UNIVERSITY OF VAASA

FACULTY OF TECHNOLOGY

TELECOMMUNICATION ENGINEERING

Ahmed Elgargouri

IMPLEMENTATION OF IEC 61850 IN SOLAR APPLICATIONS

Master´s thesis for the degree of Master of Science in Technology submitted for inspection, Vaasa, 30th of March 2012.

Supervisor Mohammed Elmusrati

Instructor Smail Menani (VAMK)
Magnus Sundell (Vacon Oyj)

Acknowledgements

Firstly, thanks God almighty for supporting me among all my life. Then I would like to thank my thesis Supervisor, Professor Mohammed Elmusrati for his support in both my thesis and my studies and for all his favors that cannot be described in words. I would like to thank also Dr. Smail Menani for supporting and motivating me; I would not be able to start this thesis topic without his help and his advice.

This thesis was founded by Vacon Oyj Finland, it was a great experience for me and I enjoyed the cooperating with Vacon's team who made the work done in a friendly environment. Thanks to Magnus Sundell, Peter Guss, Janne Kuivalainen and Mika Saarijärvi for the fast replies and supplying me with all needed documents and information.

I would like to thank all Telecommunications engineering group's staff at university of Vaasa especially Dr. Reino Virrankoski for their help and sharing their knowledge. Special thanks to Technobothnia staff as well for making all needed resources available, and to the international office staff especially Henna Huovinen.

Finally I would like to express my special thanks to my dearest parents for making it possible to be where I am now, I would not achieve any of this without their support. Thanks to all my family, my classmates and my friends for all their help and support and making last few years full of memories and achievements.

Ahmed Elgargouri

Vaasa, Finland, 21st of March 2012

TABLE OF CONTENTS **PAGE**

ABBREVIATIONS 9
ABSTRACT 12
1. INTRODUCTION 13
1.1. Introduction to IEC 61850 13
1.2. Thesis Motivation 13
1.3. Research Methods 14
1.4. Main Thesis Results 14
1.5. Thesis Outline 14
1.6. Thesis Contribution 16
2. BACKGROUD AND OVERVIEW 17
2.1. Communication in SCADA and SA 17
2.2. Telecommunication Protocols 19
2.2.1. Open System Interconnection (OSI) 19
2.2.2. Ethernet Protocol 20
2.2.3. TCP/IP Suite 21
2.2.4. Manufacturing Message Specification (MMS) 22
2.2.5. ACSI and SCSM 23
3. IEC 61850 25
3.1. History of IEC61850 25
3.2. IEC 61850 Communication Model 26
3.3. IEC 61850 Application and Communication views 27
3.3.1. IEC 61850 Parts 28
3.3.2. Virtualized Model 31

3.3.3. Logical device (LD) ... 33
3.3.4. Logical Node (LN) ... 34
3.3.5. Data Objects ... 35
3.4. Generic Object Oriented Substation Event (GOOSE) ... 36
3.5. Substation Configuration Language (SCL) ... 37
3.6. IEC 61850 Benefits ... 38
4. IEC 61850 CURRENT RESEARCHES AND IMPLEMENTATIONS ... 41
4.1. Hydroelectric Power ... 41
4.2. Wind Power ... 43
4.3. Solar applications ... 45
5. STANDARDS BASED ON IEC 61850 ... 47
5.1. UCA 2.0 ... 47
5.2. IEC 61499 ... 48
5.3. IEC 61131 ... 50
5.4. IEC 60870-5 ... 51
6. IEC 61850 AND SOLAR APPLICATIONS VERSUS MARKET NEEDS ... 53
6.1. Survey Questions ... 53
6.2. Survey Glitches ... 53
6.3. Results and Comments ... 54
6.4. Survey Feedback ... 65
7. IMPLEMENTATION OF IEC 61850 IN SOLAR APPLICATIONS ... 66
7.1. Implementation Requirements ... 66
7.2. DER Logical Nodes ... 67
7.3. Photovoltaic LDs and LNs ... 69

7.4. Vacon's PV inverter (8000 Solar) and ZINV Logical Node 72

7.5. Photovoltaic Array Simulation 78

8. CONCLUSION AND FUTURE WORK 84

REFERENCES 85

APPENDICES 90

Appendix 1. Survey for IEC 61850 users 90

Appendix 2. Survey for non-IEC 61850 users. 94

Appendix 3. IEC 61850 guide for reader (IEC-TC 57 2003) 99

Appendix 4. Vacon 8000 Solar (Vacon) 100

TABLE OF FIGURES **PAGE**

Figure 2.1 Typical SCADA and SA architecture 17
Figure 2.2 Communication in SA diagram 18
Figure 2.3 Vertical and horizontal communication in the SA 19
Figure 2.4 OSI model 20
Figure 2.5 Ethernet Stack. 21
Figure 2.5 TCP/IP protocols suite and functional layers 22
Figure 2.6 VMD Architecture 23
Figure 2.7 IEC 61850 key aspects 24
Figure 3.1 IEC 61850 and UCA 2.0 merging 25
Figure 3.2 IEC 61850 Communication Model 26
Figure 3.3 OSI and IEC 61850-7&8 stack 27
Figure 3.4 Application and communication views of IEC 61850 28
Figure 3.5 IEC 61850 parts. 28
Figure 3.6 Virtual world vs. real world 32
Figure 3.7 Physical and logical devices 33
Figure 3.8 XCBR (Circuit Breaker) Logical Node 35
Figure 3.9 Analysis of a data object 36
Figure 3.10 Example of GOOSE messages exchange 37
Figure 3.11 Creating the SCL files 38
Figure 4.1 Distribution of IEC 61400-25 wind power plant LNs 45
Figure 5.1 Encompassing UCA 2.0 in IEC 61850 48
Figure 5.2 Implementation of LNs and logical devices using composite FB 49

Figure 5.3 LN modeled as a FB 50

Figure 5.4 Beck IPC GmbH IEC 61850/IEC 61131-3 tasks chip. 50

Figure 5.5 WLAN network for substation and DERs 51

Figure 6.1 Results of question number 1. 54

Figure 6.2 Results of question number 2. 55

Figure 6.3 Results of question number 3. 56

Figure 6.4 Results of question number 4. 57

Figure 6.5 Results of question number 5. 57

Figure 6.6 Results of question number 8. 58

Figure 6.7 Results of question number 11. 60

Figure 6.8 Results of question number 12. 61

Figure 6.9 Results of question number 14. 62

Figure 6.10 Results of question number 17. 63

Figure 6.11 Results of question number 18. 64

Figure 7.1 Vampset simulates VAMP 257 front panel 67

Figure 7.3 Photovoltaic system LDs and LNs 69

Figure 7.4 DER type selection 70

Figure 7.5 PV array Simulink model 79

Figure 7.6 PV module subsystem model. 80

Figure 7.7 Relation between IPV and VPV. 80

Figure 7.8 Relation between PPV and VPV. 81

LIST OF TABLES **PAGE**

Table 3.1 LN groups. 34

Table 4.1 Hydropower plants information model. 42

Table 4.2 Wind power plant LNs. 44

Figure 7.2 Conceptual organization of DER LDs and LNs 68

Table 7.1: ZINV logical node data 73

Table 7.2 8000 Solar status word parameters 74

Table 7.3: ZINV status information 75

Table 7.4 Rest of ZINV data 77

Table 7.5 DPVC (Photovoltaic array controller) LN 82

ABBREVIATIONS

AC	**Alternating Current**
ACSI	**Abstract Communication Service Interface**
CDC	**Common Data Classes**
CEI	**Italian Electrotechnical Committee**
CID	**Configured IED Description**
DC	**Direct Current**
DER	**Distributed Energy Resource**
DNP3	**Distributed Network Protocol**
ECC	**Execution Control Chart**
EPRI	**Electric Power Research Institute**
FAT	**Factory Acceptance Tests**
FB	**Function Block**
Gbps	**Giga bit per second**
GOOSE	**Generic Object Oriented Substation Event**
GPRS	**General Packet Radio Service**
GSSE	**Generic Substation State Events**
HMI	**Human Machine Interface**
ICD	**IED Capability Description**
IEC	**International Electro-technical Commission**
IED	**Intelligent Electronic Device**
IEEE	**Institute of Electrical and Electronics Engineers**
IP	**Internet Protocol**
I_{pv}	**Photovoltaic current**
ISO	**International Standards Organization**

IT	**Information Technology**
LAN	**Local Area Network**
LD	**Logical Device**
LN	**Logical Node**
MB	**Mega Byte**
Mbps	**Mega bit per second**
MMS	**Manufacturing Message Specification**
ms	**millisecond**
OSI	**Open System Interconnection**
PC	**Personal Computer**
PLC	**Programmable logic controller**
PV	**Photovoltaic**
P_{pv}	**Photovoltaic power**
SA	**Substation Automation**
SAS	**Substation Automation Systems**
SAT	**Site Acceptance Tests**
SCADA	**Supervisory Control And Data Acquisition**
SCD	**Substation Configuration Description**
SCL	**Substation Configuration Language**
SCSM	**Specific Communication Service Mappings**
SMV	**Selectable Mode Vocoder**
SSD	**System Specification Description**
TC	**Technical Committee**
TCP/IP	**Transmission Control Protocol over Internet Protocol**
UCA	**Utility Communication Architecture**

UDP	**User Datagram Protocol**
$\boldsymbol{var}$	**Volt-ampere reactive**
VMD	**Virtual Manufacturing Device**
$\boldsymbol{V_{pv}}$	**Photovoltaic voltage**
WAN	**Wide Area Network**
WG	**Work Group**
WiMAX	**Worldwide Interoperability for Microwave Access**
WLAN	**Wireless Local Area Network**
XML	**Extensible Markup Language**

UNIVERSITY OF VAASA
Faculty of Faculty of technology

Author:	Ahmed Elgargouri
Topic of the Thesis:	Implementation of IEC 61850 in Solar Applications
Supervisor:	Mohammed Elmusrati
Instructors:	Smail Menani
	Magnus Sundell
Degree:	Master of Science in Technology
Department:	Department of Computer Science
Degree Programme:	Degree Programme in Telecommunications Engineering
Major of Subject:	Telecommunications Engineering
Year of Entering the University:	2009
Year of Completing the Thesis:	2012 **Pages: 100**

ABSTRACT

IEC 61850 has become one of the core technologies in the substation automation due its high-speed reliable operation Ethernet-based communication with a high security. Its reliability and performance makes a significant contribution to a fail-safe substation operation. IEC 61850 also allows both vertical and horizontal communications in the substation automation. Main characteristic of IEC 61850 is the use of GOOSE messages. All communication services run parallel via one LAN connection and the same GOOSE message can be broadcasted to several IEDs in once. This results in less wiring and faster data exchange between applications. Moreover, one of the core features of IEC 61850 is the interoperability between IEDs from different vendors. The separation of communication and data model allows to reliably retaining engineering data for a long time even if when upgrading or changing the system. IEC publishes updated documentations every while and add new parts to the standard due to the rabidly increase of IEC 61850 applications demand. As the market of solar applications has been increasing last few years, hence, the needs of new technologies to be implemented in solar applications is increasing as well. This thesis beside several other current researches nowadays is investigating the implementation of IEC 61850 in solar applications. The thesis outlines the current needs of solar applications by collecting statistical data using two surveys then concludes the implementation requirement. In the end of the research, IEC 61850 Data sets and current used parameters by Vacon were compared, and simulation example of photovoltaic array is given to conclude the benefits of using IEC 61850 in solar systems.

Keywords: IEC 61850, solar applications, survey, 8000 Solar

1. INTRODUCTION

1.1. Introduction to IEC 61850

IEC 61850 is a worldwide-accepted standard for Ethernet-based communication in substations. The IEC 61850 international standard, drafted by substation automation domain experts from 22 countries, seeks to tackle the aforementioned merging. This standard takes advantage of a comprehensive object-oriented data model and the Ethernet technology, bringing in great reduction of the configuration and maintenance cost. The IEC 61850 standard is designed to be capable for domains besides substation automation. The abstract data models defined in IEC 61850 can be mapped to a number of protocols. Current mappings in the standard are to MMS (Manufacturing Message Specification), GOOSE (Generic Object Oriented Substation Event), SMV (Selectable Mode Vocoder) and soon to Web Services. These protocols can run over TCP/IP networks and/or substation LANs using high speed switched Ethernet to obtain the necessary response times of e.g. less than 4ms for protective relaying.

1.2. Thesis Motivation

IEC 61850 has become a very important topic for researchers as the power system automation needs are rapidly increasing. This is in one hand. In the other hand, the requirements of solar applications and PV inverters are rapidly increasing at the same time. Hence, the need of implementing a new standard that meets these requirements is growing as well.

So far, there is not any factual implementation of IEC 61850 to meet the requirements of the whole solar applications and PV inverters yet. This comes from the fact that IEC had not published any specific documentation for Photovoltaic (PV) inverters and solar applications yet. This gives the opportunity for this thesis to be one of the first researches to investigate the implementation of the standard in solar applications. Additionally, the main motivation of the research was Vacon Oyj Finland's interest of implementing the standard in their solar inverter (8000 Solar)

1.3. Research Methods

In this thesis, qualitative and problem-solution research methodologies are used to achieve the research target. Data collection technique will be based on multiple sources of data to understand the current needs and evaluate how the IEC 61850 standard can satisfy them and What new functions can this standard add to Vacon's solar applications. Besides, quantitative research method is used in chapter six to collect samples via two surveys regarding to investigate market needs and expectations of solar applications' future then evaluate these samples statistically and generalize them.

1.4. Main Thesis Results

Two surveys have been used to conclude current needs of solar applications as well as the substation automation in general by collecting statistical data using then concludes IEC 61850 implementation requirement to be applied in solar applications and Vacon's solar inverter. IEC 61850 Data sets and current used parameters by Vacon were compared. A simulation example of photovoltaic array is given and comments are obtained to conclude the benefits of using IEC 61850 in solar applications.

1.5. Thesis Outline

The thesis contains eight chapters and is organized as follows:

Chapter 1:

Provides an introduction to the research besides the motivation of the research as well as the research methodologies. Additionally, it describes the thesis originality, contribution and main results obtained in the end of the thesis.

Chapter 2:

Presents a literature background and overview of Communication in SCADA and SA and summarization of telecommunication protocols that IEC 61850 is mapped over them.

Chapter 3:

Provides a guideline to IEC 61850. History, communication Model, Application and Communication views of the standard are described briefly with highlighting key aspects and benefits of using the standard.

Chapter 4:

Current researches and implementations of IEC 61850 in DER and green power resources. Hydroelectric power, wind power and solar application are the scope of this chapter.

Chapter 5:

Gives some examples of interplay between IEC 61850 and particular familiar substation automation standards. Moreover, an example of expected interplay with another standard in the future.

Chapter 6:

Two surveys have been used to collect the information from the costumers and power utility companies to specify the market needs and expectations of solar applications’ future then conclude the needed functionalities to be added and how to add and implement them.

Chapter 7:

Comparison between IEC 61850 Data sets and current used parameters by Vacon. Furthermore, a simulation photovoltaic array example will be shown to obtain comments regarding to the benefits of using IEC 61850.

Chapter 8:

Discusses the conclusions and future scope of this thesis.

1.6. Thesis Contribution

Since this thesis is considered as one of the first researches to investigate and simulate the implementation of IEC 61850, the obtained results will give fundamental future expectations of using the standard for all PV inverters and solar applications. This is from technical point of view. From the market point of view, costumer expectations of solar applications and the use of IEC 61850 futures are investigated by two Surveys.

2. BACKGROUD AND OVERVIEW

2.1. Communication in SCADA and SA

Substation Automation is a method of controlling power system automatically via IEDs (Intelligent Electronic Devices) using control commands from remote users. The communication in SCADA (Supervisory Control And Data Acquisition) and substation automation is more and more often TCP/IP based LAN communication.

The typical architecture of a modern SA or SCADA consists of three levels; station level where is the database, which is represented as the station computer in Figure 2.1 as well as the engineering station, which represent HMI (Human Machine Interface) and the station gateway. Bay level represents the IEDs with the LAN connection between them. Finally, the process level where the event messages are captured and controlled by the station level. The communication between IEDs is horizontal whereas it is vertical communication between two different levels (e.g. station level and bay level).

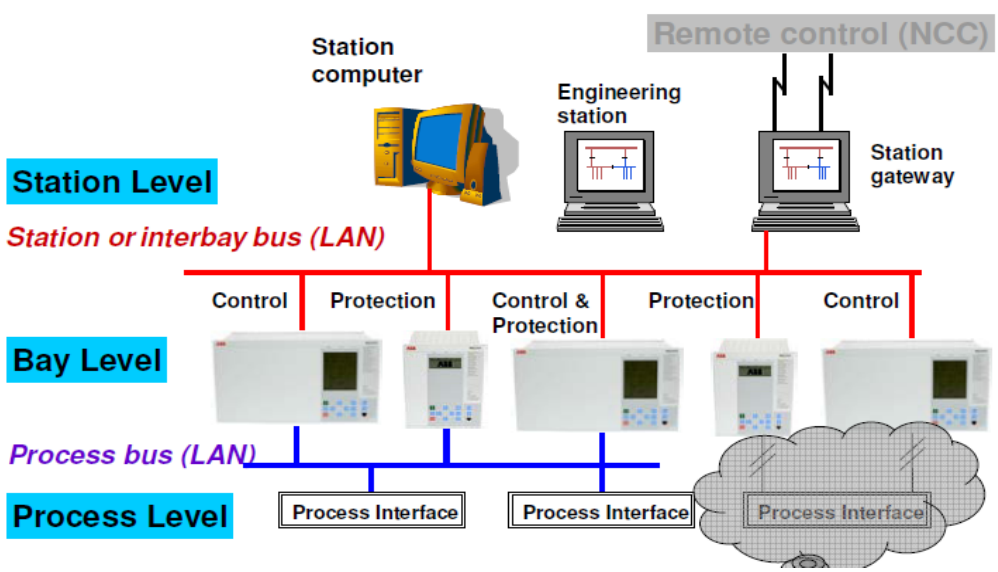

Figure 2.1 Typical SCADA and SA architecture (Gajić 2005).

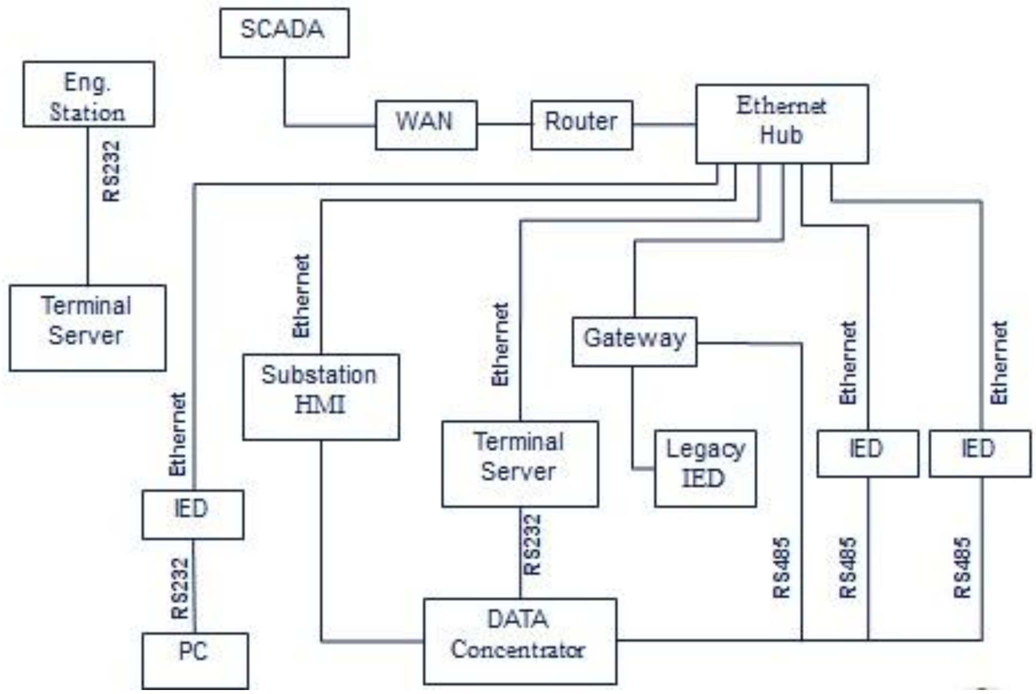

Figure 2.2 Communication in SA diagram (Menani 2009).

From the previous figures, it is clear that SCADA needs a protocol that can achieve both vertical and horizontal communication.

IEC 61850 supports vertical and horizontal communication services beside that it is used for time synchronization and file transfer. IEDs at the bay level communicate together horizontally by sending and receiving GOOSE messages whereas the communication between station level and bay level is done by sending data and receiving SCL files at the station level. All previous services refer to the part 7-2 Abstract Communication Services (ACSI). GOOSE, SCL, ACSI and IEC parts will be explained later.

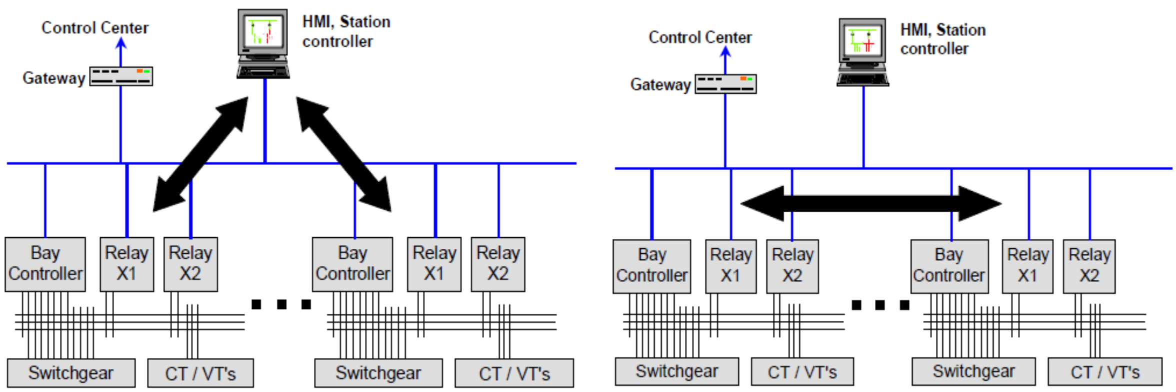

Figure 2.3 Vertical and horizontal communication in the SA (De Mesmaeker, Rietmann, Brand & Reinhardt 2005: 6-7).

