**UNIVERSITY OF VAASA**

**FACULTY OF TECHNOLOGY**

**COMMUNICATIONS AND SYSTEMS ENGINEERING**

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# INTEGRATING ELECTRIC VEHICLES INTO SMART GRID USING IEC 61850 AND ISO/IEC 15118 STANDARDS

Master's thesis for the degree of Master of Science in Technology submitted for inspection, Vaasa, 16 February, 2016.

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ACKNOWLEDGMENT

Firstly, I express my gratitude to God Almighty who is the source of life, health, knowledge and privileges to accomplish successfully my Master's degree program. Then I express my special thanks to my thesis supervisor, Professor Kimmo Kauhaniemi and my instructor Reino Virrankoski for their guidance, support, and favor throughout the thesis period. I am thankful to Professor Mohammed Elmusrati, Professor Timo Mantere, Dr. Pape Bernd Klaus, Tobias Glocker, Ruifeng Duan, and Mike Mekkanen for their contribution to the knowledge I have acquired during my studies.

I would like to express my special thanks to my family, my lovely parents Mr. Gasto Lameck and Mrs. Beatrice Gasto, my lovely grandparents Mr. Lameck and Mrs. Lowis Lameck, my siblings, my uncles and my aunts for their prayers, love, inspiration, encouragement and support during my studies. You have been a blessing in my life. I also thank my friends for wonderful time we had together and the maximum cooperation you showed to me.

Finally, my deepest appreciation goes to the University of Vaasa and to the Finnish government for this unforgettable privilege offered to pursue this academic program.

Vaasa, Finland, February 2016

Adore Gasto Lameck.

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**ABBREVIATIONS**

| | |
|---|---|
| **AC** | Alternating Current |
| **AP** | Access Point |
| **CID** | Configured IEDs Description |
| **DC** | Direct Current |
| **DER** | Distributed Energy Resources |
| **DNS** | Domain Name System |
| **DHCPv6** | Dynamic Host Control Protocol Version 6 |
| **EVs** | Electric Vehicles |
| **EVCC** | Electric Vehicle Communication Controller |
| **EVSE** | Electric Vehicle Supply Equipment |
| **EXI** | Efficient XML Interchange |
| **HPGP** | HomePlug GreenPhy |
| **HTTP** | Hypertext Transfer Protocol |
| **ICD** | IED Capability Description |
| **ICMP** | Internet Control Message Protocol |
| **IEC** | International Electro-technical Commission |
| **IEDS** | Intelligent Electronic Devices |
| **IP** | Internet Protocol |
| **IPv6** | Internet Protocol Version 6 |

| | |
|---|---|
| **ISO** | International Standard Organization |
| **LDs** | Logical Devices |
| **LNs** | Logical Nodes |
| **MAC** | Medium Access Control |
| **M2M** | Machine-to-Machine |
| **MMS** | Manufacturing Messaging Specification |
| **OPEX** | Operational Expenditures |
| **OSI** | Open System Interconnection |
| **PEVs** | Plug-in Electric Vehicles |
| **PLC** | Power Line Communication |
| **PnC** | Plug and Charge |
| **PV** | Photovoltaic |
| **PWM** | Pulse Width Modulation |
| **RBAC** | Role Based Access Control |
| **RFC** | Request for Comments |
| **SAE** | Society of Automotive Engineers |
| **SCADA** | Supervisory Control and Dada Acquisitions |
| **SDP** | SECC Discovery Protocol |
| **SECC** | Supply Equipment Communication controller |
| **SLAAC** | Stateless Auto Address Configuration |

| | |
|---|---|
| **SOAP** | Simple Object Access Protocol |
| **SOC** | State of Charge |
| **SSL** | Secure Socket Layer |
| **TCP** | Transmission Control Protocol |
| **TLS** | Transport Layer Security |
| **TOU** | Time of Use |
| **UDP** | User Datagram Protocol |
| **UPS** | Uninterruptible Power Systems |
| **V2G** | Vehicle-to-Grid |
| **V2G CI** | Vehicle-to-Grid Communication Interface |
| **V2GTP** | Vehicle-to-Grid Transfer Protocol |
| **VMD** | Virtual Manufacturing Device |
| **W3C** | World Wide Web Consortium |
| **WPT** | Wireless Power Transfer |

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**Degree:** Master of Science in Technology
**Degree Programme:** Degree Programme in Telecommunication Engineering
**Major of Subject:** Telecommunication Engineering
**Year of Entering the University:** 2013
**Year of Completing the Thesis:** 2016 **Pages:** 76

## ABSTRACT

The development of Electric Vehicle (EV) technology is evolving quickly due to the worlds growing concerns in environmental protection and energy conservation. The world is struggling to minimize $CO_2$ emissions and fossil fuel dependency in transportation sector. Standardized communication interface is a key factor for the successful integration of electric vehicle into smart grid, interoperability of charging infrastructure and mass-market acceptance of E-Mobility.

The deployment of the electric vehicle in large scale would be one of the feasible solutions because of its economical and environmentally friendly features. However, large deployment of the electric vehicle arises challenges at the grid level such as peak load impacts and charging control. Therefore, it is very crucial to investigate how to integrate electric vehicle into smart grid so that to avoid these effects.

This thesis describes how the vehicle-to-grid communication interface (V2G CI) currently being developed in ISO/IEC 15118 can be connect to IEC 61850-7-420 standard for Distributed Energy Resources (DER). The client-server application is implemented to simulate EV charging process according to the ISO/IEC 15118 standard. Also the new logical nodes for monitoring and controlling EV and Electric Vehicle Supply Equipment (EVSE) are implemented for the simulation of the concept.

**Keywords:** Electric Vehicles, Electric Vehicle Supply Equipment, Smart Grid, Vehicle-to-Grid, ISO/IEC 15118, IEC 61850.

# 1. INTRODUCTION

## 1.1. Introduction to Electric Vehicles and Smart Grid

The electric vehicle (EV) is a vehicle that is propelled by an electric motor, powered by rechargeable battery packs. The motor uses the power supplied by battery packs to rotate a transmission and the transmission turns the wheels. Electrification in transportation sector has been increasing dramatically. There are several reasons for the adoption of EVs. In the 50 years to come, the population of the world will increase from 7 billion (current world population) to 10 billion while the number of vehicles is expected to increase from 700 million to 2.5 billion. Now the main issue is where to get oil to power such huge number of vehicles if all these vehicles are to be propelled by internal combustion engines and how will they affect the globe environment? The struggle for sustainable EVs is answer to these questions.

Smart grid is the modern way the electricity is generated, transmitted, distributed, stored and consumed by integrating advanced sensing technologies, communications and control functionalities in the power grid operations, in order to enhance efficiency, security, reliability and minimizing the emissions as much as possible. The struggle to reduce the electricity bills, energy consumption and emissions has been one of the targets of Telecommunication companies and data center operators for the past several years. A good number of researches have been carried out in the field of energy-efficient communications aiming to communication networks with less Operational Expenditures (OPEX), less power consumption and reduced emissions with minimal service degradation. Therefore, smart grid driven techniques (such as Time of Use (TOU), demand management and renewable energy) can significantly bring down the bills and minimize the amount of energy consumption as well as emissions. (Erol-Kantarci & Mouftah 2015.)

## 1.2. Thesis Motivation

The depletion of oil reserves and the increase of $CO_2$ emissions due to the use of conversional engines have influenced interest in the potential use of electric vehicle. The deployment of electric vehicles in a large-scale seems to be one of the feasible solutions to relieve energy crisis, global warming and geopolitical relevant outcomes that arise due to the environmental pollution. However, uncontrolled charging of electric vehicles will cause a significant impact on the power grid operations and planning. Therefore, it is very crucial to investigate how charging and discharging of electric vehicles and interaction with the grid should be handled in order to counterpart the negative impact of EVs direct charging. Since the electric vehicles will stay remarkable part of the day on the parking spot, it would be reasonable to utilize their batteries as an electric storage in the smart grid. This stored energy can be fed in the grid when the demand of electricity is high compared to the energy generated.

According to the current studies, it shows that today's transport sector is one of the leading sectors in $CO_2$ emissions. Therefore the globe is doing the best to reduce the $CO_2$ emissions in the transport sector and EVs seems to be a solution to this problem. However, the link between the power grid and the electric vehicle is necessary. Also scheduling charging session to low price periods would minimize the transportation costs for the users, as the result many people would prefer to use the vehicles powered by electricity instead of using the vehicles powered by fossil fuel. The use of Electric Vehicles is getting popularity as the results of globe effort to reduce $CO_2$ in transport sectors and the industrial interest of using electric vehicles as the storage of electric power.

## 1.3. Thesis Objectives

The objective of this thesis is to investigate how EVs can be integrated into smart grid in a way that supports electric grid while benefitting the vehicle owners (by charging when the price of electricity is low and discharging when the price is high) and taking advantage of reduction in $CO_2$ emissions. To reach this goal, a research is done focusing on the communication protocols, interfaces and standards required in the infrastructure considering integration to the grid management system applying International Electro-technical Commission (IEC) 61850.

## 1.4. Thesis Structure

The thesis is structured in seven chapters. Chapter one presents a brief introduction to electric vehicles and smart grid concept, motivation, objectives of the thesis and organization of the thesis. Chapter two gives the concepts necessary for successful and smooth integration of electric vehicles into smart grid. It also explains the challenges associated to the integration of EVs into smart grid.

Chapter three presents the description of the standards needed for electric vehicle charging and its integration into smart grid. The details of IEC 61850 standard and the concept to use electric vehicle as distributed energy resources is covered in chapter four. Chapter five describes all protocols that are mainly involved in the V2G (Vehicle-to-Grid) communication. The simulation of the electric vehicle charging process, control and monitoring is presented in chapter six. The conclusions of this thesis and some directions to the future work are discussed in chapter seven.

# 2. ELECTRIC VEHICLES CHARGING AND DISCHARGING

EVs charging and discharging technology is referred as Vehicle-to-Grid technology. V2G technology can be defined as the system in which there is capability of controllable, bi-directional electrical energy flow between a vehicle and the electric grid (Briones, Francfort, Heilmann, Schey, Schey, & Smart 2012). The electrical energy can flow from the grid to the vehicle so that to charge the battery (EV charging). Also, the energy stored in the battery can be fed to the grid (EV discharging) when the grid requires energy, for example, when the demand of the energy is higher than the energy generated. Basically, EVs can be charged during off-peak hours (storing surplus electricity generated during that time) and discharged during peak-hours (feeding the stored electricity back into the grid to meet the current high demand). “It is also possible to pool several EVs together and provide large support to the grid where owners can obtain incentive costs (Ustun, Ozansoy, & Zayegh 2013)”. However, standardization, communication and synchronization among smart-grids entities are inevitable for achieving all of these advantages. V2G technology makes EVs act as Distributed Energy Resources (see chapter four for more details).

## 2.1. Charging Infrastructure concept

The charging infrastructure is one of the important components for the integration of the electric vehicle into smart grid. It makes the interface between electric vehicle and smart grid. For the mass market and adaptation of electric vehicle, the charging of the electric vehicle has to be automated and the charging infrastructure has to be provided with functionalities that enables a harmonized integration of renewable energy.

*Charging modes:* On January 19$^{th}$ 2011, a committee of industry associations, automotive manufacturers, electric equipment suppliers and utilities held a meeting in Washington DC and approved the IEC’s proposed international charging modes and plugs for EVs charging (PowerUP 2012). The IEC 61851-1 Standard identifies four modes for Alternating Current (AC) and Direct Current (DC) conductive charging.

***Mode1**:* This is the connection of the EV to the AC power supply through a single phase or three phase AC connection of not more than 250V (single phase) and 480V (three phase) at the range of frequency 50-60Hz. It uses the standard 16A socket outlet with a protective earth conductor. This mode mainly focuses on slow charging from standard household-type socket outlet. Therefore, it cause low load on the grid and it is more economical since the charging is done during night when electricity is usually less expensive.

***Mode 2:*** This is the connection of the electric vehicle to the AC power supply with the same voltage limits as for Mode 1. It uses the standard 16 A or 32 A socket outlet on the charging infrastructure side, but on the electric vehicle side it uses the specific plug. The cable on the infrastructure side consists of the protection device that ensures the proactive current-leakage detection through a pilot wire.

***Mode 3:*** This is the connection of EV to the AC power supply using a dedicated Electric Vehicle Supply Equipment (EVSE). In this mode of charging the EVSE manages the pilot wire which controls the charging sessions. The charging power is allowed to flow over the charging cable if and only if the EV is detected by the pilot wire and the absence of current leaks or ground defects has been verified. It is also referred as normal for the charging level of 16 A, semi-fast for the charging level of 32 A, and fast for the charging level greater than 32 A. Mode 3 is safer than Mode 1 and Mode 2, because the plug is energized only if all of the conditions are met: (Veneri, Ferraro, Capasso, & Iannuzzi 2012.)

- The power plug of the vehicle is completely inserted (the pilot pin is the last to connect)
- Ground continuity has been checked

- The vehicle has confirmed that everything is secured and charging is ready to begin.

***Mode 4:*** This mode of charging has been implemented by CHAdeMO consortium and it focuses on DC based fast charging using off-board chargers. The AC power supply is converted to DC in the charging post before is being transferred to the vehicle. Basically Mode 4 provides an optimal charging time which range from 20 to 30 minutes. This charging time is influenced by the capability of CHAdeMO charger that allows the current of 125 A and voltage of 500 V. Battery technologies have been advancing in the recent years. Therefore, using the latest battery technologies together with high power converter, this mode of charging could allow a recharge from 0 to 80% of battery State of Charge (SOC) in less than 5 minutes (Veneri et al. 2012:1-6). **Figure 1** shows a simplified scheme of the four charging modes.

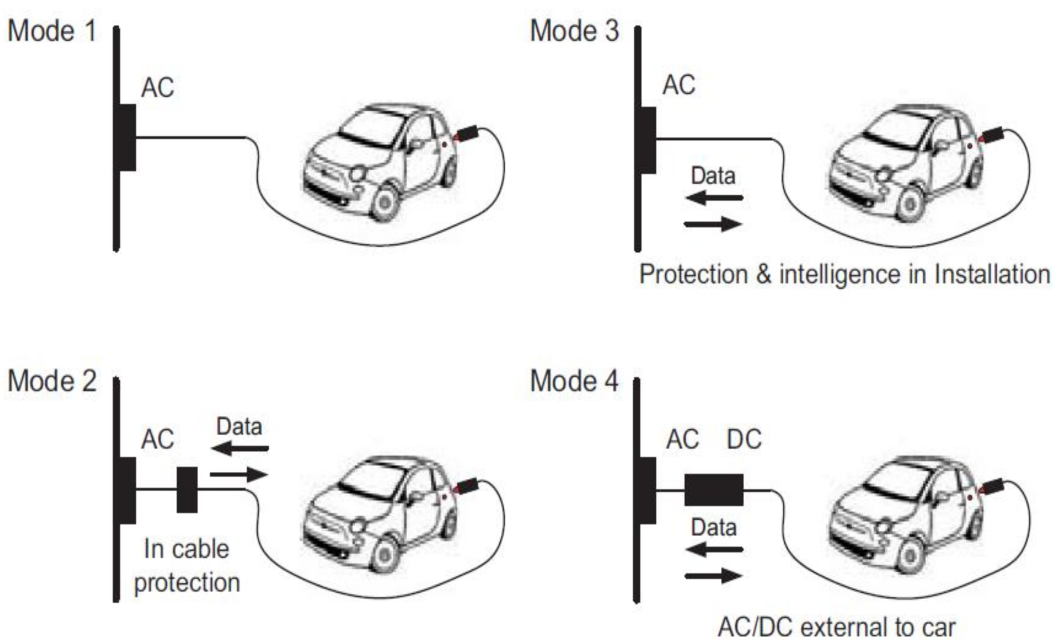


**Figure 1.** IEC 61851-1 Charging Modes (Veneri et al. 2012:1-6).

**Table 1** Analyzes the major characteristics of the charging mode according to the standard IEC 61851-1d (Veneri et al. 2012:1-6).

| **Charging Mode** | **Max Current per phase** | **Charging Time** | **Vehicle Battery Charging** |
|---|---|---|---|
| Mode 1 | 16 A | 4 ÷8 h | On Board |
| Mode 2 | 32 A | 2 ÷4 h | On Board |
| Mode 3 | 63 A | 1 ÷2 h | On Board |
| Mode 4 | 400 A DC | 5 ÷30 min | Off Board |

## 2.2. Electric Vehicles Charging Process

The charging process of electric vehicle involves the exchange of multitude of information between the electric vehicle and the charging infrastructure. This section describes the charging process between Electric Vehicle and Electric vehicle Supply Equipment according to the ISO/IEC 15118-2 standard, and only message patterns which are directly related to the charging process are briefly explained. **Figure 2** gives an overview of those defined messages in a sequence diagram.

