INTERNSHIP REPORT

USE OF IEC 61850 FOR ASSET MANAGEMENT IN LOW VOLTAGE MICROGRIDS

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Preface and acknowledgement

For four months from November 2012 till February 2013, I did an internship at Alliander, an 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.
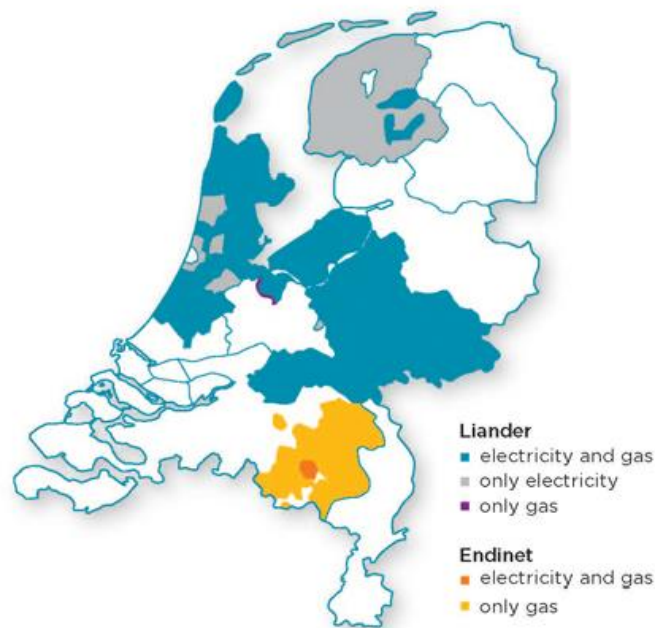

Figure 0.1 – Alliander electricity and gas distribution grid, copied from [12]

I worked on an assignment project to investigate the use of the IEC 61850 standard for asset management of LV Microgrids. The main content of the project is to use the IEC 61850 standardized data model and services to model the smart electrical equipment, and investigate the interaction between different components within a network topology for Microgrids asset management. This topic suits my major in telematics, and also brought me to a very new and interesting area of using communication technologies in electricity network. Through the assignment, I did not only gain a lot of 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, experts in the field and other staffs within and outside the company.

I am very appreciated to Mr. Frans Campfens, my supervisor at Alliander. Frans gave me very in-time valuable instructions and put me in contact with experts in the field 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 feedback 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.

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List of Abbreviations

ASN-1	Abstract Syntax Notation Number One
ACSI	Abstract Communication Service Interface
BRCB	BUFFERED-REPORT-CONTROL-BLOCK
CT	Current Transformer
DER	Distributed Energy Resource
DPWS	Devices Profile for Web Services
EPRI	Electric Power Research Institute
ES	Energy Storage
EV	Electric Vehicle
GOOSE	Generic Object Oriented Substation Events
GSE	Generic Substation Event
GSSE	Generic Substation State Event
HCMC	Home Control and Management Centre
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
LD	Logical Device
LV	Low Voltage
MMS	Manufacturing Message Specification
MV	Medium Voltage

OSI	Open System Interconnection
PUAS	Power Utility Automation System
PV	Photovoltaic
RCMC	Regional Control and Management Centre
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SCSM	Specific Communication Service Mapping
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
uPNP	Universal Plug and Play
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. [19], [20], 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 [1].

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 [21]. Power utilities still do not have much insight into distribution network, where nearly 90% of all power problems come from [16].

 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 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 [16].

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 system performs 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, IEC 61850 was originally designed for communication in 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 progress of transforming from 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 [13] – 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 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 asset management. The goal is to apply the concepts of IEC 61850 to a different domain, the LV microgrid, to perform inventory management, configuration management, device monitoring and alarm handling.

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 asset management 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 Photovoltaic (PV) panel, wind turbine, energy storage (ES), electric vehicle (EV)…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. 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 for substation automation, 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 management functions such as getting device information, configuring reporting service on the device, etc. To illustrate how those services can be applied for these tasks, a use case will be firstly defined explain the capability of the IEC61850 protocol to support asset management in LV microgrids.

1.2 Organisation of this report

The report is organized as follows. Chapter 2 will introduce a technical description about the related concepts such as IEC61850 standard, smart gird and microgrids. Chapter 3 is about communication network topology of LV Microgrids components. Chapter 4 gives a specific use case to demonstrate the usage of these models and services for asset management of LV Microgrids. The conclusion and future work will be given in Chapter 5.

Chapters 2 and 3 in both the Internship reports of T.G. Pham and A.D. Nguyen are exactly 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 from the conventional centralized electricity grid to a distributed intelligent electricity grid of the future which is called Smart Grid. An important part of the Smart Grid which supports the distribution automation of the Smart Grid is called Microgrids will also be explained within this chapter. This chapter is based largely on the official documents of the international standard IEC 61850 [1, 8] and a published document by the Smart Grid Strategy Group – SG3 about the roadmap of Smart Grid [11].

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 Microgrids and the structure of a Microgrid. Finally Section 2.4 summarizes 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 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" within the International Electrotechnical Committee (IEC) Technical Committee (TC) 57. The development of advanced and powerful microprocessors supported the possibility for building Power Utility Automation System (PUAS) [1], and consequently several Intelligent Electronics Devices (IEDs) was created each of which support proprietary communication protocol from its manufacturer. However, the co-existing of various proprietary communication protocols led to the big challenge of interoperability, and therefore required investment for complicated and costly protocol converter when using IEDs from different vendors [1].

IEC 61850 was initialized to solve the 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 communication within substation automation systems, IEC 61850 standard has been extended to support communication to Distributed Energy Resources (DER) and are being developed for communication to control centre and feeder automation domain [1].
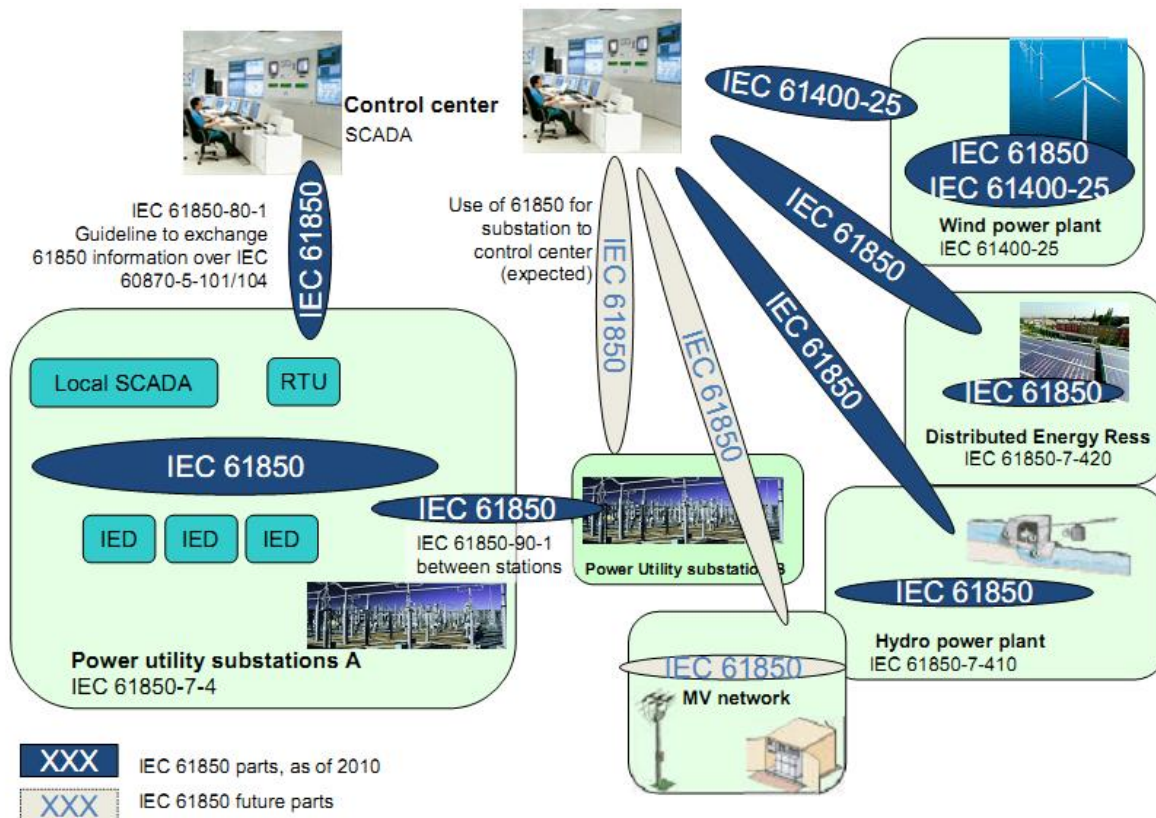
Figure 2.1 – Scope of application of IEC 61850, copied from [1]

Figure 2.1 represents the scope of the IEC 61850 with updates about the possible extension of the protocol in the future. It shows that currently, IEC 61850 has been adopted for the communications inside substation and from control centre (SCADA – Supervisory Control and Data Acquisition) to the Remote Terminal Unit – RTU and to the DERs. In the future, the standard will be extended to support the communications between the Control Centre and Power Utility substation as well as to the Medium Voltage – MV network.

2.1.2 Standardization approach

IEC 61850 provides a huge variety of communication functions which allow telecontrol, teleprotection, supervision and monitoring between different IEDs in an electric power

system. The standardization approach of IEC 61850 series as mentioned in IEC 61850-part 1 [1] is to blend the strength of three methods:

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

- *Data flow modelling:* is used to understand the communication interfaces that must support the exchange of information between distributed functional components and the functional performance requirements.

- *Information modelling:* 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 an internationally standardized abstract method of communication and integration between multi-vendor IEDs, it's needed to be mapped to specific protocols to support different functional requirements for protection, control, supervision, and monitoring. Therefore, parts 8-1, 9-1, 9-2 of the standard define the specific communication mapping.

Additionally, the standard also defines guidelines of using the logical nodes to models the functions of a substation automation system (part 7-500), a hydro power plant (part 7-510) and distributed energy resources (part 7-520). The object models for hydro power plant and distributed energy resources are defined respectively in part 7-410 and 7-420.

As the standard is still in development, it's going to cover more areas such as power inverters for DER systems (part 90-7), for electric mobility (part 90-8), for storage (part 90-9), DER scheduling (part 90-10). Figure 2.2 shows 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
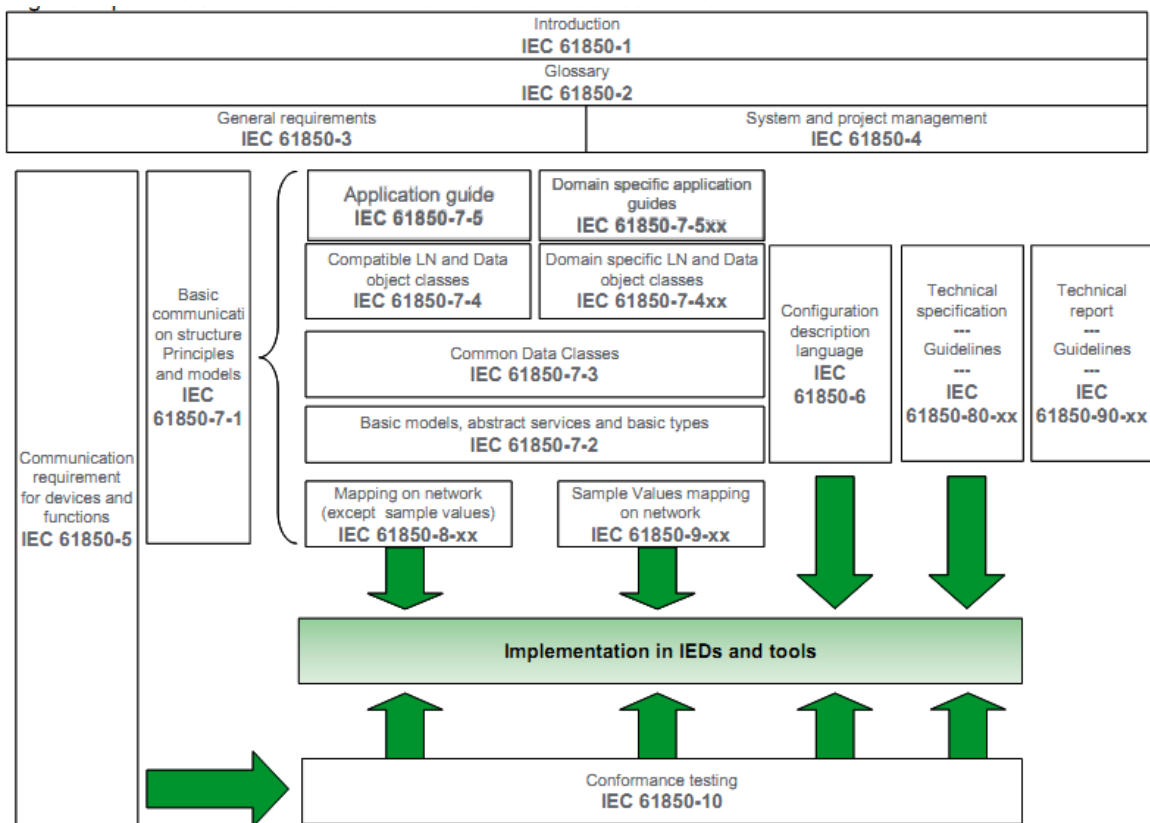
Figure 2.2 – Links between IEC 61850 parts, copied from [1]

2.1.4 Extensibility of IEC 61850

A significant advantage of IEC 61850 is the split between the communication and application as illustrated in Figure 2.3. By specifying a set of abstract services and objects, IEC 61850 allows the user to design different applications without relying on the specific protocols. As a consequence, the data models defined in IEC 61850 can be used on the diversity of communication solutions.

This fact is the source of motivation for me to propose an extension of IEC 61850 to support communication between control centre and smart appliances and DERs which has not yet been proposed by any parts or technical reports within IEC 61850 series. The method of using IEC 61850 data models and abstract services to manage microgrids electrical components will be described in details in chapter 3 and 4.
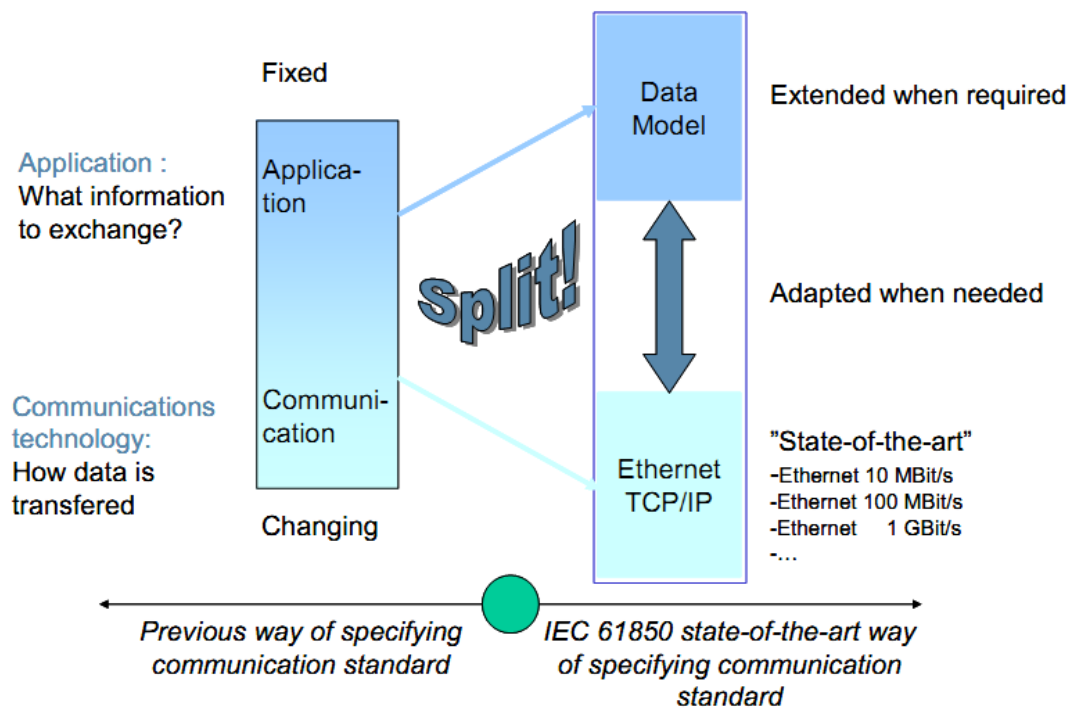
Figure 2.3 – IEC 61850 specifying approach, copied from [1]

2.1.5 IEC 61850 data modelling principle

An important remark of applying IEC 61850 is the data modelling process which brings the advantage of interoperability to IEC 61850 by modelling all the data in a standardized syntax and format following an object-oriented method.