2.2. Telecommunication Protocols

Communications protocol is a list of rules or methods for exchanging messages and data between two different systems or two different networks, it also represents exchanging messages and communicate between the devices within the same system or the same network.

Next five parts explain briefly the protocols that IEC 61850 is mapped over them.

2.2.1. Open System Interconnection (OSI)

In 1977, the International Standards Organization (ISO) defined the Open Systems interconnection (OSI) which represents the result of dividing the communication process into seven basic layers. Each layer works as an independent protocol of the others with a certain objectives and functions to perform, but a successful operation of any level is mandatory for a successful operation of the next level. OSI also defines the flow of data from one network, device or system to another and vice versa.

Two devices can communicate if and only if each layer in the model at the sending device matches with each layer in the model at the receiving device (Holzman 1991; Driscoll 1992)

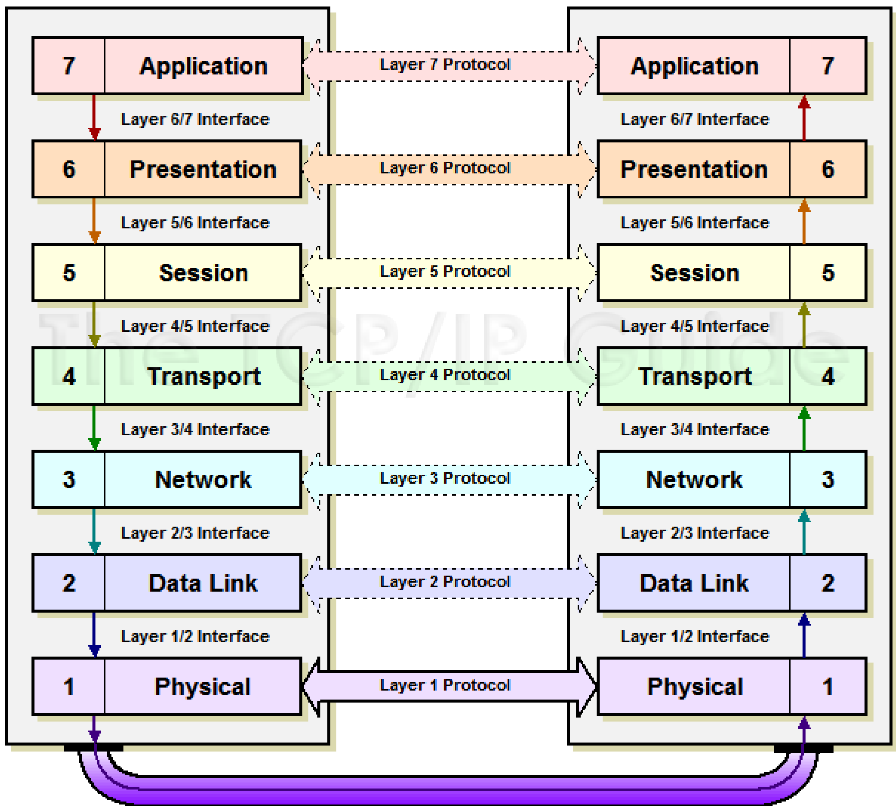

Figure 2.4 OSI model (Infocellar).

2.2.2. Ethernet Protocol

Ethernet is one of the most widely used data link layer protocols was designed for transferring data blocks that are called frames, which is described by the IEEE 802.3 standard. The used access method in Ethernet is Carrier Sense Multiple Access/Collision Detection (CSMA/CD) (IEEE 2002), which a method where each host listens to the medium before transmitting any data to the network. Ethernet transmits data with a speed of 10 Mbps up to 1 Gbps. However, for 1 to 5 devices interfaced with IEC 61850 can be mapped to a single 100Mbps Ethernet link. This mapping is specified by both parts 9.1 and 9.2 of the standard. Multiple 100Mbps Ethernet links can be then combined into a single Ethernet switch with a 1Gbps backbone (Mackiewicz Adamiak & Baigent 2009). In this case, 50 or more datasets can be published to/from all IEDs at the bay level.

Figure 2.5 Ethernet Stack.

LLC refers to Logical Link Control, which is defined by IEEE 802.2. It represents the upper portion of the data link layer in the OSI Model.

2.2.3. TCP/IP Suite

Transmission Control Protocol over Internet Protocol (TCP/IP) is a network layer where datagrams are used to communicate over packet-switched network (Wright & Stevens 1995; Forouzan 2003). It is clear that the two main protocols in this suite are TCP and IP. IP connects computers and forms a network by giving each one a unique IP address as a host address. The IP packets are transferred over IP addresses. These addresses contain the server address and the host address and it is usually transferred through routers or switches.

The major problem with IP is that there are no attempts to determine whether the packets reach their destination or not. TCP functionalities are used to avoid this problem. Error detection, flow control, congestion control and other features of TCP insure a reliable transmission of data. However, some applications (e.g. substation applications) require best effort service, which means a need of faster transmission time. UDP (User Datagram Protocol) is another protocol included in IP suite. Best effort service requires the use of UDP, which provides a datagram service that stresses reduced latency over reliability.

OSI layers	**TCP/IP layers**	**IP suite**			
Application	Application			SMTP	Talent
Presentation				FTP	DNS
Session				HTTP/HTTPS	TFTP
Transport	Transport			TCP	UDP
Network	Internet	ARP	RARP	IP ICMP	
Data Link	Network interface and hardware	Ethernet, token ring, FDDI drivers and hardware			
Physical					

Figure 2.5 TCP/IP protocols suite and functional layers (Apostolov 2002).

2.2.4. Manufacturing Message Specification (MMS)

MMS is an application layer used for exchanging real-time data and supervisory control information. The basic component of MMS is defined by VMD (Virtual Manufacturing Device) model, which is represented in Figure 2.6. The basic components show the behavior of transferring data between MMS servers and an external MMS client.

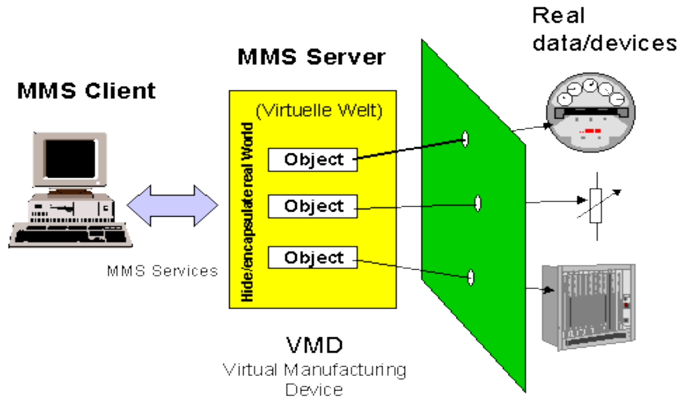

Figure 2.6 VMD Architecture (NettedAutomation b).

UCA and IEC working groups have adopted MMS application layer middleware for the fact of the high technical advantages that MMS provides. The two most important advantages are interoperability, which means the ability of the network layer applications to exchange the data among themselves, generating a communication environment is not needed. The other important advantage is the independency. It makes the interoperability independent of the developer application, connectivity and type of function being performed. Main criticism of MMS is complexity, poor performance and ISO protocol stacks high cost (Systems Integration Specialists Company 1995).

However, MMS protocol stack is required when using IEC 61850 because GOOSE and SCL files mapping requirements need such a protocol, this comes from the fact that one of the main aims of using IEC 61850 is the virtualization, which makes VMD model in MMS components highly valuable.

2.2.5. ACSI and SCSM

Abstract Communication Service Interface (ACSI) is a subject of IEC 61850 part 7 and its subparts. Abstract means the definition of the data and information to describe what the services provide. The implementation is done through the Specific Communication Service Mappings (SCSM) by mapping to e.g. MMS, TCP/IP and Ethernet.

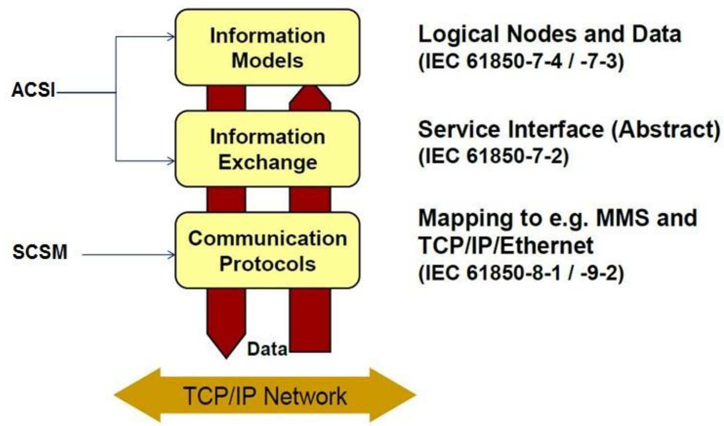

Figure 2.7 IEC 61850 key aspects (IEC-TC 57 2003).

ACSI represents the application view of IEC 61850 when SCSM, which is subject to IEC 61850 parts 8 and 9, represents the communication view. Both Application and communications views of IEC 61850 will be explained in section 3.3 of this Thesis.

3. IEC 61850

3.1. History of IEC61850

In 1964, the International Electro-technical Commission's (IEC) Technical Committee 57 (TC57) was established to urgently define a new standard that takes into account the increment of the needed functionalities to communicate between equipment and systems inside the substation automation (SA). In 1994, EPRI/IEEE (Electric Power Research Institute/ Institute of Electrical and Electronics Engineers) started a group called Utility Communication Architecture (UCA) (IEC-TC 57 2003). This group defined a standard for SA, which known as UCA 2.0. Two years later, IEC TC57 began to work on IEC 61850 to define it as an International standard for SA. This led to a combined effort in 1997 to define an international standard that would combine the work of both groups (Lidén 2006). Both groups worked on this task and in 2003 the result was the current IEC 61850 specifications.

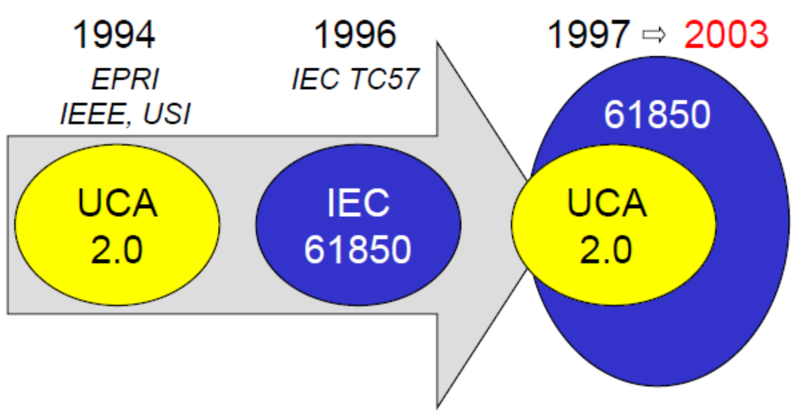

Figure 3.1 IEC 61850 and UCA 2.0 merging (Proudfoot 2002).

In 2004, TC57 started several Work Groups (WGs) to develop new standards for information exchange in different systems (e.g WG18 to develop the use of IEC 61850 in Hydroelectric power plants,WG14 to develop IEC 61968).

3.2. IEC 61850 Communication Model

Next figure describes the mapping of IEC 61850 data models over the previous mentioned communication protocols. Application level (represented in green) is mapped to the communication level through ACSI (in cyan) then represented in red color the implementation through SCSM.

Application level model is described according to state-of-art SA technology and communication level stack is described according to state-of-art communication technology.

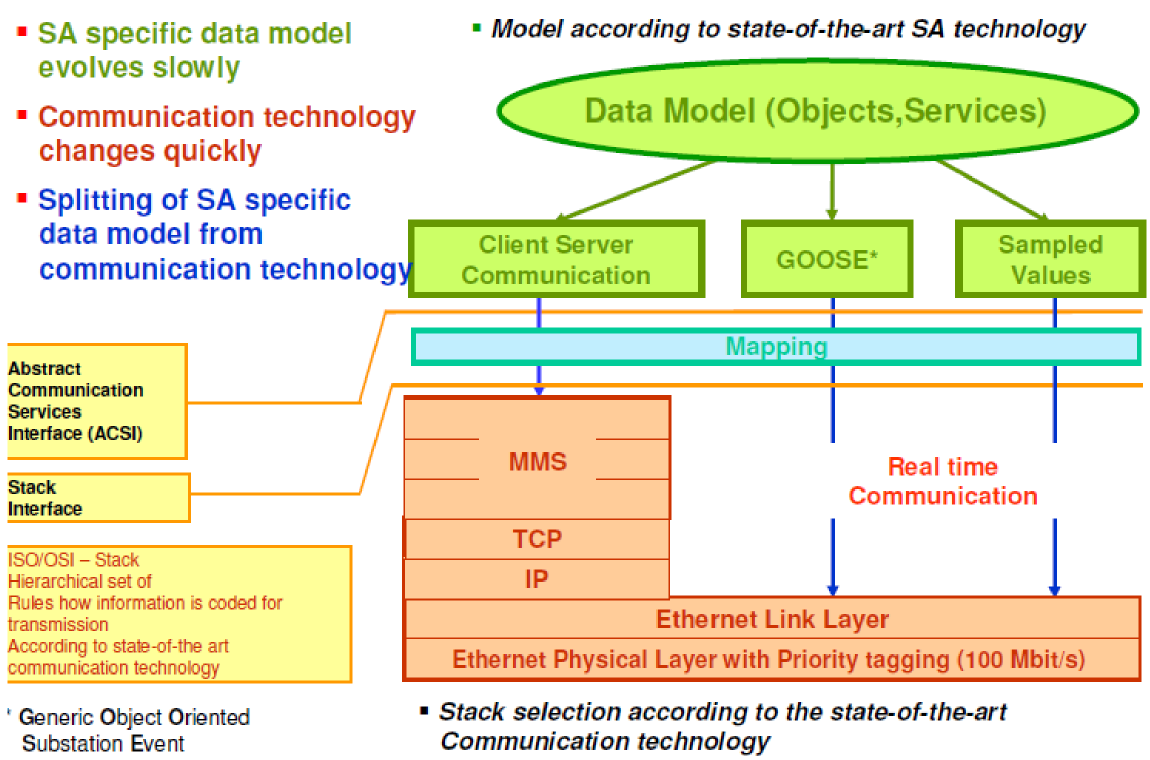

Figure 3.2 IEC 61850 Communication Model (Brand 2005).

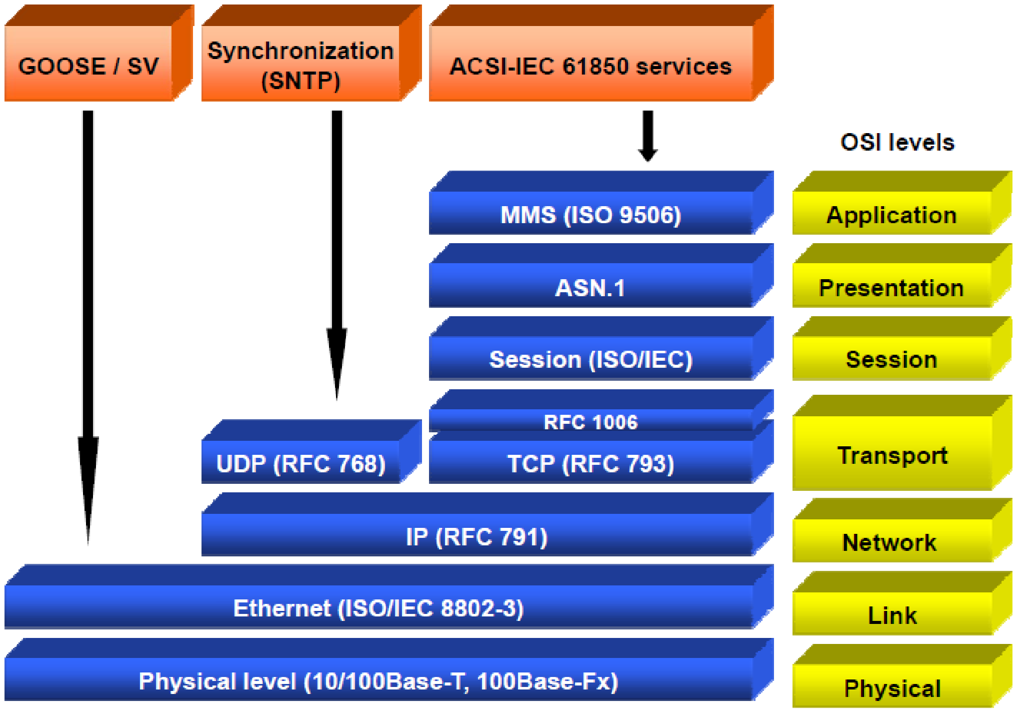

Figure 3.3 OSI and IEC 61850-7&8 stack (Pereda :66)

3.3. IEC 61850 Application and Communication views

IEC 61850 is an application layer protocol that can be useable only if it is mapped to a communication service such as MMS. Hence, short description of both application and communication views is given in this section. Summary of IEC 61850 parts is also given to have clear understanding of which parts represent the application view and which are responsible of mapping the standard's applications to a communication service. Next figure shows application and communication views represented by the IEC standard parts.

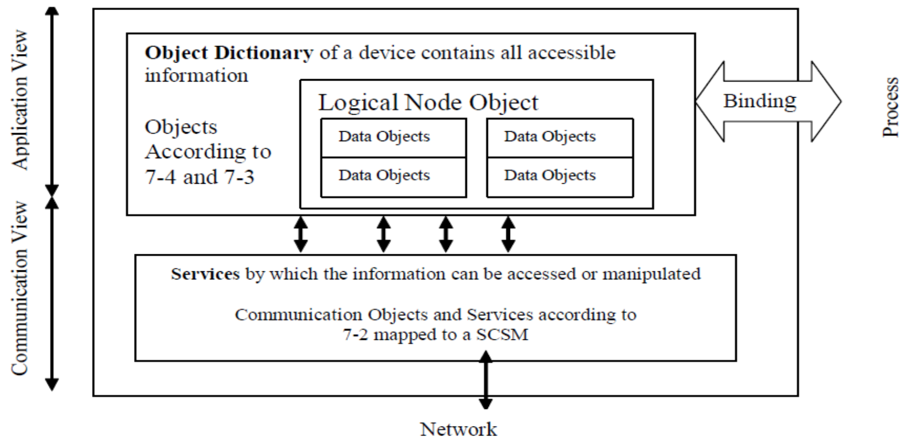

Figure 3.4 Application and communication views of IEC 61850 (IEC-TC 57 2003).

3.3.1. IEC 61850 Parts

During 2005, all parts of IEC 61850 have been issued as an official IEC standard (Lidén 2006). The standard consists of 14 parts, 10 main parts and some of them have subparts. The diagram bellow illustrates the standard's parts of the protocol and it is followed by a summarization of the whole 10 parts:

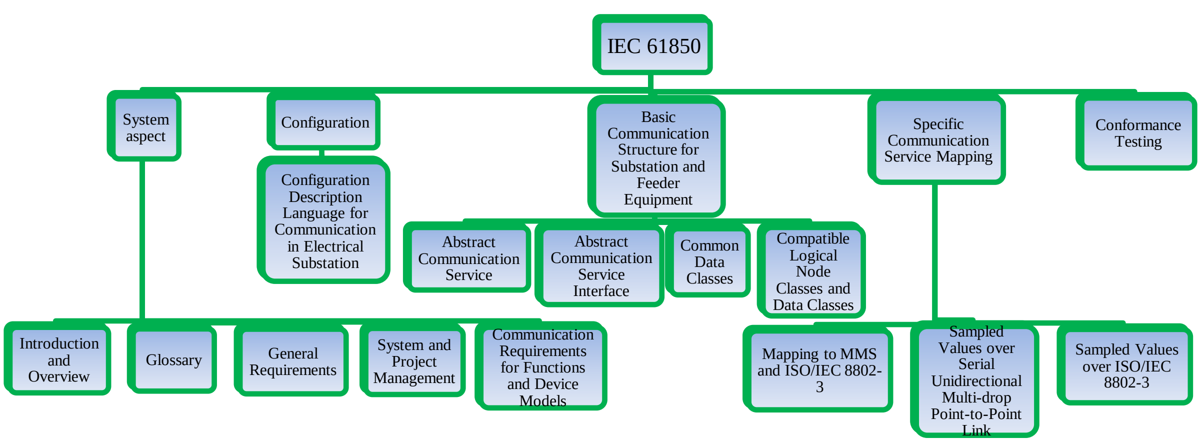

Figure 3.5 IEC 61850 parts.

First five parts of the standard represents the System aspect.

IEC 61850-1, Introduction and Overview: This part introduces IEC 61850 and a general outline for all the parts.

IEC 61850-2, Glossary: This part contains the glossary of specific terminology and definitions used in the framework of SA Systems within the various parts of the standard.