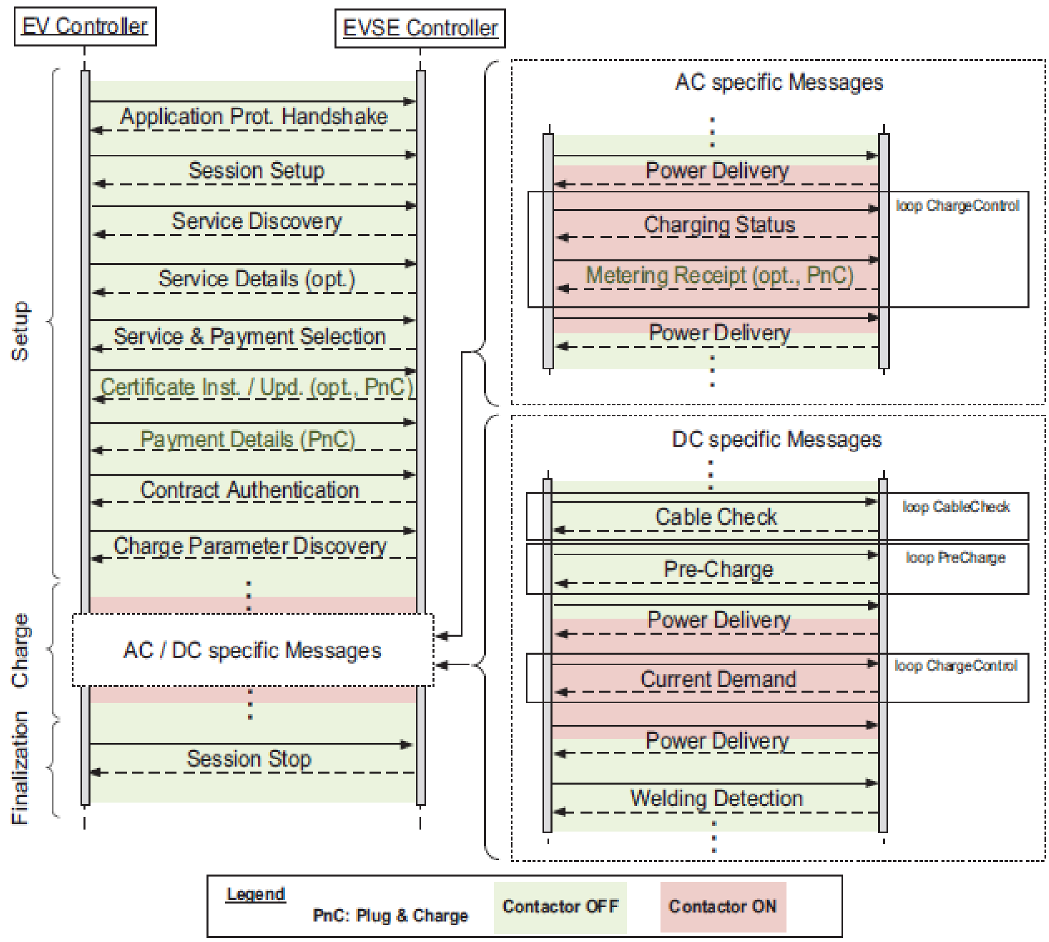


**Figure 2.** ISO/IEC 15118-2 V2G Message Flow (Schmutzler, Andersen, & Wietfeld 2013).

***Session setup:*** When an electric vehicle is plugged in, the Electric Vehicle Communication Controller (EVCC) sends a session setup request to the Supply Equipment Communication Controller (SECC) to establish a V2G communication session, and then the SECC responds to the request by using session setup response. The V2G Communication Session is identified by the Session id and all V2G messages carry a session id that is used to manage the V2G Communication Sessions between

V2G entities on application level. The Session Id also enables pausing and resuming of a charging session using multiple V2G Communication Sessions.

***Service Discovery***: The first message an EV sends to the EVSE after session setup is for the discovery of all services provided by the SECC (i.e. charging service, and the future value added services which are already considered in the standardization). The services are characterized by parameters which allow the EVCC (based on profile information) to select an appropriate service for charging. If the service discovery is successful, the SECC respond with the list of all available services for the defined criteria.

***Authorization*****:** If an EV has selected a service from an EVSE an authorization request is established by providing, among others, security and status information. In return the SECC notifies the EVCC about the success of the authorization.

***Charge Parameter Discovery*****:** After a successful authorization for charging at EVSE, the EV transfers its charging parameters (i.e. estimated energy amounts for recharging the vehicle, capability of the EV charging system, and the point in time the vehicle user intend to leave the charging post) and payment information to the EVSE. The corresponding response contains information about the result of the power discovery request, the charging parameters of the EVSE, proposed charging schedule and a pricing table.

***Line Lock***: This message pattern is used to lock the connector on the EVSE side in order to prevent unintentional removal.

***Power Delivery*****:** The EV is now able to request from the EVSE the switching of power and confirms the charging profile it will follow during the charging process. With this request the EV also accepts the pricing conditions which have been transmitted in the power discovery response.

***Metering Status and Metering Receipt***: During the charging process, periodically and in alternating order the metering status and metering receipt is requested or sent respectively. The periodical metering status exchange is used to check the proper operation of the charging process on both sides.

***Power Off*****:** The power off message by the EV requests to stop the power supply on the EVSE side which will be confirmed by the response message.

***Line Unlock*****:** This message pattern is used to unlock the connector on the EVSE side. A successful response would allow the driver to unplug its EV from the EVSE.

## 2.3. Vehicle-to-Grid Services

Frequency regulation and spinning reserves (addition unit that can deliver power quickly, upon request from the grid operator) are the form of electric power exchange called ***ancillary services***. These services are favorable market for the V2G due to the fact that, EVs are only in use for about 4% of the day time and being parked for about 96%. Therefore EVs owners get a significant benefit because they are paid for the availability of their vehicles to the grid even if they do not supply power to the grid (Kempton & Tomić 2005). Also the fast charging and discharging rate of the battery makes V2G a promising alternative for frequency control of the grid (Su 2013).

## 2.4. Factors Influencing Smart Integration of Electric Vehicles

An integration of electric vehicle into smart grid has to be done in a smart way to avoid negative effects which may arise (i.e. grid load level effect) when the fleets of vehicles connect to the grid. The availability of electric vehicle for smart integration is determined by existing infrastructure, electric vehicle user's motivation to initiate intelligent charging processes, and skills to accurately predict their upcoming departure times and trip lengths. These factors are illustrated in **Figure 3**.

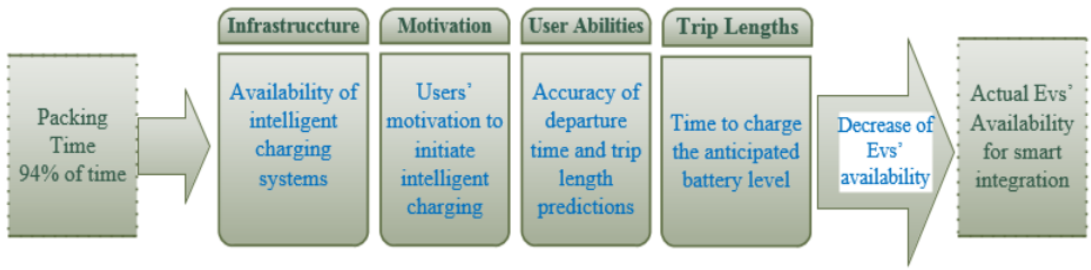


**Figure 3.** Factors influencing EVs availability for smart charging processes.

**Driver's motivation to initiate intelligent charging:** The motivation of electric vehicle user to initiate intelligent charging plays a great role in smart integration of EVs, therefore the driver has to make sure that the vehicles are constantly connected to the grid so that to maximize the time interval for charging and discharging. It is also important that the infrastructure insure that the driver have the possibility of initiating intelligent charging process. Drivers do not regularly initiate intelligent charging especially when they do not get any financial reward for intelligent charging; this is according to the research projects which were conducted to investigate motivational aspects (Stillahn, Erge, Hahnel, Vet, & Andersen).

**Accuracy of driver's mobility predictions:** The ability of the drivers to predict their next departure time and trip length is another essential factor that influences the availability of electric vehicle for smart integration. In most cases drivers are required to predict their upcoming departure time when they are willing to initiate intelligent charging. Inaccurate prediction may lead to insufficient battery levels, for example, predicting departure time as being later or trip length as being shorter than they actually are. On the other hand predicting departure time as being earlier or trip length as being longer than they actually are, reduces the availability of the electric vehicle for smart integration (Stillahn et al.).

The factors influencing EV smart charging are connected to each other. For example, for the EV driver to initiate intelligent charging there should be an intelligent infrastructure to support such intelligent charging. As already described, intelligent charging requires a driver to predict the departure time as well as the upcoming trip length. Then, if the prediction is inaccurate there might be insufficient battery levels when conducting the upcoming trip.

## 2.5. Technical Challenges to integrate Electric Vehicles into Smart Grid

Although V2G is a promising technology, there are several issues that might delay its actual implementation in a short run: the required two-way communication enabled system infrastructure and battery technology. The two-way power flow control is the key enabling technology for the V2G to become true. A reliable two-way communication network is highly required to enable V2G technology. The battery technology seems to be another factor hindering V2G from becoming a reality. The charging and discharging of the battery has a huge impact on the battery life, therefore it is very crucial to improve the life cycle of the batteries.

### 2.5.1. Communication Needs

As mentioned earlier, the deployment of electric vehicles in a large-scale seems to be one of the feasible solutions to relieve energy crisis, global warming and geopolitical relevant outcomes that arise due to the environmental pollution. However, uncontrolled charging of electric vehicles will cause a significant impact on the power grid operations and planning. Therefore, a reliable communication network is required in order to integrate a larger number of electric vehicles into smart grid successfully.

For the purpose of making utility customer rates or programs available specifically for customers with EVS, the utility must provide special services for these customers. These services are: possibility to enroll, to register, and initially setup communications between electric vehicle and utility; to provide electric vehicle charging status information to customer; to repeatedly re-establish communications for each electric vehicle; and correctly bill the electric vehicle customers for the services used (Su 2013). It is good to mention that every electric vehicle driver would likely prefer to avoid a long delay once the vehicle is plugged in for charging. Therefore, a sufficient bandwidth is required to ensure a reliable real-time communication between electric vehicle and the utility. According to Andras, Dave, Robert, & Raduz (2013) when a HomePlug GreenPhy (HPGP) is used with default settings, it imposes a delay issue of link establishment. It takes up to 30 seconds to establish the HPGP link after the electric vehicle is plugged-in, which seems to be too slow for some applications such as public transport charging.

Another issue arises when using some communication protocols such as Simple Object Access Protocol (SOAP) over Hypertext Transfer Protocol (HTTP). SOAP-Over-HTTP leads to huge message overheads, which seems to be an issue especially for wireless communication links like cellular radio access. This problem become more serious in large scale charging infrastructure and might cause extra expensive maintenance cost for operators (Schmutzler et al. 2013: 1-12).

### 2.5.2. Security Issues

Security issues must be consideration whenever different wireless communication technologies are involved. It is important to insure that wireless billing is done in a secure manner. Also the actual location of the vehicle must be kept confidential for the user privacy (Su 2013). The risk for an unauthorized transaction by a third part is another security problem. Therefore, it is import to insure security in the communication network at public charging facilities for electric vehicles.

***Vulnerabilities analysis*****:** in traditional power grid, wired communications have been used to provide reliable monitoring and control. However, in wireless networks the case is different since the data transmission is inherently public, which imposes a unique security threat at a physical layer (Su 2013).

***Client privacy:*** Electric Vehicle charging involves the exchange of multitude information between the vehicle and the charging infrastructure. Basically the vehicle provides information such as location, identity, usage patterns; payment information which have to be processed by the charging station (Su 2013). Therefore, the way clients' personal information is handled matters as far as privacy concern. For example, the EV charging reveals the vehicle location as well as distance travelled.

***Detection:*** Intrusion detection is the vital aspect in the electric vehicle charging scenarios. Therefore, it is important that the charging facilities are able to detect the attempt of any attacker aiming to get access to the communication network to possibly perform malicious actions such as unauthorized transactions. Macia, Mora, Marcos, Gil-Martinez, Ramos, & Lorenzo (2011) Carcano, Coletta, Guglielmi, Masera, Nai Foviano, & Trombetta (2011) has well studied the intrusion detection for smart grid communication, which rely on the Cyber Security field of Supervisory Control and Dada Acquisitions (SCADA) and power systems.

## 3. STANDARDIZATION OF THE E-MOBILITY V2G INTERFACE

The scalability and heterogeneous nature of the underlying systems in electric mobility and smart grids makes it necessary to have a common ground in the standards so that independently developed systems from different vendors can interoperate with each other. Therefore, standardization is the key aspect for the mass-market acceptance of electric vehicle and the integration of electric vehicle into smart grid (Schmutzler, Wietfied, & Andersen 2012). The resulting standards can be categorized based on plugs, charging topology, communication, security and safety as illustrated in **Figure 4** below.

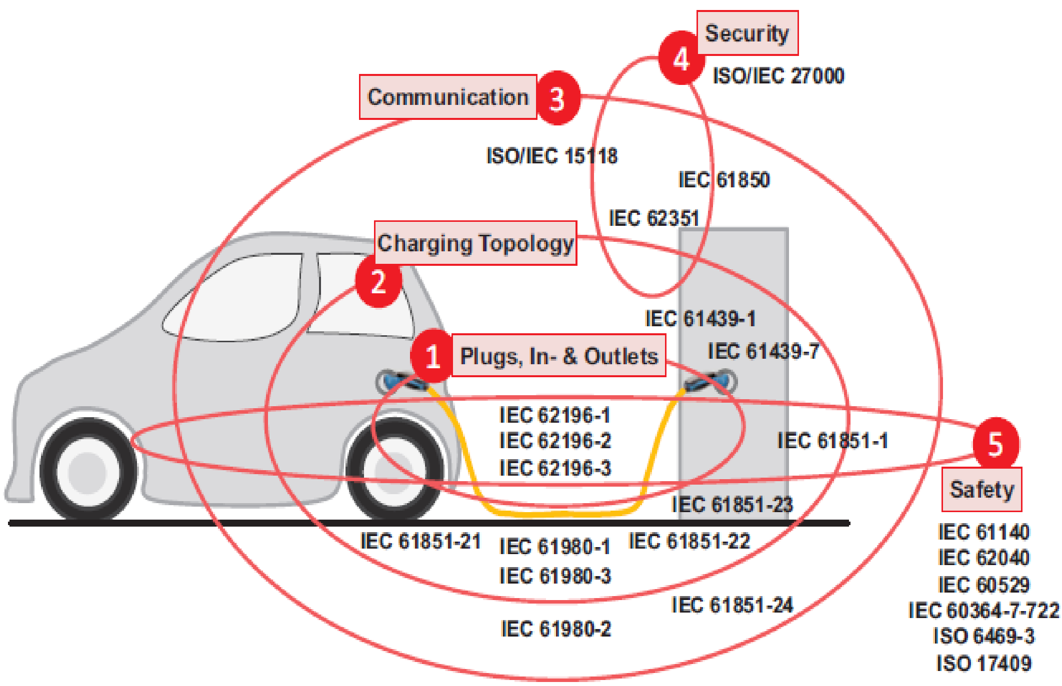


**Figure 4.** Digest of main ISO/IEC standards for the scope of the E-Mobility V2G Interface (IEC 61850-90-8 TR 2015).

### 3.1. Inlet and Outlet Plugs

IEC 62196 standard comprises three parts. The first part covers the electrical, mechanical and performance requirements for dedicated plugs, socket outlets, vehicle connectors and vehicle inlets for interfacing between charging equipment and electric vehicle. Part 2 defines the interchangeability requirements and the dimensional compatibility for the AC plugs. The standards describes three different types of physical connectors, type 1 for single phase vehicle coupler (vehicle connector and inlet) with 5 pins, a charging voltage up to 250 V and charging current up to 32 A and it can supply a full charge of up to 7 kW in 4 to 6 hours. Type 2 is originally proposed by Mennekes. It supports single and three phase charging with a charging voltage up to 500 V and a charging current up to 63 A. Type 3 supports single and three phase vehicle coupler and mains plug and socket outlet with shutters. **Figure 5** illustrates type 1, type 2 and type 3 connectors for AC charging. The third part of the standard defines dimensional compatibility and interchangeability requirements for DC plugs (in- & outlets) and Combo Plugs (combined AC & DC plugs and in- & outlets). (Schmutzler et al. 2013: 1-12)

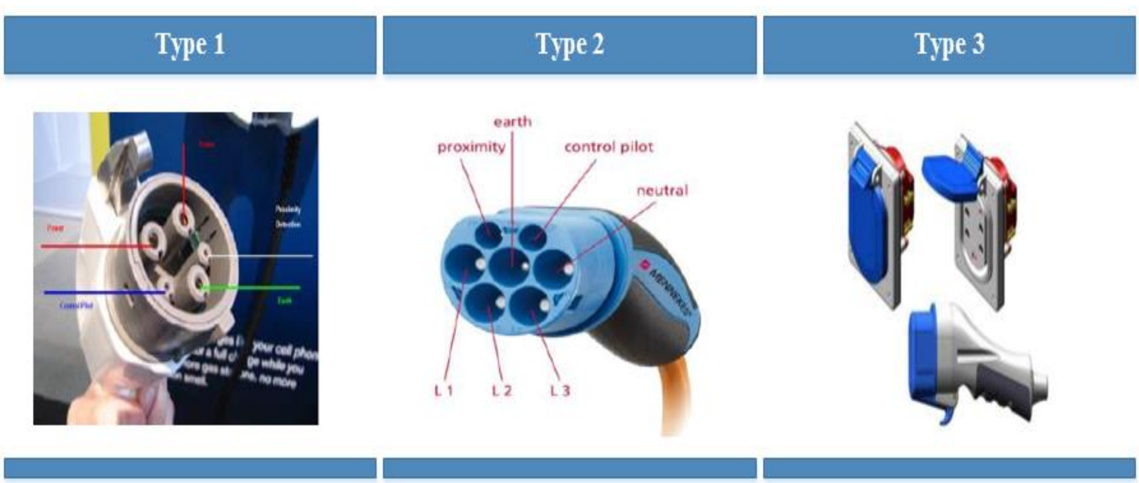


**Figure 5.** Type 1 (left), type 2 (centre), and type 3 (right) connectors.

3.2. Charging Topologies

The standardization of electric vehicle conductive charging system based on either AC or DC needs to take into account different charging topologies. The IEC 61851 standards series define such electric vehicle charging system. IEC 61851-1 specifically defines a safety-related low level signaling process between electric vehicle and charge spots based on a *Pulse Width Modulation (PWM)* signal. The PWM is applied to the *control pilot* pin and is characterized by two parameters: The first parameter is the positive voltage level of the PWM signal which indicates the connection state of an EV, whereas the second parameter is the duty cycle of PWM which indicates the maximum current that the EV is allowed to draw from the EVSE. The duty cycle also provides communication means (Schmutzler et al. 2012). The PWM signal is illustrated in the **Figure 6**.