There are two main levels of modelling [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 their functionality, a logical node contains a list of data with dedicated data attributes which have a structure and well-defined semantic.
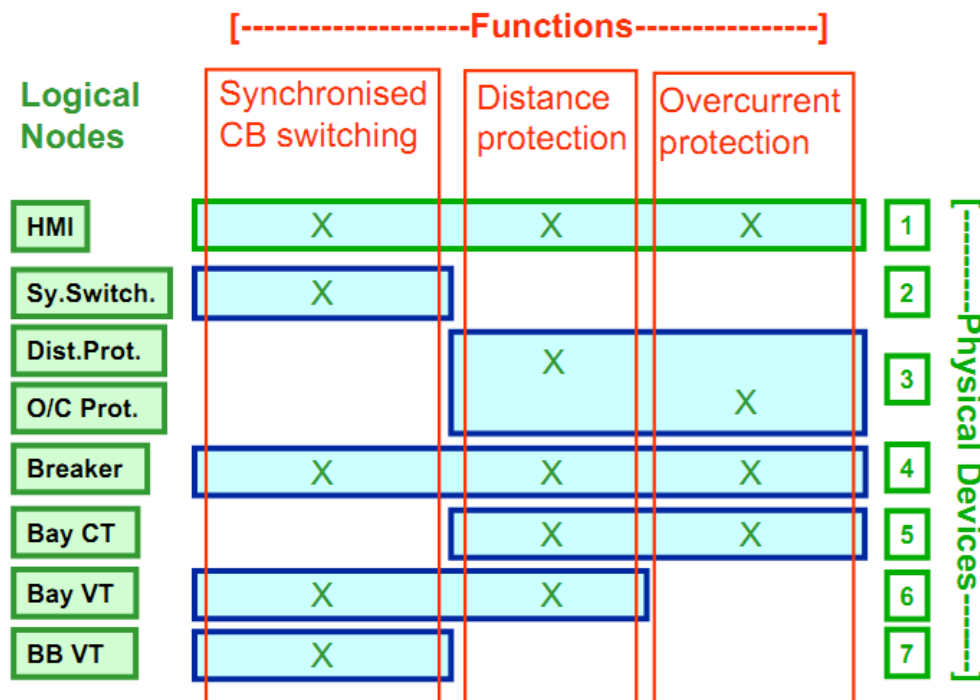
Figure 2.4 – Relationship between functions, logical nodes and physical nodes, copied from [1]

Figure 2.4 illustrates the decomposition of an application functions to multiple logical nodes which represents the smallest entities to exchange information. It also represents the

allocation of logical nodes to physical devices. For example the Distance protection function can be decomposed to 6 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 action , the breaker to break the circuit and the Bay Current Transformer (CT) and Voltage Transformer (VT) to provide measurement data for identifying the problem. These logical nodes can be placed on individual devices such as HMI on station computer (physical device 1), breaker on Bay control unit (physical device 4), and 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 located on the same physical device 3: Distance protection unit with integrated overcurrent function.

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 within IEC 61850-7-3 [5].

2.1.6 IEC 61850 communication services

Besides standardizing the data format 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 details 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 can be found in [4].

Table 2.1 – ACSI classes, copied from [4]

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

SETTING-GROUP-CONTROL-BLOCK model	Control model
SelectActiveSG	Select
SelectEditSG	SelectWithValue
SetSGValues	Cancel
ConfirmEditSGValues	Operate
GetSGValues	CommandTermination
GetSGCBValues	TimeActivatedOperate
	Time and time synchronization
REPORT-CONTROL-BLOCK and LOG-CONTROL-BLOCK model	TimeSynchronization
BUFFERED-REPORT-CONTROL-BLOCK:	**FILE transfer model**
Report	GetFile
GetBRCBValues	SetFile
SetBRCBValues	DeleteFile
UNBUFFERED-REPORT-CONTROL-BLOCK:	GetFileAttributeValues
Report	
GetURCBValues	
SetURCBValues	

- **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 it 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 will 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 mapping of the services to different protocol profiles is based on the functional and performance requirements. Due to the different requirements for transfer time of difference functions inside the substation, IEC 61850 classifies the messages exchanged between the devices to several types [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 function, for example, the "trip" message to open the circuit breaker for protection is very time critical (3 ms) in order to prevent damage to the system; however, the transfer time for file transfer functions to transfer a large amount of data is non-time-critical (can be 10000 ms).

Figure 2.5 provides the mapping of these messages to different protocol 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. require message oriented services [2, 4]. The Manufacturing Message Specification – MMS provides exactly the information modelling methods and services required by the ACSI. 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 [22]. 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].
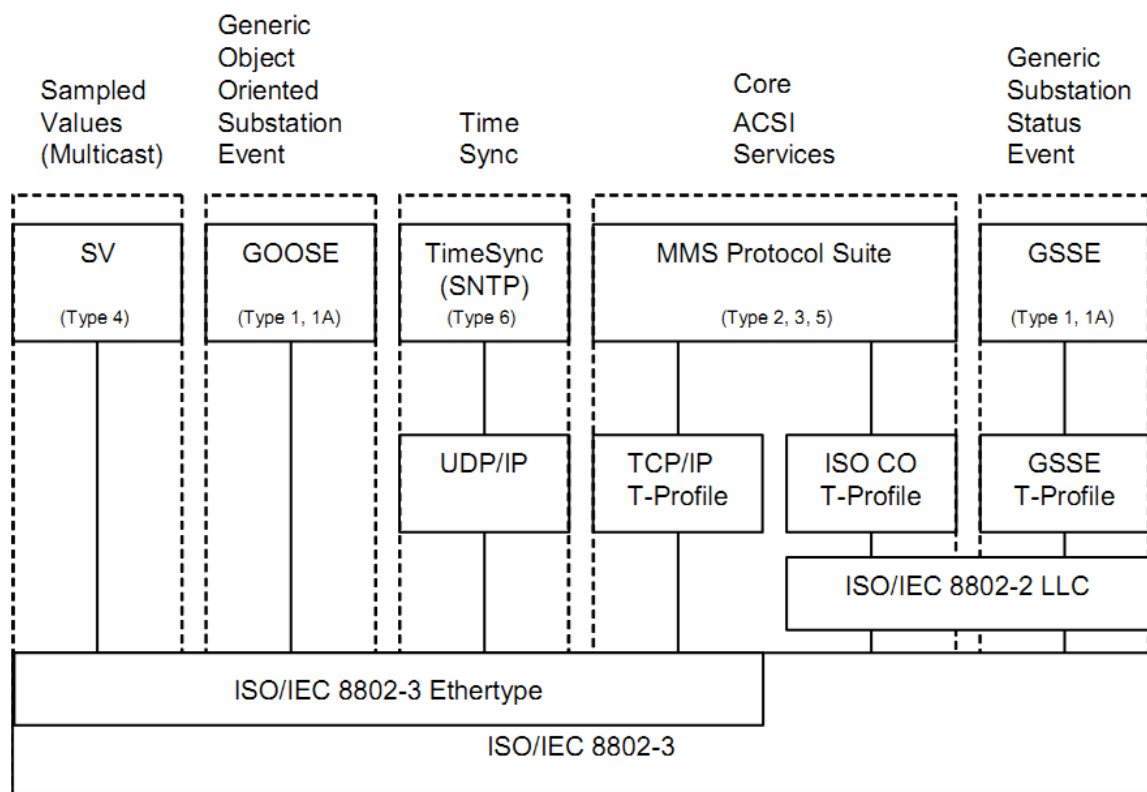
Figure 2.5 – Overview of IEC 61850 functionality and profiles, copied from [4]

2.1.7.1 Manufacturing message specification – MMS

MMS is a client/server communication model. MMS defines difference between the entity that establishes the application association and the entity that accepted the application

association. The entity that establishes the association is the client and the one that accepts the association is the server.

Due to the client/server model, the client can request for the data at any point of time when the association is valid. The message exchanged will follow a request/response manner.

MMS also supports the report service. For the report service, instances of a 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

MMS is based on Open System Interconnection (OSI) model with an adaptation layer (RFC 1006) layer for emulating OSI services over TCP/IP [22]. MMS application protocol is specified in Abstract Syntax Notation Number One (ASN-1) format that is a notation for describing the data structure.

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 2.2 – 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 to the 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 2.3 – 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 services. 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]. GOOSE sending is triggered by the server by issuing **SendGOOSEmessage** service. The event that causes the server to invoke a **SendGOOSEmessage** service is a local application issue as defined in [4], such as detecting a fault by a protection relay.

2.1.7.3 Sampled Value

Sampled Value or Samples of Measured Values (SMV) is the protocol for transmission of digitized analogue measurement from sensors (temperature, current transformer, voltage transformer).

Sampled value messages are exchanged in a peer-to-peer publisher/subscriber mechanism like GOOSE messages. However GOOSE uses the multicast model while SMV can be unicast or multicast. Figure 2.6 sketches the comparison between GOOSE and SMV communication models.
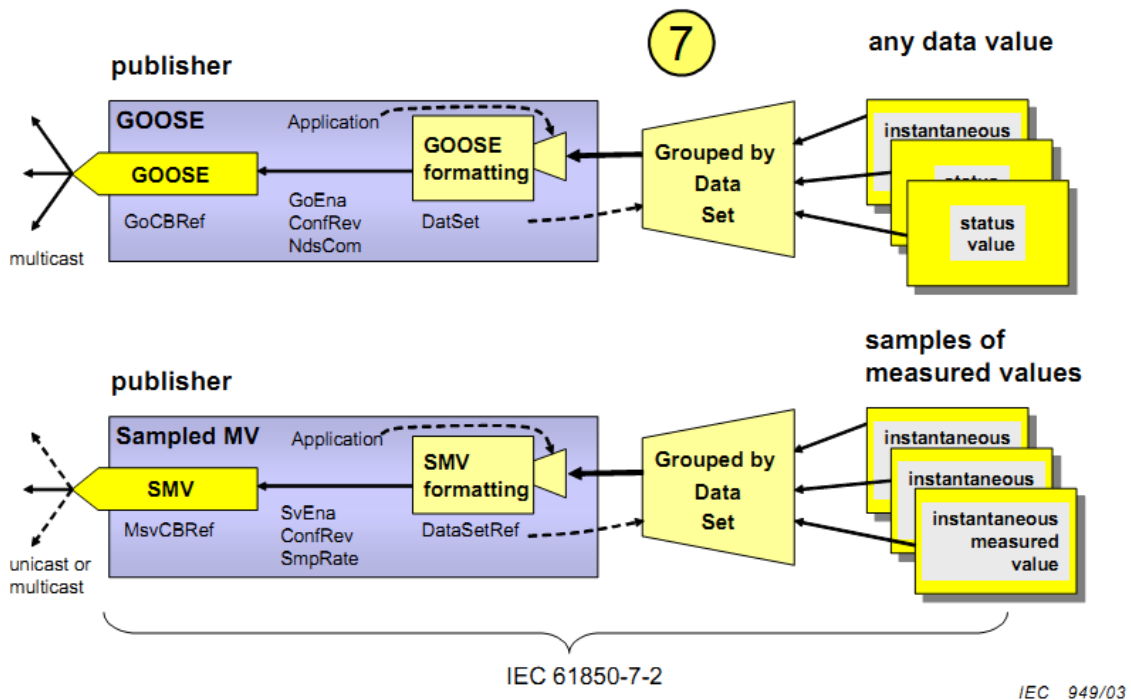
Figure 2.6 – GOOSE and SV peer-to-peer data value publishing model, copied from [4]

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 configuration as defined in part 9-1 [23] and part 9-2 [24] 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

18
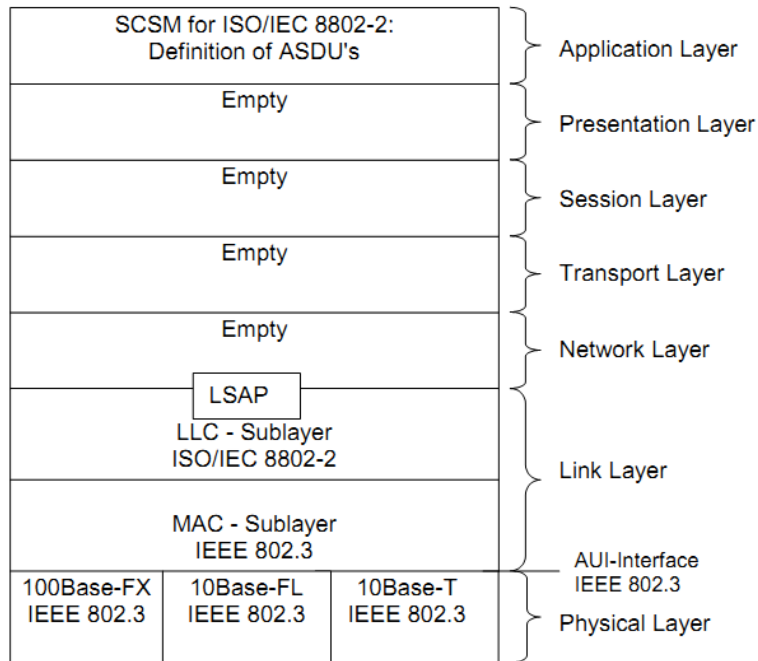
Figure 2.7 – Sampled value mapped to serial unidirectional multidrop point to point link, copied from [23]

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 2.4 – 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 [13]. 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 20th 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 Displacement Monitoring Centre [14]

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 centres.
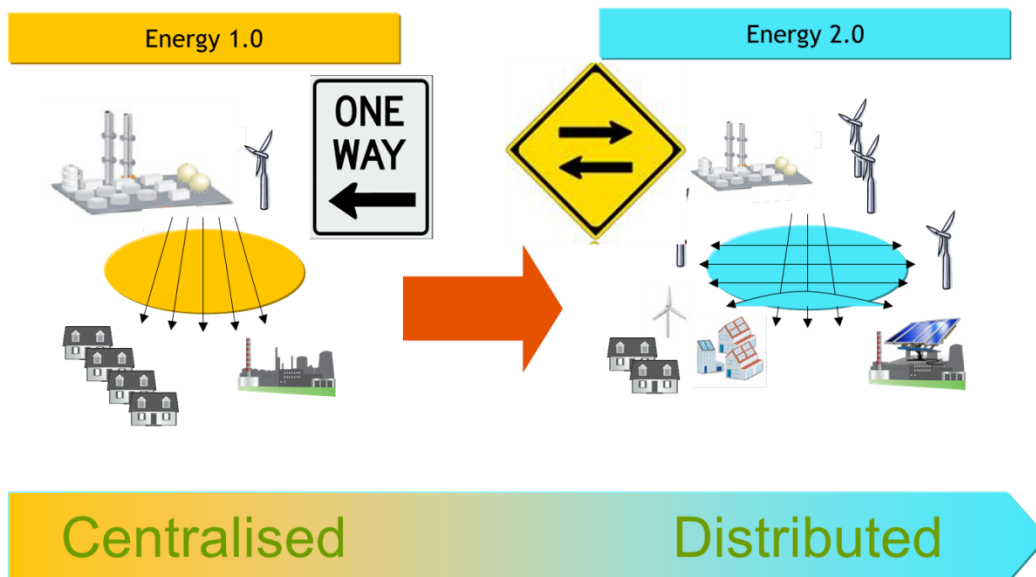
Figure 2.8 – Transformation from traditional to future electricity grid, copied from [12]

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 considerable. 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 construction of a bidirectional communication network to support all the automation, supervision and control as well as 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 centres.

2.2.1 Smart Grid

According to European Technology Platform Smart Grid, the definition of Smart grid is [13]:

"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 [13]. 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.