IEC 61850-3, General Requirements: This part describes quality requirements such as reliability, maintainability, system availability, probability, IT and security, operating conditions and auxiliary services.

IEC 61850-4, System and Project Management: This part explains engineering services requirements: documentation, parameter grouping and configuration tools and system usage cycle, as well as the quality guarantee such as responsibilities, test systems, type sets, system sets, factory acceptance tests (FAT) and site acceptance tests (SAT).

IEC 61850-5, Communication Requirements for Functions and Device Models: This part is very important to understand before logging into the next parts. It describes the logical node principle, logical communication links, items of information for communication (PICOM), logical nodes and associated PICOMs, functions, performance requirements (e.g. response times) and dynamic scenarios.

Next part defines the configuration phase of IEC 61850.

IEC 61850-6, Configuration Description Language for Communication in Electrical Substation: This part identifies a file format for describing communication related IED configurations and IED parameters, communication system configurations, functional structures, and the relations between them. The aim of this part is to exchange IED capability descriptions and SA system descriptions between IED engineering tools and the system engineering tool of different manufacturers in a compatible way (Lidén 2006) The defined language is called Substation Configuration description Language (SCL). It is based on the Extensible Markup Language (XML) version 1.0.

Part 7 of the standard refers to the Basic Communication Structure for Substation and Feeder Equipment. It is sorted into four subparts; IEC 61850-7-1 and IEC 61850-7-2 represent the Abstract Communication Services while IEC 61850-7-3 and IEC 61850-7-4 represent the Data Models.

IEC 61850-7-1, Abstract Communication Service: This part of the standard presents the modeling techniques, communication principles, and information models that are used in IEC 61850-7 parts. It provides descriptions with detailed requirements referring to the relation between IEC 61850-7-4, IEC 61850-7-3, IEC 61850-7-2 and IEC 61850-5. In addition, this part gives an overview of how the abstract services and models of IEC 61850-7 are mapped to concrete communication protocols as defined in IEC 61850-8-1.

IEC 61850-7-2, Abstract Communication Service Interface (ACSI): This part defines and specifies the Abstract Communication Service Interface (ACSI) and its use in the substation automation, which needs real-time cooperation of IEDs. Pattern of ACSI services are reporting, logging, setting, getting, publishing/subscribing, etc.

IEC 61850-7-3, Common Data Classes (CDC): This part defines common data attributes and data classes related to substation applications. These common data classes are used in IEC 61850-7-4. To define compatible data classes, the attributes of the instances of data intend to be accessed using services defined in IEC 61850-7-2 (Lidén 2006).

IEC 61850-7-4, Compatible Logical Node Classes and Data Classes: This part defines general and typical station classes for logical nodes and data. All data are defined with regard to syntax and semantics. This is required to reach interoperability between the IEDs.

IEC 61850 parts 8 and 9 both refers to the Specific Communication Service Mapping (SCSM).

IEC 61850-8-1, Mapping to MMS (ISO/IEC 9506-1 and ISO/IEC 9506-2) and ISO/IEC 8802-3: This part describes the communication mapping in the entire station (client/server communication for SCADA functions, GSSE and GOOSE data exchange for real time requirements, e.g. tripping signals).

IEC 61850-9-1, Sampled Values over Serial Unidirectional Multi-drop Point-to-Point Link: This part describes the SCSM for point-to-point and the unidirectional communication of sampled values from transformers.

IEC 61850-9-2, Sampled Values over ISO/IEC 8802-3: This part describes the SCSM for bus-type and flexible communication of sampled values.

Last part of the standard represents the testing phase.

IEC 61850-10, Conformance Testing: This part states the standard techniques for testing of implementations; it also specifies the measurement techniques to be applied when declaring performance parameters (Lidén 2006). Using these methods enhances the ability of the system integrator to integrate IEDs effortlessly and operate them correctly.

3.3.2. Virtualized Model

The core of IEC 61850 is the interoperability between IEDs from different vendors. In other words, interoperability between different functions that are performed by different Physical (real) devices. This is done by using data models, data exchange bases on these models. Virtualization means that every physical device can be represented in a Virtual world and only aspects of a real device that are of interest for the information exchange with other devices are virtualized. This method is called distributed functionality and the involved devices in data exchanging are called distributed devices. Achieving the virtualized model when using IEC 61850 comes from the fact of mapping the standard over MMS where VMD model is used (see Figure 2.6).

In IEC 61850 series, one of the core functionalities of the standard is to decompose the real device comprise into smallest entities. These entities are called logical nodes.

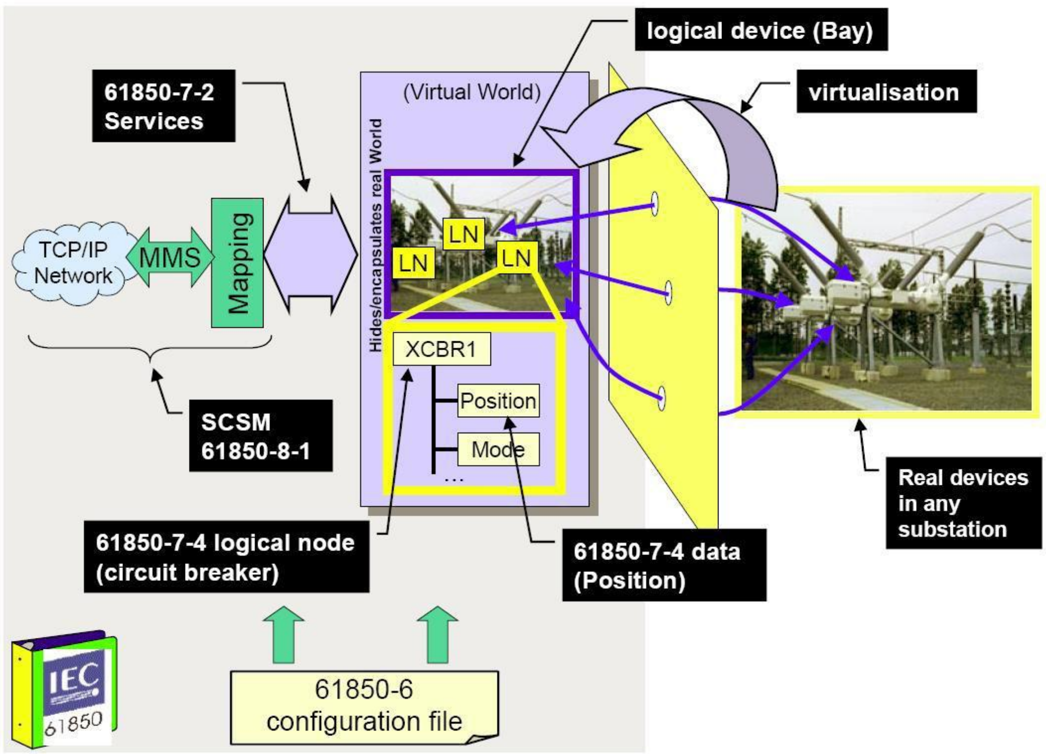

Figure 3.6 Virtual world vs. real world (IEC-TC 57 2003).

Similar functionalities performed by different devices build a logical node and several logical nodes performed by different devices or by the same device build a logical device. Logical device is represented in virtualized model it does not usually represent one real device, it mostly represents a different aspects or different logical nodes from different real devices. A logical device is always implemented in one IED even though it is built by logical nodes from different real devices, which means that logical devices are not distributed.

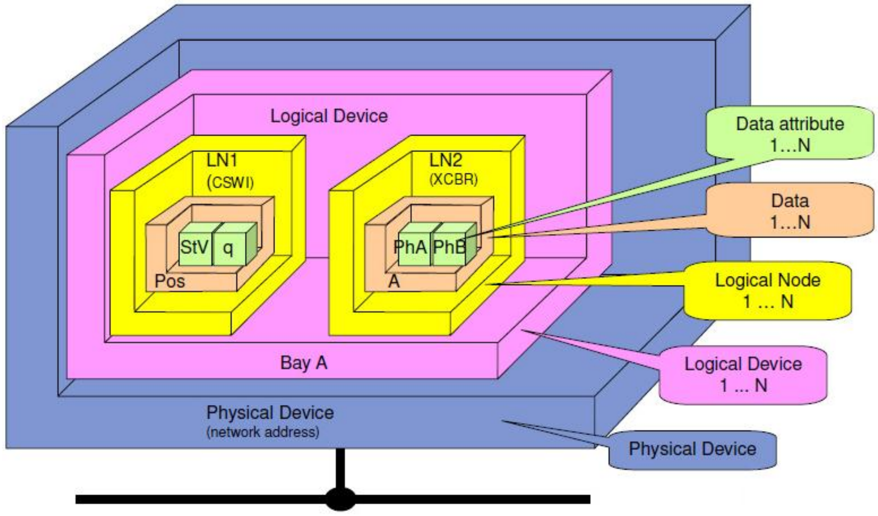

Figure 3.7 Physical and logical devices (Gajić 2005).

Each logical node contains a pre-defined set of data classes. Every data class contains many data attributes (status value, quality etc.). The logical devices, logical nodes and data objects are virtual parameters, they merely seem to exist. The logical nodes and the data contained in the logical devices are fundamental for the description and information exchange inside the power station automation systems to reach interoperability.

3.3.3. Logical device (LD)

As it was described previously, one physical device can be divided into one or more logical devices and the logical nodes are sorted as sub-functions in the logical devices. Every logical device (LD) consist of a minimum of three logical nodes.

3.3.4. Logical Node (LN)

Logical nodes are grouped into 13 main groups; each group contains a specific number LNs. 92 LNs are covering the most common applications of power stations and feeder equipment. The names of logical nodes begin with the character representing the group to which the logical node belongs.

IEC 61850 store for the future clear rules relating to extensions of the information models, including extensions to logical nodes, new logical nodes, expanded and new data and new data attributes (Lidén 2006). Next table shows the LN groups according to the last updated information models in 2006.

Table 3.1 LN groups**.**

Group Indicator	LNs groups	Number
A	Automatic Control	8
C	Supervisory Control	5
G	Generic Function References	3
I	Interfacing and Archiving	4
L	System Logical Nodes	3
M	Metering and Measurement	8
P	Protection Functions	28
R	Protection Related Functions	10
S	Sensors and Monitoring	4
T	Instrument Transformer	2
X	Switchgear	2
Y	Power Transformer	4
Z	Further (power system) Equipment	15
TOTAL		92

LNs are a kind of “Folders” which contain data that can be used or exchanged. For example, The XCBR LN implements the functionality of CB (Circuit Breaker) by grouping 16 data classes as shown in Figure 3.8. XCBR data set contains characters correspond to the used commands for the CB such as BlkOpn (block open operation), Beh (Behaviour), etc.

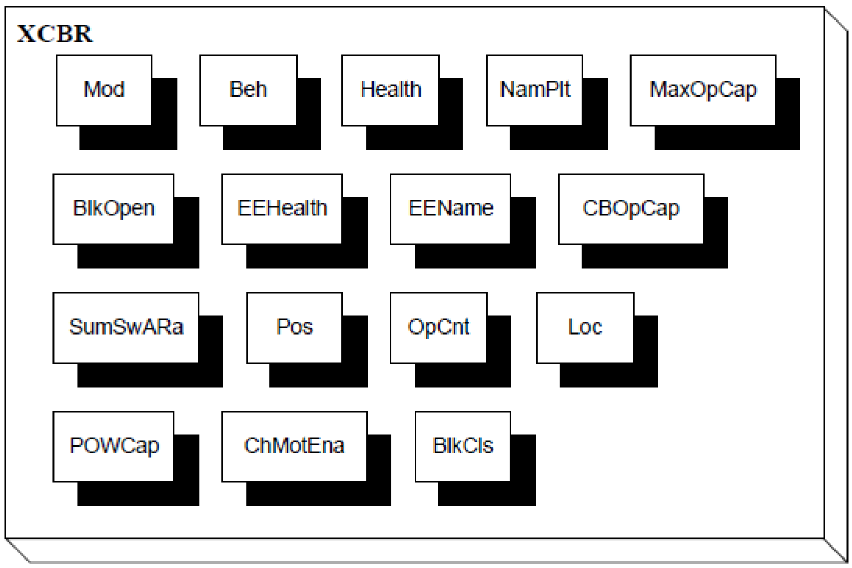

Figure 3.8 XCBR (Circuit Breaker) Logical Node (IEC-TC 57 2003).

3.3.5. Data Objects

The feature of sorting IEC 61850 logical nodes in a folders form is that every data can be formed in one line that contains details of data starting from the left with the logical device name and ends with the data attribute so it is easy to read and analyze it at the station computer and the control unit. One example is given in Figure 3.9 shows how to use the data object to read the state value of a switch position in a protection relay and how by following the contents of the data object the state value can be reached and be read. Data objects and data sets are defined in IEC 61850-7-3 but their analysis during the real-time applications is done in IEC 61850-8-1.

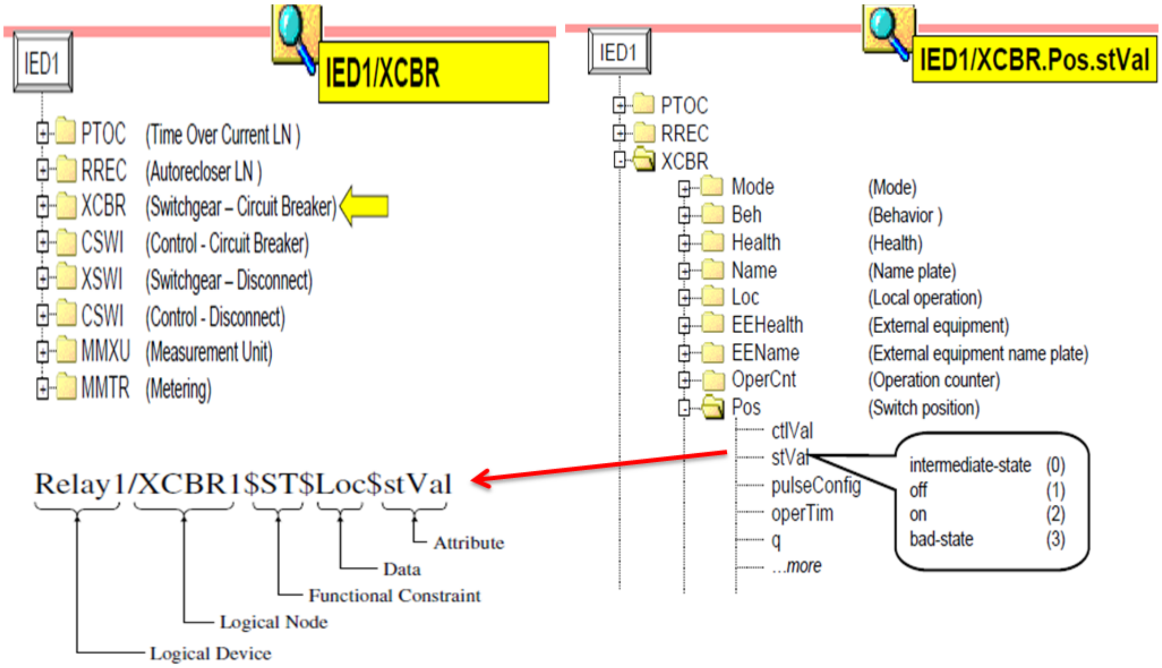

Figure 3.9 Analysis of a data object (Proudfoot 2002).

A decimal number describes each attribute; each number corresponds to a specific status. In the previous example, 0 means that the switch is in the intermediate state, 1 shows that it is off, 2 is on and 3 warns that it is in a bad state.

3.4. Generic Object Oriented Substation Event (GOOSE)

The term GOOSE is not new and was used in the UCA protocol. However, the IEC61850 GOOSE is an advanced version of the UCA GOOSE (Neteon). The major difference is that an IEC61850 GOOSE is not a static number of bits or bit pairs (binary output to binary input); this version can exchange a wide range of common data according to the use of data sets in the IEC standard. A GOOSE message is used to exchange data between IED’s and is only one part of the new standard IEC61850. GOOSE communication represents the horizontal communication in the substation automation system by broadcasting the same GOOSE message to one or several IEDs at the same time, which allows faster communication and lower cost. More benefits gained by using GOOSE in IEC 61850 are explained later.

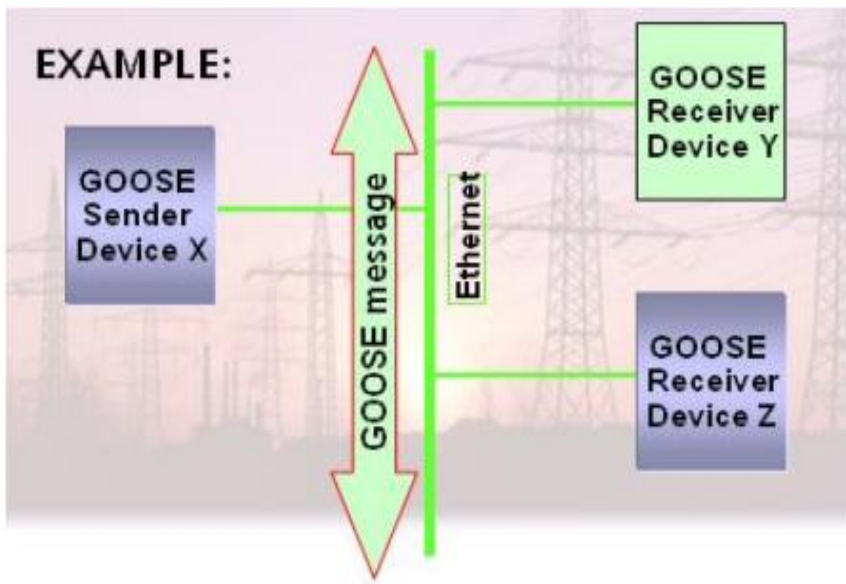

Figure 3.10 Example of GOOSE messages exchange (Neteon).

3.5. Substation Configuration Language (SCL)

SCL is introduced in Part 6 of the IEC 61850 standard. The main duty of SCL is to guarantee the interoperability by exchanging information between IEDs from different vendors and the station computer. It comes from the fact that each IED is configured by independent configuration tool developed by its manufacturer. This is done by using four types of SCL common files. These files are the IED Capability Description (ICD), Configured IED Description (CID), Substation Configuration Description (SCD) and System Specification Description (SSD) files.

All ICD files get imported into the IEC 61850 system configurator, which allows the configuration of GOOSE messages by specifying the senders (publishers) and the receivers (subscribers) of messages. The system configuration tool creates the SCD file, which includes the one line diagram of the station and the description of the GOOSE messages. Each IED Configuration tool must be able to import an SCD file and extract the information needed for the IED, then join all information in one SCL file to be sent to another IED or to the station computer and the control unit in the SA.

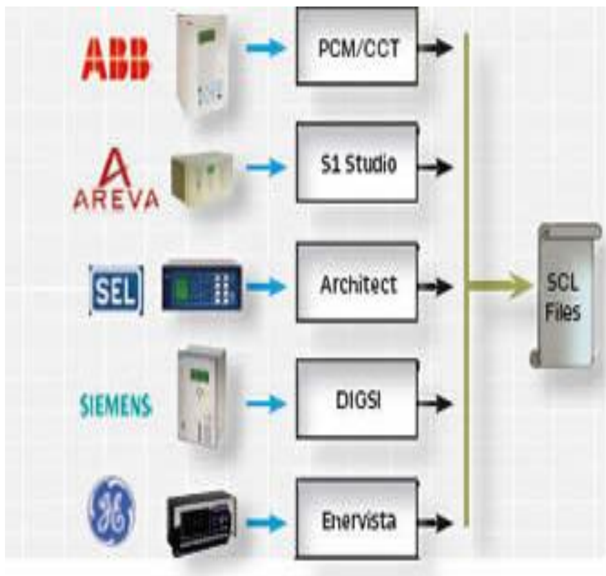

Figure 3.11 Creating the SCL files (Aguilar & Ariza 2010).

3.6. IEC 61850 Benefits

Benefits of IEC 61850 is measured according to the high requirements of IEDs inside the SA, such as high-speed IED to IED communication, guaranteed delivery times, multi-vendor interoperability, etc (Mackiewicz 2006). IEC was mainly designed to satisfy these requirements with help of GOOSE and SCL files, which adds more advantages when using the IEC standard.

The key benefit of IEC 61850 is use of The virtualized model. The virtualized model of logical devices, logical nodes, ACSI, and CDCs enables definition of the data, services, and behavior of devices to be defined besides the protocols that are used to define how the data is transmitted over the network. In addition, every element of IEC 61850 data is named using descriptive strings to describe the data. Devices are self-describing. Client applications that communicate with IEC 61850 devices are able to download the description of all the data supported by the device from the device without any manual configuration of data objects or names.

Another key benefit of IEC 61850 is the high-level services offered because of the use of ACSI model, which supports a wide variety of services that exceeds what is available in the typical legacy protocol. GOOSE, GSSE, SMV, and logs are few examples of the unique capabilities of the IEC standard besides more capabilities gained when including SCL. It enables the configuration of a device and its role in the power system to be accurately defined using XML files. The use of SCL also eliminates procurement ambiguity.

The major benefits of using IEC 61850 are (Mackiewicz 2006):

Implementation of New Capabilities: The radical services and unique features of IEC 61850 enable new capabilities that are not viable with most legacy protocols. Wide area protection schemes that would normally be cost prohibitive become much more feasible. Because devices are already connected to the substation LAN, the incremental cost for accessing or sharing more device data becomes insignificant enabling new applications that would be too expensive to yield.

Less Connection Cost: IEC 61850 allows devices to exchange data and status using GOOSE and GSSE (Generic Substation Status Event) over the station LAN rapidly without having to wire separate links for each relay. This reduces wiring costs by utilizing the station LAN bandwidth for these signals.