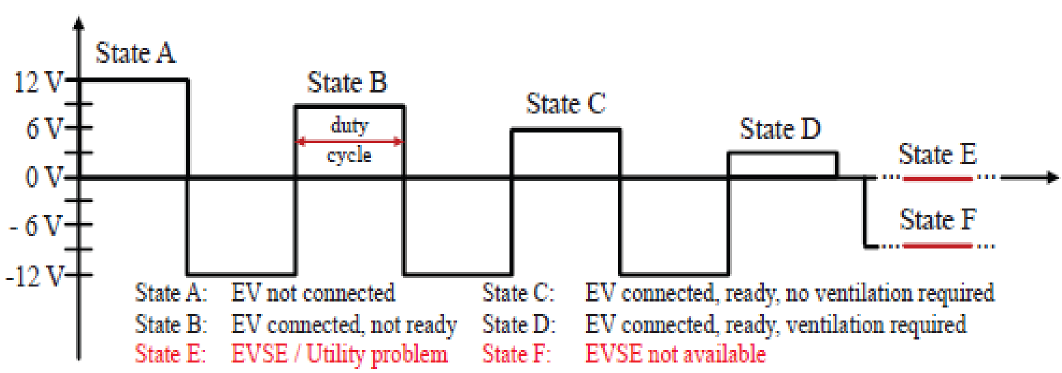


**Figure 6.** IEC 61851-1 Pulse Width Modulation Signal (Lewandowski, Böcker, & Wietfeld. 2013).

The technical requirements for EVs connected to AC or DC EVSEs are defined in IEC 61851-21. It comprises two sub-parts which detail the EMC requirements of on-board (IEC 61851-21-1) or off-board (IEC 61851-21-2) charger. The specific requirements for

AC- or DC-based EVSEs are described in IEC 61851-22 and IEC 61851-23. IEC 61980-1 defines specific requirements for inductive charging equipment, where by the specific requirements on magnetic field power transfer systems are described in IEC 61980-3. Construction, verification requirements, general rules, service conditions and technical characteristics for low voltage switch- and control gear assemblies are detailed in IEC 61439-1. IEC 61439-7 give descriptions for dedicated charging equipment (Schmutzler et al. 2013: 1-12).

### 3.3. Communication

In 2009 the ISO/IEC 15118 Joint Working Group was formed to define the *Vehicle-to-Grid Communication Interface (V2G CI)*. Its aim is to define an International standard complementary to the base level signaling defined in IEC 61851-1 offering bi-directional digital communication based on Internet protocols. The standard covers information exchange between all entities involved in the electric vehicle charging process. It defines the entire protocol stack from the Application Layer to the Physical Layer according to the OSI-model of ISO/IEC 7498-1 as illustrated in **Figure 7**.

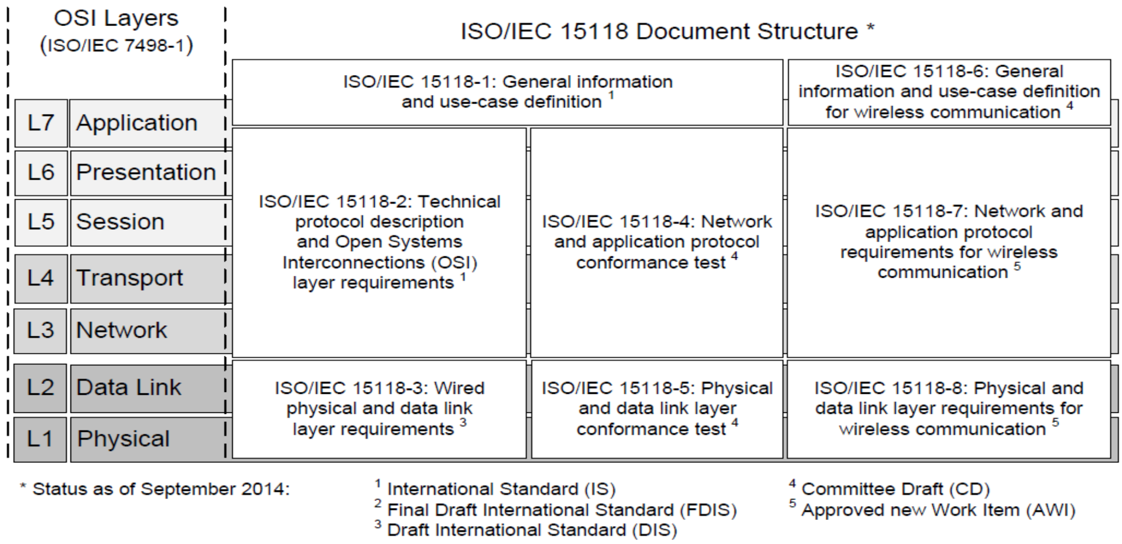


**Figure 7.** ISO 15118 document structure according to ISO/IEC 7498-1 OSI-layers (IEC 61850-90-8 TR 2015).

The standard ISO 15118 Vehicle to grid communication interface comprises the following parts:

- Part 1: General information and use case definition. This part defines all relevant terms for V2G Interface, definitions and use cases. Several use cases are described varying from immediate charging to delayed charging.
- Part 2: Technical protocol description and Open Systems Interconnections (OSI) layer requirements. This part defines the complete message flows between communication partners (Application Layer), the associated data and data types (Presentation Layer) via TCP/IP based Transport and Network Layer.
- Part 3: Wired physical and data link layer requirements. This part defines the physical and data link layer for which a Power Line Communication (PLC) technology is used that does not require any additional lines.
- Part 4: Network and application protocol conformance test. In 2012-06 this part was approved as new project.

- Part 5: physical and data link conformance test. This part of the standard was approved as new project in 2012-06.
- Part 6: General information and use-case definition for wireless communication. In 2013-01 this part of the standard was approved as new project.
- Part 7: Network and application protocol requirements for wireless communication. It was approved as new project in 2013-01.
- Part 8: Physical and data link layer requirements for wireless communication. This part of the standard was approved as new item in 2013-01. (IEC 61850-90-8 TR 2015)

IEC 61851-24 define the digital communication between a DC charging station and electric vehicle for the control of DC charging process. The standard 61980-2 defines the specific requirements for communication between electric vehicle and infrastructure regarding wireless power transfer (WPT) systems. However, it should be noted that, at the time being all works regarding wireless communication are still under standardization.

## 3.4. Security

Since the level of Machine-to-Machine (M2M) communication seems to be high in E-Mobility, it is very crucial to have information and communication security in smart charging of electric vehicles. Usually electric vehicles roam over several charging station and exchange some confidential information, therefore there is a necessity of addressing security issues. A Transport Layer Security (TLS) channel is established to ensure secure communication between EVCC and SECC, some end-to-end security requirements are addressed between the EVCC and secondary actors like charge spot operators and service provider.

To ensure security the message elements of ISO/IEC15118-2 are carried out through end-to-end security by XML security specifically by XML Signature and XML Encryption in the application layer. IEC 62351 covers a security issues for IEC 61850 by starting a security policies and procedures like *Role Based Access Control* (RBAC). Secure Socket Layer (SSL) or TLS with digital signature ensure the prevention of eavesdropping, playback and spoofing. ISO/IEC 27000 defines the scope of *Information Security Management System* (Schmutzler et al. 2013: 1-12).

## 3.5. Safety

In order to ensure protection of persons and animals against electric shocks, IEC 61140 defines fundament principles and requirements necessary for electrical installation, systems and equipment. IEC 60529 defines the degree of protection which is ensured by enclosures of electric equipment. Safety requirements for supply equipment of EV in low voltage electrical installations are described in IEC 60364-7-722. The standard IEC 62040 defines general and safety requirements for Uninterruptible Power Systems (UPS) with an electrical energy storage device in a DC link. The standard is related to movable UPS in low-voltage distribution system whereby the aim is to install them in any operator accessible area or in restricted access locations. It defines the requirements to ensure safety for the operator, service personnel and whoever comes into contact with the equipment. ISO 6469-3 defines safety specifications for EVs so that to ensure protection of persons inside and outside the vehicle against electric shocks. ISO 17409 defines safety requirements regarding the connection of an EV to an external electric power.

## 3.6. The SAE Standards

In North America, all PEVs manufactured must comply with the Society of Automotive Engineers (SAE) J1772 standard. The standard SAE J1772 gives the general requirements for EV conductive charge systems for use in North America, and it describes a common architecture for those systems, encompassing both operational requirements and the functional and dimensional requirements for the vehicle inlet and mating connector. Su, Wang and Hu (2015) give a summary of the vehicle-to-grid communication standard and the vehicle-to-grid energy transfer standard in North America, respectively.

It is important to note that the EVs' charging levels varies depending on location (e.g., Europe, North America, and Asia). For example, in Europe connectors must comply with the IEC 62196 standard. In early 2013, the European Commission announced that the 'Type 2' plug developed by the Germany Company Mennekes will be the common standard for EVs charging across European Union. The standard IEC 61851 has been adopted in China. However, there are slight differences in the technology used in these standards. For example, the IEC standard refers to "modes" or "types" while the SEA standard refers to "levels", but they are virtually the same (Su 2013).

# 4. ELECTRIC VEHICLES AS DISTRIBUTED ENERGY RESOURCES

The IEC Technical Report 61850-90-8 defines the relatively important information and proposes an object model for E-Mobility so that to establish an EV plugged into the electric grid as Distributed Energy resources (DER) according to the IEC 61850-7-420 paradigms. However, at the moment EVs are not yet considered in IEC 61850-7-420 as Distributed Energy Resources. Although they could be used as storage of energy generated from volatile energy generators such as wind power plants or Photovoltaic (PV) plants.

## 4.1. IEC 61850 Standard Overview

IEC 61850 is an International standard for substation automation that has been defined by the IEC Technical Committee 57-Architecture for Electrical Power Systems (Binding,Gantenbein, Jansen, Sundström, Bach, Marra, Poulsen & Træholt 2010). It is a core standard for the future Smart Grid deployment. Initially, IEC 61850 targeted at internal substation automation. However, the scope of IEC 61850 was continuously extended integrating several types of *Intelligent Electronic Devices* (IEDs) in energy distribution process, especially Distributed Energy Resources (Schmutzler et al. 2013: 1-12). The current most outstanding standard for various types of DERs is IEC 61850-7-420. **Figure 8** (marked in red) gives an overview on how IEC 61850-7-420 is integrated into IEC 61850 standard series. Mackiewicz (2006) provides a general introduction to the concepts of IEC 61850.

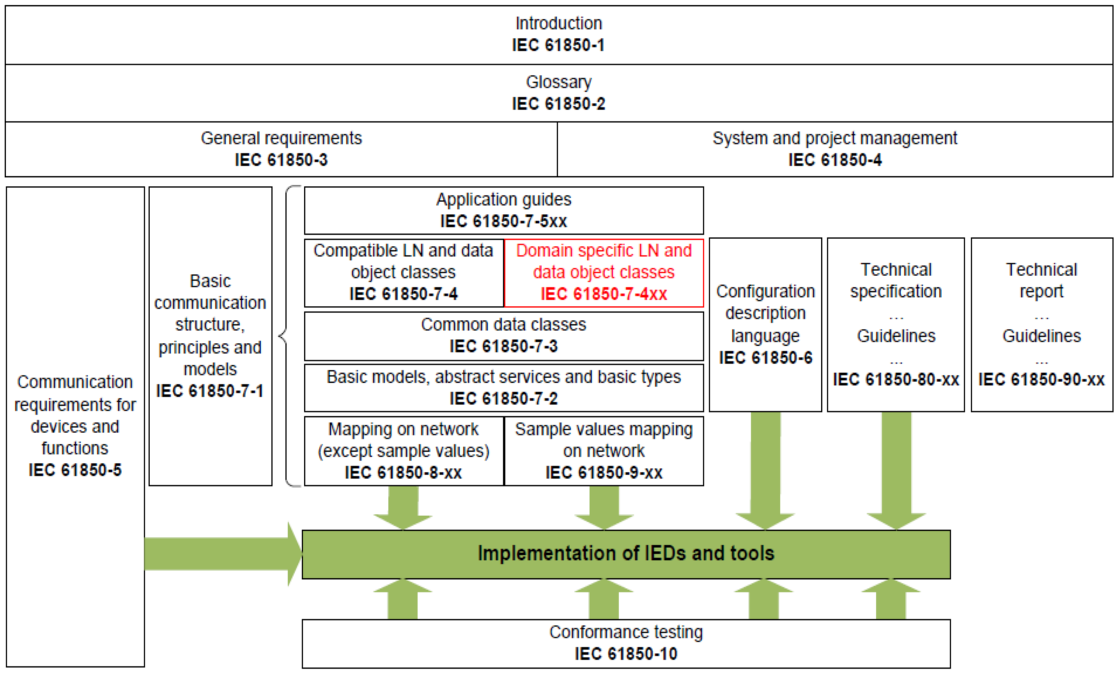


**Figure 8.** Overview and structure of the IEC 61850 standards series (IEC 61850-90-8 TR 2015).

IEC 61850-7-420 is referred as "Basic Communication Structure-Distributed energy resources logical nodes" (IEC 61850-90-8 TR 2015) and it extends the generally described Logical Nodes (LNs) of IEC 61850 for substation automation towards DER specific Logical Nodes. IEC 61850-7-420 describes the IEC 61850 information model for the information exchange among distributed energy resources. It consist distributed generating units and storage devices, including reciprocating engines, fuel cells, micro turbines, PV, combined heat and power unit as well as energy storage. IEC 61850-7-420 re-uses existing logical nodes of IEC 61850-7-4 as much as possible and defines new DER specific logical nodes when necessary. Up to the moment, EVs are not considered as DERs in any IEC standards. However, EVs could be used to store energy generated from volatile energy sources such as wind power plants or PV plants (Schmutzler et al. 2012). **Figure 9** illustrates the organization of various types of DER systems according to the IEC 61850-7-420 paradigms.