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 domain of IEC 61850 proposed by this research.
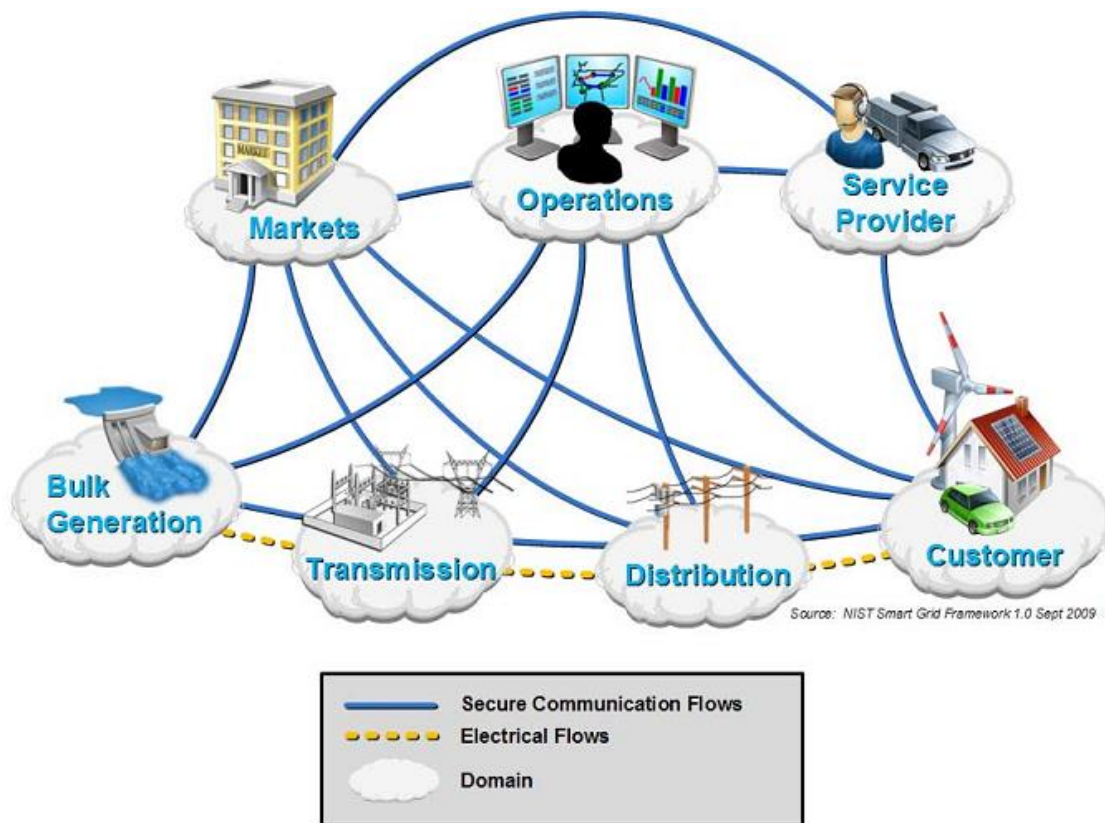
Figure 2.9 – Conceptual model of smart grid, copied from [13]

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 Microgrids

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" [15]. Therefore, Microgrids are crucial part in order to achieve an overall Smart Grid with the participation of consumers.

From the above definition of Microgrids, we can decompose the three main parts of a 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 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 [11]
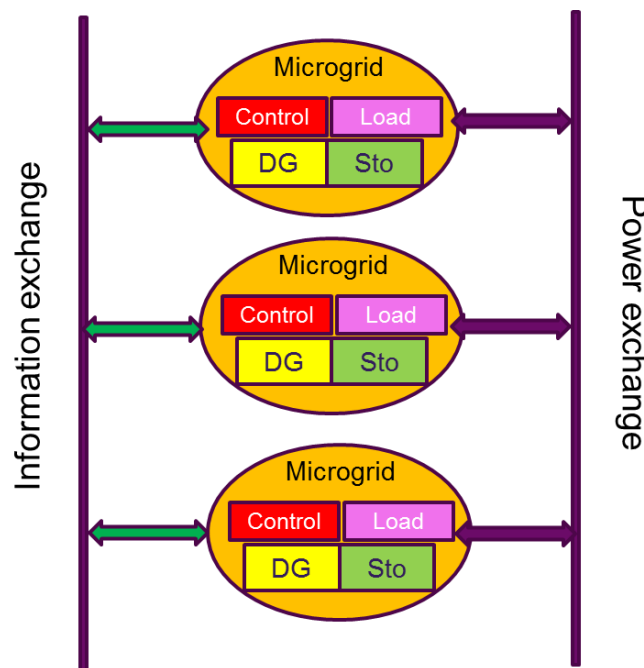
Figure 2.10 – Microgrids architecture, copied from [16]

Basically, there are three elements for control and management within a microgrid: the distributed energy generators, the energy storages, and the household appliances which

consume energy. The design of the control algorithm and management system should be able to provide best energy efficiency and resilience to failures.

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

Chapter 3

IEC 61850 network designing and data modelling for microgrids components

Chapter 3 describes the communication network designing and data modelling processes which are the two very important research tasks in order to allow power control and asset management of Microgrids through using IEC 61850 data models and services. As being emphasized above, the current covering areas of IEC 61580 include communication in substation automation systems, between substations and to DERs. Therefore, for microgrids distribution automation and home automation systems, before we can use the IEC 61850 services for communication between devices, we have to model those devices as IEC 61850 data models and design a network topology to support seamless communication between different components. Moreover, although IEC 61850 facilitates modelling 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 will explain 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 presented to allow the communication between different actors in a Microgrid which support the use of IEC 61850 data models and services for power control and asset management.

3.1.1 Microgrids power diagram

Normally, LV Microgrids consist of three building blocks: the DERs including energy distributed generators like PV panel and energy storage, and the electrical loads which consumes energy. LV Microgrids can operate in islanding mode or grid connected mode but

the latter is chosen for the scope of this research. Therefore, a typical LV Microgrid can be illustrated in the following figure:
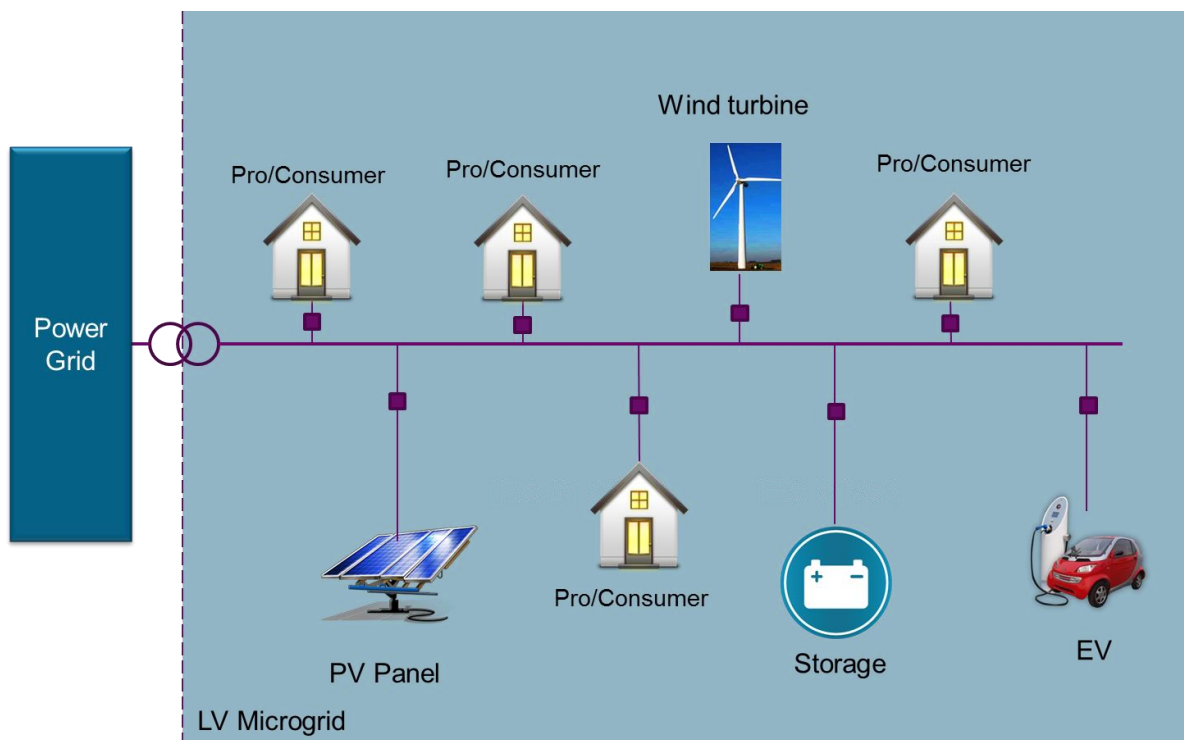
Figure 3.1 – LV microgrids diagram

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 this 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 the possible DERs in the houses. The energy storages which can be a controllable battery systems are used to store the energy that can be used for emergency or other future plans. A special component here is the Electric vehicle (EV) which can be seen as both the energy load and energy storage.

3.1.2 Communication network topology for LV Microgrids power control and asset management

According to the current version of IEC 61850, the underlying communication network infrastructure is standardized is Ethernet. Therefore, we need to build an Ethernet-based

communication network to connect all the Microgrids equipment. Within this research, a network topology was designed for that purpose.

According to the current version of IEC 61850, the standardized underlying communication network infrastructure is Ethernet. Therefore, we need to build an Ethernet-based communication network to connect all the Microgrids equipment.

This network was designed as a hierarchical topology in which each Smart house will be represented as a subnet and these subnets create a kind of field area network. The control and management part of this regional microgrid is the Regional control and management centre (RCMC) which is also connected to the field area network. Physically, the each subnet and RCMC should connect to an Ethernet switch to establish communication links between RCMC and each subnet.

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

Another important aspect is protection which is handled by the protection device and the Circuit breaker (modelled by XCBR Logical Node). However, because the messages for protection are very time-critical, they are handled by another protocol (GOOSE) instead of the protocol for control and management purposes (MMS) which produces higher delay.

Due to the scope of this research, the protection part will not be analysed. The protection device and circuit breaker in Figure 3.2 is just for illustration of a typical LV Microgrid with the control, protection, and asset management functions.
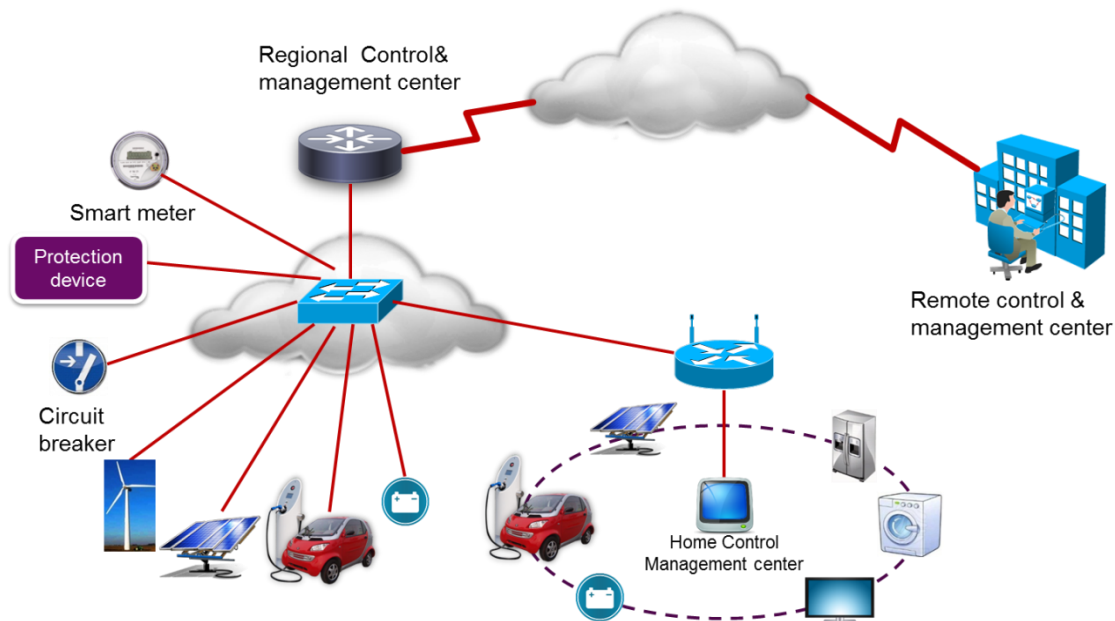
Figure 3.2 – Communication network topology for LV Microgrids power control and asset management

As shown in Figure 3.2, within a smart home, there is a Home control and management centre (HCMC) which is in charge of controlling and managing all the in-home private DERs and smart household appliances.

There are some motivations behind this hierarchical topology. First, by having HCMC control and manage in-home the equipment, we achieve a highly distributed management layer which reduces the amount of information to be kept at the regional level. Second, the users have their control over the information they share with the utility. A HCMC can work as a proxy or gateway in the home-neighbourhood boundary using the IEC 61850 proxy feature that will be discussed later in this chapter.

The Home control and management centre can handle the Demand Response Signal sent from the Regional control and management centre to manage the energy consumption/production of the house. HCMC can control the household appliances to modulate their energy consumption and the DERs to modify their power production ability. RCMC is capable of monitor and if permissible manage the HCMCs in order to efficiently utilize the available energy of the grid.

3.2 IEC 61850 data modelling

The main idea of IEC 61850 is to breakdown a physical device in to 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 derived from the application functions. Logical nodes are the building blocks of the standard since they represents the smallest functions of the device. The scope of this project is about microgrids control and asset management which is very different from the scope of substation automation systems; therefore, many new functions must be modelled. The next clause will describe how to model a new function as IEC 61850 Logical Nodes.
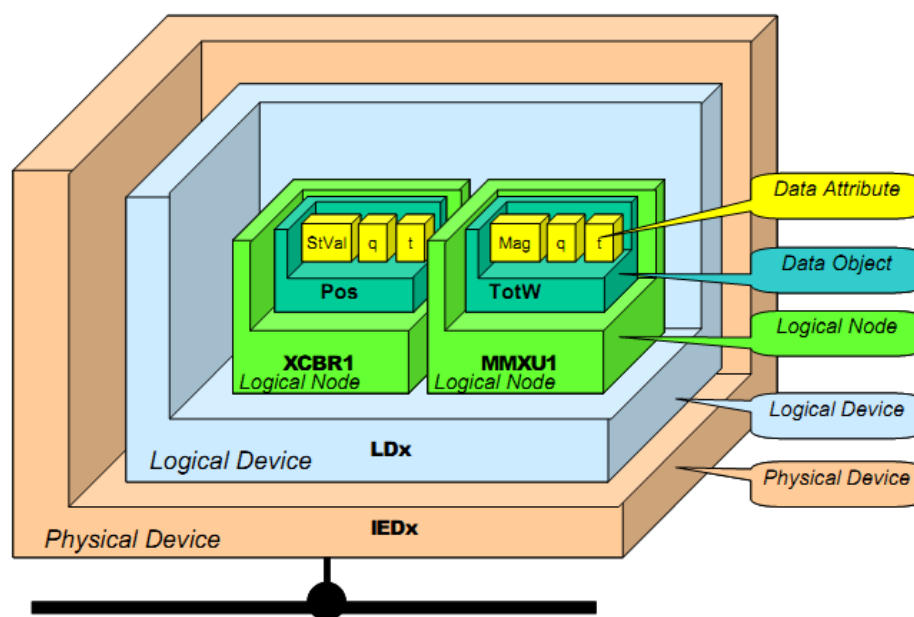
Figure 3.3 – IEC 61850 data modelling, copied from [1]

Figure 3.3 illustrates the principle of IEC 61850 data modelling. In this case, a 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 two 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 object. In this example, logical node XCBR1 contains the data object **Pos** which represents the position of the circuit breaker. This data object consists of many data attribute 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 rule for extension or definition of new logical nodes is defined in IEC 61850 part 7-1 [3]
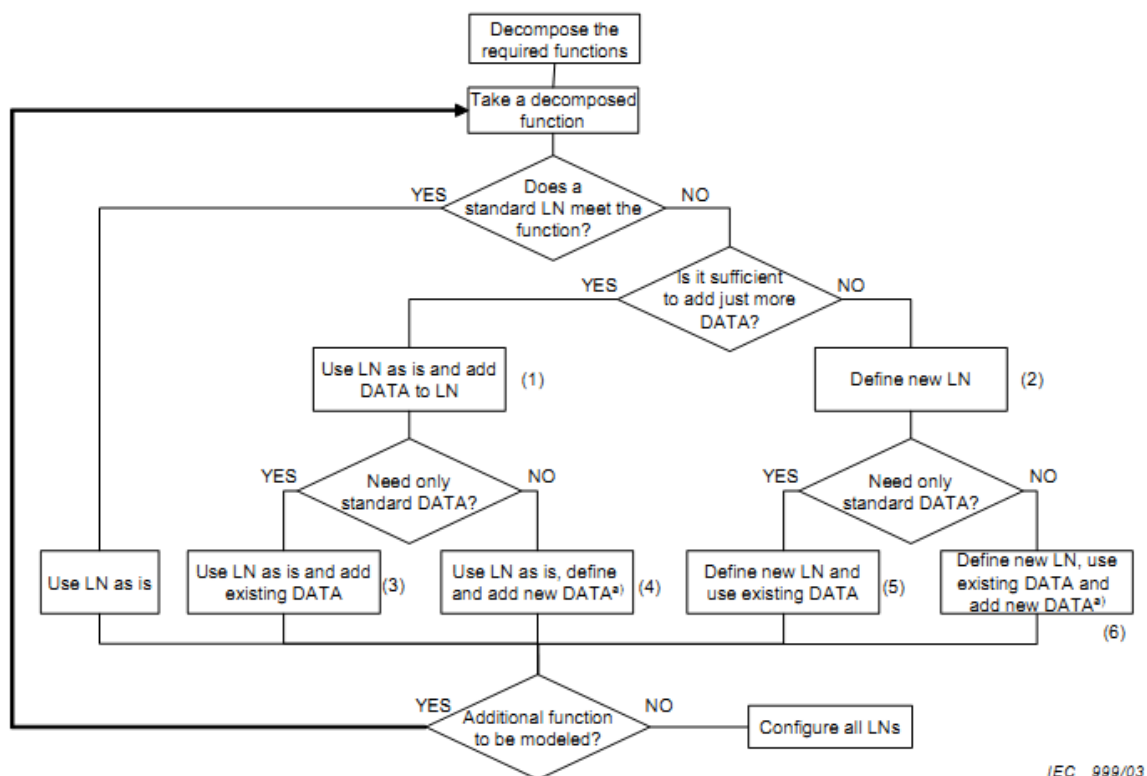
Figure 3.4 – Basic extension rules diagram, copied from [3]

The rules modelled in Figure 3.4 can be briefly summarized as follow [3]:

- If there is any Logical Nodes Class which fits the function to be modelled, 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 modelled, a new logical node shall be created according to the rules for new Logical Nodes.