Less Transducer Costs: instead of separate transducers for each device needing a particular signal, a single merging unit supporting SMV can deliver these signals to many devices using a single transducer lowering transducer, wiring, calibration, and maintenance costs.

There are several other costs reduced by using IEC 61850 due to the fact that devices don't require as much manual configuration as legacy devices and that reduces the Commissioning cost. Because IEC 61850 defines more of the externally visible aspects of the devices besides just the encoding of data on the wire, the cost for equipment migrations is minimized. Because IEC 61850 devices don't have to be configured to expose data, new extensions are easily added into the substation without having to reconfigure devices to expose data that was previously not accessed. This results a lowering in the extension costs. In addition, integration costs are reduced by utilizing the same networking technology that is being widely used across the utility enterprise (UCA 2.0). As it was mentioned previously, IEC 61850 is UCA 2.0 plus new added functionalities.

High Performance of GOOSE: The increment of IEC 61850 overall benefits is also related to the use of GOOSE messages, which brings a number of highly performed functions. One of the essential preconditions for using GOOSE is that it performs adequately compared with a hardwired solution. In addition, due to the non-deterministic nature of Ethernet, reliability is guaranteed under difficult communication load conditions (Hakala-Ranta, Rintamäki & Starck 2009).

By using GOOSE messages, a high operational speed (e.g. less than 4ms for protective relaying) can be achieved. However, GOOSE messages can be delayed using certain DELAY commands when it is needed. Operational speed is 30-50% faster when comparing with the operating speed of classical hardwired (Hakala-Ranta et al. 2009). Moreover, Three LAN configurations (10 MB switched hub, 100 MB shared hub, and 100 MB switched hub) are able to deliver 100 messages within these 4ms (Proudfoot 2002).

4. IEC 61850 CURRENT RESEARCHES AND IMPLEMENTATIONS

Nowadays, IEC 61850 is a very important topic for researches as the power system automation needs are rapidly increasing, especially with the wide use of smart grids, renewable energy resources and distributed energy resources (DERs). There are several updates and new researches regarding to IEC 61850 to study the opportunities of meeting the requirements of whole electrical energy supply chain (Schwarz 2005), as well as implementing the standard in smart grid and green power applications as a new technology or based on another related standard.

The most interesting topics currently are wind power and solar applications, but hydroelectric power is remaining under research and development sensation. This chapter summarizes the current research scope regarding to the three mentioned fields.

4.1. Hydroelectric Power

IEC TC 57 WG 18 has defined an extension of IEC 61850 standard for Hydroelectric power plants by introducing new information models. "The extension of the information models focuses on the communication between hydroelectric power plant components and actors within the power plant and its related systems" (Schwarz 2005). The additional documents are supposed to cover the typical required data of hydroelectric power plants, such as water level, water flow, dam gate and turbine control etc. There are four different groups of data objects needed for typical hydroelectrical power plant (Schwarz 2005):

Electrical functions: Currently, IEC 61850 covers all substation objects part. Hence, all needed LNs for this group are included already in the standard's documents.

Mechanical functions: This group is specified for hydropower plants since it includes functions related to the turbine and its supplementary equipment.

Hydrological functions: This group includes the main functionalities to control the hydropower plant. It contains LNs to control water flow, dams, reservoirs etc.

Sensors: In this group, LNs for monitoring and measuring of other than electrical data are included. This group is also specified for hydropower plants. Table 4.1 below describes the LNs used for hydropower plants.

Table 4.1 Hydropower plants information model.

LN	Description
AFCO	Flow Controller
AKVR	Automatic Voltage/var regulator
ALCO	Level Controller
AMWR	Active Power regulator
ASPC	Speed controller
CCGR	Cooling group control
DPC	Controllable double point
GAPC	Generic automatic process control
HBRAK	Brakes
HGOV	Hydraulic Governing system
HJCL	Hydraulic Joint control
HPPU	High Pressure pumping unit
MMDE	Density logical node
MMDP	Dewpoint logical node
MMFE	Flow element logical node
MMHE	Humidity logical node
MMLE	Level element logical node
MMPE	Pressure element logical node
MMRF	Rainfall logical node
MMSF	Snowfall logical node
PPAM	Phase angle/out-of-step
PSDE	100% stator earth-fault
PSDE	Directional earth-fault
PSDE	100% stator earth-fault
RTEM	Temperature monitoring system
RVIB	Vibration monitoring system
VPCO	Valve opening position controller
WMET	Meteorological station

WHYD	Hydrological station
ZTCR	Thyristor controlled reactive component

4.2. Wind Power

In 2001, IEC TC88 introduced IEC 61400-25 based on IEC 61850 and as an extension in order to meet the requirements of wind power systems. First draft of the standard documents was published in 2006 and it was ready to use in 2009. Like IEC 61850, IEC 61400-25 is also object-oriented, which allows the use of virtualized models (Logical devices, LNs, etc). IEC 61400-25 consist of 5 parts (NettedAutomation a):

IEC 61400-25-1, Overall description of principles & models: It is similar to IEC 61850-1 and 7-1. This part contains introduction and overview of the standard.

IEC 61400-25-2, Information models (Logical Nodes, Data and common data classes (CDC)): It contains the wind power plant specific information models. Definitions are selected from IEC 61850-7-3 and 7-4. In this part of the standard, new models are defined to meet the wind power plant requirements.

IEC 61400-25-3, Information exchange models: Almost all services defined in IEC 61850-7-2 are referenced and explained in this part.

IEC 61400-25-4, Mapping to communication profiles: This part is still being developed to be optional in order for the supplier and customer to agree on a solution that meets the needs for a certain monitoring and control application. So far, MMS mapping according to IEC 61850-8-1 is already available. Several researches are still running to add four more optional mappings; Web services, OPC XML DA, EC 60870-5-104 and DNP3.

IEC 61400-25-5, **Conformance testing:** It is based on IEC 61850-10. It contains measuring and testing aspects.

IEC 61400-25-6, LN classes and Data classes for Condition Monitoring: This part was designed mainly for IEC 61400-25 in order to meet the new defined needs of wind power plants. It is not based on any of the IEC 61850 parts. It contains new defined LNs for monitoring and control of wind power plants.

The table below lists all assigned LNs to wind power systems. First four LNs are for a whole wind power plant and the rest are specified for the wind turbine.

Table 4.2 Wind power plant LNs.

LN	Description
WALM	Wind power plant alarm information
WMET	Wind power plant meteorological information
WAPC	Wind power plant active power control information
WRPC	Wind power plant reactive power control information
WTUR	Wind turbine general information
WROT	Wind turbine rotor information
WTRM	Wind turbine transmission information
WGEN	Wind turbine generator information
WCNV	Wind turbine converter information
WTRF	Wind turbine transformer information
WNAC	Wind turbine nacelle information
WYAW	Wind turbine yawing information
WTOW	Wind turbine tower information
WSLG	Wind turbine state log information
WALG	Wind turbine analogue log information
WREP	Wind turbine report information

Figure 4.1 below explains the missions of LNs on the whole wind power plant. Some of the LNs e.g. XCBR are specified in IEC 61850 but they are also included in IEC 61400-25-2

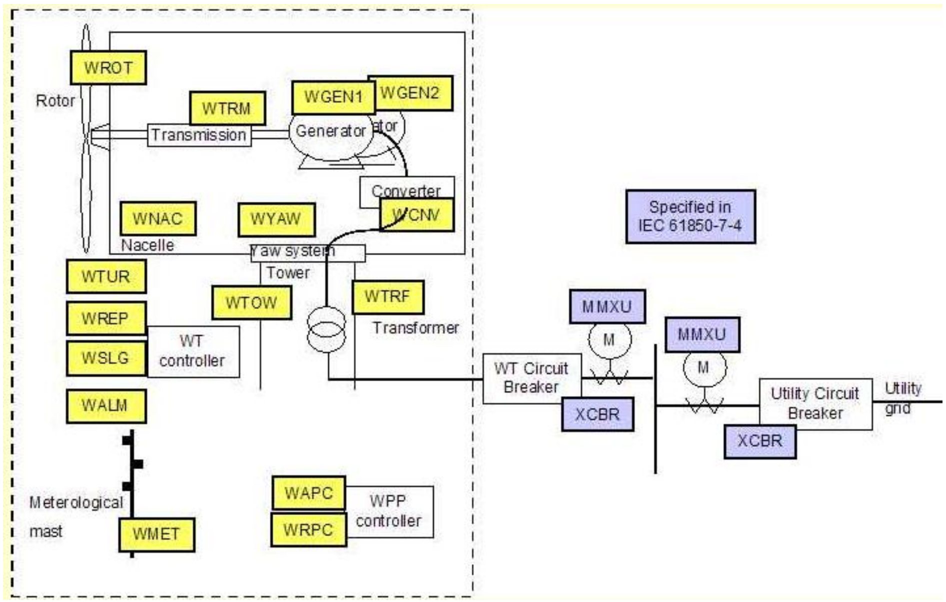

Figure 4.1 Distribution of IEC 61400-25 wind power plant LNs (NettedAutomation a).

4.3. Solar applications

As it has been mentioned in part 1.2, until the date of submitting this thesis, there was no factual implementation of IEC 61850 in solar application yet. In addition, IEC had not published any specific documentation for Photovoltaic (PV) inverters and solar applications yet. There was one draft published recently describes in general some LNs that might be beneficial to be implemented in solar applications and Distributed Energy Resources (IEC-TC 57 2009).

In December 2011, the Italian Electrotechnical Committee, which known as CEI (in Italian: Comitato Elettrotecnico Italiano), has published a norm that strongly proposes to use IEC 61850 to connect PV inverters (IEC 61850 blog).

“The document IEC 61850-90-7 (IEC 61850 object models for inverters in DER systems) is about to published in a few months. This document is a perfect fit for the needs of PV inverters” (IEC 61850 blog). Defining and publishing this subpart’s documents is the current duty of IEC TC57 WG17.

A recent document “IEC 61850-7-420 DER Logical Nodes”, which was a subpart of IEC 61850-7-4, defined some useful LNs to be applied on DER and PV. Chapter 7 will investigate the implementation of IEC 61850 in solar applications and then conclude the benefits and the results of using it.

5. STANDARDS BASED ON IEC 61850

This part discusses the interplay between IEC 61850 and some of the well-known substation automation standards. The purpose of this part is to investigate which standards might interplay with IEC 61850 instead of replacing a current existed protocol with IEC standard.

Additionally, Section 4.2 of this thesis defined another IEC standard that based on IEC 61850, which is IEC 61400-25.

Below are some examples of interplay between IEC 61850 and few familiar SA standards.

5.1. UCA 2.0

As it has been mentioned previously in part 3.1, IEC 61850 is a result of cooperating between UCA and IEC TC57 to define more international standard for SA than UCA previous standard (UCA 2.0). In other words, IEC 61850 contains most of the UCA 2.0 specification, plus several additional features (see Figure 3.1). The objective of the added functions in the resultant standard (IEC 61850) is to fulfill the 21st century electricity network's requirements since they have risen rapidly during last decennium. There are certain features in UCA 2.0 that have been omitted from IEC 61850 and replaced by new features that match nowadays' technologies.

Figure 5.1 below shows how application and communication views of UCA 2.0 are mapped to IEC 61850 layers.

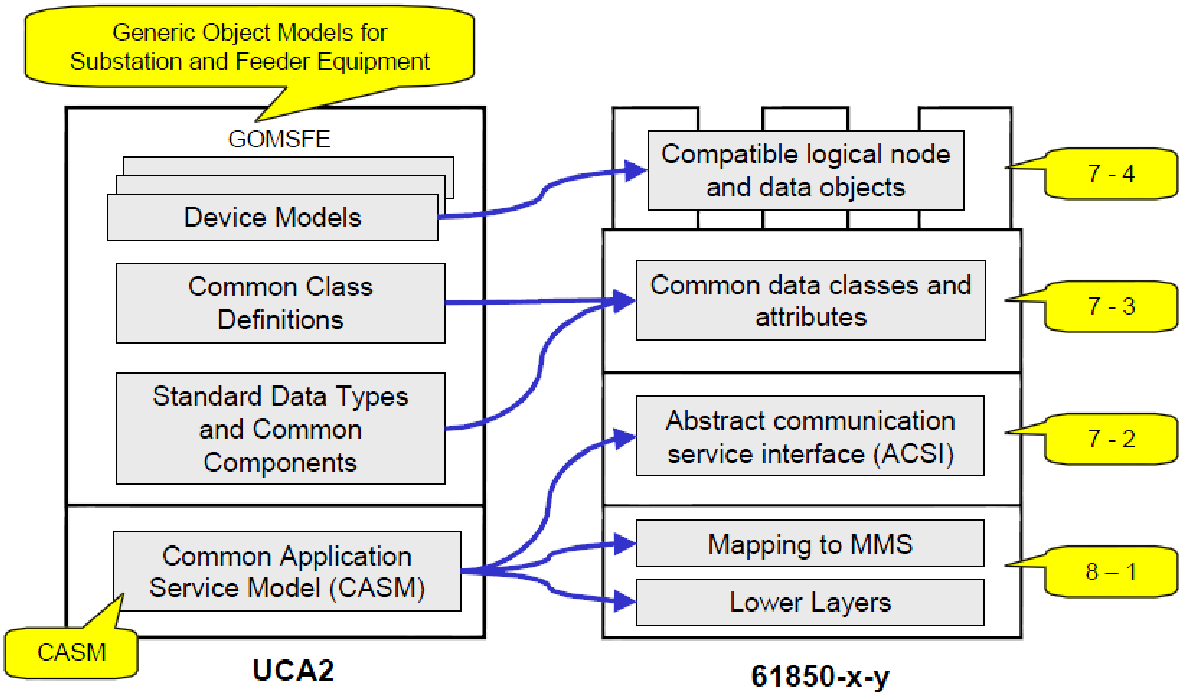

Figure 5.1 Encompassing UCA 2.0 in IEC 61850 (Proudfoot 2002).

5.2. IEC 61499

IEC 61499 is another accepted standard for substation and power system automation. IEC Technical Committee 65 (TC65) approved the standard in 1991 and assigned it to the Working Group 6 (WG6) in 1993. WG6 members were experts from 7 countries (USA, Germany, Japan, UK, Sweden, France and Italy) The same group was also responsible on parts 3 and 8 of IEC 61131 (IEC standard for PLC applications). The standard was completed and published in 2005.

The idea of the interplaying between IEC 61499 and IEC 61580 comes from the fact that their architectures have certain aspects in common. As IEC 61850 uses logical nodes to sort data classes and data attributes, IEC 61499 uses a similar functionality which so called function blocks (FBs). There are three classes of FBs; basic FBs, composite FBs, and service interface FBs. "For each FB there is a set of input and output variables" (Higgins, Vyatkin, C. Nair & Schwarz 2010).

IEC 61499 FBs have an internal state machine called the Execution Control Chart (ECC), which contains algorithms that read the input values, execute them then write them to the outputs.

LNs and logical devices with their functions can be implemented using a composite FB. Most of IEC 61850-7-4 LNs are possible to be modeled as FBs (Higgins et al. 2010). The concept of mapping LNs to a FB is shown in Figure 5.2.

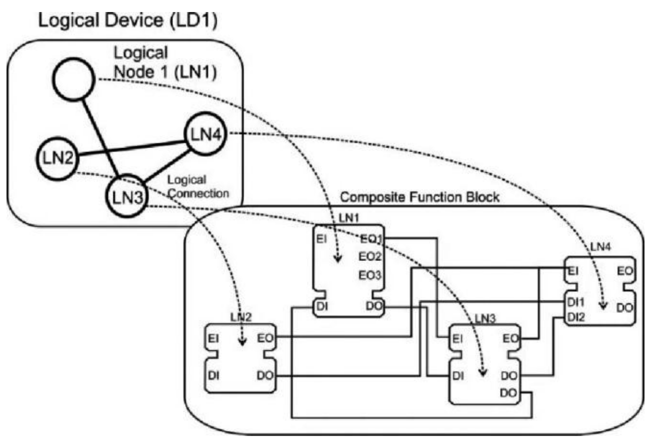

Figure 5.2 Implementation of LNs and logical devices using composite FB (Higgins et al. 2010: 5).

The output data object can be then communicated using the communication service IEC 61850-7-2 using peer-to-peer GOOSE messages, then these communication services are mapped onto Manufacturing Message Specification (MMS, ISO 9506) in IEC 61850-8-1 (Higgins et al. 2010). An example of a LN mapped as FB is shown in figure below.

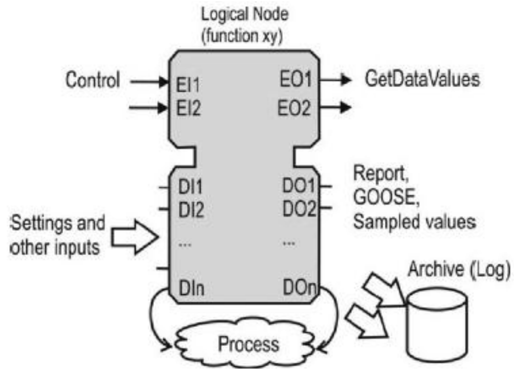

Figure 5.3 LN modeled as a FB (Higgins et al. 2010: 5).

5.3. IEC 61131

IEC 61131 is an accepted world-wide standard for programmable logic controllers (PLCs). It has almost the same architecture as IEC 61499 since both have been the main mission of TC56 WG6 (see part 5.2). It is known that IEC 61131 was defined for communicating the PLC inside the substation automation. As it has been shown previously, IEC 61850 LNs can be mapped to IEC 61499/IEC 61131 FBs. Hence, IEC 61850 LNs can be implemented on PLC system's FBs (Lidén 2006).

Few years ago, Beck IPC GmbH has designed Chip that contains IEC 61850 and IEC 61131 models to merge both IEC standards' models so that instead of replacing a full standard that is applied already on PLC system, IEC 61131 might remain used while IEC 61850 additional tasks are available to work side by side with it.

<table>
<tr><td colspan="2">IEC 61850 Information Model</td><td rowspan="4">User application(s)
(executed as task of the RTOS)</td></tr>
<tr><td colspan="2">IEC 61850 Client/Server Task(s)</td></tr>
<tr><td colspan="2">IEC 61131-3 Task(s)</td></tr>
<tr><td>SysLib</td><td>Co DeSys-Kemel</td></tr>
</table>

Figure 5.4 Beck IPC GmbH IEC 61850/IEC 61131-3 tasks chip.

5.4. IEC 60870-5

As future demands of SA are incrementing, there are currently several researches investigating the possibilities of sending IEC 61850 GOOSE through wireless channels by using WLAN networks, which is also known as wireless Ethernet (P. Parikh, Mitalkumar & S. Sidhu 2010) and Ethernet-to-Modbus switches. For example, in 2011 it was the first project to send GOOSE messages over WiMAX. So far, transferring GOOSE through wireless channel is still slow, a total end-to-end latency takes 30-50ms over WiMAX and 800ms over GPRS (Goraj, Lipes & McGhee 2011) Figure 5.5 below shows a basic architecture of a WLAN communication for substation and distributed energy resources (DERs).

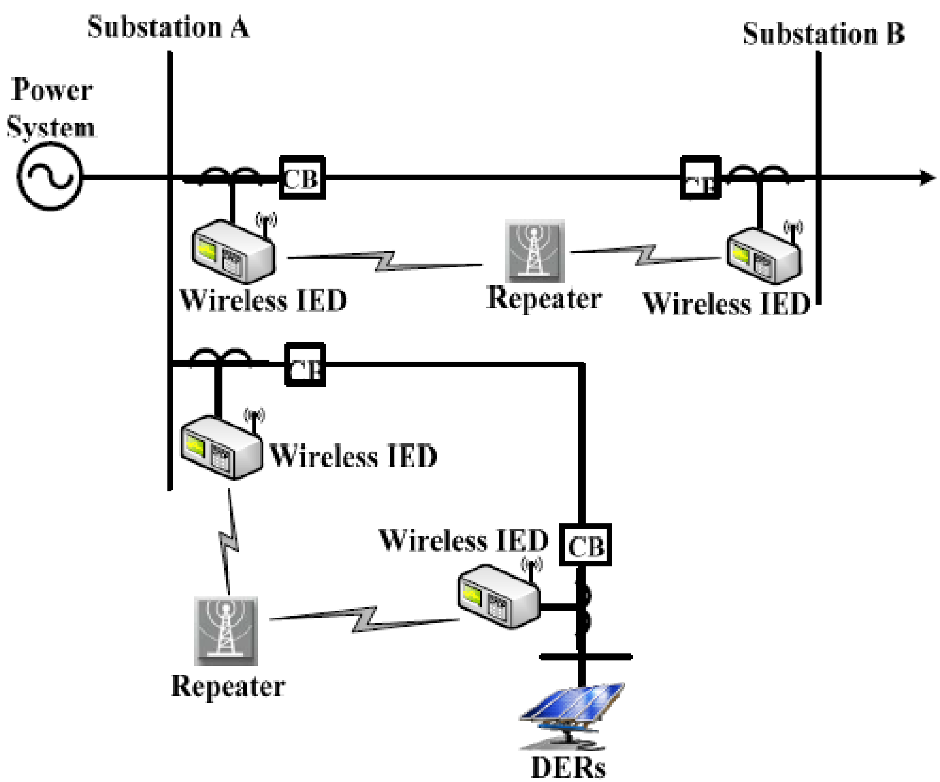

Figure 5.5 WLAN network for substation and DERs (P. Parikh et al. 2010: 3).