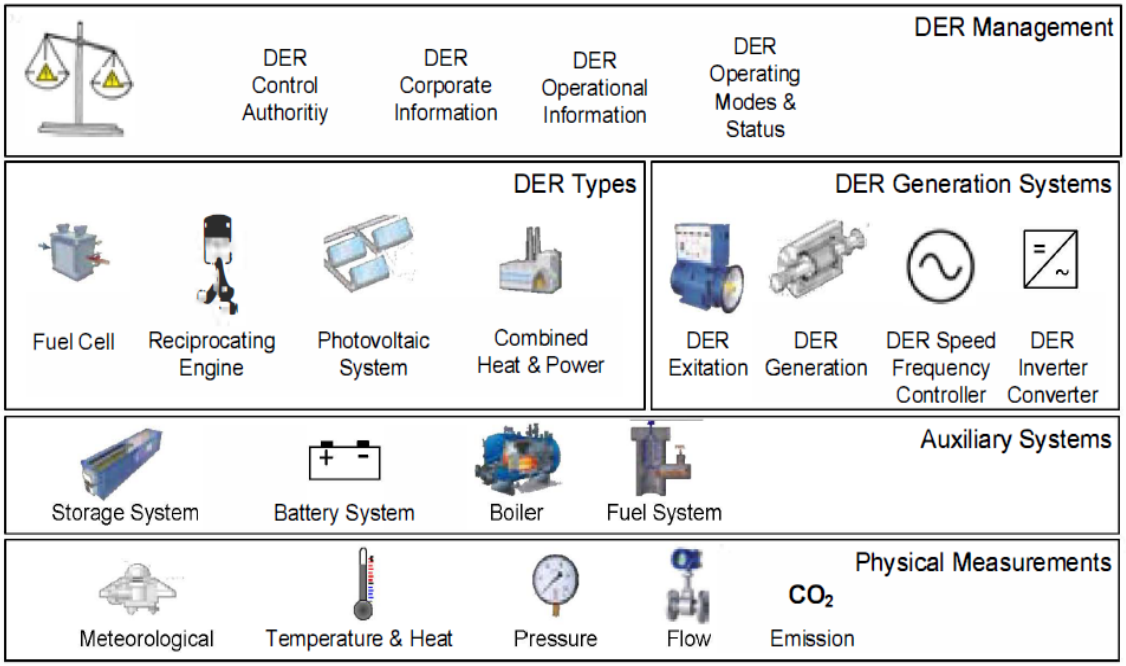


**Figure 9.** Overview of DERs defined in IEC 61850-7-420 (Schmutzler et al. 2012).

## 4.2. Technical Principles of IEC 61850

### 4.2.1. IEC 61850 Model

Smart grid infrastructure consist smart devices from different vendors. The applications which are used to read data from smart devices are vendor specific. Therefore, this rises an issue how to integrate and interoperate the applications and devices at the station level. It is also likely that the advanced devices purchased by one vendor do not necessarily operate with another vendor application due to differences in communication protocols. Hence, interoperability problem becomes a crucial aspect to be resolved in smart grid. The IEC 61850 is the promising standard that resolves these interoperability issues among IEDs/devices within the system (Thomas, Ali, & Gupta 2015).

The IEC 61850 model uses the concept of virtualization. It virtualizes the physical devices in smart grid as Logical Nodes. According to IEC 61850 specifications, the application functions are split into smallest entities called Logical Nodes. These LNs are used to exchange information. The virtual concept used by IEC 61850 specification to model the common information obtained in real devices is illustrated in **Figure 10**.

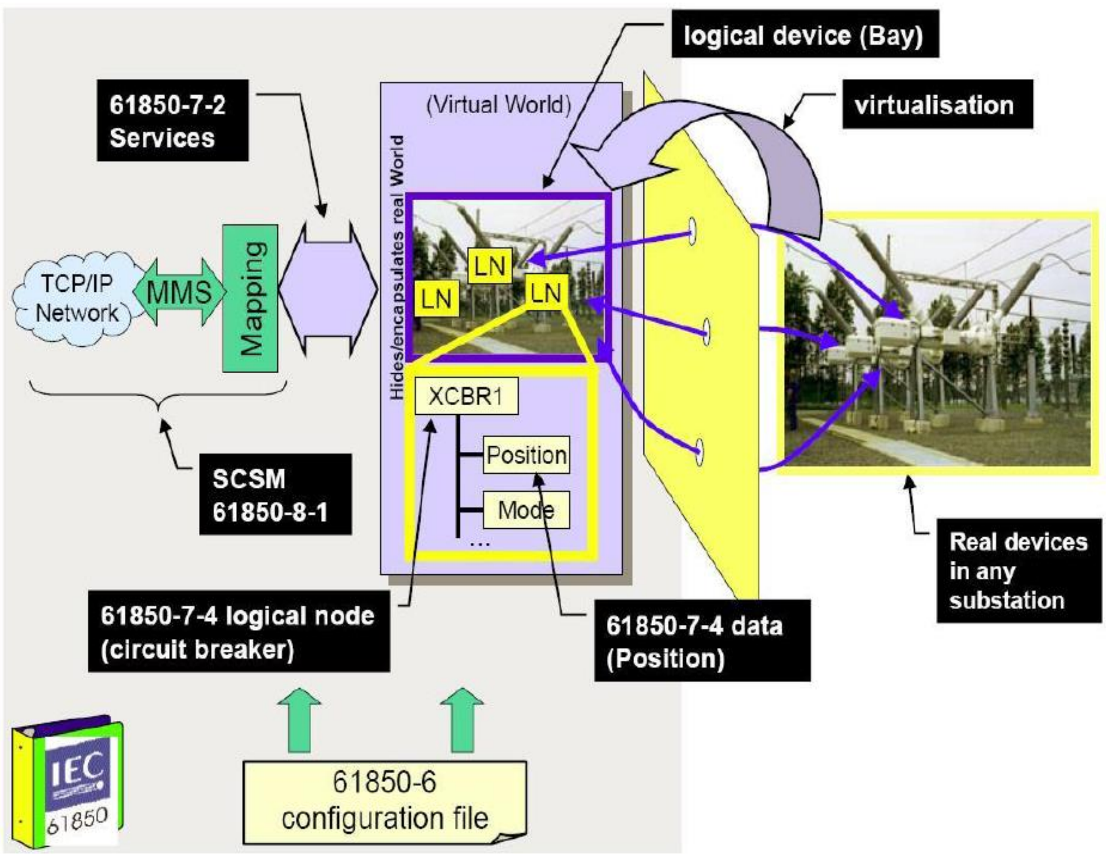


**Figure 10.** IEC Virtual world against real world (IEC 61850-7-1 2003).

IEC 61850 uses a hierarchical model as depicted in **Figure 11**. The model is composed of the server which provides a communication access to a given component in the power grid. The Internet Protocol (IP) address and the port number must be specified for the server. A server consist one or more Logical Devices (LDs), which represent a logical view of IED components.

A Logical device is composed of set of Logical Nodes, which describes the functionality of the logical device. Each Logical Node contains a set of data objects and data attributes. “The data model and services with their associated information are mapped to a network communication protocol, such as Manufacturing Messaging Specifications (MMS), transport control protocol TCP/IP, Ethernet, etc. (Mekkanen 2015)”. The LN is the key element of the information model because through it, the interoperability between different IEDs is achieved.

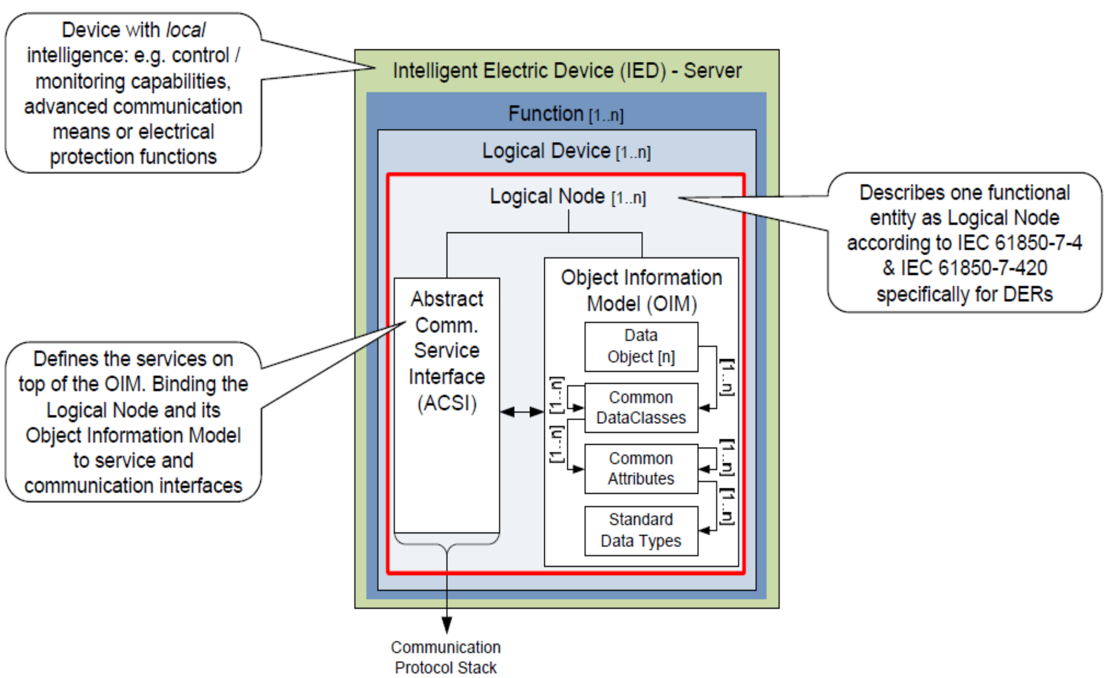


**Figure 11.** Modeling of IEDs in IEC 61850 (Schmutzler et al. 2013: 1-12).

### 4.2.2. Manufacturing Messaging Specifications

Manufacturing Messaging Specifications is an application layer protocol which is used for exchanging real-time data and monitoring of control information between IEDs and computer applications. The MMS possess two features which make it an outstanding component of IEC 61850 as it rely on virtualization concept. The first feature is interoperability, which enables the exchange of real-time information among different IEDs and Network application. Second feature is the independence, through which the interoperability becomes independent of the developer application, connectivity, and the function that is executed. The generic nature of the MMS makes it suitable for different types of devices, applications and industries.

The Virtual Manufacturing Device (VMD) is the key element of the MMS services. The major role of VMD is to define three things: First, it defines the MMS objects which are the variables in the server. Through these objects, it is possible to access operations, control, and other parameters defined in a real device. Second, it describes how the server behaves upon receiving service request from the client. Third, it defines the services (such as read, write, start, stop, etc.) that a client devices or application can use to access status information or to manipulate the objects in the physical IED (Tomas et al. 2015). **Figure 12** illustrates how the real data and devices are represented from client point of view by the VMD.

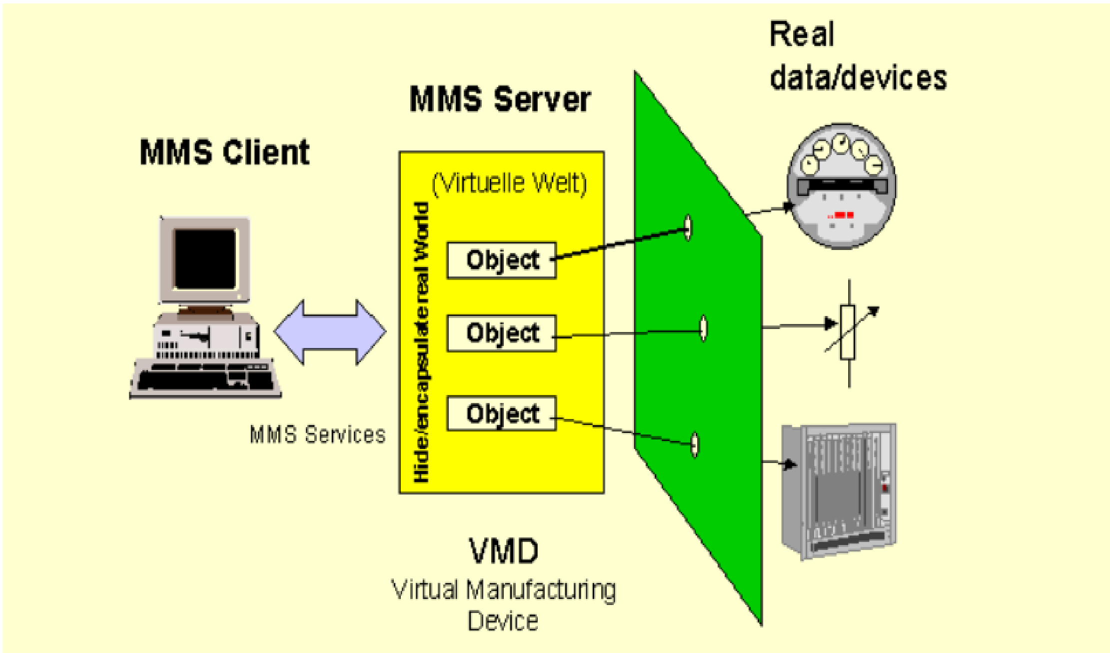


**Figure 12.** Virtual Manufacturing Device Architecture (NettedAutomation 2002).

4.3. Distributed Energy Resource Model for Electric Vehicles

In order to integrate electric vehicle into smart grid successfully, an adequate information model for EVs must be defined. The common information model for a given type of DERs for grid operation and automation defined in IEC 61850-7-420 seems to be adequate for EVs. According to the existing standards for connected EVs, a multitude of control and monitoring information is exchanged between technical components being involved in the charging process in order to ensure an automated and safe charging process. However, for the successful integration of EVs as DERs into the grid, only a subset of these information is required and must be sorted out.

The modeling approach adheres to IEC 61850-7-420 paradigms. An overview which entities are involved in the information provisioning process is illustrated in **Figure 13**. It shows what information originates from which entity and how this information is finally mapped to the proposed DER model for EVs (Schmutzler et al. 2012).

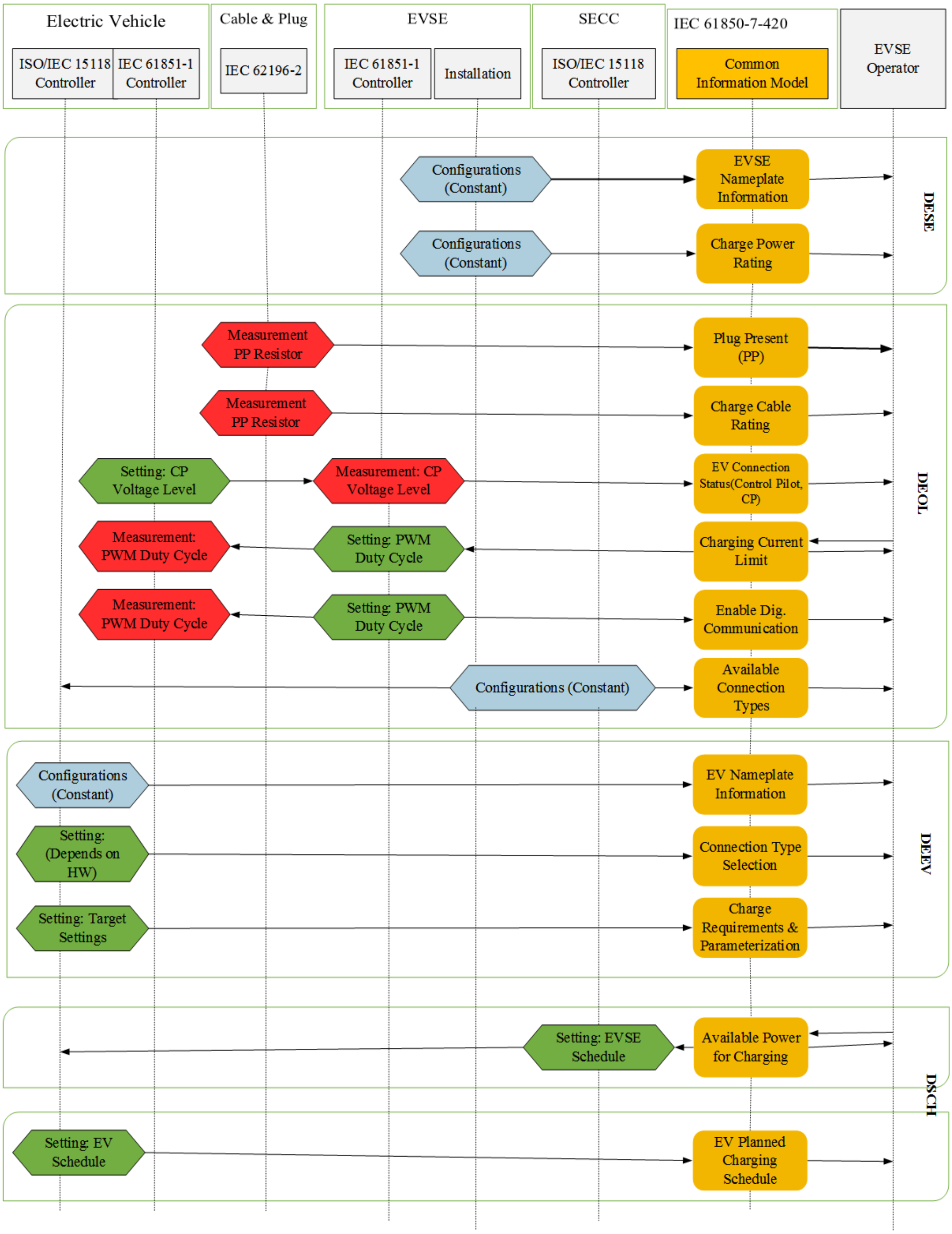


**Figure 13.** Mapping of Information Sources for EV Charging Process to DER Information Model (Schmutzler et al. 2012).

Different shapes and colours are used to describe the information in the model. There are three types of information which are described by the diamond shaped elements in the diagram (Schmutzler et al. 2012):

- ✓ Configurations (blue) describe persistent information of an entity mostly depending on hardware installation and therefore do not change over time.
- ✓ Settings (green) describe dynamic information of an entity which may change over time
- ✓ Measurements (red) are retrieved at the respective entity and also represent dynamic information

The actual information being provided by the respective entities is shown in **Figure 13** in the common information model column (orange) and is mapped to three newly defined LNs for electric mobility (Schmutzler et al. 2012):

1) DESE: This logical node represents an EVSE which may house several outlets and contains information related to monitoring and controlling of the EVSE.
2) DEOL: This logical node represents an individual EVSE outlet and contains information related to monitoring and controlling of the outlet.
3) DEEV: This logical node represents a connected EV and contains information on an EV connected to an EVSE. If the connection/plug status indicates that no EV is connected the data in DEEV is to be considered invalid.