3.2.2 IEC 61850 data modelling for Microgrids components

There are 3 types of equipment to be modelled 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 centres: Regional/Home control and management centre.

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 modelling 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 many existing logical nodes defined for substation automation systems were applied for DERs, and also many new logical nodes defined to represent the new functions of DERs.
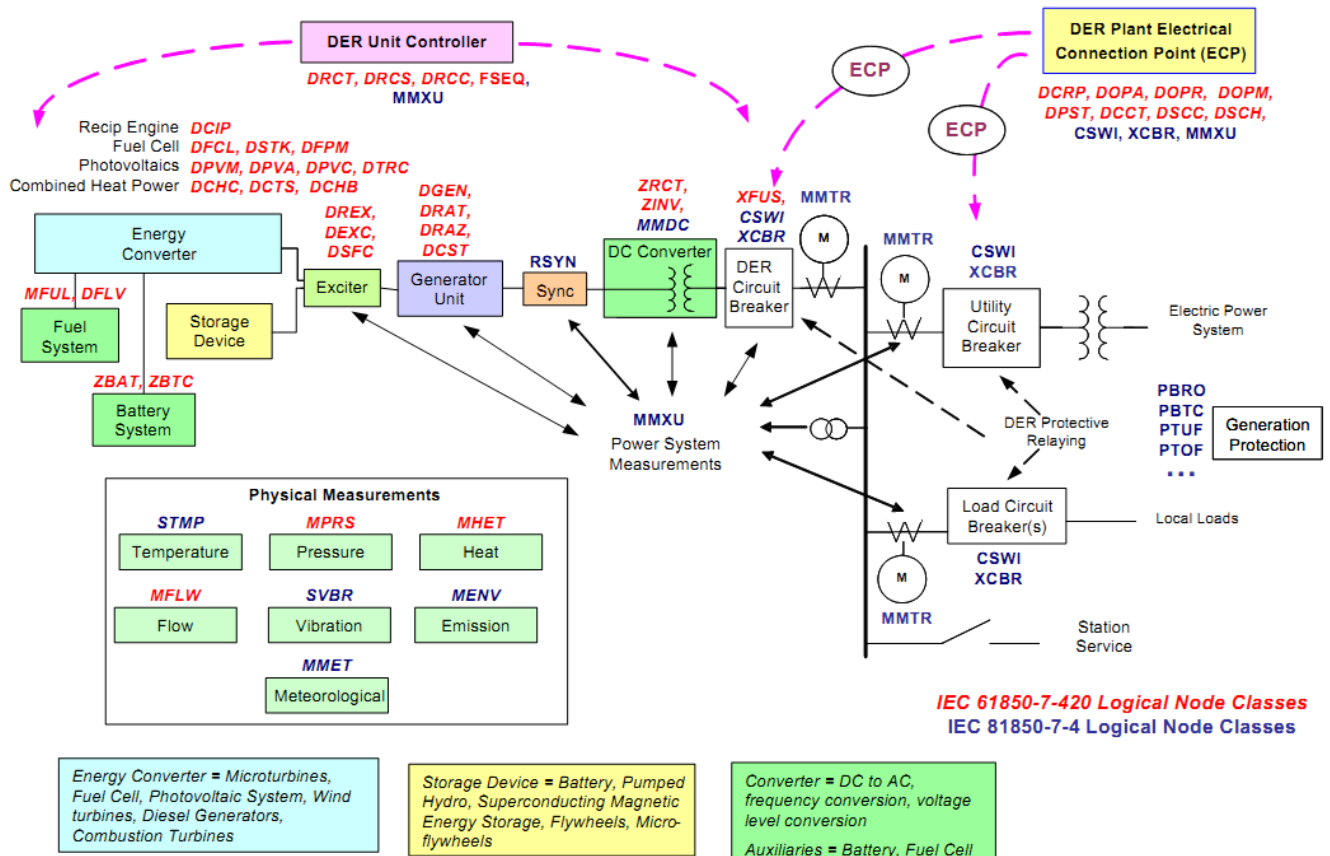
Figure 3.5 – Conceptual organization of DER logical devices and logical nodes, copied from [7]

Because there's no strict rule on the arrangement of logical devices on physical device, it's not necessary to implement all of the logical nodes in Figure 3.5 to a DER. Actually, depend on the specific locations and application requirements of the DER, only respective logical nodes should be added.

For simplification in home automation systems, 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. 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 signal issued by the RCMC as a consequence of peak demand periods.

3.2.2.2 Smart household appliances

As the household appliances are the very new devices to be modelled within IEC 61850, the first step of modelling should be identification of their characteristics. 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 modelled.

Table 3.1 – Smart household appliances and their typical characteristics

Household Electric Appliances / Properties	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
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 to the appliances parameters listed above, the basic functions required for control and management of household appliances should be:

- switching ON/OFF the equipment

- monitoring the device status

- 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, we can see that 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] consist 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 kind of information for management purposes.

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

Although there are many Logical Nodes existing in the standard that are applicable, some functions for control services not been defined due to the difference in scope between substation automation systems and home automation systems. Energy modulation is the most important function needed to be modelled but it lacks from 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 new 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 controlled by the user.

The function of turning ON/OFF the device is also modelled in ZAPL Logical Node since it is a basic and mandatory function for all devices.

This Logical Node represents the energy tuning function which is indispensable to manage the energy consumption of the appliances in order to assure energy efficiency. By setting the load target set-point, the Home control and management centre or the user can modulate the energy consumption of the appliances.

By setting the load target, HCMC can manage the energy consumption of all smart appliances; however, 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 the temperature of a heater or refrigerator.

IEC 61850-7-4 defines a Logical Node called STMP for temperature supervision, so it is convenient to utilize this Logical Node and add more data objects to model the temperature tuning function.

Table 3.3 – Extension to STMP class

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

As shown in Table 3.3, a temperature set-point to the STMP class was added 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 centre

Within the scope of this research, management of the in home automation systems is the main issue for concentration. HCMC can use IEC 61850 services for communication with the Logical Nodes in smart appliances to perform management tasks. The models for the smart appliances have been defined in the section above.

In the regional area, it is necessary to model the data and function of HCMC that RCMC can access and manage. For this purpose, a new Logical Node ZHCM has been defined as 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 <table><tr><td>Value</td><td>Explanation</td></tr><tr><td>1</td><td>Autonomous</td></tr><tr><td>2</td><td>Controllable</td></tr><tr><td>99</td><td>Other</td></tr></table>		M
Settings				
MaxWh	ASG	Set-point of maximum energy consumption		O

In this Logical Node, there is a data object **OperMod** which represents the operating mode of HCMC. If HCMC is configured to be controllable then 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.

As stated earlier in this chapter, HCMC can be used to control the amount of information that the users want to share with their utility. HCMC can act as a gateway/proxy by "hosting" the logical devices that it permits the outside world to see. An illustration of this feature is shown in Figure 3.6.
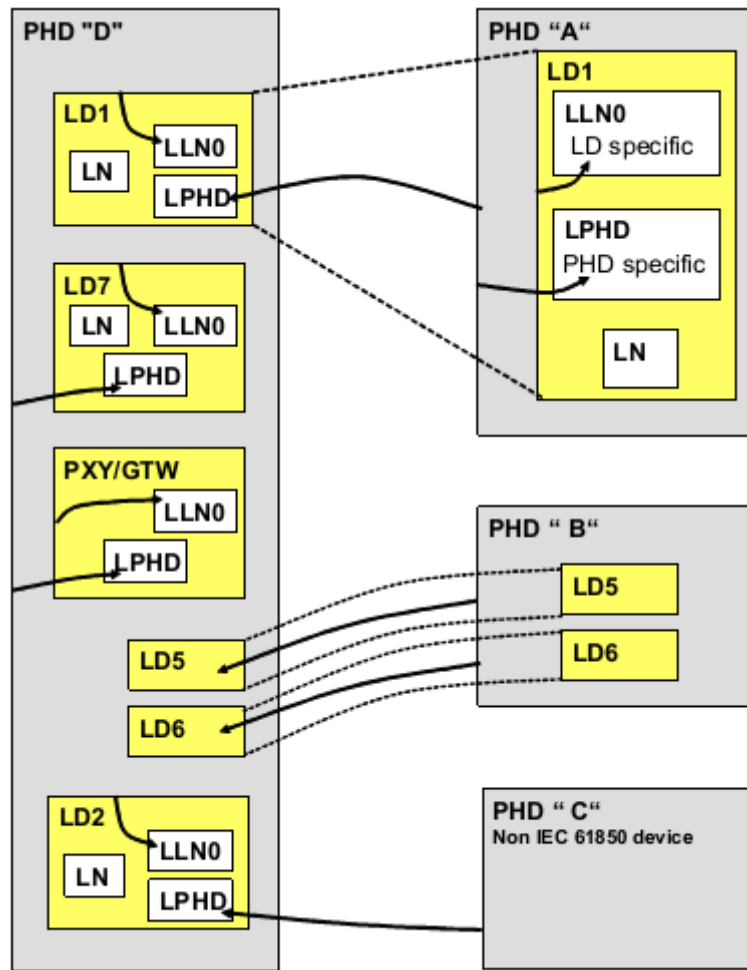
Figure 3.6: Logical devices in proxies or gateways

The HCMC can be viewed as the physical device D in the figure. A, B and C can be different smart appliances or DER within the home system. If HCMC permits the devices to be viewed by the outside world, it can "copy" the logical device from them. As only HCMC should connect with the RCMC, this feature can be employed to provide privacy for the users.

3.3 Summary

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

In section 3.1, a communication network topology was designed to allow the information transmissions among the Home Control and Management Centre – HCMC to all the Smart

appliances inside the smart houses as well as connecting all the HCMCs and public DERs to the Regional Control and Management Centre at regional domain. 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 on applying another underlying protocol for transmitting the IEC 61850 information such as wireless or cellular networks.

Section 3.2 gives a further details about IEC 61850 data modelling principles which were mentioned in chapter 2. More importantly, this section described how to use those principles in practice by modelling the LV microgrid electrical components with IEC 61850 data objects. This section also defined some new logical nodes to represent for the very important control and management functions such as ZAPL and ZHCM logical nodes. However, it is crucial to realize that this research has utilized almost the existing logical nodes defined in IEC 61850 documents to model very 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 for LV microgrid asset management

The goal of this chapter is to apply the IEC 61850 services on the object models that have been defined in chapter 3 in order to support asset management within the LV microgrids in a specific use case.

The use case is not meant to cover all the functionalities of LV microgrid management tasks, as there have to be hundreds of use cases to achieve this. Instead, the use case is provided to illustrate some typical behaviours and interactions of the components within smart home system (considered as a LV microgrid) for the specific management tasks. In the use case, the management tasks are performed by the Home Control and Management Centre (HCMC). It is the entity that manages other equipment in the home system, such as smart appliances, DER, and also networking devices. The advantage of this design is the HCMC has an overall picture of the equipment to be managed inside the home, and provides a single portal for the users to keep track of their equipment (e.g. health, operation status and settings), and notifies the users when a problem happens via the alarm handling functions.

IEC 61850 has been applied for the IEDs within substation automation systems and had tremendous success. Its object models have been extended to cover also DERs, EVs, power plants, etc. The main contribution of this chapter and also of this report is to demonstrate that with the IEC 61850 models defined in chapter 3 and the existing IEC 61850 services, IEC 61850 is capable of performing management tasks, which is a new application in a new domain for IEC 61850.

4.1 Overview on asset management

An asset management system is a crucial part in an electrical system as it provides a systematic way to maintain and ensure normal operation of physical assets, and also provides an information base for other applications, such as smart control, system planning, etc.

In this report, asset management is defined as the composition of the following tasks:

- Inventory management: the management system keeps track of the list of devices to be managed together with their related information, e.g. vendor, serial number, location, etc.

- Configuration management: the management system maintains the configuration and settings of the devices.

- Device monitoring: the management system acquires the current status of the devices, e.g. device health, measurement data, etc.

- Alarm management: the management system handles the alarm generated by the devices when certain problems occur.

Within a smart home context, the devices to be managed are smart appliances, DERs and also networking devices (such as switches). In order to do the management of these assets, there are two possible approaches [17]:

The first approach is the HCMC uses SNMP for management tasks. SNMP is a well-known protocol and is supported by almost all networking devices. The management information is structured into Management Information Base (MIB) objects. SNMP an extensible protocol as different vendors can define their private MIBs beside the list of standard MIBs. To follow this approach, data objects and attributes of smart appliances and DERs need to be mapped to SNMP MIBs, and HCMC has to implement SNMP.

The second approach is to use IEC 61850 MMS protocol for management tasks. This alternative to SNMP protocol requires the networking equipment to support IEC 61850, and models for these devices have to be defined.

The following sections will further describe the second approach, which is using IEC 61850 MMS services for management tasks. Considering IEC 61850 has been used for the control functions, using the same protocol for management tasks would enable the simpler design and implementation of the system. It also allows seamless integration of networking devices, smart appliances and DERs for both control and management functions.

As stated above, models for networking devices have to be defined. IEC 61850-90-4 describes the extension to existing Logical Nodes (LPHD, LCCH) to support information models for the physical bridge (LPHDB), bridge ports (LCCHB) and also the information that these models contain in relation with SNMP MIB objects. Some of these models are listed in Table 4.1 and 4.2.

Table 4.1: Additional Bridge-data objects in LPHDB added to LN LPHD [17]

Data				
Data Name	**CDC**	**Explanation**	**T**	**M/O**
TmpAlm	SPS	IED thermal alarm – usable in general		O
Root	SPS	Indicates if this bridge is the root bridge in the spanning tree		O
Bridge settings / capabilities				
VidFilter	SPG	True: Filtering on VIDs is enabled		O
McFilter	SPG	True: Filtering on Multicast addresses is enabled		O

In Table 4.1, the existing logical node LPHD is extended to add additional physical characteristics of a bridge, e.g. whether the bridge is the root of the layer 2 spanning tree, or the settings of VLAN ID or Mac address filtering.

Table 4.2: Additional Bridge-data objects in LCCHB added to LN LCCH [17]

LCCH class				
Data Object Name	**Common Data Class**	**Explanation**	**T**	**M/O/C**
Data Objects				
		Status information		
BitRte	INS	Port bit rate in kbit/s. Static or chosen dynamically at a port based on the connected IED; Applies to ports of a HSR/PRP LRE simultaneously if used; preferably used for bridges		O
Duplex	SPS	TRUE if the port runs in full duplex mode. q=invalid if the mode is not known. Static or chosen dynamically at a port based on the connected IED; preferably used for bridges		O
PortPvid	INS	Default value of the port's VID		O
PortPpcp	INS	Default value of the port's priority		O
PortPtag	SPS	TRUE if the port is able to tag and untag frames		O
		Measured and metered values		
RedTxCnt	BCR	Number of sent messages through the redundant channel. Not used for bridges, used with HSR/PRP; indicates the messages sent through channel B – This is an extension done in TR IEC 61850-90-4		O
TopChgCnt	INS	Number of topology changes that occurred since last device reset and timestamp of last recorded topology change event based on the local bridge clock; only applicable to bridges supporting RSTP	T	O
RstpPortSt	ENS	RSTP port state; only applicable to bridge supporting RSTP (1 – disabled; 2 – blocking; 3 – listening; 4 – learning; 5 – forwarding; 6 – broken)		

Table 4.2 provides some extensions to the existing LN LCCH (Physical Communications Channel Supervision) including the port status (bit rate, duplex mode, port VLAN ID, etc.)

These additions shown in Table 4.1 and 4.2 are important especially for large layer 2 Ethernet network, where maintaining the forwarding spanning tree is important. Within smart home automation, what we are interested in is the status of the bridge port connected to IEDs. The status is contained in the existing data object ChLiv (physical channel status) in LN LCCH.