IEC 60870 is another international standard for power system automation that was defined by IEC TC 57 WG. The same working group generated also parts 5 and 6 of the standard. IEC 60870-5 was developed for providing a communication profile to telecontrol (two-way remote control) and teleprotection, messages between two different networks (Wikipedia). Few researches nowadays are checking the possibilities of mapping IEC 61850 to IEC 60870-5. This will lead to enhance the speed of transferring the messages inside the SA.

6. IEC 61850 AND SOLAR APPLICATIONS VERSUS MARKET NEEDS

The main thesis motivation is the opportunity to be one of the lead researches to investigate the implementation of the IEC standard in solar applications. Regarding to the previous, market and costumer interests and needs are important issue to be considered when adding a new technology value to solar applications.

To investigate theses interests and needs, I have created two surveys then I forwarded it to several utility companies in Finland and worldwide. First survey was meant for IEC 61850 users and the second one was meant for non-IEC 61850 users. The idea of creating two different sets of questions is to investigate deeper the non-users interest of start using IEC 61850. Nevertheless, the two surveys had several questions in common.

6.1. Survey Questions

The full content of both surveys can be found in Appendices 1&2. It was not possible to ask straight questions regarding to IEC 61850 and what will be the impact if it is applied in solar applications because I tried to conceal the idea and the topic so that the thesis does not lose its originality before it is submitted. However, the surveys revealed sufficient details about the topic so that companies who were surveyed could know what is the question and provide accurate answers.

6.2. Survey Glitches

The surveys were expected to have generalized samples so that it gives as clear scan of the study case as possible, but they faced certain glitches, which are listed below:

- Most of participants were from utility companies, just one participant was a vendor
- Nine out of 10 samples were IEC 61850 users. Therefore, the interest of start using IEC 61850 was not investigated deeply.

- Managers who were mostly from Industrial management or business background always filled the surveys. Engineer's thoughts were not possible to be shared.
- Only 1out of 10 contacts who received the request agreed to arrange an appointment to fill in the survey face-to-face.
- Only 10 samples were received after more than 350 emails and about 56 phone calls.
- All participants were from Finland. So, the surveys did not collect worldwide samples as it was expected.

6.3. Results and Comments

In this part, each question of both surveys will be analyzed statistically. Common questions are displayed in the same chart and sorted according to first survey since it collected multiple samples while second survey collected only one sample. Comments on the results are observed below each chart.

- "Do you use/install solar applications?"

The choices to answer this question were "Yes" or "No".

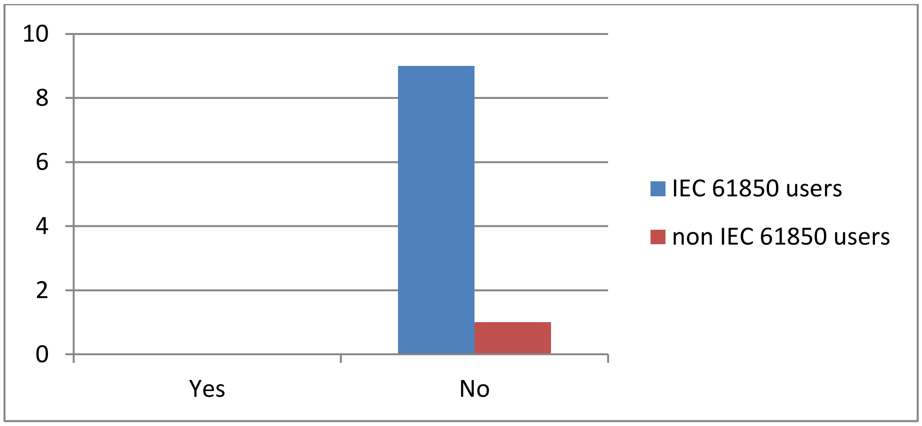

Figure 6.1 Results of question number 1.

From the previous chart, it is clear that all participants answered by “No”. As the market of solar application is becoming a hot spot, the previous question were followed by next question to investigate the interest of to use solar applications as a costumer or supply them as a vendor.

- “If no, are you interested in installing solar system?”

The choices to answer this question were “Yes”, “No”, “Maybe” or to have no result if the previous question was answered by “Yes”

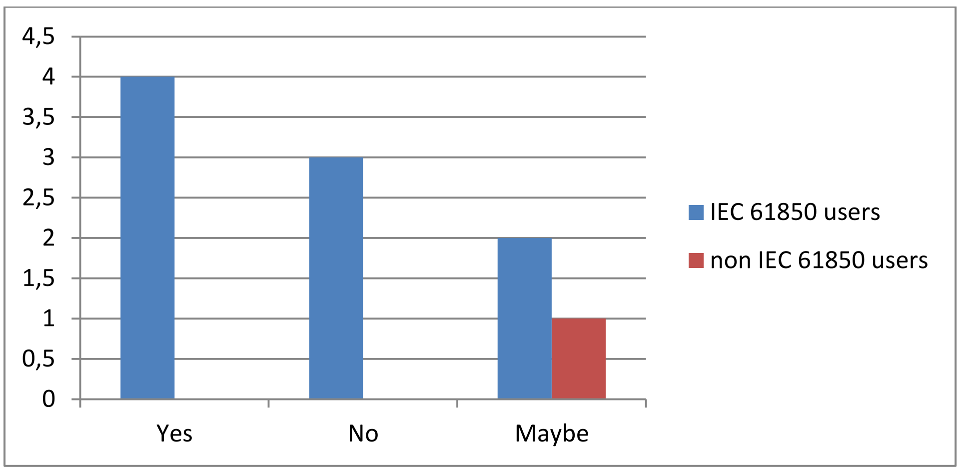

Figure 6.2 Results of question number 2.

From the previous graph, 7 out of 10 answers showed an interest of using solar applications in future, which give positive expectations of solar market to be increased in the early future.

- “What kind of communication is used in your Substation Automation”

Multiple choices of typical communications were given with one empty field to specify any other used communication.

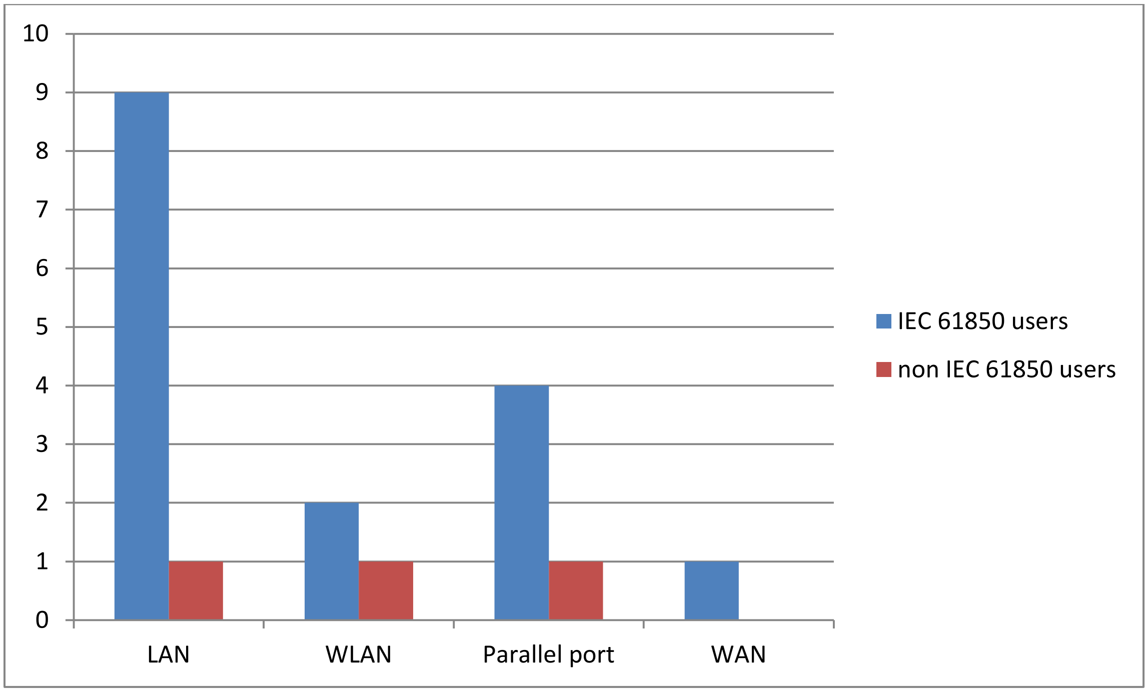

Figure 6.3 Results of question number 3.

As almost all participants are IEC 61850 users, it is expected to have LAN communication in their substation automation since the IEC standard is Ethernet-based. Additional purpose of the question was to investigate other current used communications since it might be possible in the future to send IEC 61850 over Wi-Fi or WiMAX channels (see part 5.4).

- "Which one of the two factors do you consider more, cost (less cost for communication networks, using economic available devices in the market, etc) or quality (Security, protection, efficiency, response time, etc)?"

Five choices were given to grade if cost is considered more or quality. As the grade of cost increases, the grade of quality decreases and vice versa.

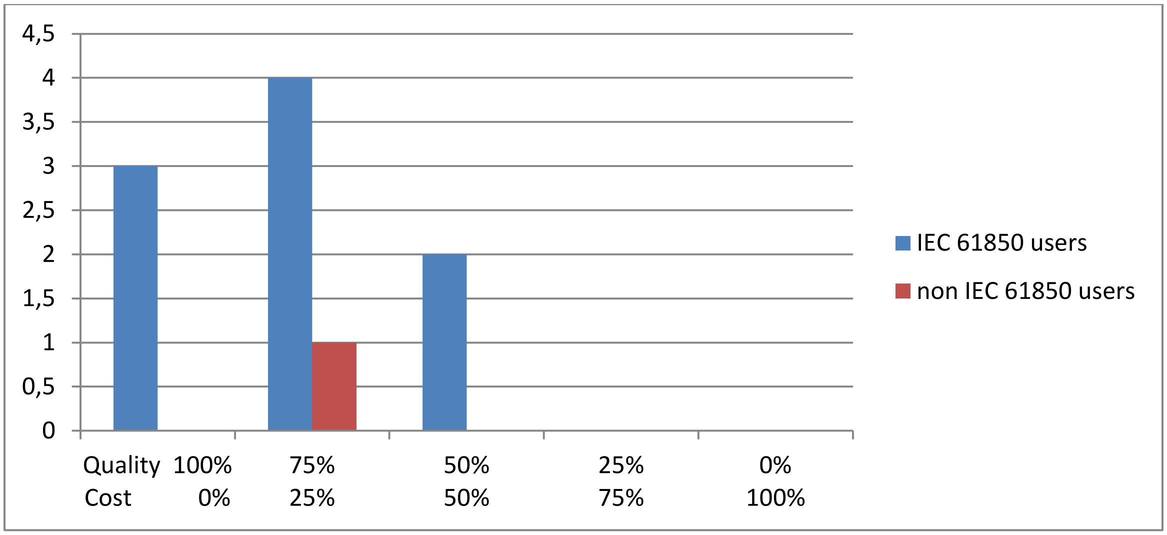

Figure 6.4 Results of question number 4.

The chart above clarify that costumers choose quality over cost. This remove the negative impact of solar cells and solar systems cost, which are still considered as an expensive applications especially at the installation phase comparing with other classic energy resources. Question 17 describes one of solar application quality aspects, which is the environment safety, and how costumers consider it.

- "How satisfied are you with IEC 61850?"

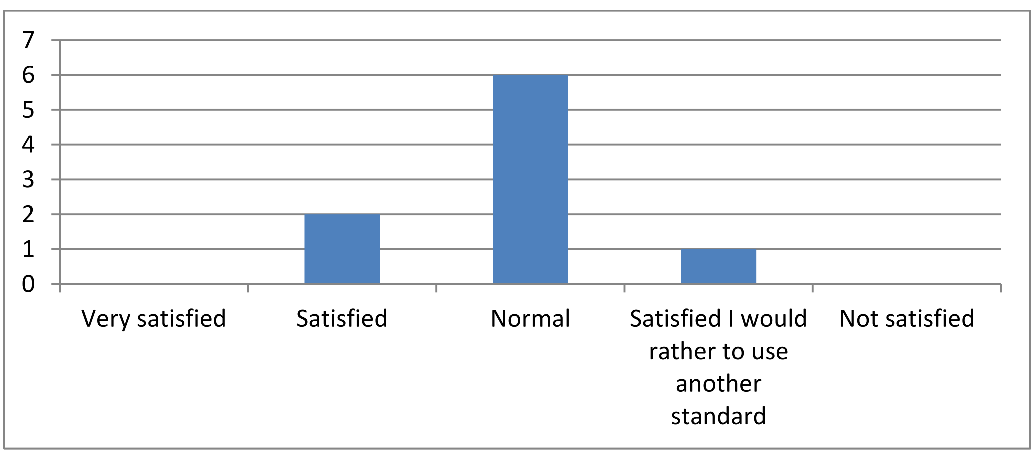

Figure 6.5 Results of question number 5.

Satisfying with IEC 61850 is expected to increase rapidly. Based on several researches, the standard will have new implementations in all types of energy resources and substations with different types of communication (WLAN, WAN, LAN, etc).

- How fast is the response time of the system using IEC 61850?

There was no answer for the exact response time of the system, but all the companies thinks it is sufficient for their current systems.

- “How important are fast response, fast fault detection and fast circuit breaking?”

For this question, an empty gap was given so the participants feel free to fill in the suitable answer to their point of view.

According to collected data, fast response is important only when IEC 61850 or any telecommunication protocol is used for protection or network supervision. Otherwise, it is beneficial and recommended to apply a standard that provides fast response but not so important.

- “Do you use IEDs from different vendors?”

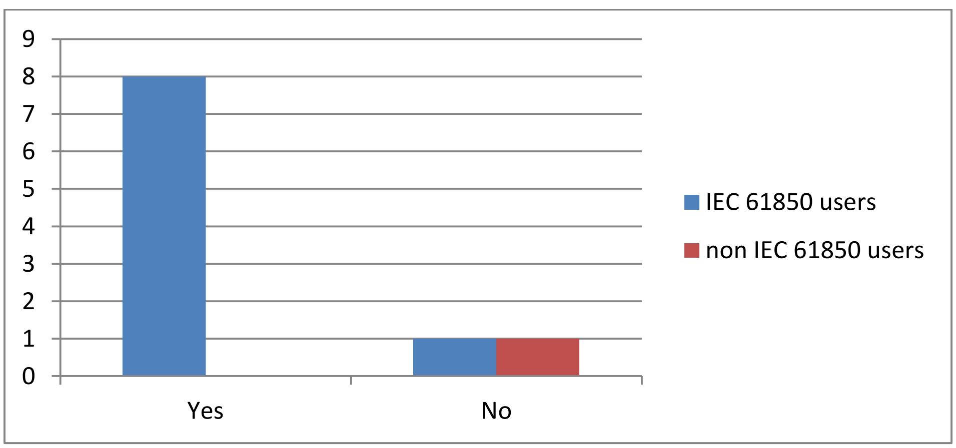

Figure 6.6 Results of question number 8.

Another opportunity that can be observed by Figure 6.6 for implementing IEC 61850 in solar applications is the Interoperability provided by the IEC standard. Most of participated companies use IEDs from different vendors. This is sufficient motivation to add e.g. PV inverter in the substation without the need of using different protocol.

- From your point of view, which aspects/subdomains of security are considered important?

Questions number 9 and 10 were optional. Regrettably, not all participants has answered them. Even though, beneficial information was collected from certain companies. The given important security aspects are: User authority management, Firewalls, Virus protection, isolated substation internal LAN from outside network, cyber security and security from unnecessarily tripping.

- From your point of view, which aspects/subdomains of reliability are considered important?

The given important reliability aspects are: reliability of protection, reliability of control side (remote operation and monitoring) and Reliability to trip when required

- If a new application is applied in the SA, do you prefer that your engineers develop your own configuration tool to configure the new application or you would rather another software engineering company/organization to design it?

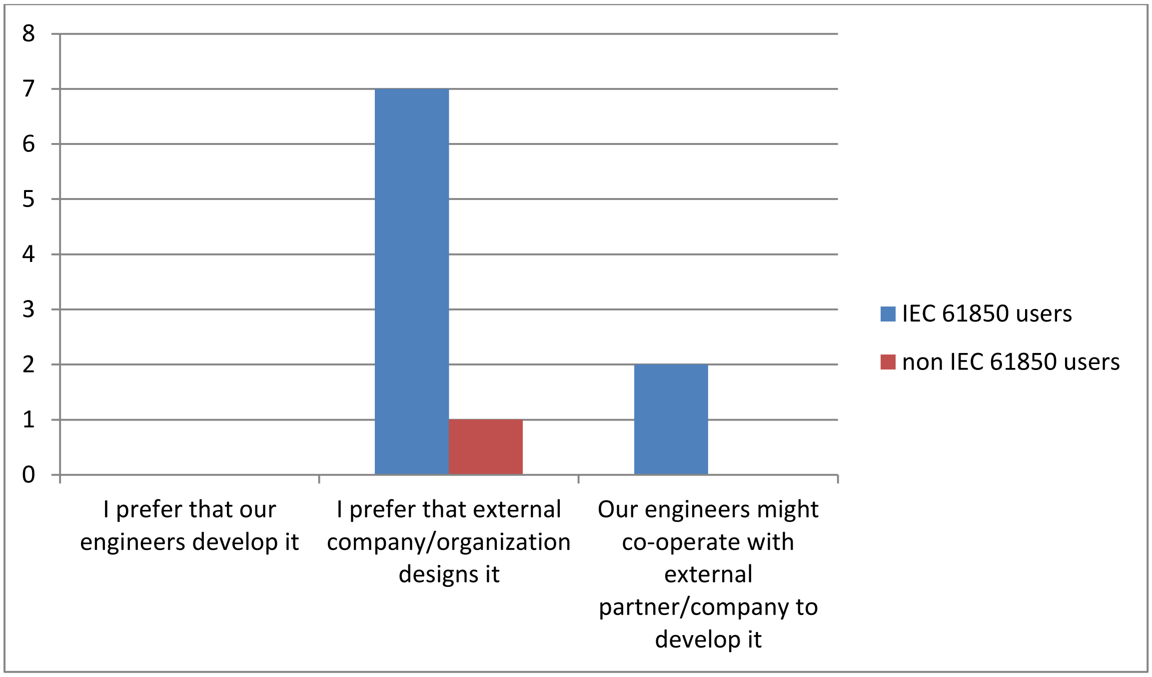

Figure 6.7 Results of question number 11.

Every IED needs its own configuration tool that can meet the control requirements and simulate the device in some cases, then all data from different devices and different configuration tools can be sent via one SCL file (see part 3.5). Figure 6.7 shows that power utility companies expect the configuration tool to be included when buying a device. The configuration tool does not need to be designed by the supplier or the manufacturer of the device. It is possible to co-operate with an external software company to design the tool.

- "From 1-5 how do you grade your current engineers understanding of IEC 61850?"

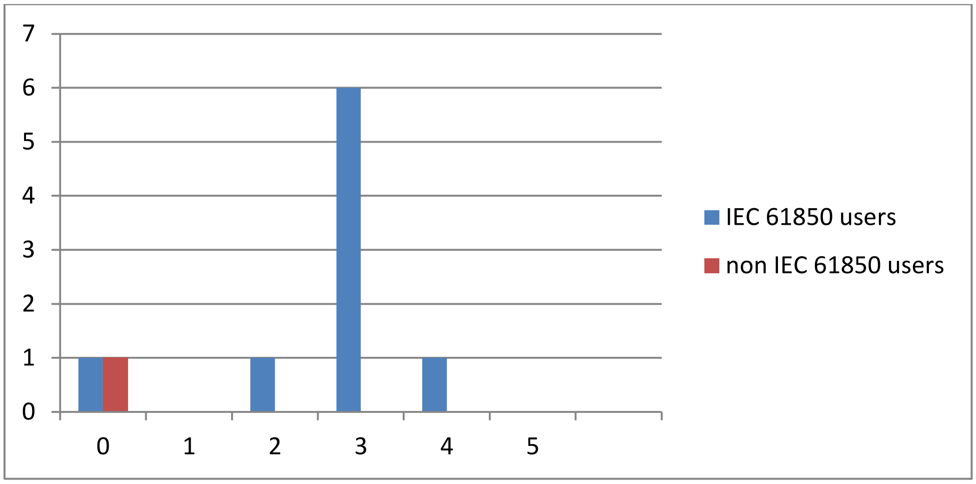

Figure 6.8 Results of question number 12.

Several companies commented that IEC 61850 documents are not easy to understand, some problems related to IEC 61850 are not solved due to the low understanding of the standard. This can be solved by providing particular courses related to the standard to improve the engineer's knowledge. Besides, IEC specifies each part of the 10 parts' documents to be read by whom. If this division is followed carefully, it might increase the average knowledge of a certain company staff (see appendix 3).

- "Describe briefly how do you measure the benefits of the virtualized Models (logical nodes, logical devices) when IEC 61850 is used comparing with the situation before using the standard?"

Because of the complexity of understanding IEC 61850 as most of the company mentioned, it is not possible to define the standard contribution by them yet. Indeed, faster communication is realizable due to the use of Ethernet. Even though, certain companies think that IEC 61850 documents will become more complicated after the expected new publications. Hence, presentations about benefits and added values when using IEC 61850 might be a possible solution.

- “Are all the 10 parts of IEC 61850 used in your SA?”