The DSCH LNs in **Figure 13** are re-used from IEC 61850-7-420 and cover the two way charge schedule negotiation handshake of ISO/IEC 15118. In addition and as shown in **Figure14**, a charging infrastructure operator may include further LNs known from IEC 61850-7-2, -7-4, -7-420 or others in order to represent his infrastructure setup according to his own requirements (Schmutzler et al. 2012).

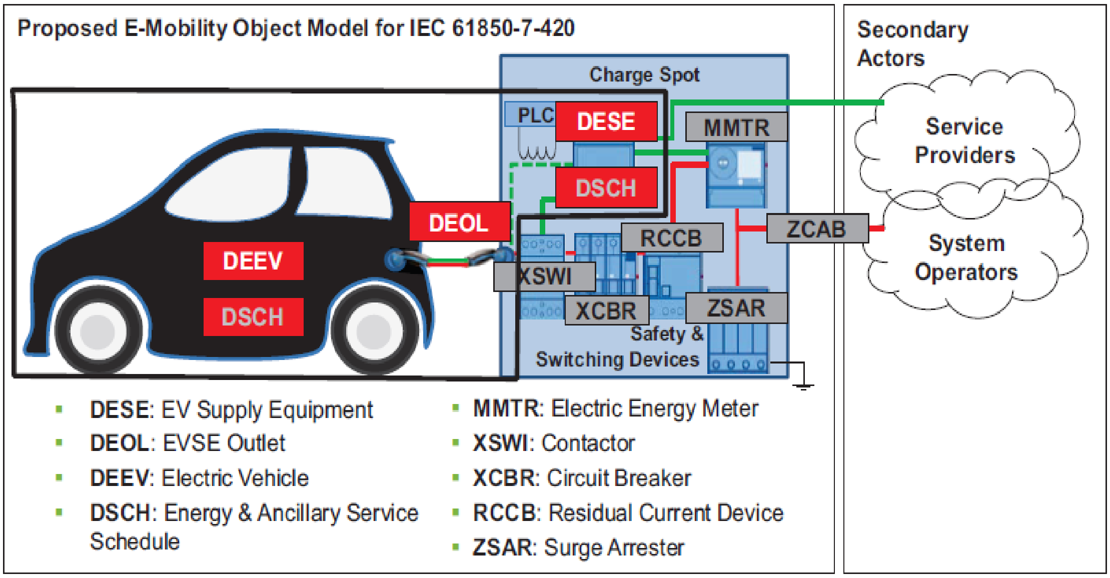


**Figure 14.** AC-Charging Deployment Scenario of the E-Mobility Object Model (Schmutzler et al. 2013: 1-12).

4.4. Distributed Energy Resource Model mapped to typical Charging Infrastructure

According to the proposed model, it is clear that connected EVs can be represented as DERs in IEC 61850. Since electric vehicle batteries have limited capacity and charging rates, it is important to see how the proposed model can support fast charging spots or grouped charge spot installations serving fleets of electric vehicles (Schmutzler et al. 2012). A summary of how a physical charging setup can be modeled as IEC 61850 compliant *Logical Device* and *Logical Node* configurations, resulting in a DER data representation of a plugged in EV is shown in **Figure 15**.

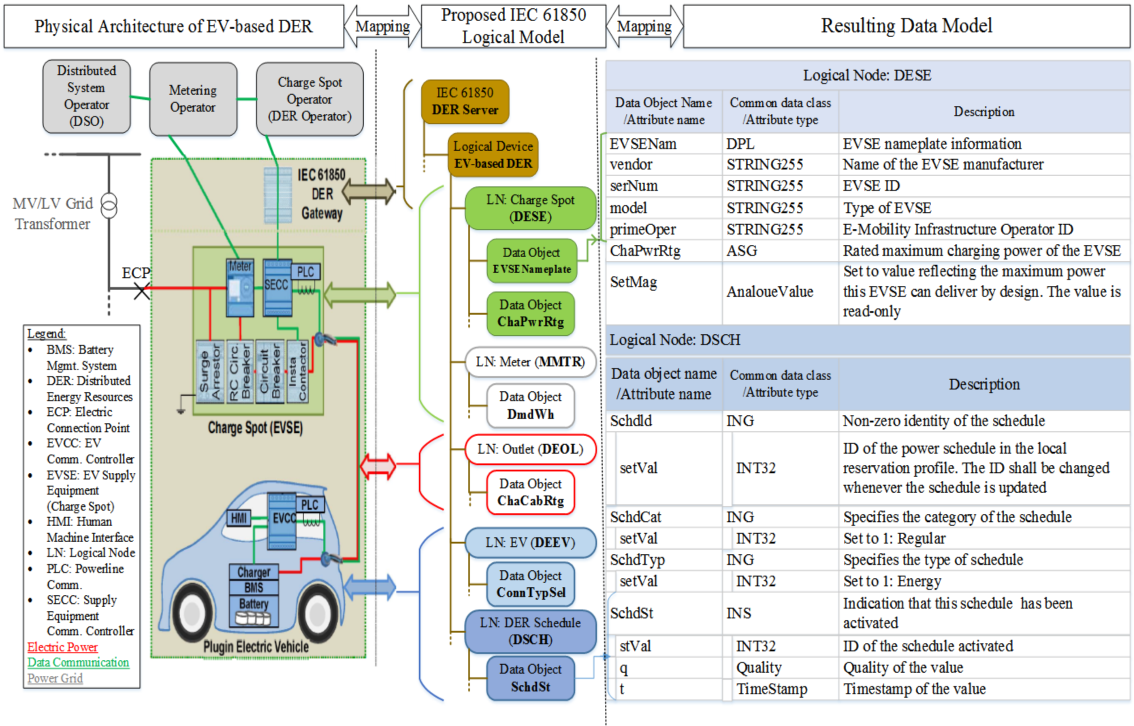


**Figure 15.** From Physical Charging Infrastructure to IEC 61850-7-420-based DER Model (Schmutzler et al. 2012).

## 5. VEHICLE TO GRID COMMUNICATION PROTOCOLS

In order to ensure a sophisticated communication between different entities involved in electric vehicle charging, V2G communication protocols should be specified. Therefore, all protocols necessary for V2G communication are described in this chapter. **Figure 16** illustrates communication protocols between EVCC and SECC according to ISO/IEC 15118-2.

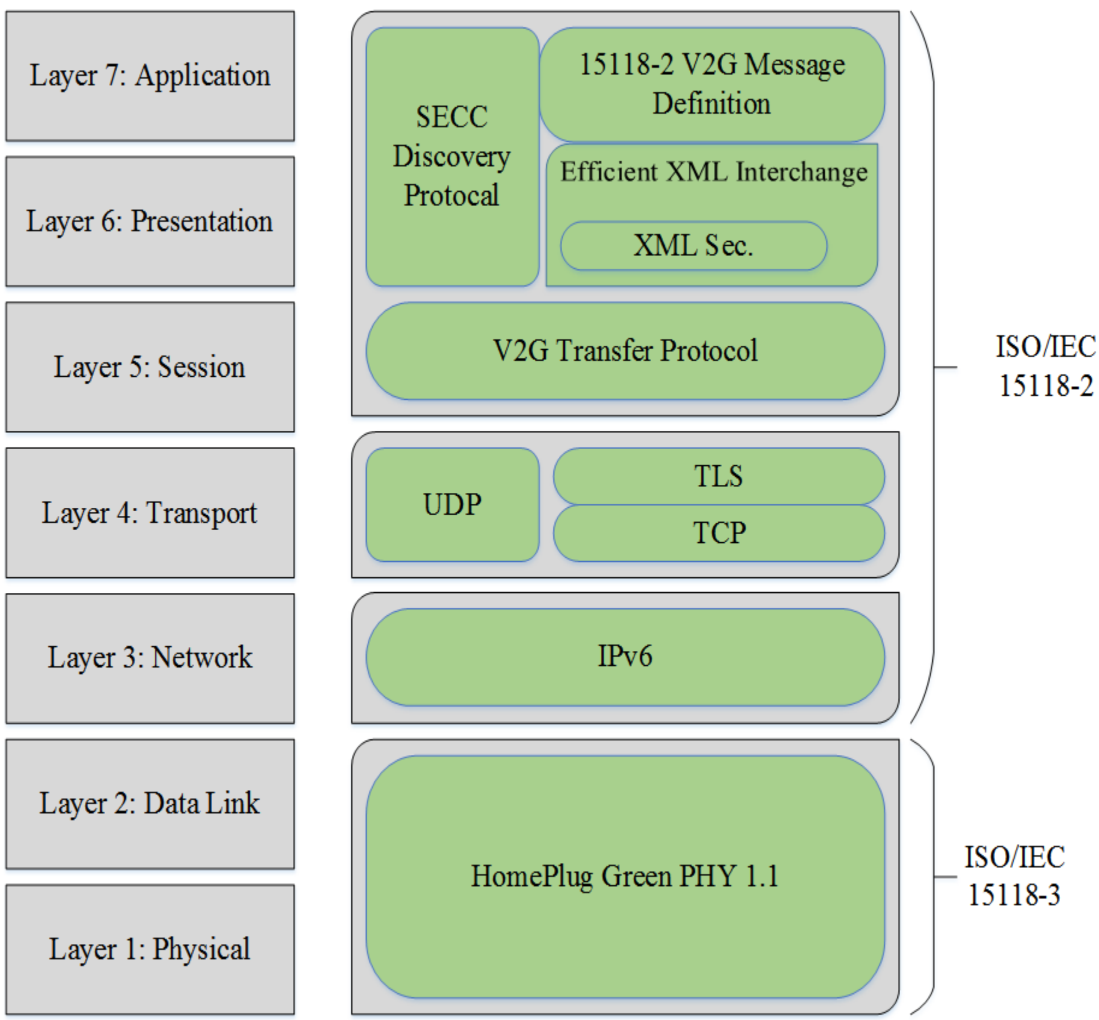


**Figure 16.** V2G protocol stack.

5.1. Data Link and Physical Layer

This part describes the medium through which the V2G data is transmitted from the vehicle to the charging station. According to the ISO/IEC 61851-1 standard, a Pulse Width Modulation is applied to the Control Pilot Line of the charging cable to insure basic low level charging control (PowerUP 2012). As illustrated in **Figure17**, the PLC Signal is coupled onto the Control Pilot Line. The ISO/IEC 15118-3 standard defines the HPGP PLC Technology for the communication between the vehicle and the charging station. However, there are some other candidates PLC technologies such as G3 and Prima. HPGP is a low power, optimal cost power line communication technology (Park, Lee, & Park 2012:572).

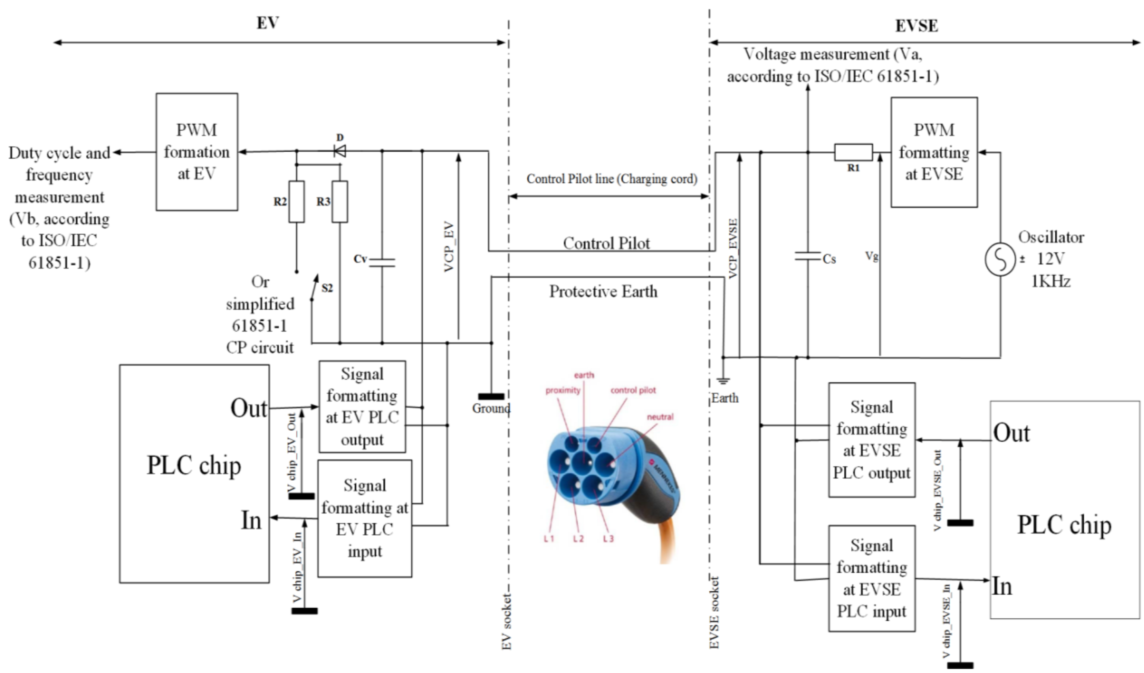


**Figure 17.** Coupling of PLC onto the Control Pilot Line.

In Addition to the PLC, EVs will implement wireless interfaces so that to extend the scope of communication beyond charging. Wireless communication could be used to buck up an unreliable PLC link. ZigBee and 802.11 wireless are the examples of wireless communication technologies that could provide connectivity between the EV and EVSE.

## 5.2. Network Layer

According to ISO/IEC 15118-2, network layer is based on IP protocol Internet Protocol Version 6 (IPv6) and it describes all required functionalities for the establishment of suitable high-level communication. The IPv6 protocol specifies mandatory Request for Comments (RFCs) for V2G communication. The RFC 5220 which extends the RFC 2460 is a core standard for IPv6. Therefore, it should be implemented by each entity involved in V2G communication. According to the RFC 5722, handling of overlapping IP fragments shall be supported by each V2G entity. A dynamic Host Control is used to assign IP address and responsible Domain Name System (DNS) server for each charging post. Thus, each client needs to implement RFC 3315 and RFC 3484 which defines the requirements associated to the client. The neighbor discovery protocol is used to support global addresses, whereby Internet Control Message Protocol (ICMP) is used to send error messages. Each V2G entity shall have a link-local address as specified in RFC 4291. This configuration is based on Stateless Auto Address Configuration (SLAAC). However, Dynamic Host Control Protocol Version 6 (DHCPv6) may be used as optional (PowerUP 2012).

## 5.3. Transport and Session Layer

***Transmission control Protocol (TCP)*** enables the establishment of reliable data connection among V2G entities. In order to enhance performance, TCP implements details associated to congestion control, retransmission, initial window size, timing and selective acknowledgement.

***User Datagram Protocol (UDP)*** is a connectionless protocol that does not offer the reliability as TCP does. In case of packet lose or arrive out of order, a receiver or sender is not notified of the situation. However, UDP is faster and more efficient for many lightweight and time-critical applications.

***Transport Layer Security (TLS)*** is used to provide security for TCP sessions. It allows to establish an authenticated and encrypted sessions between EVCC and SECC.

***V2G Transfer Protocol (V2GTP)*** is a communication protocol that is used to transfer V2G messages between V2GTP. It basically defines the payload and the header. The payload contains the application data like V2G message whereby the header separates payloads within a byte steam and provides required information for the processing of the payload as illustrated in **Figure 18**.