4.2 Asset management use case

The scope of this use case is about the management of smart appliances, networking devices, DERs (referred to as "managed devices", or "devices" for the rest of this chapter) within Smart Home Automation system. The management system is implemented in the HCMC. The information exchange using IEC 61850 data models and services among the devices will also be specified.

4.2.1 Description of the Use Case

In IEC 61850, the configuration of devices must be done offline using engineering tools. Currently IEC 61850 does not specify the auto-configuration or auto-discovery of the devices. This is considered disadvantages of IEC 61850 when applied to the Smart Home domain, where ideally the equipment should have the "plug-and-play" capability. This feature is being proposed by [18], in which the combination of Universal Plug and Play (uPnP) and Devices Profile for Web Services (DPWS) is investigated for a plug-and-play reference architecture of IEC 61850.

This Use Case presumes that the HCMC and the managed device have been configured to be able to exchange information, and the Use Case is divided into two scenarios:

In the first scenario, the HCMC obtains the capabilities of the new managed device, creates a database entry for it and configures the device for additional services such as reporting. This is an important task for asset management as it provides a database of devices that are working within the smart home context. This information can then be used for other tasks such as power control.

In the second scenario, the configured managed device interacts with the HCMC. HCMC keeps an up-to-date database of the device when there is change to ensure normal operation. The HCMC generates alarms under abnormal conditions.

4.2.2 Actor (Stakeholder) Roles

Below are the actors within this use case. These are the entities that have interaction through information exchange to perform the use case.

Table 4.3: Actor (Stakeholder) Roles

Actor Name	Actor Type (person, organization, device, system, or subsystem)	Actor Description
HCMC	Subsystem	Home Control and Management Centre controls and manages DERs, Smart Appliances, network devices
Managed device	Device	The device to be managed (smart appliances, DER, network devices)

4.2.3 Information exchanged

The information exchange among the actors is listed in the table below.

Table 4.4: Information exchanged between actors

Information Object Name	Information Object Description
DeviceCapability request	The request from HCMC to a managed device to obtain its capabilities
DeviceCapability response	The capabilities of a managed device sent to HCMC
NamePlateData request	The request from the HCMC to the device to get name plate information of the device.
NamePlateData	The name plate information provided by the devices to the

Information Object Name	Information Object Description
response	HCMC. This information is defined in the IEC 61850 object models. The name plate contains information about the vendor, serial number, location, etc. of the devices.
StatusSetting request	A command sent from the HCMC to request the status and settings of the device.
StatusSettingData	A message which contains information about the status and settings of the device.
Configuration	A command sent from the HCMC to configure the device (e.g. reporting services)
ConfigurationConfirm	A message which contains confirmation about the current configuration of the device.
Report	A report contains a set of data attributes that are configured to be sent from the device to the HCMC

4.2.4 Step by Step Analysis of Function

4.2.4.1 Step to implement function – Scenario 1

In order to perform the function listed in Scenario 1, there are preconditions and assumptions for HCMC and device, see Table 4.5.

Table 4.5: Preconditions and Assumptions

Actor/System/Information/Contract	Preconditions or Assumptions
Managed device	Has been implemented with auto-discovery functions to join, discover and self-configure to work with HCMC.
HCMC	Has known the existence of the device (e.g. having the IP address of the device by the discovering process) and needs to connect to the device to acquire more information.

The step-by-step analysis of the activities needed to perform the defined task in Scenario 1 is shown in Table 4.6.

Table 4.6: Steps to implement function - Scenario 1

#	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
1.1	HCMC	Browses device capabilities	HCMC browses device for its capabilities	HCMC	Managed device	DeviceCapability request
1.2	Managed device	Returns device capabilities	Managed device returns its capabilities to HCMC	Managed device	HCMC	DeviceCapability response
1.3	HCMC	Requests name plate information	HCMC polls the device for name plate information using an IEC 61850 browser	HCMC	Managed device	NamePlateData request
1.4	Managed device	Responds with name plate information	Managed device responds with name plate information	Managed device	HCMC	NamePlateData response
1.5	HCMC	Checks for duplicate devices	HCMC checks the database for existing device entry	HCMC	HCMC	
1.6	HCMC	Creates a database entry for the device	HCMC creates a database entry for the device	HCMC	HCMC	
1.7	HCMC	Requests status and settings of the device	HCMC polls the device for status and settings using an IEC 61850 browser	HCMC	Managed device	StatusSettings request
1.8	Managed device	Responds with status information	Device responds with status information	Managed device	HCMC	StatusSettings Data
1.9	HCMC	Updates the device status and settings in the DB	HCMC updates the status and settings of the device in the DB	HCMC	HCMC	

#	Primary Actor	Name of Process/Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
1.10	HCMC	Configures additional service on the device	HCMC configures additional service on the device	HCMC	Managed device	Configuration Data
1.11	Managed device	Confirms the new configurations	Managed device confirms the new configurations	Managed device	HCMC	Configuration Confirm

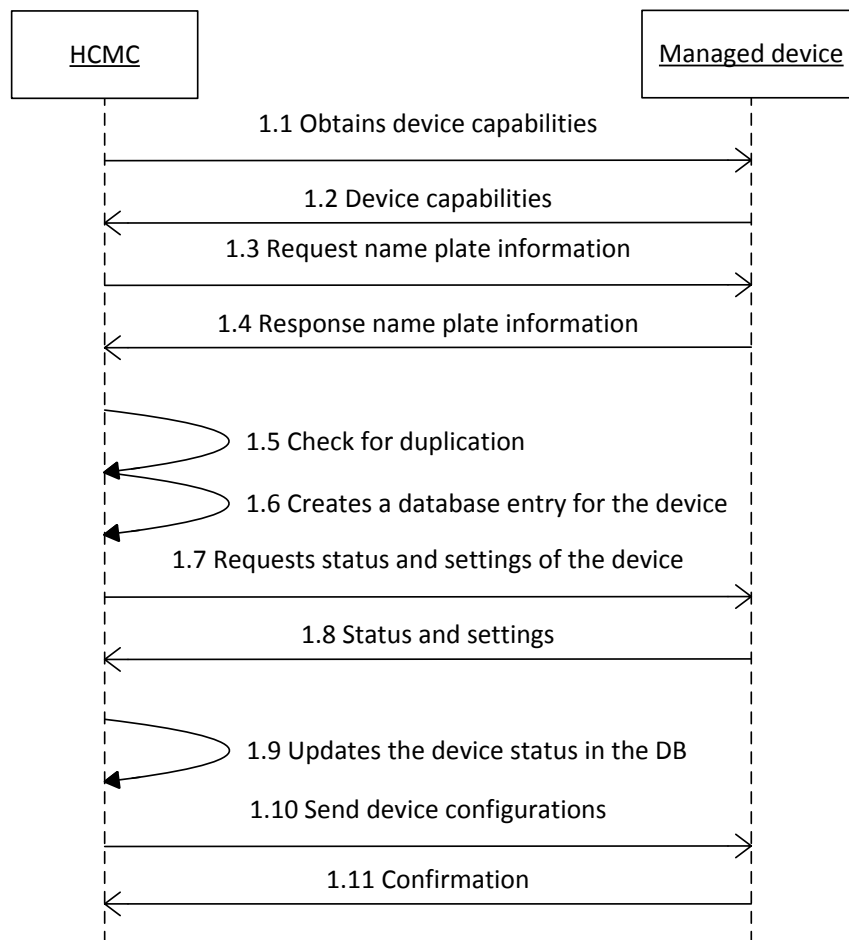Figure 4.1 shows the interaction between the actors with the activities defined in Table 4.6.

Figure 4.1: Message flow for Scenario 1 of Asset Management use case

4.2.4.2 Step to implement function – Scenario 2

The step-by-step analysis of the activities needed to perform the defined task in Scenario 2 is shown in Table 4.7

Table 4.7: Steps to implement function - Scenario 2

#	Primary Actor	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged
1.1A.1	Managed device	Managed device sends report to HCMC	Managed device	HCMC	Report
1.1B.1	HCMC	HCMC polls devices for status and settings	HCMC	Managed device	StatusSettings request
1.1B.2	Managed device	Managed device responds with status information	Managed device	HCMC	StatusSettings Data
1.2	HCMC	HCMC updates the status and settings of the device in the DB	HCMC	HCMC	
1.3	HCMC	HCMC notifies the user if an alarm is detected	HCMC	HCMC	
1.4	HCMC	HCMC loses communicate with the managed device	HCMC	HCMC	
1.5	HCMC	HCMC waits for a hold-down timer	HCMC	HCMC	
1.6	HCMC	HCMC deletes the device entry from the database	HCMC	HCMC	

 (*) HCMC detects a time-out for communication link, or get an alarm from network devices.

(**) This is to prevent frequent database delete/insert when there is a frequent change in communication link between HCMC and the managed device.

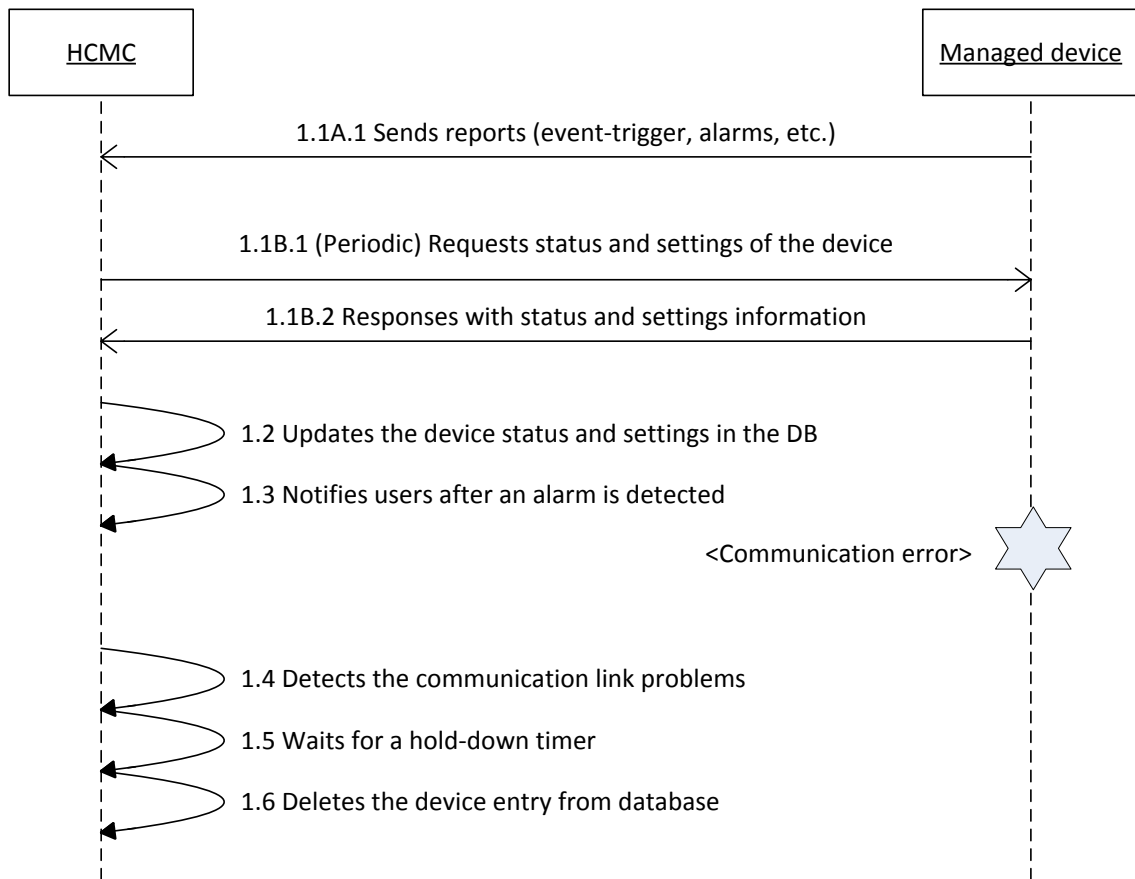Figure 4.2 shows the interaction between the actors with the activities defined in Table 4.7.

Figure 4.2: Message flow for Scenario 2 of Asset Management use case

4.3 Realization of use case with IEC 61850

This section is the core of the chapter in which it describes how the IEC 61850 object models defined in chapter 3 and existing IEC 61850 services can be integrated to realize the management tasks in the 2 scenarios the use case. An example will be given to show the interaction between the HCMC and some managed devices working in a home automation system using IEC 61850. The mapping between IEC 61850 models to underlying protocol is also described.

4.3.1 Scenario 1

In this scenario, HCMC has to retrieve information about managed device to build the entries for its device database. IEC 61850-7-2 provides multiple services to retrieve data. However, before performing these services, an application association needed 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].

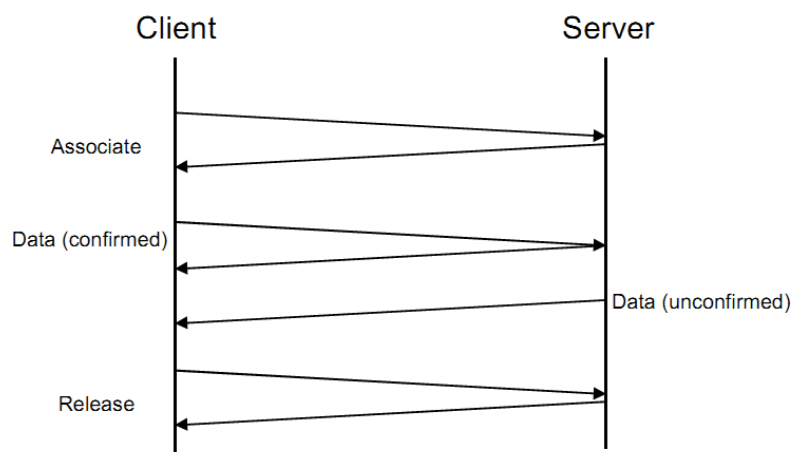**Figure 4.3: TWO-PARTY-APPLICATION-ASSOCIATION (TPAA) class syntax [4]**

Figure 4.3 shows the communication pattern of an IEC61850 client and server. In this case, the managed device acts as an IEC 61850 server and the HCMC is the client within the context of the Smart Home automation system. The client can request data from the server in a request/response fashion (confirmed method), or the server can send data to the client

without the client initiating the request (unconfirmed method). The confirmed method can be used when the HCMC wants to get specific information from the devices, such as polling the operation status or getting the current settings on the devices. The unconfirmed method can be used in the reporting services, where the manage devices are configured to send some specific data to the client without having to wait for the client request.

The structure of a server implementation is depicted in Figure 4.4.
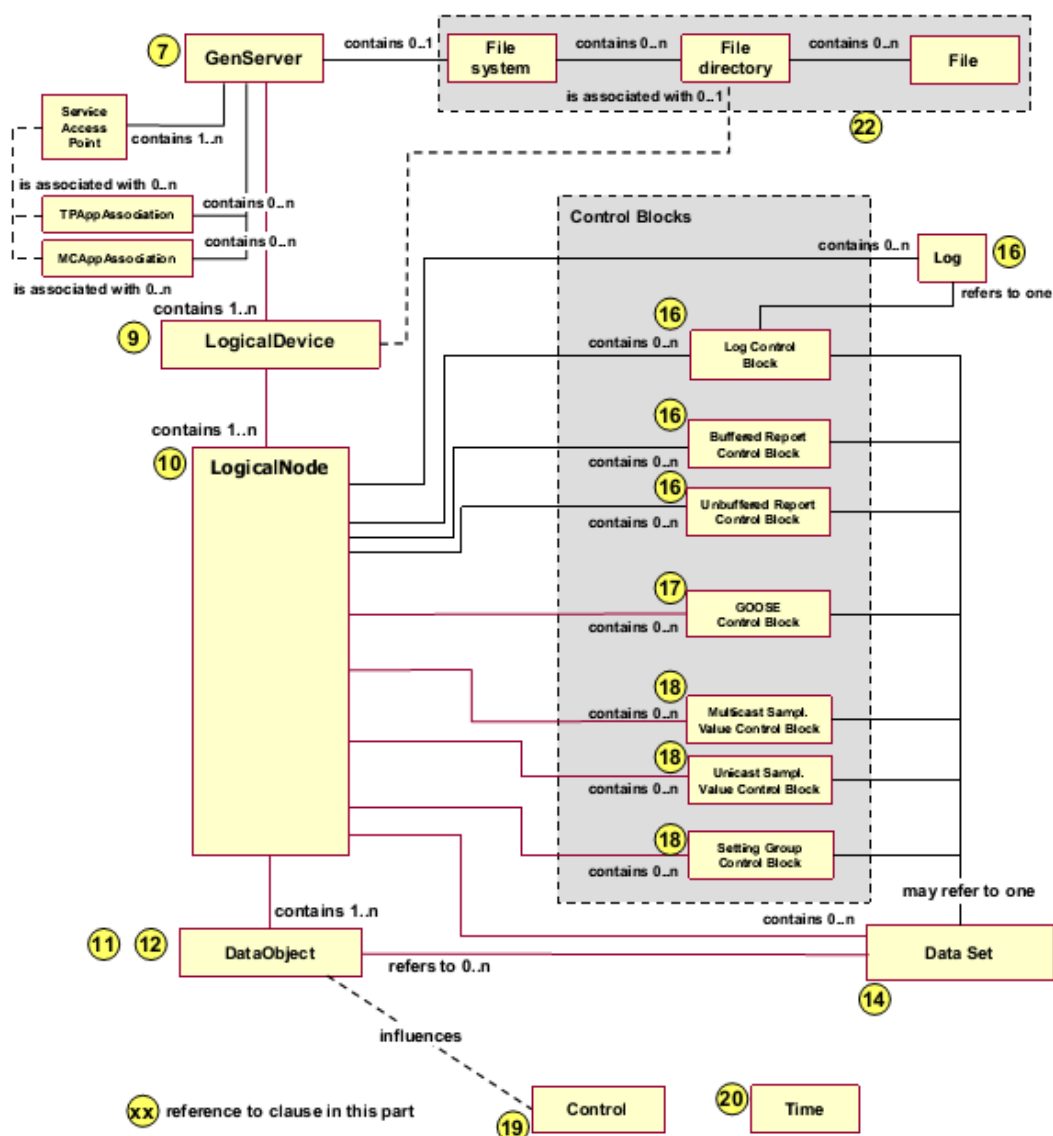

Figure 4.4: Relations between classes in an IEC 61850 server

The Meta Model in IEC 61850-7-2 part defines several generic classes, such as **GenServerClass**, **GenLogicalDeviceClass**, **GenLogicalNodeClass**, **GenDataObjectClass**

for the servers (7), logical devices (9), Logical Nodes (10) and data objects (11, 12), as well as services that are supported for each class.