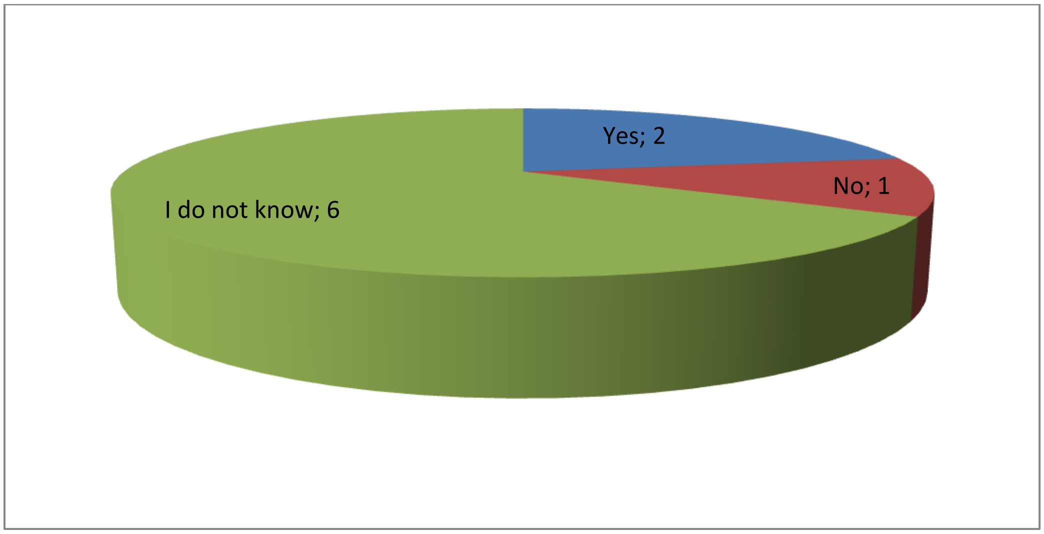

Figure 6.9 Results of question number 14.

The reader guide of IEC 61850 (see appendix 3) is the key point to understand the standard parts and hence the knowledge of these parts will allow the user to answer which parts are used. Technically, all parts are needed when using the protocol.

- “Do you hire different engineers for different parts of IEC 61850 (IEC 61850-1, IEC 61850 IEC 61850-7-1, IEC 61850-7-2, etc.)?”

All participants answered by “No” and this might refer to the fact that 90% of the participants were from utility companies. In case of consultant or vendor, application and communication engineers are needed for different parts of IEC 61850.

- “Please define negative aspects of IEC 61850 (if there are any).”

Regarding to the survey participants, IEC users are satisfied with the standard from application point of view but they are still not fully satisfied with it from the learning point of view. Most of the comments refers that IEC 61850 is complex, difficult to learn and more complicated than older communication protocols.

- “As renewable resources are considered as a nature friends, how important is the environment safety over the annual revenue to you?”

Figure 6.10 Results of question number 17.

Nowadays and especially in Finland, environmental laws are getting stricter and hence the environment safety has become a major factor to be considered when applying a new defined technology. Solar applications or renewable energy resources in general are nature friends, as well as they are developing continually. According to this, renewable energy resources’ market is expected to increase rapidly. Besides, as it can be seen in Figure 6.10 all participants agrees to take into account the environment safety.

- “Do you think solar applications are expensive?”

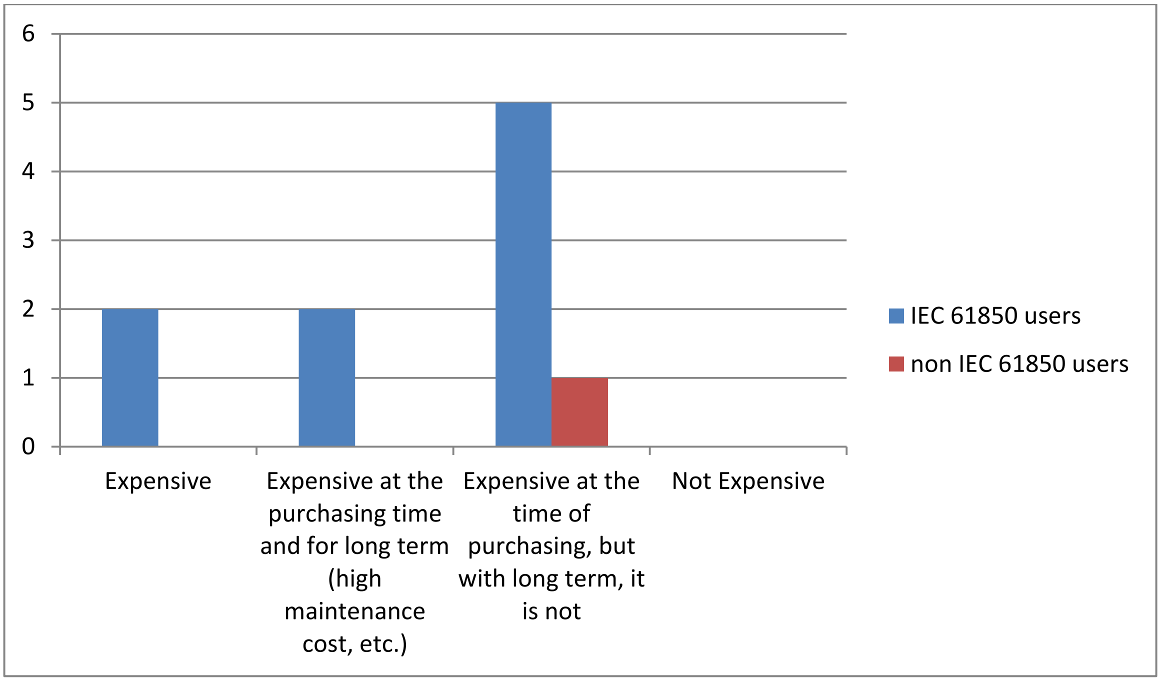

Figure 6.11 Results of question number 18.

Solar application's expenses are still subject of controversy. All participants think that solar applications are expensive at the purchasing and installation phase, but more than 50% think that they have low costs for long term comparing with other energy resources. However, price of solar applications is decreasing, several governments (e.g. USA) have started to support solar producers with the electricity user taxes (according to one of the answers).

- "Do you think the market of solar applications will increase within next 5 years?"

All participants answered by "It will increase", which shows optimistic expectations towards solar applications' future. Nevertheless, two companies think that in northern part of Europe, solar applications are seldom and solar market in there is more or less limited in researches.

- "Please fill in your future wishes for the current communication protocols/standards situation in your current SA, what do you think it needs to be added, needs to be developed, etc.?"

Participants suggested more strict standards. Besides, fixed solutions and different manufacturers' tools should be integrated. For five years, IEC 61850 used for new and refurbish applications. Process bus applications and better tools for IEC 61850's station level are expected to be the next steps. Additional point to be considered is that electrical utilizes (at least in Finland) do not have enough competence for detailed SAS engineering. Every utility rely on manufacturers and service providers.

For non-IEC 61850, there was few isolated to investigate the future interest to use the IEC standard in the future. Unfortunately, only one company (Finn-D Ky) filled in the survey. Finn-D showed an interest to host a seminar about the standard since they are planning to install substations in the middle east area in the early future and they are wishing to use the newest available technologies.

6.4. Survey Feedback

At the end of each survey, I asked participants to give feedback and comments regarding to surveys quality and questions usefulness. Due to concealing the thesis topic, feedback and comments were odd and showed that participants were less satisfied with the surveys as it was expected. According to participants, the purpose of the survey was not so clear and questions were complicated. These negative aspects can be easily solved in the future when this thesis is published and then the surveys can be updated and straight questions regarding to the implementation of IEC 61850 in solar applications will be asked.

7. IMPLEMENTATION OF IEC 61850 IN SOLAR APPLICATIONS

In this part, a matlab/Simulink model is given to show an example of PV array and how power can be utilized from a certain insolation then explain briefly what functionalities IEC 61850 can add to a solar system.

Before starting to investigate the implementation impact, implementation requirements and the current status of the study case, which is Vacon's PV-inverter (8000 Solar), has to be studied first.

7.1. Implementation Requirements

To implement a new technology in a certain device, hardware and software components are needed. For implementing IEC 61850 in a specific IED, the device should contain LAN card, which is existed in most IEDs of nowadays. Horizontal and vertical Ethernet connections with the other IEDs and control unit respectively are needed then to communicate with the rest of the network. Exchanging data attributes between the computer and the device can be done by using one of the well-known programming languages such as C or C++. However, this method might be complex and will cost utility companies to hire a software engineer, which is not needed according to appendix 3.

An efficient way and especially when using IEDs from different vendors is to communicate with each device via its own configuration tool where all needed IEC 61850 LNs and data classes are saved. In addition, the configuration tool might contain a simulation of the device so it is easier to control and set its values. Configuration tools are designed also to send the four types of SCL (see part 3.5) so it guarantees the interoperability between all IEDs in the network. Figure 7.1 below explains is an example of simulating the device using an appropriate configuration tool. VAMP's configuration tool (Vampset) simulates VAMP 257 protection relay.

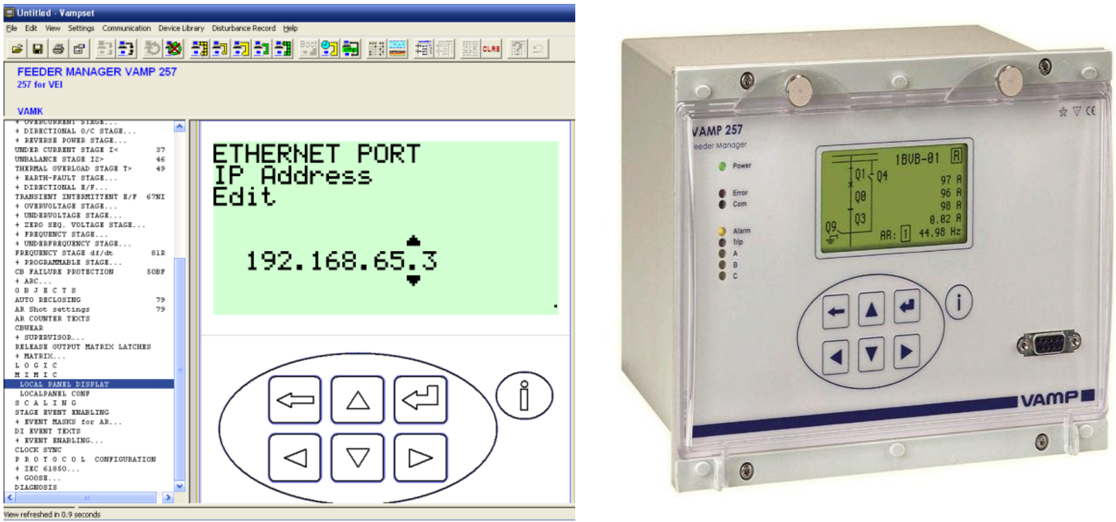

Figure 7.1 Vampset simulates VAMP 257 front panel (VAMP)

7.2. DER Logical Nodes

Figure 7.2 shows a conceptual distribution of IEC 61850 LN over a typical power system with assuming four different distributed energy recourses, which they are: reciprocating engine, fuel cell, photovoltaic and combined heat power. LNs in blue are the standard previous defined LNs in part 7-4 of IEC 61850, while the LNs in red belongs to the new subpart of the standard (IEC 61850-7-420) that was defined by IEC-TC 57 in 2009 in order to implement the standard in DER systems.

The applied IEC 61850-7-420 LNs in the system depends on which kind of resource is used. For example, if the energy resource is PV then the value of DERtyp (Type of DER) within the logical node DRCT should be set to the value “4” at the DER unit controller and hence the LD at the DC converter level will be a DC-AC inverter and ZINV logical node will be used. More examples and details regarding to PV LNs are given in part 7.3.

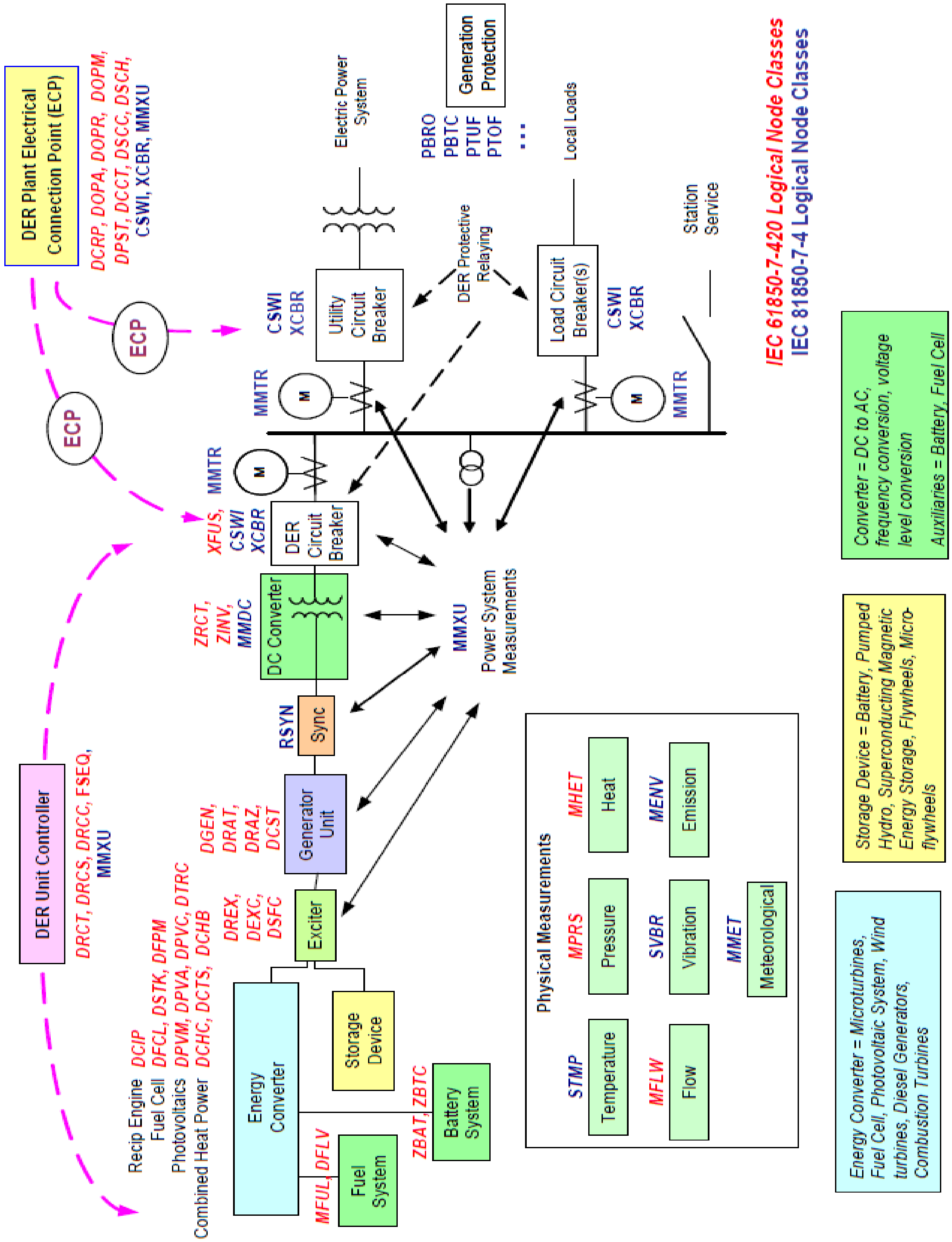

Figure 7.2 Conceptual organization of DER LDs and LNs (IEC-TC 57 2009).

7.3. Photovoltaic LDs and LNs

Figure 7.3 below defines a conceptual distribution of PV system LDs and LNs.

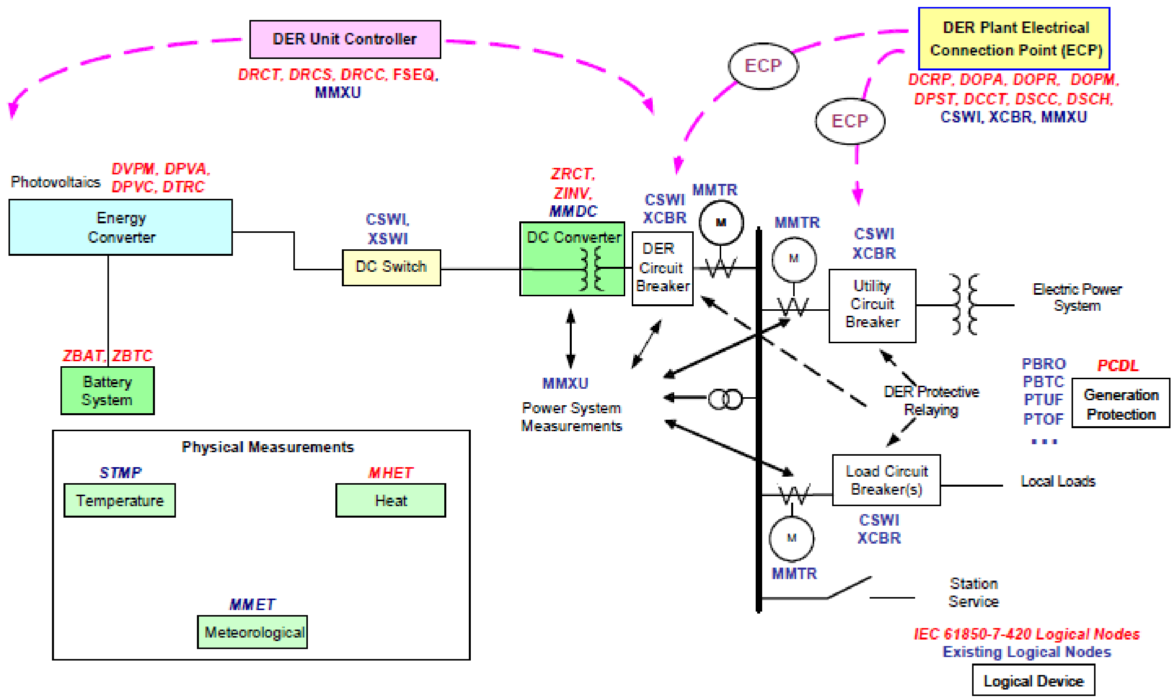

Figure 7.3 Photovoltaic system LDs and LNs (IEC-TC 57 2009).

This part concentrates only on PV systems LDs and LNs. Therefore, general DER LNs (DRCT, DRCS, etc.) are not discussed in details. However, it is needed to mention that in case of using DER control unit when more than one DER used in the substation, several values of DER logical nodes' data has to be set in a way to match the use of PV common data classes. An example was given in part 7.2 to set DERtyp value to "4" and this setting is mandatory as shown in Figure 7.4 below.

<table>
<tr><th colspan="4">DRCT class</th></tr>
<tr><th>Data name</th><th>CDC</th><th>Explanation</th><th>M/O/C</th></tr>
<tr><td>LNName</td><td></td><td>Shall be inherited from logical-node class (see IEC 61850-7-2)</td><td></td></tr>
<tr><td colspan="4">Data</td></tr>
<tr><td colspan="4">System logical node data</td></tr>
<tr><td></td><td></td><td>LN shall inherit all mandatory data from common logical node class</td><td>M</td></tr>
<tr><td></td><td></td><td>Data from LLN0 may optionally be used</td><td>O</td></tr>
<tr><td colspan="4">Settings</td></tr>
<tr><td>DERNum</td><td>ING</td><td>Number of DER units connected to controller</td><td>M</td></tr>
<tr><td>DERtyp</td><td>ING</td><td>Type of DER unit:
<table><tr><th>Value</th><th>Explanation</th></tr><tr><td>0</td><td>Not applicable / Unknown</td></tr><tr><td>1</td><td>Virtual or mixed DER</td></tr><tr><td>2</td><td>Reciprocating engine</td></tr><tr><td>3</td><td>Fuel cell</td></tr><tr><td>4</td><td>Photovoltaic system</td></tr><tr><td>5</td><td>Combined heat and power</td></tr><tr><td>99</td><td>Other</td></tr></table></td><td>M</td></tr>
</table>

Figure 7.4 DER type selection (IEC-TC 57 2009)

Notice that M/O/C means the data is one of three possible sorts: M=Mandatory, O=Optional or C=Conditional.

A PV system directly converts solar energy into electricity without using heat to generate it. Therefore, no turbine or generator is involved. Actually, a PV module has no moving part. Solar cell is a semiconductor device and it is the basic unit of photovoltaic. Several interconnected individual solar cells is called PV module. Many PV modules are then interconnected using combinations of parallel and series connections to form a PV array.

Since the power system requires AC power for interconnected generation, an inverter is required to transform the DC output of the PV array into AC. Inverters used in PV systems have an additional task, which is adjusting the DC current and DC voltage levels to maximize efficiency during changing solar irradiance and temperature conditions (IEC-TC 57 2009).

IEC-TC 57 defined several LNs to fulfill the previous component's tasks. Below is a brief definition for each of them (IEC-TC 57 2009):

Photovoltaic module ratings (DPVM): It describes the photovoltaic characteristics of a module.

Photovoltaic array characteristics (DPVA): It describes the configuration of the PV array. Besides, it might be used to provide configuration information on the number of strings and panels or the number of sub-arrays in parallel (In a large system, PV arrays are usually divided into groups of separately controlled sub-arrays composed of series-connected PV modules and parallel connected PV strings).

Photovoltaic array controller (DPVC): The photovoltaic array controller information required for remote monitoring of critical photovoltaic functions and states. If the strings are separately controlled, one DPVC per string is required to describe the controls. DPVC also provides a list of the possible control modes that can be applied by the array controller. The control mode may change during the operation. The current status is then given by the array control status attribute.

Tracking controller (DTRC): It provides overall information on the tracking system to external users. This LN can still be used for defining array or device orientations even if no active tracking is included.

Inverter (ZINV): ZINV logical node defines the characteristics of the inverter, which transforms DC to AC. The DC may be the output of the generator or may be the intermediate energy form after a generator's AC output has been rectified. However, In case of using a rectifier within the solar system, the logical node ZRCT, which defines the characteristics of the rectifier, can be used. Otherwise, only ZINV is needed to be implemented.