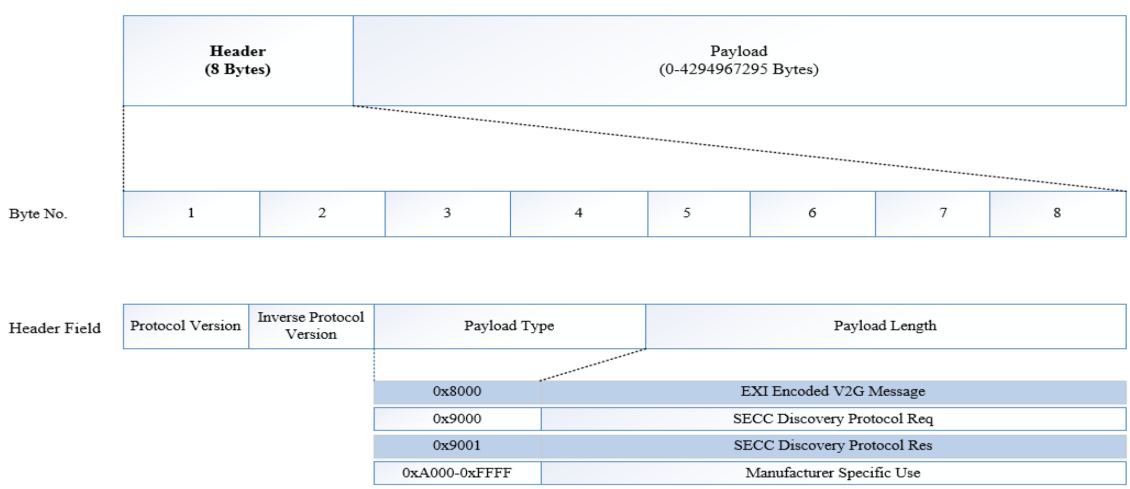


**Figure 18.** V2GTP Message Structure

## 5.4. Presentation Layer

This section briefly describes the presentation layer according to the standard ISO 15118-2. The presentation layer uses the mostly adopted XML data representation to define the V2G message set. The World Wide Web Consortium (W3C) XML is used to define the message format according to the constraints associated to the data structure and content data type.

The structure of V2G message consists of three elements as illustrated by **Figure 19** below, which are: *V2G_message*, *Header*, and *Body*. *V2g_message* element is the core element which identifies the XML-based document as a V2G message and embeds the *Header* and the *Body* element. The Header element identifies the generic information such as session identifier, protocol version, and information concerning security issues. Whereby, the actual message content is carried by the body element. The messages which are carried by the body element can be either EV request message to EVSE or EVSE response message to the electric vehicle (Sebastian, Anton, Martin, & Jörg 2010).

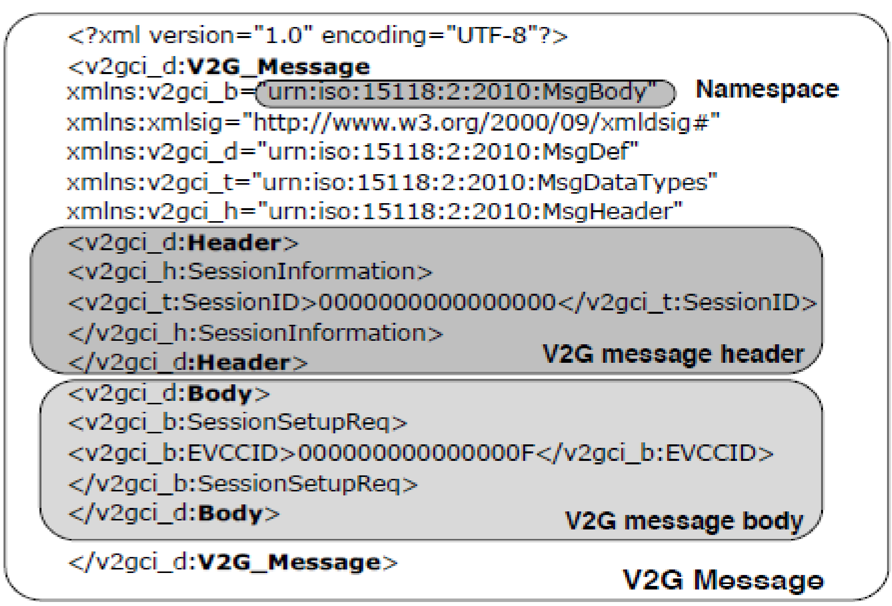


**Figure 19.** Example of EXM-based V2G Message (PowerUP 2012).

***Efficient Encodings:*** The usage of V2G messages in a plain-text XML presents a significant disadvantage due to the parsing overhead XML data structures and memory usage. Efficient XML Interchange (EXI) addresses this issue since it allows to use and process XML-based messages on a binary level. Thus, the EXI format increases the processing speed of XML-based data as well as minimizes memory usage. The EXI format uses relatively simple gramma driven approach that achieves very efficient encodings for a wide range of use cases. The EXI is very efficient to the extent that the EXI message can be up to 100 times smaller than equivalent XML document. The EXI specification defines in a predefined process how schema information has to be transformed into EXI grammar. The factor for doing so is that EXI grammar is much simpler to process, compared to XML Schema information. However, the parsing can be done in the same accurate way as it is possible in XML (ISO 15118-2 2014).

## 5.5. Application Layer

Application layer is the layer which is responsible for generating, receiving, and handling payload as well as monitoring and adjusting the charging status of electric vehicle.

***SECC Discovery Protocol (SDP):*** In order EVCC to retrieve the IP address and port number of the SECC it uses SECC Discovery Protocol. The SDP client sends out SECC Discovery Request message to the local link (multicast) expecting any SDP server to answer its request with a SECC Discovery Response message containing this information. Once the EVCC receives the IP address and the port number of the SECC, it can establish a transport layer connection to the SECC.

# 6. SIMULATION OF ELECTRIC VEHICLE CHARGING PROCESS, CONTROL, AND MONITORING

The implementation of electric vehicle as DER requires a complete chain of communication from EV through the charging spot to an operator administration panel. The communication between the EV and the charging sport is based on ISO/IEC 15188-2 standard while the communication between the electric vehicle supply equipment and the infrastructure operator is based on the proposed object model for electric mobility published as IEC Technical Report 61850-90-8. The report provides necessary background information and proposes an object model for E-mobility in order to establish plugged-in Electric Vehicles as DER according to the principles of IEC 61850-7-420.

The V2G CI charging architecture integrated into a common IEC 61850 client-server setups is shown in **Figure 20**. It illustrates architecture mappings between ISO/IEC 15118 and IEC 61850. Based on the principles of ISO/IEC 15118-2 V2G communication interface, the EVCC is always the client whereby the SECC is always a server. Information provided from the EV is transferred to the ISO/IEC 15118 server side through the Vehicle-to-Grid Communication Interface. Then, all relevant information is mapped to the IEC 61850 information model and provided to the client-side of the infrastructure operator.

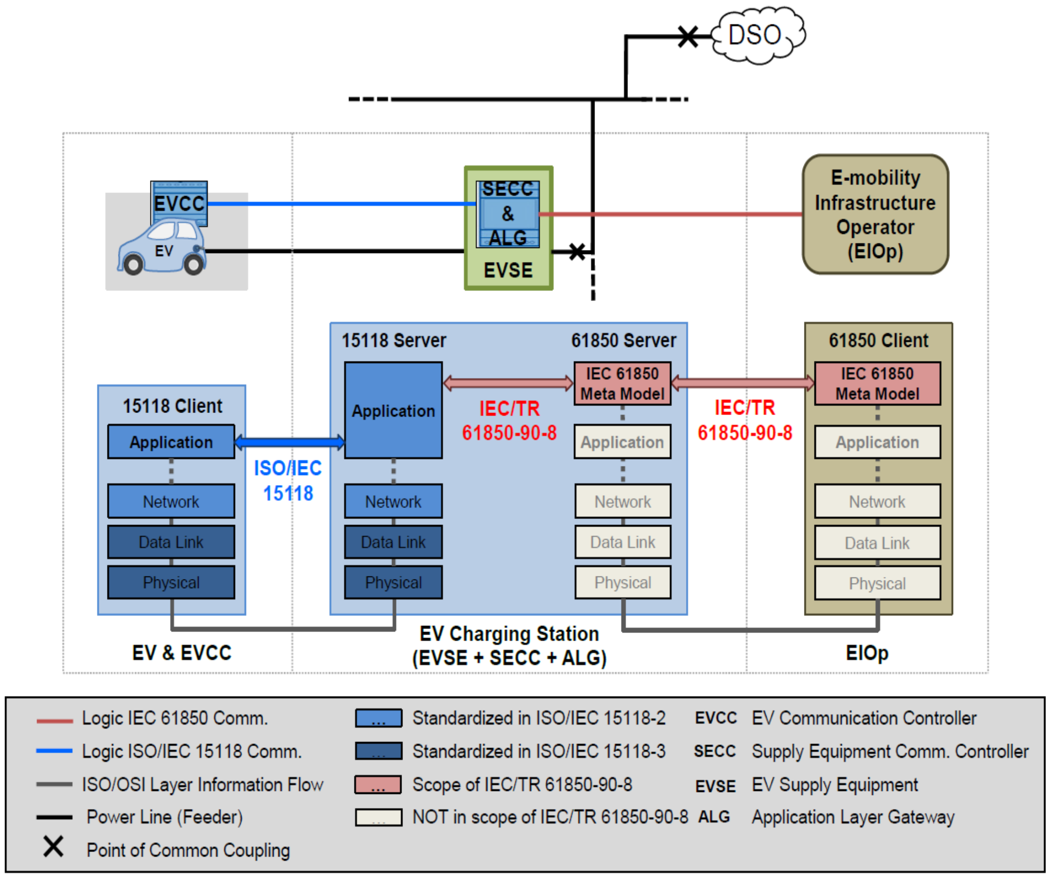


**Figure 20.** Basic concept of mapping ISO 15118 V2G Communication Interface to IEC 61850 DERs with dedicated SECC in the EVSE managing one EV (IEC 61850-90-8 TR 2015).

## 6.1. Simulation of Electric Vehicle Charging Process between Electric Vehicle and Electric Vehicle Supply Equipment

In order to demonstrate the exchange of charging information (The information exchanged for charging is discussed in Chapter 2.2) between the Electric Vehicle Communication Controller and the Supply Equipment Communication Controller, a client-server application is implemented. This client-server application is based on java socket client-server programming. The platform used for developing the application is Eclipse and the programming language used is Java. As seen earlier, EVCC is always a client whereas SECC is always a server. The EVCC connect to the SECC using IP address and the port number. **Figure 21** shows the structure of the program.

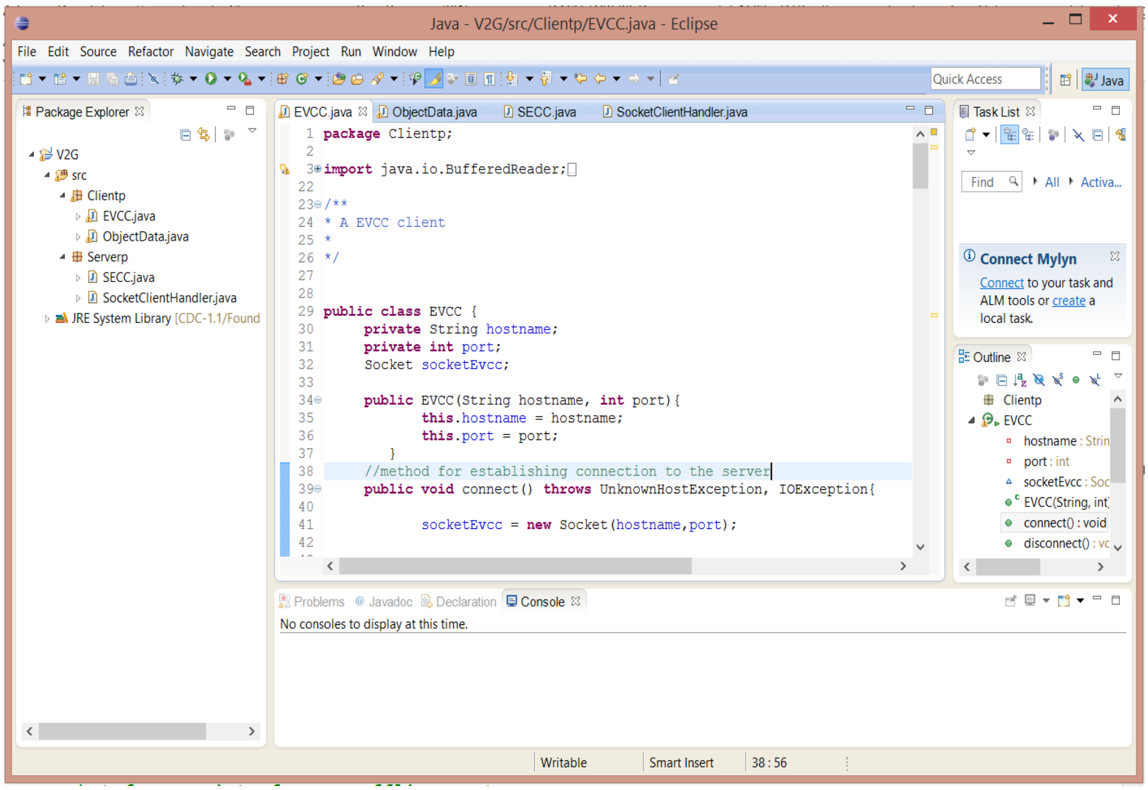


**Figure 21.** An Overview of EVCC and SECC program structure in Eclipse.

The EVCC program consists the following methods; connect(), disconnect(), readResponce(), ServiceDiscoveryReq(), ChargeParameterDiscoveryReq(), and SessionSetupReq(). The description of the methods is given in the program. The ObjectData class is used to send an object data from EVCC to SECC.

The SECC program represents a multi-thread server which can serve multiple clients (electric vehicles) at the same time. A ‘start’ method is called from the ‘main’ method of the server class (SECC). When thread.start() is called, Java creates a thread and calls the run function in the thread class. Therefore, the run function is called in the execution of the thread. This means that whenever a client establishes a connection with the server, the run function is executed in a new thread. Then the readResponse() method is called so that to read whatever the client sends to the server. The server class program is shown below. For the complete program see Appendix 1.

```java
/**
 * A SECC server
 *
 */
public class SECC {

    private ServerSocket serverSocket;
    private int port;

    public SECC(int port) {
        this.port = port;
    }

    public void start() throws IOException {

        serverSocket = new ServerSocket(port);

        Socket client = null;

        while(true){

            client = serverSocket.accept();
            System.out.println("Message from client :"+client.getInetAddress().getCanonicalHostName());
            //A client has connected to this server
            Thread thread = new Thread(new SocketClientHandler(client));
            thread.start();
        }
    }

    /**
    * Creates a SocketServer object and starts the server.
    *
    * @param args
    */
    public static void main(String[] args) {
        // Setting a default port number.
        int portNumber = 9990;

        try {
            // initialising the Socket Server
            SECC socketServer = new SECC(portNumber);
            socketServer.start();

            } catch (IOException e) {
            e.printStackTrace();
        }
    }
}
```

### 6.1.1. Results and analysis

For demonstration purpose, only few request-response messages of charging process are shown. **Figure 22** shows the request messages sent by the client (EVCC) to the server (SECC), and the response messages it receives from the server while the request-response messages on the server side are illustrated in **Figure 23**. The server program must be run before running the client program. Firstly, the EVCC sends a session setup request to establish connection with the SECC. If connection establishment is successful, the SECC replies with the ok status, and sends EVSE Id and the timestamp. Then, the EVCC sends a request to the SECC for the available services. The SECC sends a response message to the EVCC which consists the payment option, charging services (described by service identification, service name, service category, energy transfer mode, and free services), and list of other services available. After service discovery, the EVCC transfer the charging parameter request to SECC. Based on these parameters the SECC can check its charging compatibility with the connected EVCC and calculates the price table for the requested amount of energy. The SECC respond with its charging parameters.