One important notice in IEC 61850 is that the services operate on instances of classes only. The generic classes have to be instantiated into entities that have unique identities (termed instances, or objects). Figure 4.5 shows some specific instances of generic classes. MMXN1 is an instance of a generic logical node class **MMXN**, the data object Amp is an instance of the Common Data Class MV (Measured Values), etc.
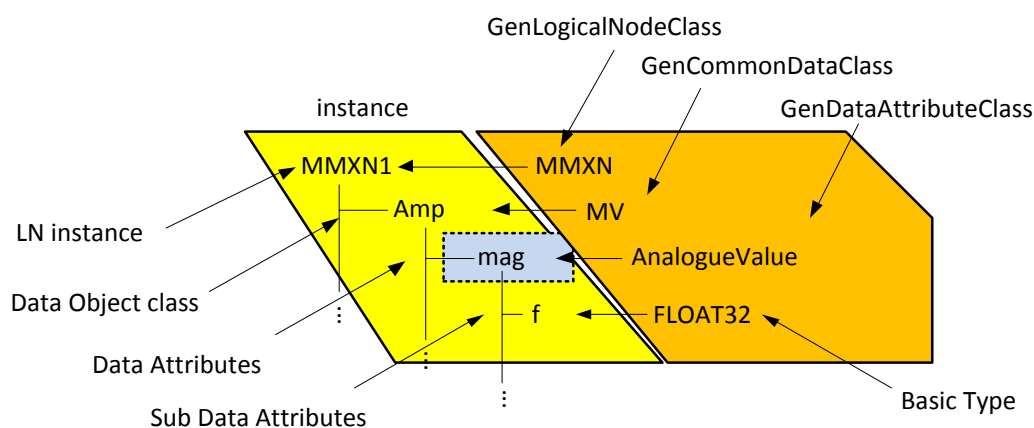

Figure 4.5: Instantiation of generic classes

An IEC 61850 server (e.g. a washing machine) has an access point that determines how it can be reached. The server can serve one or more clients (associations). A server can host several logical device instances, each has different logical nodes instances (functions as defined in chapter 3). For example, a washing machine can have a logical device instance WM01 which is broken down into logical nodes instances **LPHD1**, **LLN0**, **MMXN1**, **MMTN1**, **ZAPL1**. Each of these LN has its own data objects and attributes. These attributes can be put in data sets which can be used for other services such as MMS Services, GOOSE, SV, etc.

The next sections will described in details how IEC 61850 services can operate on these instances to support information exchange as described in Scenario 1.

4.3.1.1 Device capabilities

As logical nodes represent specific functions of a device, the HCMC can obtain the list of LNs within a device to get its functional capabilities. This is made possible thanks to the self-description of IEC 61850, in which several **GetXXDirectory** and **GetXXDefinition** services

are supported. The services that are supported in each level of the information object tree is shown in Figure 4.6.
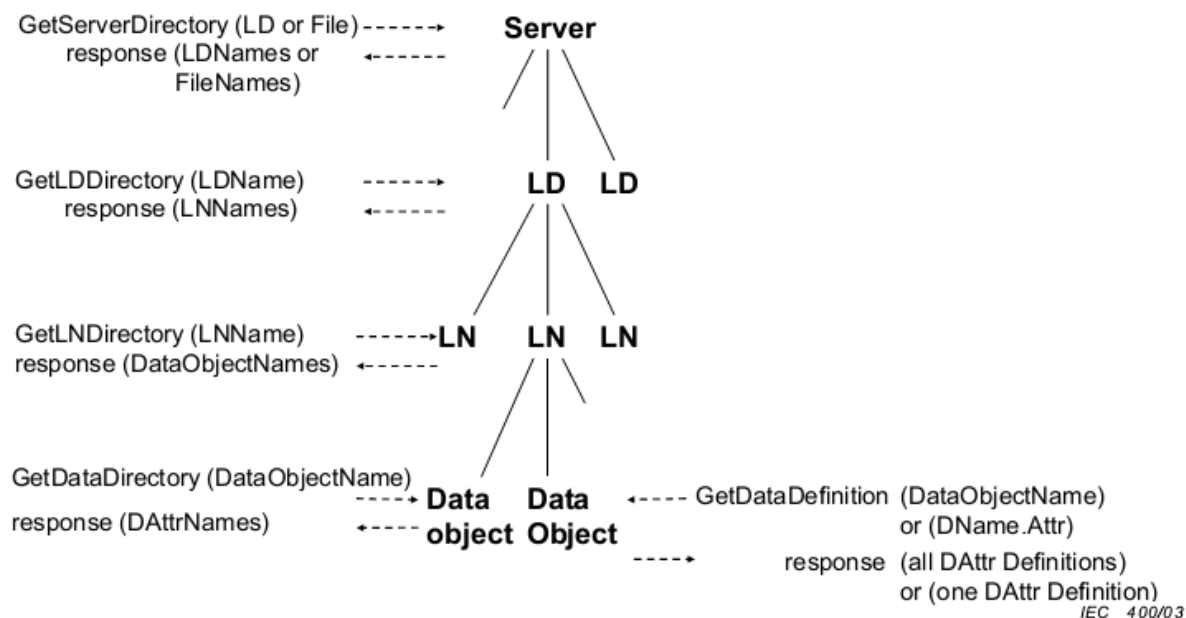
Figure 4.6: IEC 61850 server structure and the related services

The HCMC (client) can use the **GetServerDirectory** service to retrieve a list of the names of all logical devices made visible on the washing machine (server). The parameters needed to perform the **GetServerDirectory** service include:

Parameter name
Request
ObjectClass
Response+
Reference [0..n]
Response–
ServiceError

Request:

- **ObjectClass**: shall contain an identification of the selected class. The client shall select one of the following classes: **LOGICAL-DEVICE** or **FILE-SYSTEM**

Response+: shall indicate that the service request succeeded. A successful result shall return the following parameter.

- **Reference** [0..n]: shall contain the **ObjectReference** of the logical devices and file systems. **Response**-:

Response-: The parameter Response– shall indicate that the service request failed. The appropriate **ServiceError** shall be returned

After retrieving the list of logical device instances on the device, the HCMC shall use the **GetLogicalDeviceDirectory** service to retrieve the list of the **ObjectReferences** of all Logical Nodes made visible and thus accessible to the HCMC by the referenced logical device. The parameters needed to perform the **GetLogicalDeviceDirectory** service include:

Parameter Name
Request
LDName
Response+
LNReference [1..n]
Response–
ServiceError

Request:

- **LDName**: shall contain the object name of a logical device.

Response+: shall indicate that the service request succeeded. A successful result shall return the following parameter.

- **LNReference** [1..n]: shall contain the **ObjectReference** of the logical devices and file systems.

Response-: The parameter **Response**– shall indicate that the service request failed. The appropriate **ServiceError** shall be returned

Assuming that there are no errors with these 2 **GetServerDirectory** and **GetLogicalDevice**-Directory requests, the HCMC obtains the list of logical nodes of the device; hence it knows its functional capabilities of the device. Figure 4.7 shows an example of the interaction between the HCMC with a washing machine, an electric fan, and an electric heater whose logical nodes are different.
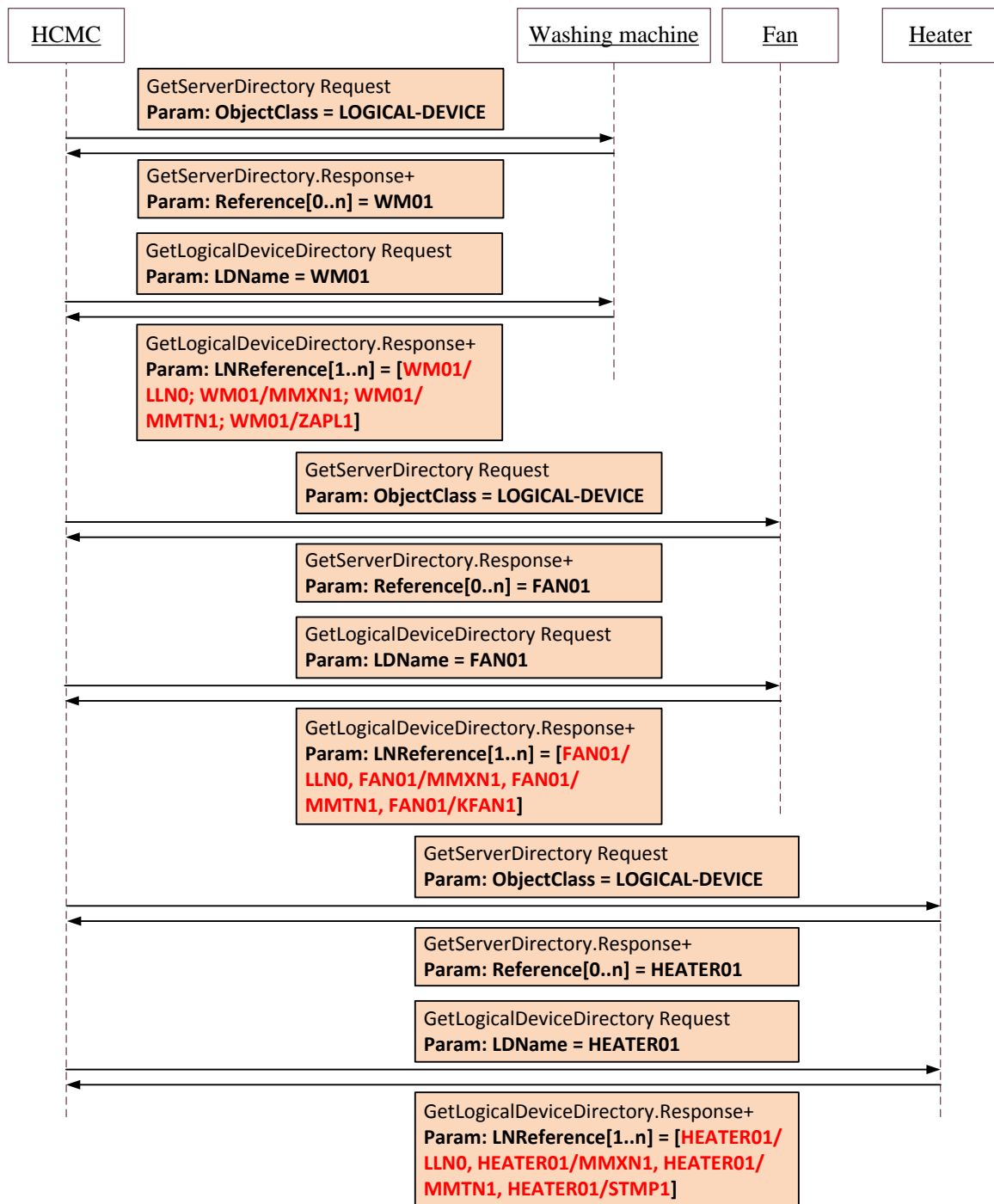
Figure 4.7: Example of GetServerDirectory and GetServerDirectory service used by HCMC

4.3.1.2 Device status and settings

After retrieving the list of Logical Node instances on the device, the HCMC has several options to retrieve the status and settings of the device.

Option 1: HCMC uses **GetDataValues** service to retrieve individual data object value

A logical node may have many different data objects, each with many data attributes. This option is suitable when HCMC only needs a single value for a particular data attribute (e.g. only current power usage, or the load set-points of the device). This option provides the selectivity for the data retrieval from HCMC and also suits the bandwidth-limited network. Currently Ethernet bandwidth is sufficient, but in the future when the protocol is mapped onto lower bandwidth protocol such as ZigBee, this option will help reduce the bandwidth consumption. The parameters needed to perform the **GetDataValues** service.

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

Request:

- **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]: The parameter **DataAttributeValue** [1..n] shall 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.

The Reference in the **GetDataValues** Request should have the functional constraint (FC) set. Functional constraint is the property of a data attribute that indicates the services, e.g. read

value, write value, substitute value, etc. that may be applied to that data attribute. Figure 4.8 shows a data attribute reference **WM01/MMXN.Watt.mag** that represents the power consumption for the washing machine in Figure 4.7. This attribute has FC=MX which means the attribute represent a measurand information whose value may be read, substituted, reported, and logged but shall not be writeable.
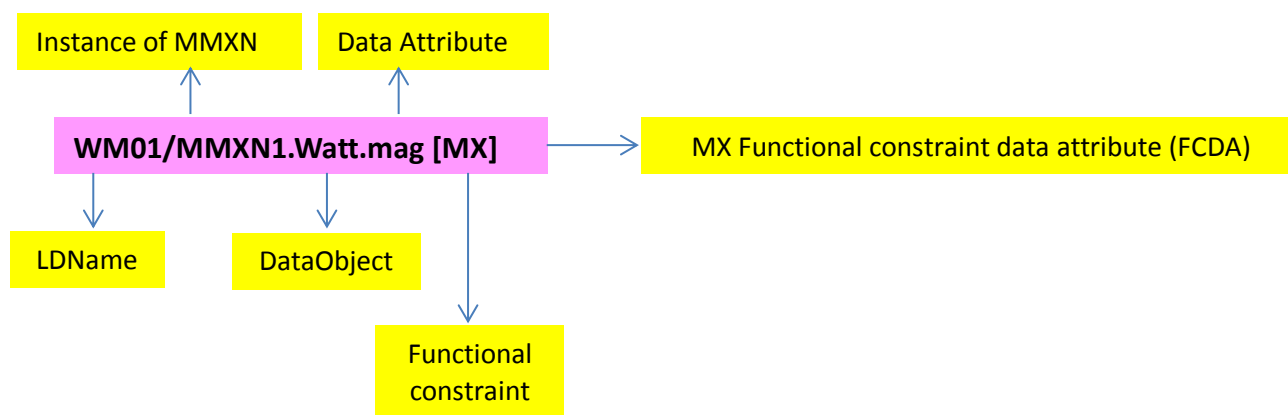
Figure 4.8: A reference with a functional constraint

