. From the functional point of view, these logical devices are transparent [3]. The information objects of none-IEC 61850 devices can also be mapped to IEC 61850 physical devices. In this case, this device is called a gateway which translates protocols to other protocols. In figure 5.1, PHD "D" is both proxy and gateway.

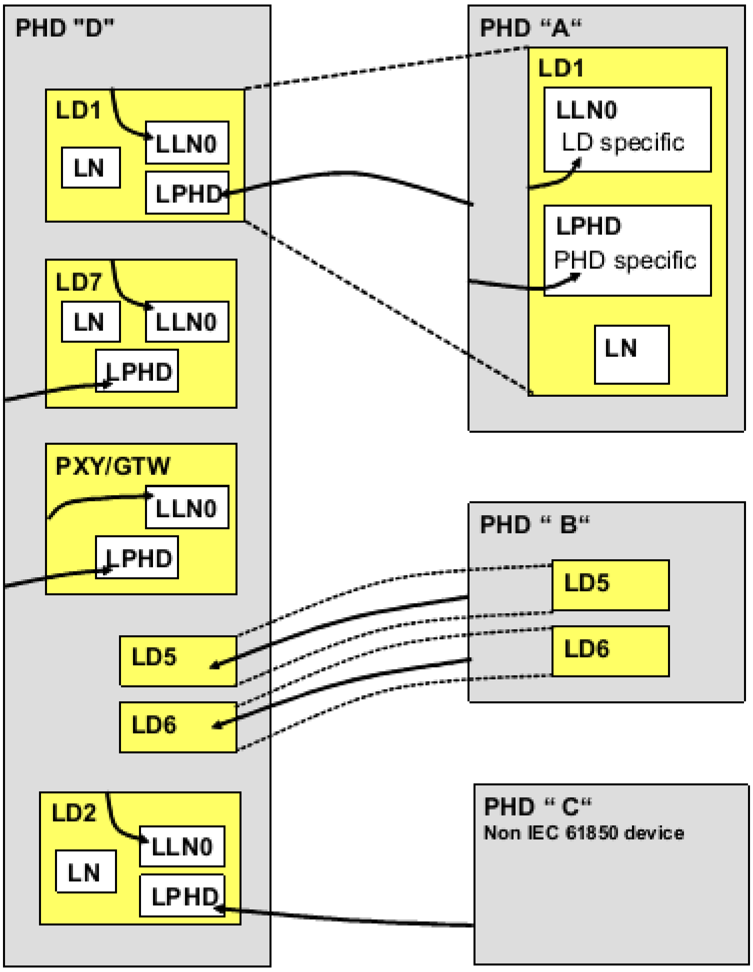

Figure 5.1 – Logical devices in proxies or gateways, copied from [3]

Applying the concept of proxy, HCMC can mirror the logical devices of the DERs so that RCMC can have access and control to those devices through HCMC.

Another possible direction for future work is about the mapping of IEC 61850 application protocols to the underlying communication network. IEC 61850 defines the mapping between ACSI services and underlying protocols such as Ethernet, MMS, etc. In this report, the actual message format exchange has been examined. The next step is to investigate how communication technologies, such as ZigBee, 802.11, 3G, LTE, etc., can support the use of IEC 61850 for different applications from different domains, e.g. metering, control and automation.

References

[1]. IEC 61850-1 TR Ed.2, “Communication networks and systems for power utility automation – Part 1: Introduction and Overview”, 2012.

[2]. IEC 61850-5, “Communication networks and systems for power utility automation – Part 5: Communication requirements for functions and device models”, 2012.

[3]. IEC 61850-7-1 Ed.2, “Communication networks and systems for power utility automation – Part 7-1: Basic communication structure – Principles and models”, 2008.

[4]. IEC 61850-7-2 Ed.2, “Communication networks and systems for power utility automation – Part 7-2: Basic information and communication structure – Abstract communication service interface (ACSI)”, 2008.

[5]. IEC 61850-7-3 Ed.2, “Communication networks and systems for power utility automation – Part 7-1: Basic communication structure – Common data classes”, 2008.

[6]. IEC 61850-7-4, “Communication networks and systems for power utility automation – Part 7-4: Basic communication structure – Compatible logical node classes and data classes”, 2008.

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Annex

IEC 61850 services parameter tables

1. **GetDataValues** service and **SetDataValues** service parameters table

GetDataValues service

Parameter name
Request
Reference
Response+
DataAttributeValue [1..n]
Response–
ServiceError

SetDataValues service

Parameter name
Request
Reference
DataAttributeValue [1..n]
Response+
Response–
ServiceError

- **Reference**: shall define the functional constrained data (**FCD**) or functional constrained data attributes (**FCDA**) of the data object whose data attribute values are to be retrieved. The Reference shall be FCD or FCDA
- **Response+:** shall indicate that the service request succeeded.
- **DataAttributeValue [1..n]:** contain the values of all data attributes of a data object referenced by FCD; or the value of a data attribute referenced by FCDA.
- **Response-*:*** shall indicate that the service request failed. The appropriate **ServiceError** shall be returned.

2. **GetAllDataValues** service parameters table

Parameter name
Request
LNReference
FunctionalConstraint [0..1]
Response+
LNReference
DataAttributeReference [1..n]
DataAttributeValue [1..n]
Response–
ServiceError

- **LNReference**: shall contain the **ObjectReference** of the logical node (which shall be LDName/LNName)
- **FunctionalConstraint (FC)**: shall contain the functional constraint parameter (FC) to filter the respective data attributes of all data objects contained in the logical node.
- **Response+/-**: shall indicate the request succeeded/failed
- **DataAttributeReference [1..n]**: shall contain the **ObjectReference** of a data attribute contained in the logical node that shall be returned according to the value of the FunctionalConstraint received in the request.
- **DataAttributeValue [1..n]:** shall contain the value of a data attribute of the data object contained in the referenced logical node. If the parameter **FunctionalConstraint** is present in the service request then only values of those data attributes that have the **Functional Constraint** as given in the service request shall be returned.

3. **GetDataSetValues** service parameters table

Parameter name
Request
DataSetReference
Response+
DataSetReference
DataSetMemberValue [1..n]
Response–
ServiceError

- **DataSetRefercence:** define the **ObjectReference** of the **DATA-SET** which shall be one of the following two options: **LDName/LNName.DataSetName** to reference a persistent **DATA-SET**, or **@DataSetName** to reference a non-persistent **DATA-SET.**
- **DataSetMemberValue [1...n]:** shall contain values of a member of the DATA-SET. The value may be simple or complex depending on the definition of the member.
- **Response–**: indicates that the service request failed