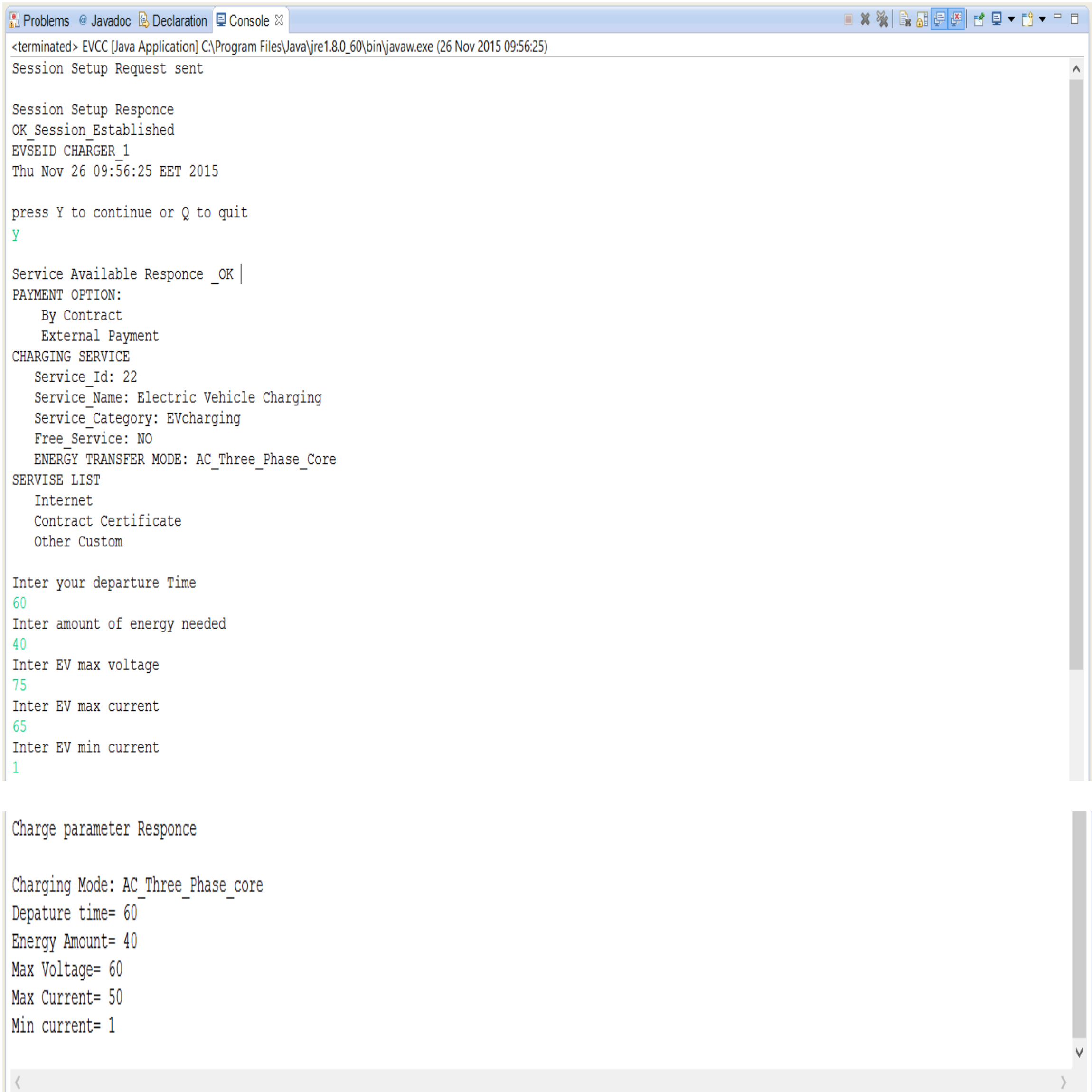


**Figure 22.** Simulation results of charging process (client side).

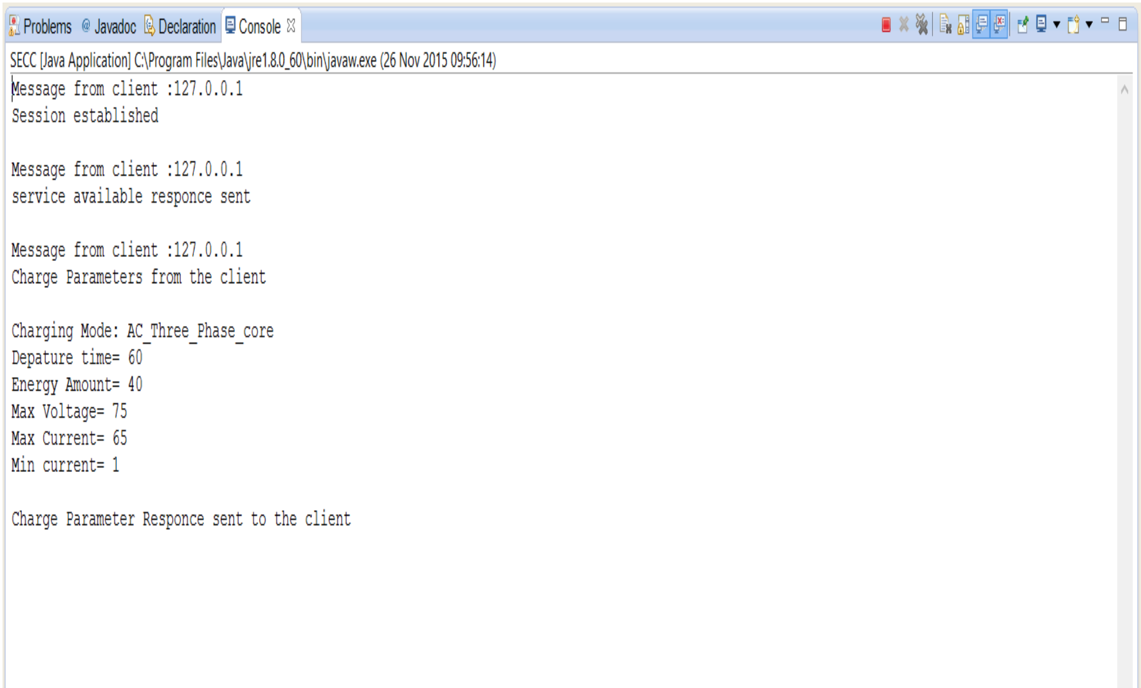


**Figure 23.** Simulation results of charging process (server side).

The ISO/IEC 15118 client/server protocol has been implemented by eclipse (Mueltin 2015). The program (RISEV2G) code can be used to test the client representing the electric vehicle communication controller against the server which represents the supply equipment communication controller. All information required for testing the program is provided on the website.

## 6.2. The IEC 61850 Implementation

The implementation of IEC 61850 is based on openIEC61850 (Openmuc 2014) and the Manufacturing Messaging Specification is used as a communication protocol binding between the charging spot and the operator's panel. The new logical nodes for monitoring and controlling electric vehicle and electric vehicle supply equipment are implemented using the SystemCorp IED Capability Description (ICD) Designer shown in the **Figure 24**.

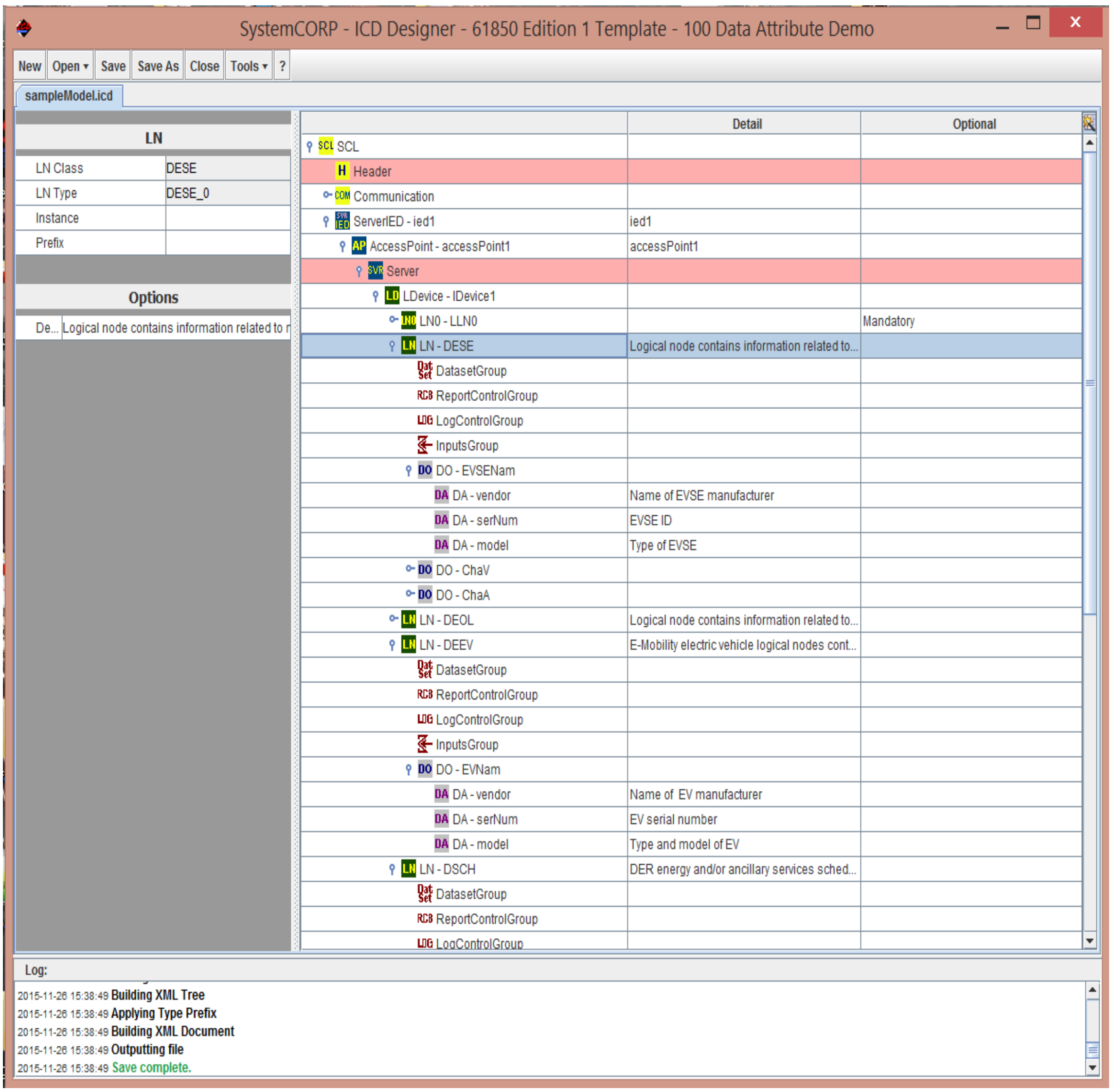


**Figure 24.** Hierarchical Data Model of IEC 61850 based IED in ICD Designer.

6.2.1. The configurations of a server CID file.

The server Configured IEDs Description (CID) file must contain the local server IED and a connected access point to be useful. The local IED must be listed first in case the CID file contains more than one IED. The connected Access Point (AP) configuration must have an Address with valid parameters set for IP, Subnet, Gateway and Medium Access Control (MAC) Address. It is located in a Sub-Network Node in the Communication section as shown in the **Figure 25**. The Server IED node contains the access point node, which must have an access point selected from the once configured in the communications section. The access point node comprises a server node, which includes the logical devices of the server.

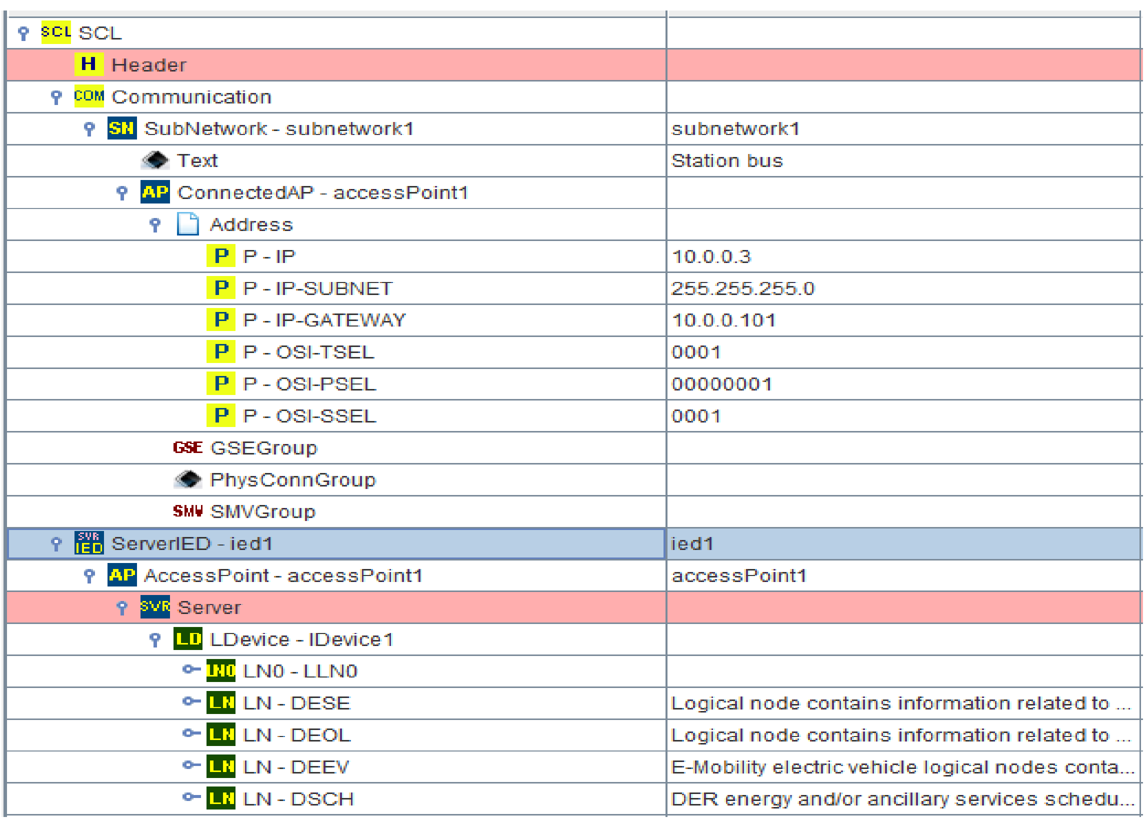


**Figure 25.** Overview of the Server CID file configuration.

Also a report Publishing must be set. It lets a client interact with selected data attributes in the server logical devices. To allow interaction with the server's data attributes, the required data attributes must be selected in a data set. Then a report control block is added, the data set selected and options should be configured as required.

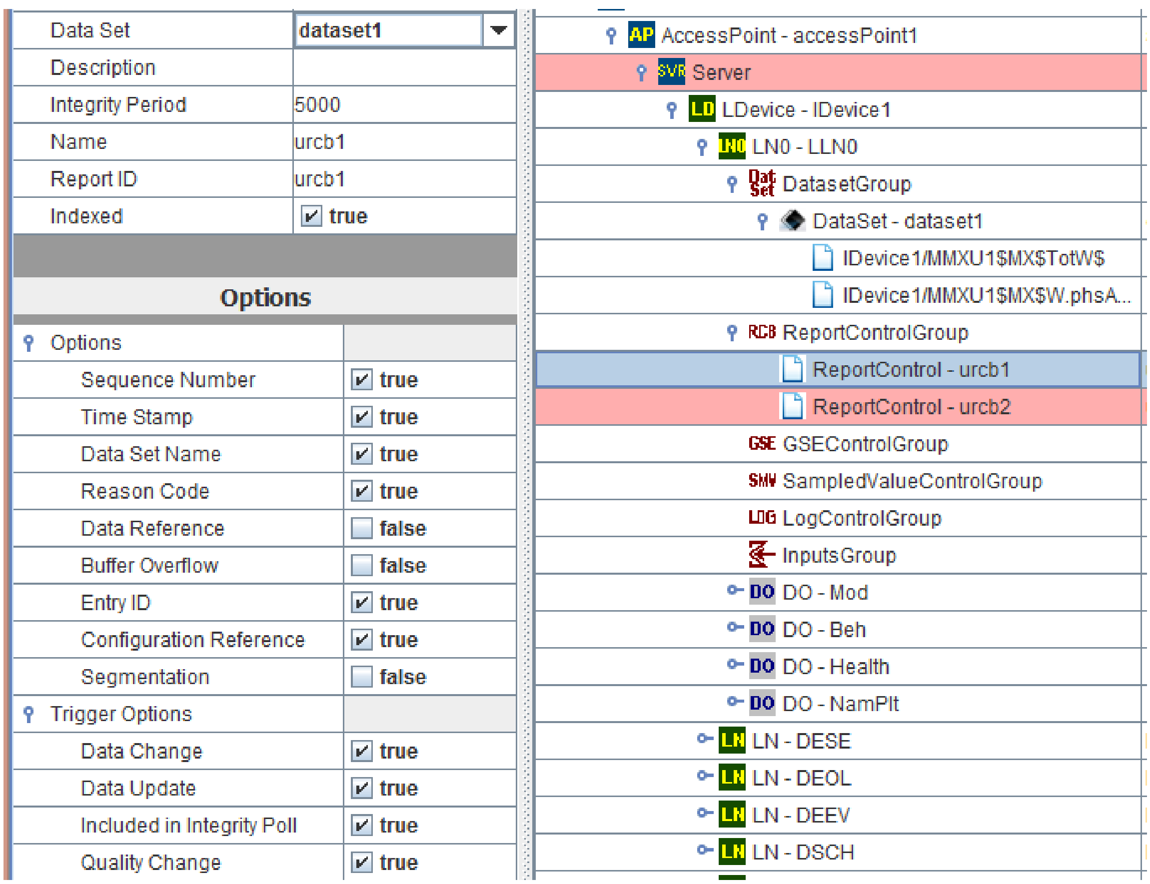


**Figure 26.** Overview of report Publishing and report control block configuration.

A client CID file contains the configuration of the IEDs with which the client application intends to interact. It includes all sections of the Server IEDs that are to be used. A report subscription must be configured. It allows the client application to interact with data attributes in the reports published by servers.