For example, the HCMC uses **GetDataValues** service to retrieve the power usage and operation status of the washing machine, the speed set point of the fan and the temperature set point of the heater. These values are contained in the logical nodes of the appliances that have been defined in Chapter 3. Specifically, the power usage of the washing machine can be obtained by getting the value of the Watt data object in LN MMXN; the operation status is visible by getting the **Oper** data object in LN ZAPL (newly defined); the speed set point of the fan is represented by the **Spd** data object in LN KFAN; and the temperature set point is included in **TmpSpt** data object in LN STMP (extended from existing LN). The message flows and parameters are shown in Figure 4.9.
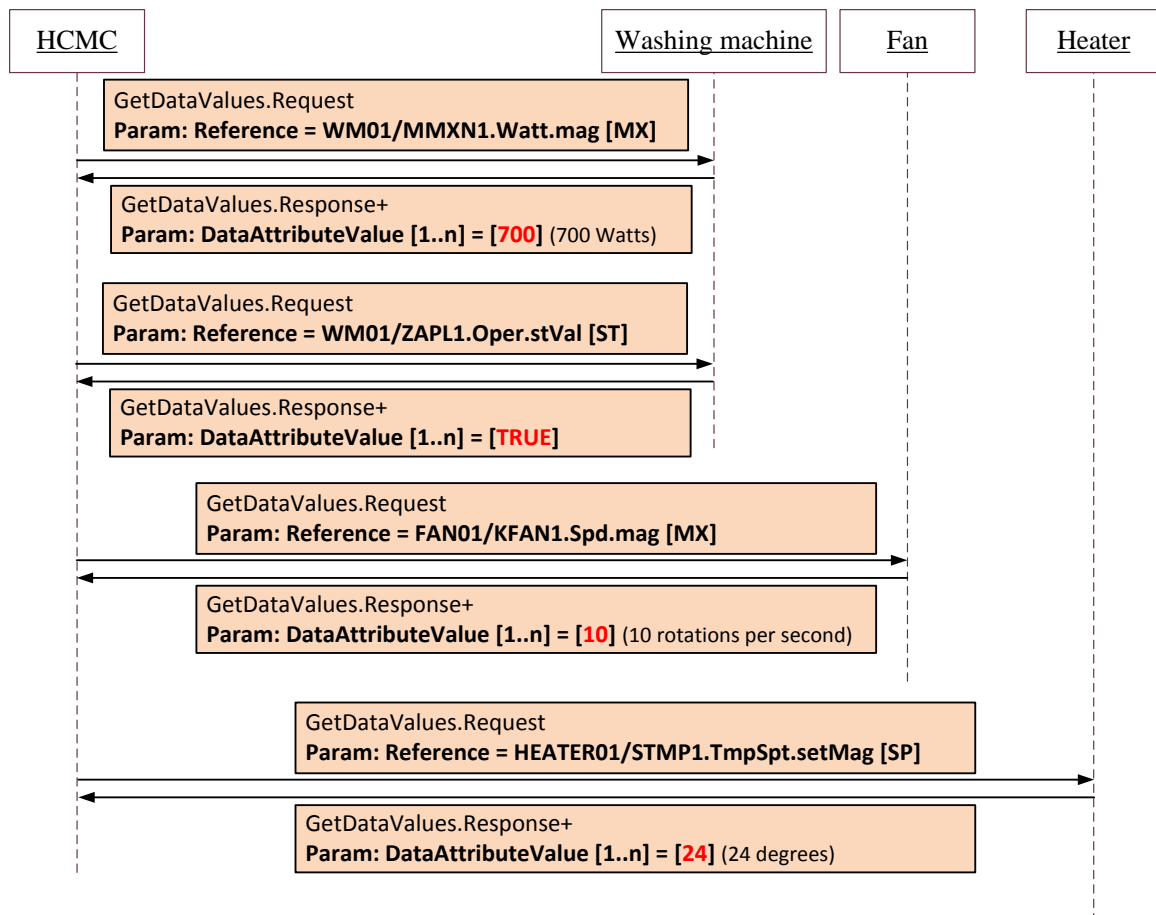
Figure 4.9: Example of GetDataValues service used by HCMC

The HCMC can recursively use the **GetDataValues** service to get the needed data values. However this is not a very effective method as the HCMC typically needs a lot more data object values. Therefore it can use the **GetAllDataValues** service (Option 2).

Option 2: HCMC uses **GetAllDataValues** service in **GenLogicalNodeClass** to retrieve all data object values of a Logical Node instance in the washing machine.

The parameters needed to perform the **GetAllDataValues** service include:

Request:

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.

Response-: shall indicate that the service request failed. The appropriate **ServiceError** shall be returned.

For example, Figure 4.10 illustrates the the HCMC using **GetAllDataValues** service to retrieve all the measurand values of the measurement function (Functional Constraint = MX) from Logical Node instance **MMXN1** of the washing machine, **KFAN1** of the fan, and **STMP1** of the heater.
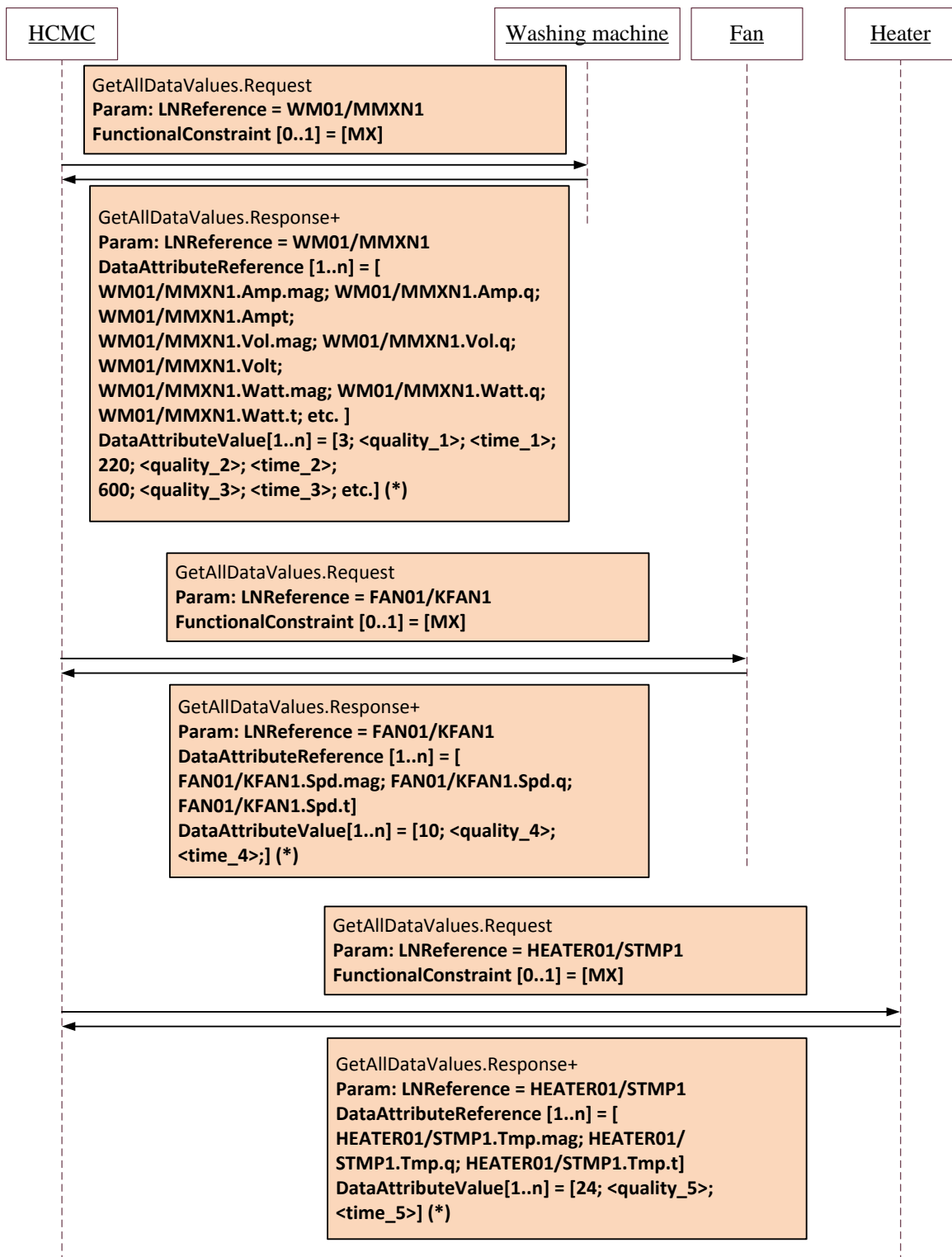
Figure 4.10: Example of GetAllDataValues service used by HCMC

(*) The represented values are for illustrative purposes only. The actual data format has to conform to specific data types defined in IEC 61850--3 Common Data Classes.

4.3.1.3 Device name plate

The name plate (information about vendor, serial number, hardware/software revision, etc.) of the washing machine is included in the LPHD and LLN0 Logical Nodes. This information will be used to keep track of the device in the database. The HCMC can use the **GetDataValues** or **GetAllDataValues** services that have been described in section 3.3.1.2 to retrieve the name plate information of the device.

For example, the HCMC can retrieve the information about the vendor and serial number of the washing machine, fan and heater (Figure 4.11)
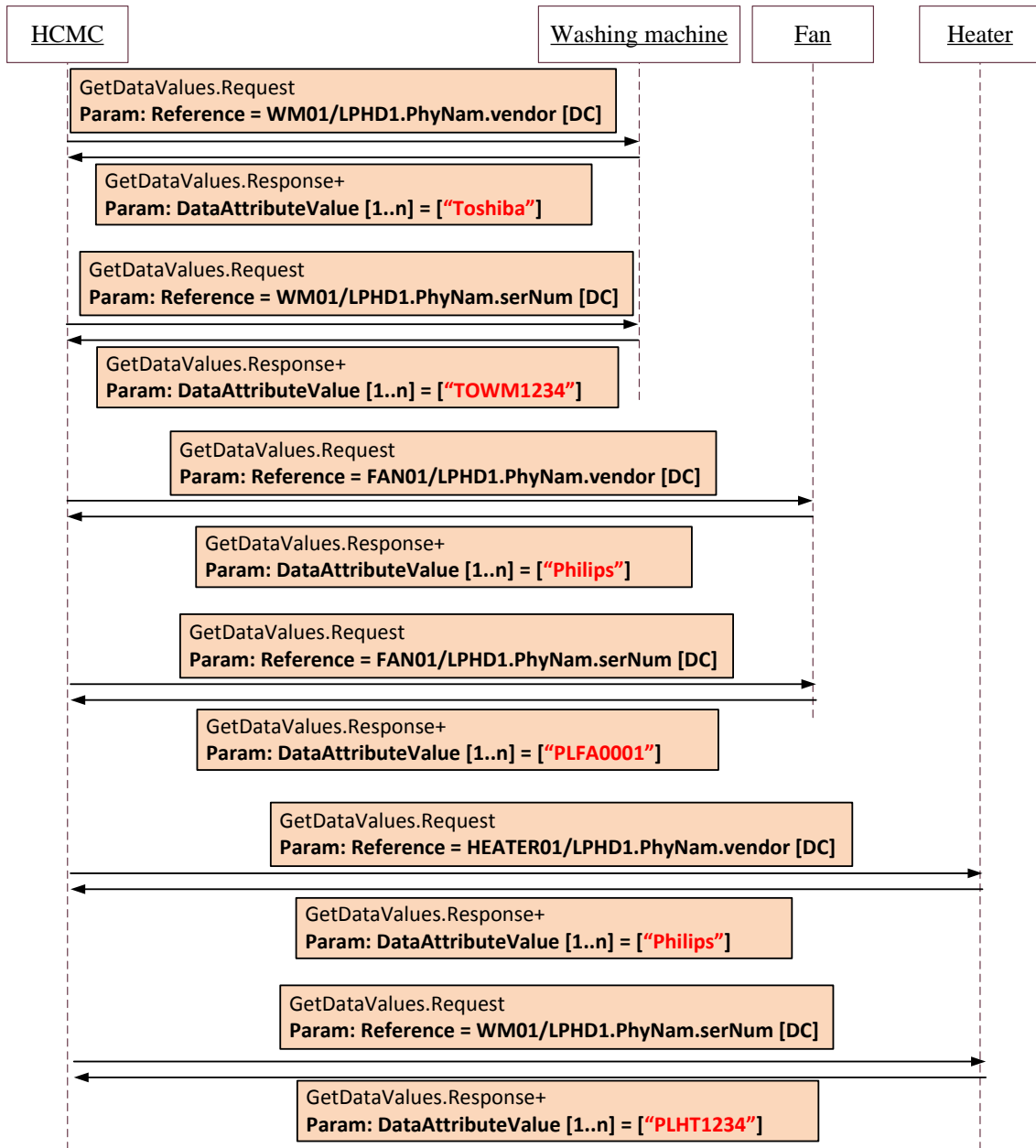
Figure 4.11: HCMC retrieves device name plate information

4.3.1.4 Device configuration

This section only discusses the reporting service configuration of the device. It is because the configuration of the operating status and set points is in the scope of equipment control within home automation system, not asset management. The reporting service is important because it does not require the HCMC to keep polling the devices to get data values. Instead, if a report control block is configured in the device (this is the presumption described in section 3.2.1), HCMC can use ACSI services to change the configuration of the report control block, so that when a triggering event happens, the reports are sent automatically to the

HCMC. However, HCMC cannot create a new report control block in the device, as this has to be done by IEC 61850 engineering tools. This is considered a disadvantage of IEC 61850.

We assume there is an **UNBUFFERED-REPORT-CONTROL-BLOCK** (URCB) configured in the device. Then the HCMC can use the **SetURCBValues** service to change some parameters for this URCB:

- **RptEna**: enabling or disabling the report service on the device

- **TrgOps**: triggering options of the report, whether it is due to data change, data update, quality change of the attributes.

- **DatSet**: the data set that comprises of different data attributes which are of interest to be included in the report.

For example, the HCMC can enable the report with data change triggering options and a data set on the heater so that when a temperature rises above the defined threshold, a report is sent. (See Figure 4.12)
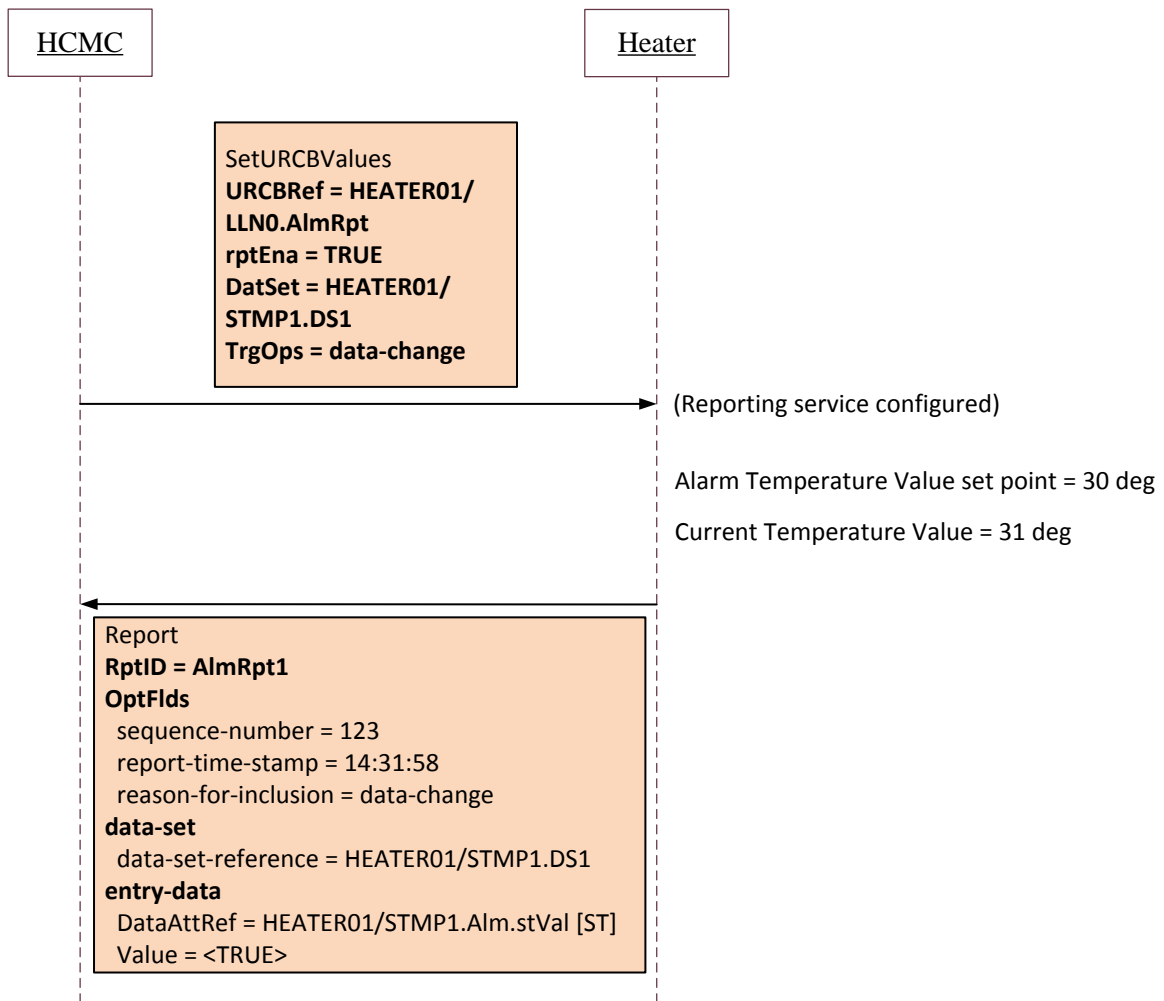
Figure 4.12: An example of report service configuration

4.3.2 Scenario 2

In Scenario 2, the HCMC monitors the operation status of the devices (by polling or by receiving reports from the devices). The HCMC generates alarms under abnormal conditions. In this Scenario, the HCMC also has to monitor the communication link to the devices and update the device database accordingly.