ZINV's tables are explained in next part in order to compare them with Vacon's PV inverter's current used parameters.

7.4. Vacon's PV inverter (8000 Solar) and ZINV Logical Node

In 2010, Vacon entered to the solar market by introducing their PV inverter, 8000 Solar. In this part, 8000 Solar present parameters and data will be compared with ZINV data and CDC to see how beneficial to implement IEC 61850 in 8000 Solar beside or instead of the current used protocol and what the added values and functionalities could be.

The scope of this part is not only to add IEC 61850 alongside the present implemented protocol in 8000 Solar; it is to investigate the possibility of involving the IEC standard in all the solar system including Vacon's PV inverter. This will result more synchronization between the inverter and the rest of the solar system, then between the solar system and the rest of the substation automation when the whole of it is controlled and monitored by the same protocol.

Before starting the comparison between 8000 Solar application parameters and ZINV data, it is important to mention that ZINV is meant to all types of inverters, which means it is not specified only for PV inverters. This is in one hand, in the other hand, Vacon's application parameters that will be mentioned later on are specified only for 8000 Solar.

First example below is to analyze the ZINV system LN data. As it can be seen from the next table, most of well-known switching and cooling methods have a corresponding value, it makes IEC 61850 able to virtualize any type of physical inverter into a logical device by selecting the suitable switching and cooling methods. Additional values are also included when setting up the LN such as Maximum power and var rating to give more reliability and quality of the ZINV operations.

Table 7.1: ZINV logical node data (IEC-TC 2009).

<table>
<tr><th colspan="4">ZINV class</th></tr>
<tr><th>Data name</th><th>CDC</th><th>Explanation</th><th>M/O/C</th></tr>
<tr><td>LNName</td><td></td><td>Shall be inherited from logical-node class (see IEC 61850-7-2)</td><td></td></tr>
<tr><td colspan="4">Data</td></tr>
<tr><td colspan="4">System logical node data</td></tr>
<tr><td></td><td></td><td>LN shall inherit all mandatory data from common logical node class</td><td>M</td></tr>
<tr><td></td><td></td><td>Data from LLN0 may optionally be used</td><td>O</td></tr>
<tr><td>WRtg</td><td>ASG</td><td>Maximum power rating</td><td>M</td></tr>
<tr><td>VarRtg</td><td>ASG</td><td>Maximum var rating</td><td>O</td></tr>
<tr><td>SwTyp</td><td>ENG</td><td>Switch type:
<table>
<tr><th>Value</th><th>Explanation</th></tr>
<tr><td>0</td><td>Not applicable / Unknown</td></tr>
<tr><td>1</td><td>Field effect transistor</td></tr>
<tr><td>2</td><td>Insulated gate bipolar transistor</td></tr>
<tr><td>3</td><td>Thyristor</td></tr>
<tr><td>4</td><td>Gate turn off thyristor</td></tr>
<tr><td>99</td><td>Other</td></tr>
</table></td><td>O</td></tr>
<tr><td>CoolTyp</td><td>ENG</td><td>Switch cooling method:
<table>
<tr><th>Value</th><th>Explanation</th></tr>
<tr><td>0</td><td>Not applicable / Unknown</td></tr>
<tr><td>1</td><td>Passive air cooling (heatsink)</td></tr>
<tr><td>2</td><td>Forced air cooling (fan + heatsink)</td></tr>
<tr><td>3</td><td>Fluid cooling (water)</td></tr>
<tr><td>4</td><td>Heat pipe</td></tr>
<tr><td>99</td><td>Other</td></tr>
</table></td><td>O</td></tr>
<tr><td>PQVLim</td><td>CSG</td><td>P-Q-V set of limiting curves</td><td>O</td></tr>
</table>

Next two tables are to compare the status information of both Solar 800 parameters and ZINV.

Tables 7.2 and 7.3 show that almost all status information of 8000 Solar are covered within ZINV data and attributes. Additional feature of ZINV is that unlike 8000 Solar parameters it is possible of send data via GOOSE message in different numbering format not only binary. Moreover, the parameters of 8000 Solar has to be sent in a word format, which means every time one status needs to be changed, all other 7 bits current value has to be checked whether it is “1” or “0” then resent again. Whereas, ZINV and referring to part 3.3.5 of the thesis, it is possible to change any data attribute individually.

Table 7.2 8000 Solar status word parameters (Vacon)

Bit	Name	Value = 0	Value = 1	Description
0	Ready Status	Not Ready	Ready	Not only if motor control is ready, but if all “Ready Criterions fulfilled”
1	Activation Status	Stopped	Activated	When active, the inverter can be in either in Standby or Inverter Running mode.
2	*Reserved*			
3	Fault Status	No Fault	Fault	
4	Alarm Status	No Alarm	Alarm	
5	Standby Status		Standby	
6	*Reserved*			
7	Inverter Running Status		Inverter Running	

8	Master Mode Status	Drive works in slave mode and uses “DC Voltage Reference” calculated by master.	Drives works independently and calculates its own DC reference.	
9	Heartbeat bit			The inverter toggles this bit on and off. 500ms on, 500ms off.
10	*Reserved*			
11	*Reserved*			
12	*Reserved*			
13	*Reserved*			
14	*Reserved*			
15	*Reserved*			

Table 7.3: ZINV status information (IEC –TC 57 2009)

ZINV class			
Data name	**CDC**	**Explanation**	**M/O/C**
Status information			
GridModSt	ENS	Current connect mode: Value – Explanation 0 – Not applicable / Unknown 1 – Disconnected 2 – Power not delivered 3 – Power delivered 99 – Other	O
Stdby	SPS	Inverter stand-by status – True: stand-by active	O
VarRtg	SPS	DC current level available for operation – True: sufficient current	O

<table>
<tr><td>CmutTyp</td><td>ENG</td><td>Type of commutation:<table><tr><th>Value</th><th>Explanation</th></tr><tr><td>0</td><td>Line commutated</td></tr><tr><td>1</td><td>Self commutated</td></tr></table></td><td>O</td></tr>
<tr><td>IsoTyp</td><td>ENG</td><td>Type of isolation:<table><tr><th>Value</th><th>Explanation</th></tr><tr><td>0</td><td>Not applicable / Unknown</td></tr><tr><td>1</td><td>Low frequency transformer isolated</td></tr><tr><td>2</td><td>Hi frequency transformer isolated</td></tr><tr><td>3</td><td>Non-isolated, grounded</td></tr><tr><td>4</td><td>Non-isolated, isolated DC source</td></tr><tr><td>99</td><td>Other</td></tr></table></td><td>O</td></tr>
<tr><td>SwHz</td><td>ASG</td><td>Nominal frequency of switching</td><td>O</td></tr>
<tr><td>GridMod</td><td>ENG</td><td>Power system connect modes to the power grid:<table><tr><th>Value</th><th>Explanation</th></tr><tr><td>0</td><td>Not applicable / Unknown</td></tr><tr><td>1</td><td>Current-source inverter (CSI)</td></tr><tr><td>2</td><td>Voltage-controlled voltage-source inverter (VC-VSI)</td></tr><tr><td>3</td><td>Current-controlled voltage-source inverter (CC-VSI)</td></tr><tr><td>99</td><td>Other</td></tr></table></td><td>O</td></tr>
</table>

The comparison could not be continued because 8000 Solar document has much more parameters than ZINV for the inverter since as is specified to a PV inverter when ZINV is used for all types of inverters. However, It is still needed to use inverter’s LNs at least beside the current used protocol to add flexibility to certain control tasks as well as allowing IEC 61850 to be used for the whole solar system. Next table shows the rest of ZINV logical node’s data.

Table 7.4 Rest of ZINV data (IEC-TC 57 2009)

<table>
<tr><th colspan="4">ZINV class</th></tr>
<tr><th>Data name</th><th>CDC</th><th>Explanation</th><th>M/O/C</th></tr>
<tr><td colspan="4">Settings</td></tr>
<tr><td>ACTyp</td><td>ENG</td><td>AC System Type:
<table><tr><th>Value</th><th>Explanation</th></tr><tr><td>1</td><td>Single phase</td></tr><tr><td>2</td><td>Two phase</td></tr><tr><td>3</td><td>Three phase</td></tr></table></td><td>M</td></tr>
<tr><td>PQVLimSet</td><td>CSG</td><td>Active curve characteristic curve for PQV limit</td><td>M</td></tr>
<tr><td>OutWSet</td><td>ASG</td><td>Output power setpoint</td><td>M</td></tr>
<tr><td>OutVarSet</td><td>ASG</td><td>Output reactive power setpoint</td><td>O</td></tr>
<tr><td>OutPFSet</td><td>ASG</td><td>Power factor setpoint as angle</td><td>O</td></tr>
<tr><td>OutHzSet</td><td>ASG</td><td>Frequency setpoint</td><td>O</td></tr>
<tr><td>InALim</td><td>ASG</td><td>Input current limit</td><td>O</td></tr>
<tr><td>InVLim</td><td>ASG</td><td>Input voltage limit</td><td>O</td></tr>
<tr><td>PhACnfg</td><td>ENG</td><td>Inverter phase A feed configuration:
<table><tr><th>Value</th><th>Explanation</th></tr><tr><td>0</td><td>Not applicable / Unknown</td></tr><tr><td>1</td><td>Feeding from N to A</td></tr><tr><td>2</td><td>Feeding from N to B</td></tr><tr><td>3</td><td>Feeding from N to C</td></tr><tr><td>4</td><td>Feeding from A to B</td></tr><tr><td>5</td><td>Feeding from A to C</td></tr><tr><td>6</td><td>Feeding from B to A</td></tr><tr><td>7</td><td>Feeding from B to C</td></tr><tr><td>8</td><td>Feeding from C to A</td></tr><tr><td>9</td><td>Feeding from C to B</td></tr><tr><td>99</td><td>Other</td></tr></table></td><td>O</td></tr>
<tr><td>PhBCnfg</td><td>ENG</td><td>Inverter Phase B feed configuration: see PhACnfg for enumerated values</td><td>O</td></tr>
<tr><td>PhCCnfg</td><td>ENG</td><td>Inverter Phase C feed configuration: see PhACnfg for enumerated values</td><td>O</td></tr>
</table>

Measured values			
HeatSinkTmp	MV	Heat sink temperature: Alarm if over max	O
EnclTmp	MV	Enclosure temperature	O
AmbAirTemp	MV	Ambient outside air temperature	O
FanSpdVal	MV	Measured fan speed: Tach or vane	O

7.5. Photovoltaic Array Simulation

A simulation of a simple photovoltaic array is given in order to study the structure of a solar module then discuss what is the impact of implementing IEC 61850 PV arrays LNs.

An insolation of 1000 W/m^2 is implemented on a parallel PV modules then the output power is measured. A ramp signal is applied to work the same as the feeder PV current with setting its value to 6A.

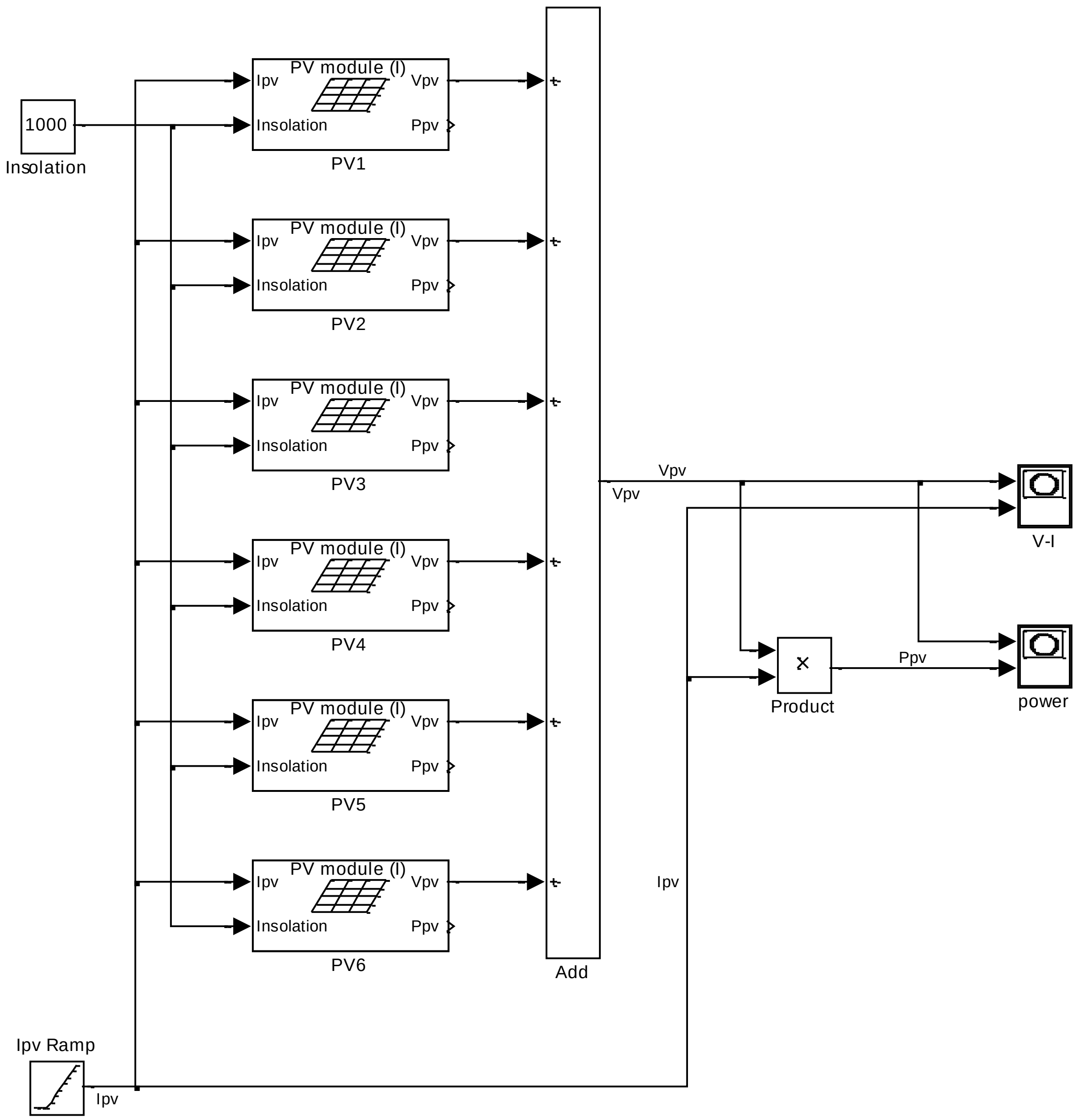

Figure 7.5 PV array Simulink model

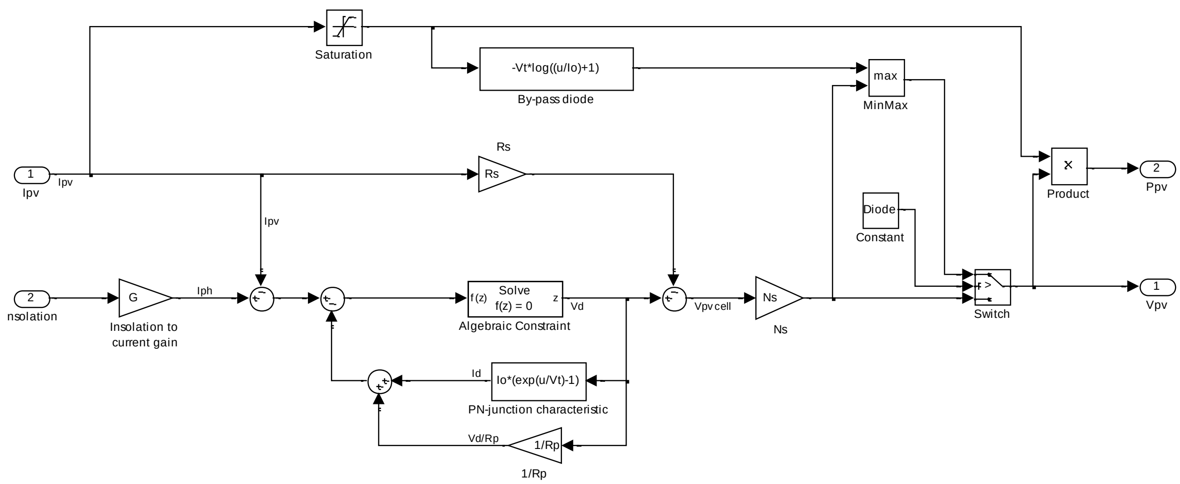

Figure 7.6 PV module subsystem model.

XY plots below describe the relation between PV current and PV voltage and the relation between PV power and PV voltage respectively.

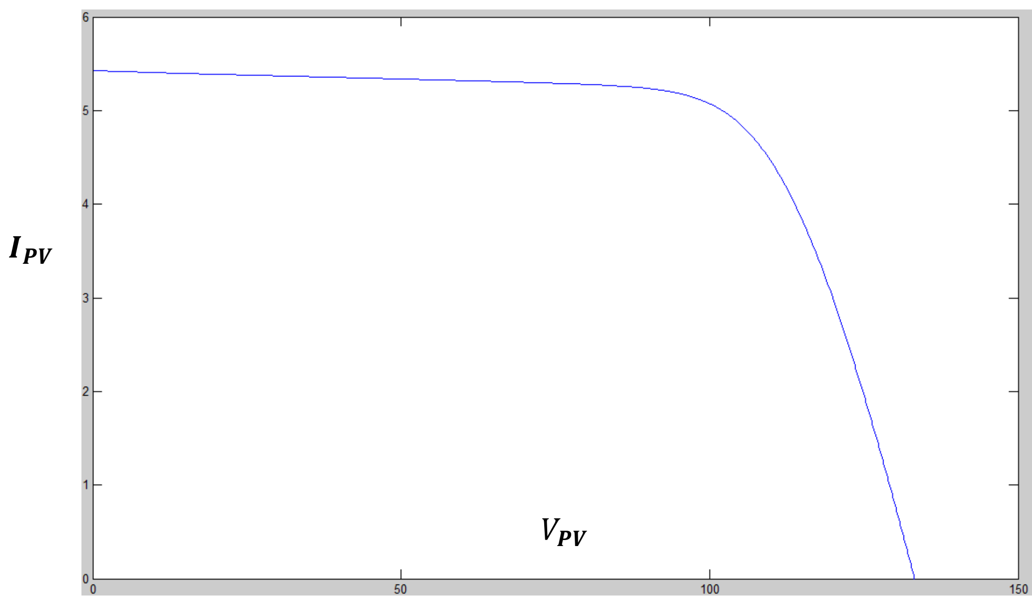

Figure 7.7 Relation between $\boldsymbol{I_{PV}}$ and $\boldsymbol{V_{PV}}$.

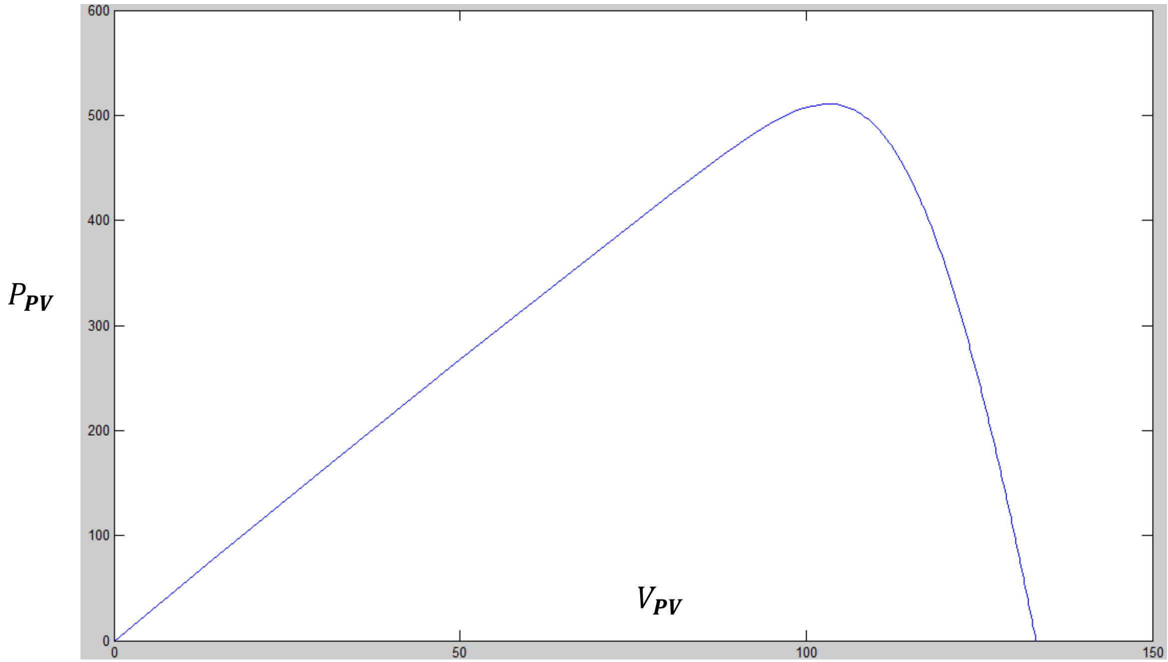

Figure 7.8 Relation between $\boldsymbol{P_{PV}}$ and $\boldsymbol{V_{PV}}$.

It can be observed from the previous two figures that at the output voltage of 100V the power reaches its maximum value before the insolation starts to decrease. After reaching the saturation level in Figure 7.7, the relation between $\boldsymbol{V_{PV}}$ and I_{PV} is not absolutely constant as it is supposed to be, which causes the power to not to reach its assumed maximum power (600W). This is caused by the complexity of the PV module. The challenge is how to control the tasks in the PV module and PV array in order to observe better power utility.