### 6.2.2. Results and analysis

The user interface shown in the **Figure 27**, allows the client (grid operator) to access the data attributes in the server logical devices.

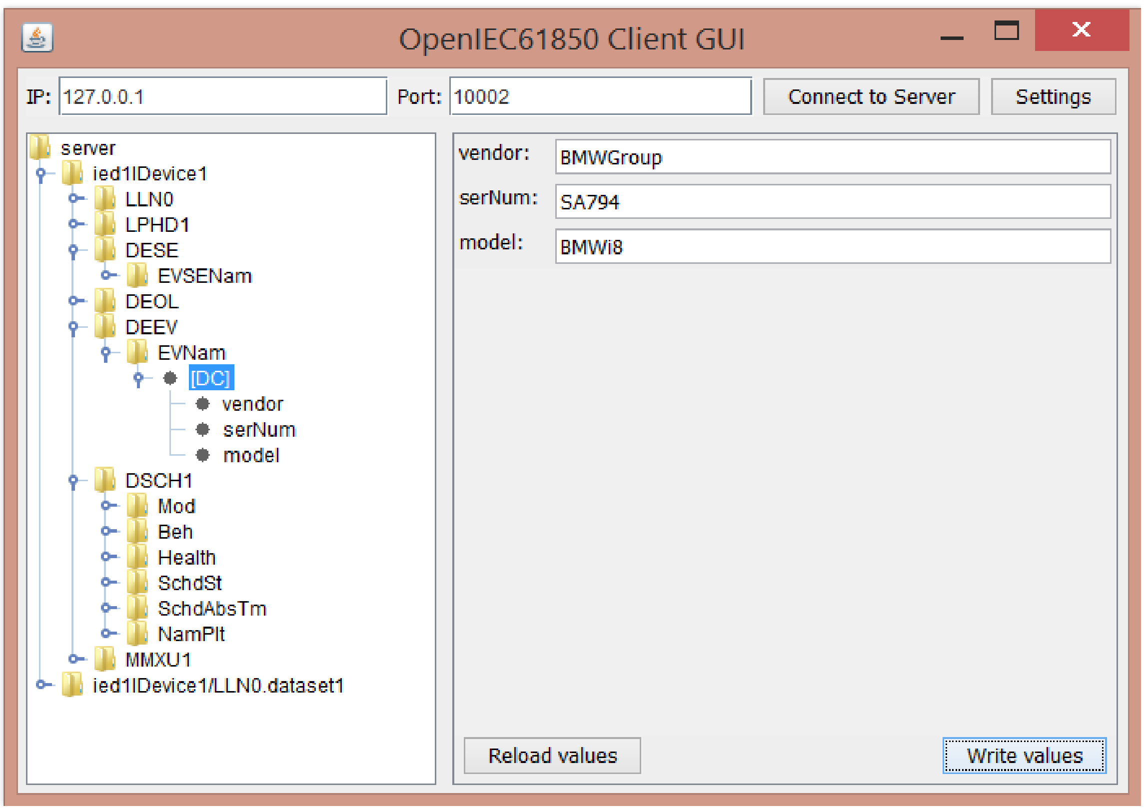


**Figure 27.** IEC 61850 user interface.

The client can perform settings, configurations and retrieves status information of the physical devices as illustrated in **Figure 28** and **Figure 29**.

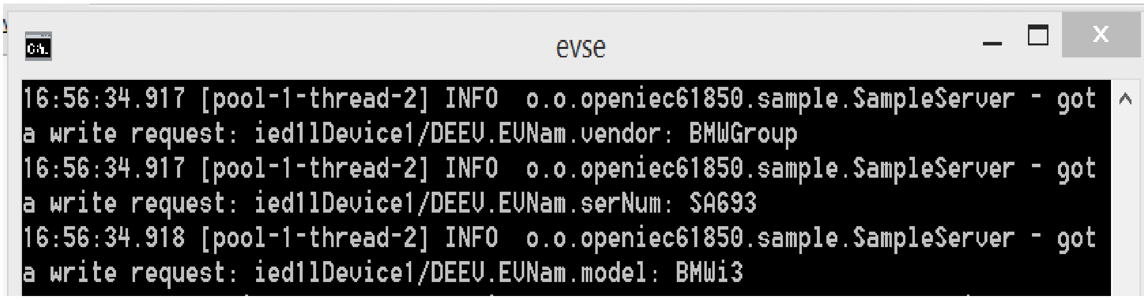


**Figure 28.** Example of data setting.

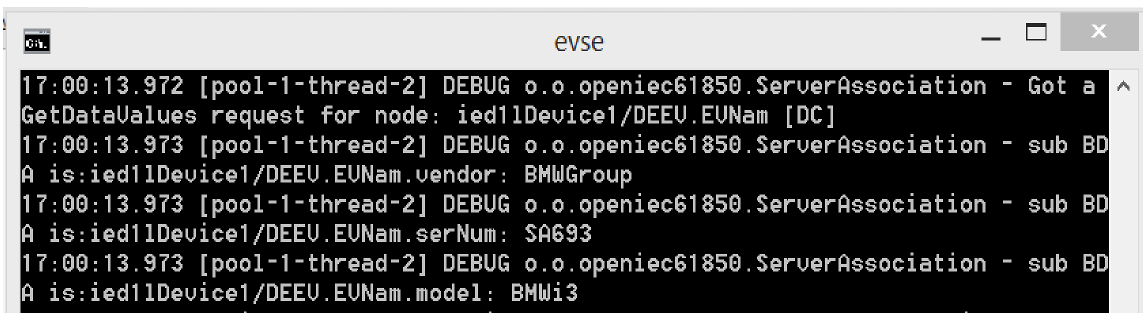


**Figure 29.** Example of data reloading.

# 7. CONCLUSIONS AND FUTURE WORK

This thesis first presents a literature survey and standard descriptions and then there is a simulation regarding the discussed topic. It provides a detailed description of the basic principles of the Vehicle-to-Grid Communication Interfaces between EV and EVSE, V2G standardization, the basic concept of IEC 61850, and the information model for establishing and managing EVs as DERs taking into consideration today's standardization struggle for integration of electric vehicles into smart grid. It provides the descriptions of the underlying modeling approach through which an E-Mobility infrastructure operator can adopt DER services offered through EV.

As mentioned earlier, uncontrolled charging of electric vehicle would cause a significant impact on the grid operations and planning. Therefore, taking into account an increasing amount of distributed energy supply, the need for integrating EVs as DERs that possess certain storage capacity and controllable demands curves will become more crucial in the future.

A computer program has been developed to simulate the charging process between the vehicle and the charging post. Also the new logical nodes have been implemented based on IEC 61850 for monitoring and controlling of electric vehicle. However, this thesis does not cover the demonstration of information mapping between the ISO 15118 server and the IEC 61850 server in order to make a complete communication chain from the vehicle though the charging post to the operator panel. Therefore, this is considered as the future work of the thesis.

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# APPENDICES

## Appendix 1. The Program Code for the EV charging process

```
package Clientp;

import java.io.BufferedReader;

/**
 * A EVCC client
 *
 */


public class EVCC {
    private String hostname;
    private int port;
    Socket socketEvcc;
    // a constructor
    public EVCC(String hostname, int port){
        this.hostname = hostname;
        this.port = port;
    }
    //method for establishing connection to the server
    public void connect() throws UnknownHostException, IOException{

        socketEvcc = new Socket(hostname,port);

    }
    //method for terminating connection
    public void disconnect() throws UnknownHostException, IOException{

        socketEvcc.close();
    }
```

```
//method for reading response from the server
        public void readResponse1() throws IOException, ClassNotFoundException {


            ObjectInputStream clientInputStream = new ObjectInputStream(socketEvcc.getInputStream());


            ObjectData obj= (ObjectData)clientInputStream.readObject();
            System.out.println("Charge parameter Responce \n");
            System.out.println("Charging Mode: " + obj.getChargeMode());
            System.out.println("Depature time= "+ obj.getDeparturetime());
            System.out.println("Energy Amount= "+ obj.getEAmount());
            System.out.println("Max Voltage= "+ obj.getVoltage());
            System.out.println("Max Current= "+ obj.getMuxCurrent());
            System.out.println("Min current= "+ obj.getMinCurrent());
             clientInputStream.close();


        }
    //method for reading response from the server
    public void readResponse() throws IOException, ClassNotFoundException {
          String readInput;
          BufferedReader buffer = new BufferedReader(new InputStreamReader(socketEvcc.getInputStream()));

           while((readInput = buffer.readLine()) != null) {
               System.out.println(readInput);
           }
        }
```

```java
 //method for sending request to the server for the available services
public void serviceDiscoveryReq() throws IOException{
   String userInput;
   BufferedReader in = new BufferedReader(new InputStreamReader(System.in));

   System.out.println("\npress Y to continue or Q to quit");
   userInput = in.readLine();

   if(userInput.equals("y") )
   {

       ObjectData obj = new ObjectData("serviceavailable");
       ObjectOutputStream clientOutputStream = new ObjectOutputStream(socketEvcc.getOutputStream());
       clientOutputStream.writeObject(obj);
   }
   else
       disconnect();
   }


public void ChargeParameterDiscoveryReq() throws IOException{
   int userTime, AEnergy, EVMaxV, EVMaxC, EVMinC;
    Scanner sc= new Scanner(System.in);
   //BufferedReader in = new BufferedReader(new InputStreamReader(System.in));
   System.out.println("\nInter your departure Time");
   userTime = sc.nextInt();
   System.out.println("Inter amount of energy needed");
   AEnergy=sc.nextInt();
   System.out.println("Inter EV max voltage");
   EVMaxV=sc.nextInt();
   System.out.println("Inter EV max current");
   EVMaxC=sc.nextInt();
   System.out.println("Inter EV min current ");
   EVMinC=sc.nextInt();
```

```
        ObjectData obj1 = new ObjectData("AC_Three_Phase_core",userTime, AEnergy, EVMaxV, EVMaxC,EVMinC);
        ObjectOutputStream clientOutputStream = new ObjectOutputStream(socketEvcc.getOutputStream());
        clientOutputStream.writeObject(obj1);

        }
    //method for establishing charging session with the server
     public void SessionSetupReq() throws IOException{

         ObjectData obj = new ObjectData("0b110110");
         ObjectOutputStream clientOutputStream = new ObjectOutputStream(socketEvcc.getOutputStream());
         clientOutputStream.writeObject(obj);
          System.out.println("Session Setup Request sent \n ");

            }

    public static void main(String[] args) throws IOException, ClassNotFoundException {

        //Creating a EVCC object
        EVCC evcc = new EVCC ("localhost",9990);


        try {


            int i=1;
             while(i<=3)
             {
            //trying to establish connection to the server
            evcc.connect();

            if(i==1)
            {
            evcc.SessionSetupReq();
            //waiting to read response from server
            evcc.readResponse();
            }


             else if(i==2)
             {
             evcc.serviceDiscoveryReq();
             evcc.readResponse();
             }

             else //
             {
             evcc.ChargeParameterDiscoveryReq();
             evcc.readResponse1();
             }
             i++;
              }


         }
         catch (UnknownHostException e) {
             System.err.println("Host unknown. Cannot establish connection");
         }
         catch (IOException e) {
             System.err.println("Cannot establish connection: "+e.getMessage());
         }

      }

 }
```

```java
package Clientp;
import java.io.Serializable;
 /**
  * class ObjectData
  */
public class ObjectData implements Serializable {
    private static final long serialVersionUID = 1L;
    private int time,energy,voltage,currentmax,currentmin ;
     private String str;
     private String str1;
//a constructor method
     public  ObjectData(String s,int time,int energy, int voltage, int currentmax, int currentmin  ){
     this.time=time;
     this.energy=energy;
     this.voltage=voltage;
     this.currentmax=currentmax;
     this.currentmin=currentmin;
     this.str=s;
     }

     public ObjectData(String st){
        this.str=st;
     }
     public String getstring() {
          return str;
       }

     public int getDeparturetime() {
          return time ;
       }
     public void setDeparturetime(int t) {
          time=t;
       }

     public int getEAmount() {
          return energy ;
       }


     public void setEAmount(int e) {
         energy=e;
       }

     public int getVoltage() {
          return voltage ;
       }

     public void setVoltage(int v) {
         voltage=v;
       }

     public int getMuxCurrent() {
          return currentmax;
       }

     public void setMaxCurrent(int maxc) {
         currentmax=maxc;
       }

     public int getMinCurrent() {
          return currentmin;
       }

     public void setMinCurrent(int minc) {
         currentmin=minc;
       }

     public String getChargeMode() {
          return str;
       }

     public void setChargeMode(String st) {
         str=st;
       }
    }
```

```java
package Serverp;
import java.io.BufferedWriter;
/**
 * A Thread program
 *
 */

public class SocketClientHandler implements Runnable {

  private Socket client;
  ObjectData objectdata=null;
  public SocketClientHandler(Socket client) {
    this.client = client;
  }


  public void run() {
     try {
    readResponse();
       } catch (IOException e) {
     e.printStackTrace();
       } catch (InterruptedException e) {
         e.printStackTrace();
       } catch (ClassNotFoundException e) {
        // TODO Auto-generated catch block
        e.printStackTrace();
    }
   }


// method for reading request from the client
   private void readResponse() throws IOException, InterruptedException, ClassNotFoundException {

      ObjectInputStream ois = new ObjectInputStream(client.getInputStream());
      ObjectData   objectdata = ( ObjectData)ois.readObject();

        if(objectdata.getChargeMode().equals("0b110110")){
            System.out.println("Session established  \n");
            SessionSetupRes();

        }
        else if(objectdata.getstring().equals("serviceavailable") ){
            System.out.println("service available responce sent \n");
            ServiceDiscoveryRes();

        }
        else if(objectdata.getChargeMode().equals("AC_Three_Phase_core"))
        {
            System.out.println("Charge Parameters from the client  \n");
            System.out.println("Charging Mode: " + objectdata.getChargeMode());
            System.out.println("Depature time= "+ objectdata.getDeparturetime());
            System.out.println("Energy Amount= "+ objectdata.getEAmount());
            System.out.println("Max Voltage= "+ objectdata.getVoltage());
            System.out.println("Max Current= "+ objectdata.getMuxCurrent());
            System.out.println("Min current= "+ objectdata.getMinCurrent());
            if (objectdata.getMuxCurrent()>=50){
                objectdata.setMaxCurrent(50);
            }
            if (objectdata.getVoltage()>=60){
                objectdata.setVoltage(60);
            }
            ObjectOutputStream serverOutputStream = new ObjectOutputStream(client.getOutputStream());
            serverOutputStream.writeObject(objectdata);
            System.out.println("\nCharge Parameter Responce sent to the client ");
        }

    }
```

```java
//method for sending a session setup response to the client
private void SessionSetupRes() throws IOException, InterruptedException {
    BufferedWriter writer = new BufferedWriter(new OutputStreamWriter(client.getOutputStream()));
    writer.write("Session Setup Responce \n");
    writer.write("OK_Session_Established \n");
    writer.write("EVSEID CHARGER_1 \n");
    writer.write(new Date().toString());
    writer.flush();
    writer.close();
    }
// method for sending services available to the client
private void ServiceDiscoveryRes() throws IOException, InterruptedException {
    BufferedWriter writer = new BufferedWriter(new OutputStreamWriter(client.getOutputStream()));
    writer.write("\nService Available Responce _OK \n");
    writer.write("PAYMENT OPTION: \n");
    writer.write("    By Contract \n");
    writer.write("    External Payment \n");
    writer.write("CHARGING SERVICE \n");
    writer.write("   Service_Id: 22 \n");
    writer.write("   Service_Name: Electric Vehicle Charging \n");
    writer.write("   Service_Category: EVcharging \n");
    writer.write("   Free_Service: NO \n");
    writer.write("   ENERGY TRANSFER MODE: AC_Three_Phase_Core \n");
    writer.write("SERVISE LIST \n");
    writer.write("   Internet \n");
    writer.write("   Contract Certificate \n");
    writer.write("   Other Custom\n");
    writer.flush();
    writer.close();
    }


}
```