4.3.2.1 Device health monitoring

Health monitoring is a critical task within asset management, as it ensures the normal operation of the devices. The devices have the capability to self-assess and report the current

problem it might have, e.g. with the physical (hardware) or logical (software) aspects. This information is contained in **PhyHealth** data object in LN **LPHD** and Health data object in LN **LLN0**, which can be value 1 (OK - "green" - no problems, normal operation), 2 (Warning - "yellow" - minor problems, but in safe operation) or 3 (Alarm - "red" - severe problem, no operation possible).

The HCMC can use the **GetDataValues** or **GetAllDataValues** services for health monitoring of the devices by retrieving the attributes values of the health data objects.
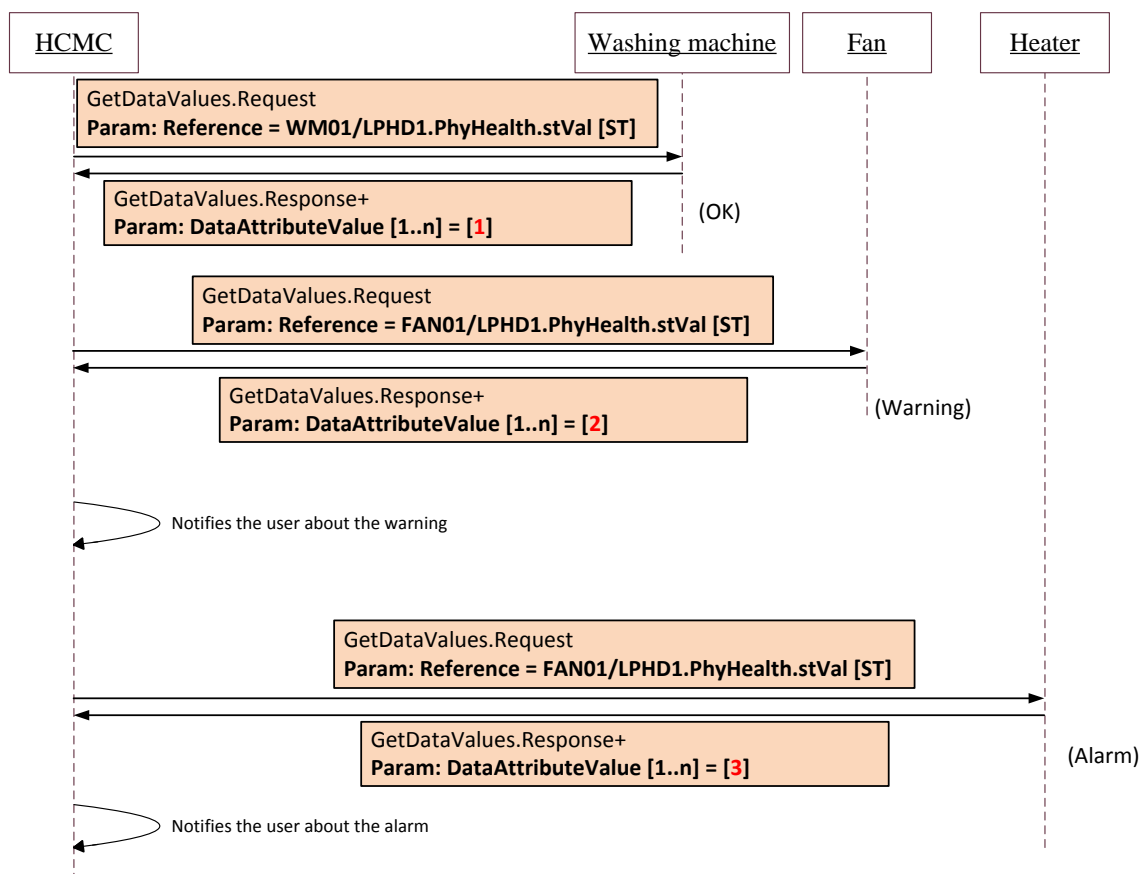
Figure 4.13: HCMC performs health monitoring using GetDataValues service

If the HCMC can use reporting services for health monitoring of the devices by including the health data object attributes in the report. In this case, whenever there is a change to the health data object attribute, the device will send reports to the HCMC. This option brings less overhead for the health monitoring, as only the changes are sent and the HCMC does not have to perform polling. This method is illustrated in Figure 4.14.
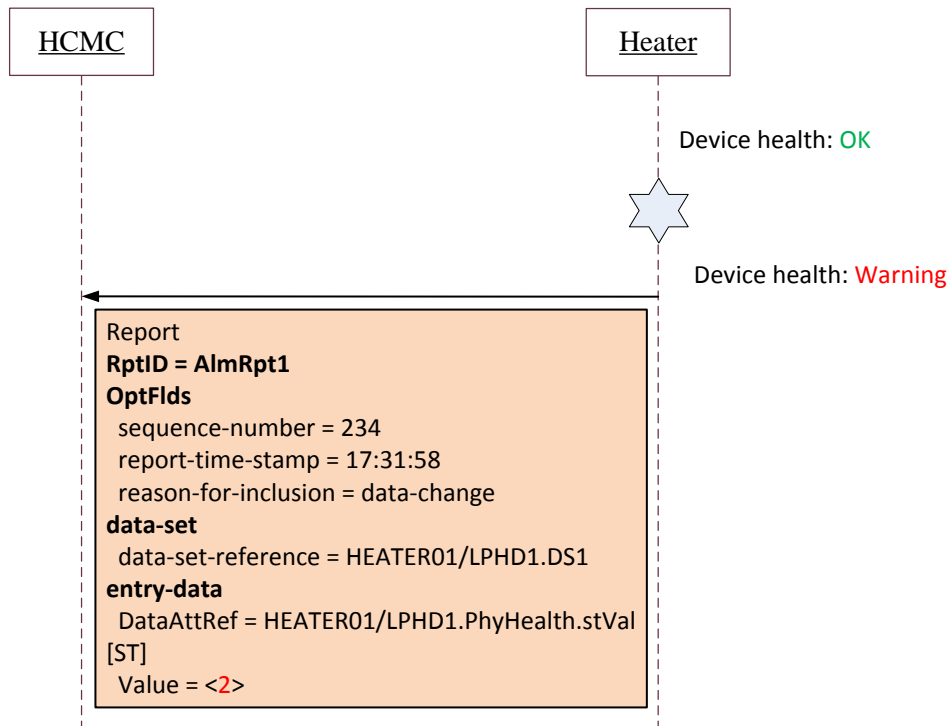
Figure 4.14: HCMC uses reporting services on the device to perform health monitoring

4.3.2.2 Communication link monitoring

Communication links from the HCMC to the devices have to be continuously monitored to ensure normal operation of the system. The HCMC has to know whether it can reach the devices it manages. If a device is unplugged from the network, then the HCMC has to notice that as well. The HCMC can employ the existing keep-alive mechanisms of the transporting protocol in order to detect link failures with the devices.

The HCMC can also detect layer 1 and layer 2 problems via communicating with the switch using IEC 61850. We assume that the switch supports IEC 61850, and it has LN **LCCH** implemented as described in section 4.1. The switch has an instance of LN **LCCH** for every switch port, and then can represent the communication status of the ports connecting to the devices. The data object attributes **ChLiv** in the LN **LCCH** instances can be put in a data set and be sent as report to the HCMC when there is any change to the data value (port status changes). Upon receiving this report, the HCMC knows of the changes in the communication links.

Figure 4.15 shows an example in which the washing machine is unplugged from the network. The HCMC notices the communication link is broken after receiving the report from the switch.

```
                                                              Washing Machine
         HCMC                              Switch

                    SW01/LCCH1.ChLiv.stVal = TRUE

                                                  Data-change
                                                  In LN
                                                  LCCH1.ChLiv

                                                              Unplugged

    ┌─────────────────────────────────────────┐
    │ Report                                    │
    │ RptID = SwRpt1                            │
    │ OptFlds                                   │
    │   sequence-number = 1                     │
    │   report-time-stamp = 19:31:58            │
    │   reason-for-inclusion = data-change      │
    │ data-set                                  │
    │   data-set-reference = SW01/LCCH1.DS1     │
    │ entry-data                                │
    │   DataAttRef = SW01/LCCH1.LCCH1.ChLiv.stVal│
    │ [ST]                                      │
    │   Value = <FALSE>                         │
    └─────────────────────────────────────────┘
```
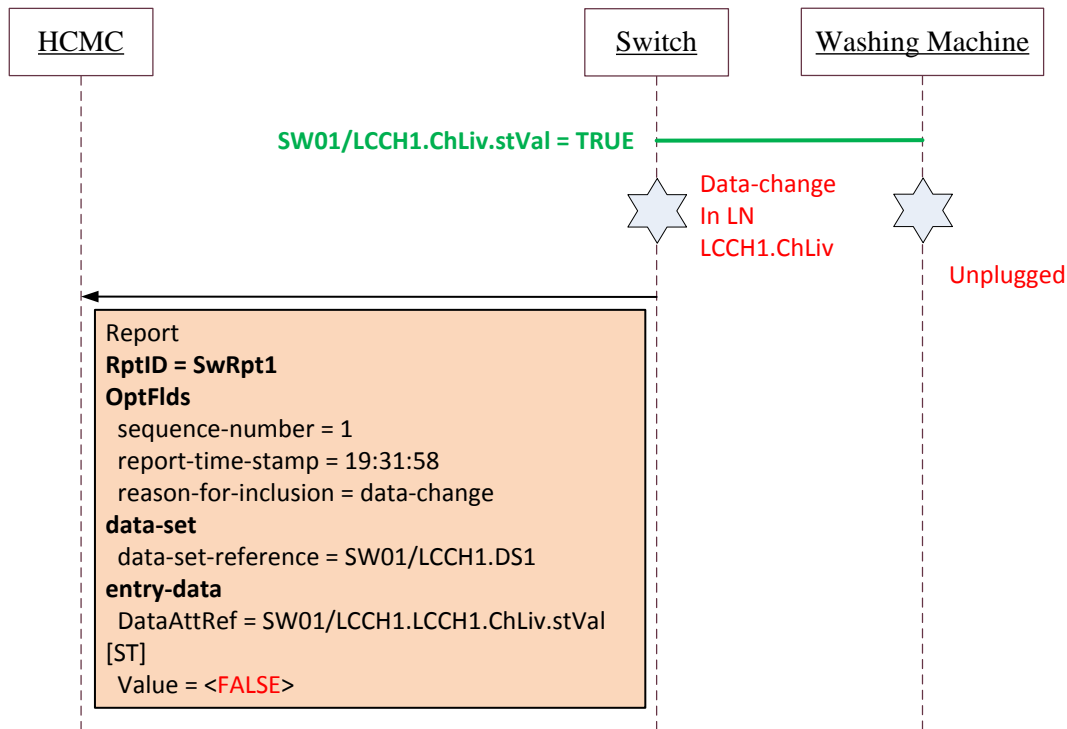
Figure 4.15: HCMC uses reporting service on a switch to detect communication problems

4.3.3 Mapping ACSI services to MMS

In section 3.3.2, we have seen that the ACSI services of IEC 61850 are capable of performing management tasks within the home automation system. Since ACSI services are abstract services, they must be mapped to an underlying protocol to allow communication between HCMC and the devices. As described in chapter 2, there are several message types within IEC 61850. Because management service does not require fast message exchange, and employs the client/server interaction between the HCMC and the managed devices, the ACSI services are mapped to MMS services as shown in Table 4.8 [8].

Table 4.8: 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 and IEC 61850-7-3 data attributes can also be found in IEC 61850-8-1 [8]. For example, Table 4.9 lists the mapping of the GetDataValues service to MMS Read service.

Table 4.9: Mapping of GetDataValues service parameters, copied from [8]

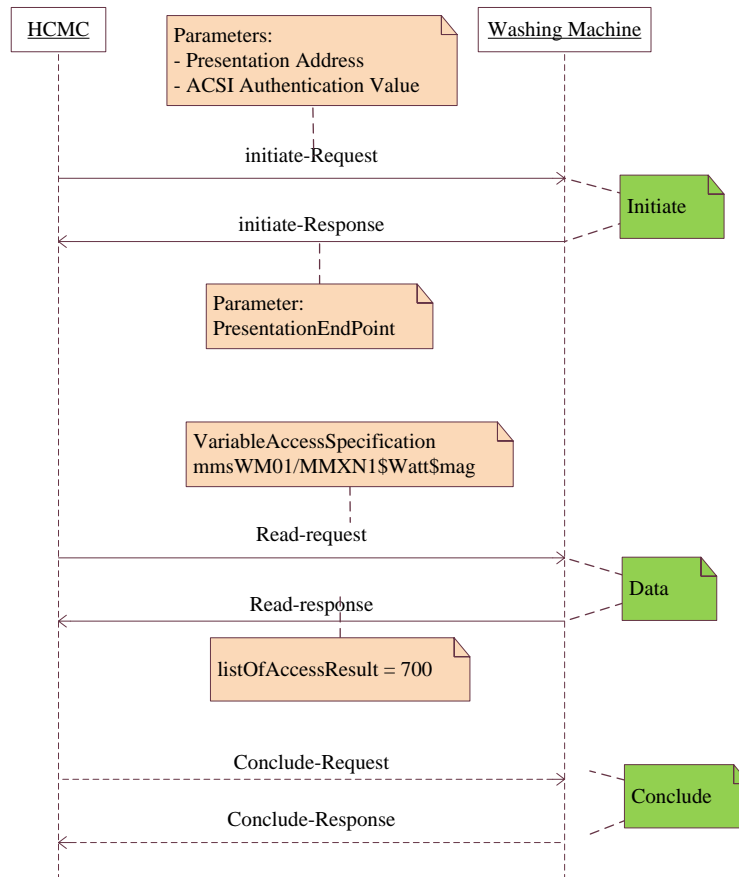| GetDataValues parameters	MMS service or parameter	Constraint
Request	Read request service	
Reference	variableAccessSpecification	Maps to a 8-1VARSPEC
Response+	Read response service	
DataAttributeValue[1..n]	listOfAccessResult	
Response−	Read response service	
ServiceError	listOfAccessResult	See **Table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

Figure 4.16: Mapping GetDataValues to MMS Read service to get measurement value

Figure 4.16 sketches the mapping of ACSI **GetDataValues** service to MMS **Read** service that allows the HCMC to establish a two-party association with the washing machine and retrieve the power consumption in the logical node instance MMXN1. For other services used in this use case such as **GetAllDataValues** service, **SetURCBValues**, etc. a detailed mapping can be found in IEC 61850-8-1 [8]. The MMS PDU (Protocol Data Unit) will be encoded using ASN.1 to have the format of TLV (Tag, Length, Value) and will be transported through communication links by the TCP/IP transport profile (T-Profile) that MMS supports [8].

4.4. Summary

This chapter is the core of the report, where a typical management tasks are introduced in a specific use case. IEC 61850 services are applied on the object models that have been defined in chapter 3 in order to support asset management within the LV microgrids, including the inventory management, health monitoring, device reporting service configuration, and alarm handling functions.

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.

The main goal of the research is to apply the concepts of IEC 61850 to a different domain, the LV microgrid, to perform inventory management, configuration management, device monitoring and alarm handling. Each chapter has fulfilled a specific objective to achieve the main goal.

Specifically, a communication network topology is presented in chapter 3, which allows for the distributed control and management of the LV microgrid with user privacy taken into account. The object models for the components within the LV microgrid are also analysed in chapter 3. Some of the existing logical nodes for substation domain can be reused, while the missing models are defined either by extending the data objects of the existing logical nodes, or defined as new logical nodes.

Based on the defined logical nodes in chapter 3, the IEC 61850 services shown in chapter 4 allow the asset management of the LV microgrid components in a specific use case that covers typical management tasks. The IEC 61850 services that can be used to fulfil these management tasks are also presented in chapter 4 with the associated parameters of the services and the mapping to the communication protocol.

This research contributes to the development of IEC 61850 by introducing a new domain that the standard has not yet covered: the low voltage network microgrid. Within the research, IEC 61850, originally used for substation automation, is shown to be capable of performing asset management within the LV microgrid.

There is room for improvement of the standard within the scope of LV microgrid asset management. Future work can define more use cases for different purposes, such as voltage stabilization, microgrid islanding, etc. to see whether IEC 61850 can be used to support these use cases.

One shortage of IEC 61850 is the lack of auto-configuration and device discovery process that have been described in chapter 4. Currently, IEC 61850 requires the use of engineering tools to configure the devices in offline mode, and it would not be convenient within a Smart Home context. More work can be done on the plug-and-play features of IEC 61850, such as [18].

IEC 61850 defines the mapping between ACSI services and underlying protocols such as Ethernet, MMS, etc. 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.

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