IEC 61850 DER logical nodes and specifically the PV logical nodes, which were defined in part 7.3, are designed to guarantee the highest possible power utilization as well as more flexibility of controlling the PV system.

Table 7.5 displays the photovoltaic array controller LN. It contains useful data to enhance the PV array tasks, such as ArrModCtr (Mode selected to control the power output of the array), TrkRefV (Peak power tracker reference voltage), etc.

Table 7.5 DPVC (Photovoltaic array controller) LN (IEC-TC 57 2009).

DPVC class			
Data name	**CDC**	**Explanation**	**M/O/C**
LNName		Shall be inherited from logical-node class (see IEC 61850-7-2)	
Data			
System logical node data			
		LN shall inherit all mandatory data from common logical node class	M
		Data from LLN0 may optionally be used	O
Status information			
CtrModSt	INS	Array control mode status	O
Settings			
TrkRefV	ASG	Peak power tracker reference voltage	O
TrkWupV	ASG	Power tracker wake-up voltage	O
TrkDlWupTms	ING	Time delay for PV wake-up	O
TrkDlSlpTms	ING	Time delay for PV sleep test	O
TrkSlpW	ASG	PV power point to begin sleep test timer	O
TrkRte	ING	Power tracker update rate	O
TrkVStp	ASG	Voltage perturbation step of power tracker	O
Controls			
ArrModCtr	ENC	Mode selected to control the power output of the array: Value – Explanation 0 – Not applicable / Unknown 1 – Maximum power point tracking (MPPT) 2 – Power limiter controller 3 – DC current limit 4 – Array voltage control 99 – Other	O

For example, when selecting “Array voltage control” under “Mode selected to control the power output of the array” it gives the ability to regulate and enhance the peak value of output voltage, which will result more stability in the voltage curve and increase the quality of the PV output power.

More settings to guarantee the stability of the system and enhance the output power curve are included within DPVC LN, such as TrkDlWupTms (Time delay for PV wake-up) and TrkDlSlpTms (Time delay for PV sleep test). These delays help with avoiding the instability of the system when a sudden insolation is applied on the solar cells or sudden shading happens.

The rest of PV and DER logical nodes that are defined in IEC 61850-7-420 contain several data attributes to enhance and develop the work of the solar system and solar applications. Once IEC publishes the final document of this part besides the other expected document to be published soon (IEC 61850-90-7), which will contain IEC 61850 object models for inverters in DER systems, the door will be wide open for researches and implementations of IEC 61850 in solar applications.

8. CONCLUSION AND FUTURE WORK

The thesis covered mainly three major points. First is the literature part that can be a useful reference for those who want to learn about IEC 61850 and its basic concepts. Secondly, the investigation of solar market future and costumers requirements using two surveys, with studying the opportunities of implementing IEC 61850 in PV and solar applications in the early future. The IEC standard and its applications have become an interest of most of the utility companies and R&D institutions. With the rapid growing of solar applications, the merging between the IEC standard and these applications is expected to be the next scope of power system developers. Last point is the comparison between Vacon's PV inverter (8000 Solar) parameters and IEC 61850 DER logical nodes then give a practical examples of what are the benefits and the added functionalities if IEC 61850 is implemented in solar systems.

The surveys returned an efficient feedback from its participants. Although most of participated utility companies do not use solar applications yet, they showed positive expectations of solar power future. Since IEC 61850 is widely used nowadays, it will be easier to define any new technology were the IEC standard is implemented. This refers to the Interoperability of it, which allows an IED that is interfaced with IEC 61850 to be added to any system based on the IEC standard.

However, the surveys can be modified and enhanced for the future use when the idea of it is more visible and face-to-face interview with participants will guarantee more trusted feedback than the online link, which can be filled by random individuals.

The incomplete IEC-TC 57 Drafts for DER and PV inverter prevent the thesis from having clear results of implementing IEC 61850 in solar applications. Despite this, Chapter 7 gave a base study case which can be continued once in IEC 61850-7-420 and IEC 61850-90-7 are published and then it will be possible to have an actual implementation with expected great results.

REFERENCES

Aguilar, Rene & James, Ariza (2010). *Experience with Testing and Configuration of IEC 61850 Multivendor Protection Schemes* [online] [cited 4 Jul. 2011]. Megger, USA. Available from the Internet: <URL: http://www.pacw.org/fileadmin/images_content/SeptemberIssue2010/LessonsLearned/figure_3.jpg>

Apostolov A.P. (2002). *Application of High-Speed Peer-to-Peer Communications for Protection and Control*. California, USA: ALSTOM T&D Protection & Control.

Brand, Klaus-Peter (2005). *IEC 61850 Short Tutorial* [online] [cited 27 Sep. 2011]. Available from the Internet <URL: http://www.ceb5.cepel.br/arquivos/eventos_setor/iec61850_tutoria.pdf>

De Mesmaeker, Ivan, Peter, Rietmann, Klaus-Peter, Brand & Petra Reinhardt (2005). *Substation Automation based on IEC* 61850 [online] [cited 9 Sep. 2011]. Cairo, Egypt: Cigré SC B5 6th Regional CIGRÉ conference, November 21 – 23 2005. ABB Switzerland Ltd. Available from the Internet: <URL: http://www05.abb.com/global/scot/scot221.nsf/veritydisplay/f169c6ca0710df26c12570d1005396b5/$file/cairo-dfn.pdf>

Driscoll, Frederick (1992). *Data communications*. International Ed. Florida, USA: Harcourt Brace Jovanovich Publishers. 233-235.

Forouzan, Behrouz (2003). *TCP/IP Protocol Suite*. 2nd Ed. New York, USA: McGraw-Hill Professional. 19-47. ISBN: 0072460601.

Gajić, Zoran (2005). *IEC 61850* [online] [cited 28 Feb. 2012]. Sweden: ABB Power Technologies AB. Available from the Internet: <URL: http://www.cigresrbija.org/doc/simpozijumi/13/13abbstrucnopredavanje.pdf>

Goraj, Maciej, Lee, Lipes, & Jim, McGhee (2011). *IEC 61850 GOOSE over WiMAX for Fast Isolation and Restoration of Faults in Distribution Networks* [online] [cited 12

Jan. 2012]. Dublin, Ireland. Available from the Internet: <URL: http://www.scribd.com/doc/74994185/Iec-61850-Goose-Over-Wimax-Pac-World-2011>

Hakala-Ranta, Antti, Olli, Rintamäki & Janne, Starck (2009). *Utilizing Possibilities of IEC 61850 and GOOSE* [online] [cited 17 Jul. 2011]. Prague, Czech Republic: 20th International Conference on Electricity Distribution. ABB Oy, Distribution Automation. Available from the Internet: <URL: http://www05.abb.com/global/scot/scot229.nsf/veritydisplay/3ff2dbcff3a10556c12575e60043b35f/$file/abb_whitepaper_cired_2009_0741.pdf>

Higgins, Neil, Valeriy, Vyatkin, Nirmal-Kumar, C. Nair & Karlheinz, Schwarz (2010). *Distributed Power System Automation With IEC 61850, IEC 61499, and Intelligent Control* [online] [cited 7 Jan. 2012]. Available from the Internet: <URL: http://www.nettedautomation.com/download/HVNS_SMC_IEEE%20final.pdf>

Holzmann, Gerard (1991). *Design and Validation of Computer Protocols*. 2nd Ed. New Jersey, USA: Prentice Hall. 27-30.

IEC 61850 blog. *Italian Norm about to Require IEC 61850 for almost all PV Inverters* [online] [cited 7 Feb. 2012]. Available from the Internet: <URL: http://blog.iec61850.com/2012/02/italian-norm-about-to-require-iec-61850.html>

IEC-TC 57 (2003). 1st Ed. *Communication networks and systems in substations*. IEC Standard IEC/TR 61850.

IEC-TC 57 (2009). *IEC 61850 Part 7-420 DER Logical Nodes*. Final Draft International Standard (FDIS). IEC Standard IEC/TR 61850

IEEE (2002). Information Technology - Telecommunications and information exchange between systems - Local and metropolation area networks - Spesific requirements - Part 3. *Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications*. IEEE 802.3/ISO 8802-3.

Infocellar. *The OSI (Open System Interconnection) Model* [online] [cited 28 Aug. 2011]. Available from the Internet: <URL: http://www.infocellar.com/networks/images/OSI-1.png>

Lidén, Jonas (2006). *Design and Implementation of an IEC 61850 gateway for PLC Systems*. Stockholm, Sweden: KTH Electrical Engineering. Master Thesis. XR-EE-ICS 2006:021.

Mackiewicz, Ralph (2006). *Overview of IEC 61850 and Benefits*. IEEE: 1-4244-0493-2/06/$20.00.

Mackiewicz, Ralph, Mark, Adamiak & Drew, Baigent (2009). *IEC 61850 Communication Networks and Systems In Substations: An Overview for Users* [online] [cited 3 May. 2011]. Available from the Internet: <URL: http://www.gedigitalenergy.com/multilin/journals/issues/Spring09/IEC61850.pdf>

Menani, Smail (2009). *Feasibility of IEC 61850 on the Soccer Robots*. Vaasa: Vaasa University of Applied Sciences (VAMK). 31 p. Presentation slides.

Neteon, Industrial Networking Solutions. *What Is Goose (Generic Object Oriented Substation Event)* [online] [cited 16 March. 2011]. Available from the Internet: <URL:http://www.neteon.net/media/PDFFiles/Goose_Generic-Object-Oriented-Substation-Event.pdf>

NettedAutomation (a). *IEC Technical Committee 88: Wind Turbines* [online] [cited 21 Jan. 2012]. Available from the Internet: <URL: http://www.nettedautomation.com/standardization/IEC_TC88/index.html >

NettedAutomation (b). *The MMS Client/Server model* [online] [cited 22 Sep. 2011]. Available from the Internet: <URL: http://www.nettedautomation.com/standardization/ISO/TC184/SC5/WG2/mms_intro/pictures/Image6.gif>

P. Parikh, Palak, Mitalkumar, Kanabar & Tarlochan, S. Sidhu (2010). *Opportunities and Challenges of Wireless Communication Technologies for Smart Grid Applications* [online] [cited 2 Feb. 2012]. Available from the Internet: <URL: http://userspages.uob.edu.bh/mangoud/577-smartgrid.pdf>

Pereda, Rodolfo. *IEC 61850 : Communication Networks and System in Substation* [online] [cited 8 Mar. 2012]. Tehran, Iran: Ingeteam, Transmission & Distribution SA. Available from the Internet: <URL: http://www.padrayenergy.com/Index%20Files/Products/Ingeteam%20Co/25%20SAS%20document/61850_Solution_Technical_Data_Sheet/Standard%20IEC%2061850_eng.pdf>

Proudfoot, Douglas (2002*). UCA and IEC61850 for Dummies* [online] [cited 24 Mar. 2011]. Florida, USA: 2002 DistribuTECH conference. Available from the Internet <URL:http://www.nettedautomation.com/download/UCA%20and%2061850%20for%20dummies%20V12.pdf>

Schwarz, Karlheinz (2005). *IEC 61850 ALSO OUTSIDE THE SUBSTATION FOR THE WHOLE ELECTRICAL POWER SYSTEM* [online] [cited 3 Feb 2012]. Karlsruhe, Germany: Schwarz Consulting Company (SCC). Available from the Internet: <URL: http://www.pscc-central.org/uploads/tx_ethpublications/fp678.pdf>

Systems Integration Specialists Company (1995). *Overview and Introduction to the Manufacturing Message Specification (MMS)*. Revision 2. Michigan, USA: SISCO, Sterling Heights.

Vacon. *ARFIFF04 Vacon 8000 Solar, Application Manual.* Vacon Oyj distributer.

VAMP. VAMP 257 [online] [cited on 11 Mar. 2012]. Available from the Internet: <URL: http://www.vamp.fi/Product%20Images/Relays/VAMP257-B-LR.jpg>

Wikipedia. IEC 60870 [online] [cited 18 Jan. 2012]. Available from the Internet: <URL: http://en.wikipedia.org/wiki/IEC_60870>

Wright, Gary & Richard, Stevens (1995). *The Protocols: TCP/IP Illustrated*. Vol. 1. Boston, USA: Addison-Wesley Professional. 33-53. ISBN 020163354X.

APPENDICES

APPENDIX 1. Survey for IEC 61850 users

1. Do you use/install solar applications?
    - Yes
    - No
2. If no, are you interested in installing solar system?
    - Yes
    - No
    - Maybe
    - Previous question was answered by “Yes”
3. What kind of communication is used in your Substation Automation/Solar Applications?
    - LAN
    - Parallel port
    - WLAN
    - Other, Specify ……………
4. Which one of the two factors do you consider more, cost (less cost for communication networks, using economic available devices in the market, etc) or quality (Security, protection, efficiency, response time, etc)?
    - Cost is priority
    - Cost is majority
    - 50%-50%
    - Quality is priority
    - Quality is majority
5. How satisfied are you with IEC 61850?
    - Very Satisfied
    - Satisfied
    - Normal
    - Quite satisfied but I would rather using another standard
    - Not satisfied

6. How fast is the response time of the system using IEC 61850?
   ……………………………
7. How important are fast response, fast fault detection and fast circuit breaking? ……………………………………
8. Do you use IEDs from different vendors?
   - Yes
   - No
9. From your point of view, which aspects/subdomains of security are considered important?
   …………………………………………………………………………………………
   …………………………………………………………………………………………
   …………………………………………………………………………………………
   ………………
10. From your point of view, which aspects/subdomains of reliability are considered important?
    …………………………………………………………………………………………
    …………………………………………………………………………………………
    …………………………………………………………………………………………
    ………………
11. If a new application was applied in the SA, would you prefer that you engineers develop your own configuration tool to configure the new application or you would rather another software engineering company/organization to design it?
    - I prefer that our engineers develop it
    - I prefer that external company/organization designs it
    - Our engineers might co-operate with external partner/company to develop it
12. From 1-5 how do you grade your current engineers understanding of IEC 61850?
    - 0/5
    - 1/5
    - 2/5
    - 3/5
    - 4/5
    - 5/5
13. Describe briefly how do you measure the benefits of the virtualized Models (logical nodes, logical devices) when IEC 61850 is used comparing with the situation before using the standard?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

………………

14. Are all the 10 parts of IEC 61850 used in your SA?
    - Yes
    - No, specify which parts are used …………………………………..
    - I do not know
15. Do you hire different engineers for different parts of IEC 61850 (IEC 61850-1, IEC 61850 IEC 61850-7-1, IEC 61850-7-2, etc)?
    - Yes
    - Yes, but the same engineers are able to supervise all parts of IEC 61850
    - No
16. Please define negative aspects of IEC 61850 (if there are any).

    …………………………………………………………………………………………

    …………………………………………………………………………………………

    …………………………………………………………………………………………

    ………………
17. As renewable resources are considered as a nature friends, how important is the environment safety over the annual revenue to you?
    - Earnings and revenue are priority
    - Earning with trying to not hurting the environment as much as it is possible
    - Environment safety is priority
18. Do you think solar applications are expensive?
    - Expensive
    - Expensive at the purchasing time and for long term (high maintenance cost, etc)
    - Expensive at the time of purchasing, but with the long term because of the low maintenance cost and because it is renewable resource, it is not
    - Not Expensive
    - Other, explain …………………………………………………..

19. Do you think the market of solar applications will increase within next 5 years?

- It will increase
- It will stay at the same level
- It will decrease
- I do not know

20. Please fill in your future wishes for the current communication protocols/standards situation in your current SA, what do you think it needs to be added, needs to be developed, etc

    …………………………………………………………………………………………

    …………………………………………………………………………………………

    …………………………………………………………………………………………

    ………………..

21. What are your expectations for the future of solar applications market and the use of them as an energy resource within the next five years?

    …………………………………………………………………………………………

    …………………………………………………………………………………………

    …………………………………………………………………………………………

    ………………

22. Your feedback is important to increase the future surveys quality, please write your comments on the survey.

    …………………………………………………………………………………………

    …………………………………………………………………………………………

    …………………………………………………………………………………………

    ………………

APPENDIX 2. Survey for non-IEC 61850 users.

1. Do you use/install solar applications?
    - Yes
    - No
2. If no, are you interested in installing solar system?
    - Yes
    - No
    - Maybe
    - Previous question was answered by “Yes”
3. What kind of communication is used in your SA?
    - LAN
    - Parallel port
    - WLAN
    - Other, Specify ……………
4. Which one of the two factors do you consider more, cost (less cost for communication networks, using economic available devices in the market, etc) or quality (Security, protection, efficiency, response time, etc)??
    - Cost is priority
    - Cost is majority
    - 50%-50%
    - Quality is priority
    - Quality is majority
5. Which Telecommunication protocol(s)/Standard(s) is currently used in your SA? …………………………………
6. How satisfied are you with the current used Telecommunication protocol(s)/Standard(s)?
    - Very Satisfied
    - Satisfied
    - Normal
    - Quite satisfied but I would rather using another standard
    - Not satisfied

7. Please describe briefly positive and negative aspects of the current used protocol(s)/Standard(s).

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

……………...

....

8. Would you like to implement IEC 61850?
    - Yes
    - No
    - Maybe
    - I do not know what is IEC 61850
9. If you chooses other answer than “No”, are you interested in inviting IEC 61850 expert for several agreed presentations regarding to the standard to have knowledge about it?
    - Yes
    - No
    - Maybe
10. If question 7 was answered by “No”, explain why?

    …………………………………....

11. How fast is the response time of the system with the used standard?

    ……………………………………

12. How important is fast response, fast fault detection and fast circuit breaking?

    ……………………………………

13. Do you use IEDs from different vendors?
    - Yes
    - No
14. If yes, how do they communicate with each other?
    - ……………………………..
    - Previous question was answered by “No”

15. As IEC 61850 offers both horizontal and vertical communication, is the communication in your SA horizontal (as in bay-to-bay communication, GOOSE) or vertical (as in RTU and SCADA)?

- Horizontal
- Vertical
- Both
- Other
- I do not know

(Horizontal communication concerns exchange of information between bays (e.g. station interlocking) and exchange of information between functions inside the bay (e.g exchange of information between line protection and re-closer. Vertical communication concerns exchange of information between the control station level (e.g control center, HMI, station controller) and bay level (e.g protection relays, circuit breakers), starting from station control level down to bay level.)

16. From your point of view, which aspects/subdomains of security are considered important?
    ……………………………………………………………………………………………
    ……………………………………………………………………………………………
    ……………………………………………………………………………………………
    ………………
17. From your point of view, which aspects/subdomains of reliability are considered important?
    ……………………………………………………………………………………………
    ……………………………………………………………………………………………
    ……………………………………………………………………………………………
    ………………
18. If a new application was applied in the SA, would you prefer that you engineers develop your own configuration tool to configure the new application or you would rather another software engineering company/organization to design it?
    - I prefer that our engineers develop it
    - I prefer that external company/organization designs it
    - Our engineers might co-operate with external partner/company to develop it
19. From 1-5 how do you grade your current engineers/managers Knowledge of IEC 61850?
    - 0/5

- 1/5
- 2/5
- 3/5
- 4/5
- 5/5

20. As renewable resources are considered as a nature friends, how important is the environment safety over the annual revenue to you?
    - Earnings and revenue are priority
    - Earning with trying to not hurting the environment as much as it is possible
    - Environment safety is priority
21. Do you think solar applications are expensive?
    - Expensive
    - Expensive at the purchasing time and for long term (high maintenance cost, etc)
    - Expensive at the time of purchasing, but with the long term because of the low maintenance cost and because it is renewable resource, it is not
    - Not Expensive
    - Other, explain …………………………………………………..
22. Do you think the market of solar applications will increase within next 5 years?
    - It will increase
    - It will stay at the same level
    - It will decrease
    - I do not know
23. Please fill in your future wishes for the current communication protocols/standards situation in your current SA, what do you think it needs to be added, needs to be developed, etc

    ……………………………………………………………………………………

    ……………………………………………………………………………………

    ……………………………………………………………………………………

    ………………..

24. What are your expectations for the future of solar applications market and the use of them as an energy resource within the next five years?

    ……………………………………………………………………………………

    ……………………………………………………………………………………

………………………………………………………………………………………………

………………

25. Your feedback is important to increase the future surveys quality, please write your comments on the survey.

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

………………

APPENDIX 3. IEC 61850 guide for reader (IEC-TC 57 2003)

User		IEC 61850-1 (Introduction and overview)	IEC 61850-5 (Requirements)	IEC 61850-7-1 (Principles)	IEC 61850-7-4 (Logical nodes and data classes)	IEC 61850-7-3 (Common data classes)	IEC 61850-7-2 (Information exchange)	IEC 61850-6[a] (Configuration language)	IEC 61850-8-x IEC 61850-9-x[a] (Concrete communication stack)
Utility	Manager	x	–	Clause 5	–	–	–	–	–
Utility	Engineer	x	x	x	x	x	In extracts	x	–
Vendor	Application engineer	x	x	x	x	x	In extracts	x	In extracts
Vendor	Communication engineer	x	x	x	–	–	x	–	x
Vendor	Product manager	x	x	x	x	In extracts	In extracts	In extracts	–
Vendor	Marketing	x	x	Clause 5	In extracts	In extracts	In extracts	In extracts	–
Consultant	Application engineer	x	x	x	x	x	–	x	–
Consultant	Communication engineer	x	–	x	–	–	x	x	x
All others		x	x	x	–	–	–	–	–

The "**x**" means that this part of the IEC 61850 series should be read.

The "**In extracts**" means that extracts of this part of the IEC 61850 series should be read to understand the conceptual approach used.

The "**–**" means that this part of the IEC 61850 series may be read.

[a] These documents are under consideration.

APPENDIX 4. Vacon 8000 Solar (Vacon)