USE CASES FOR V2X IMPLEMENTATION

Lappeenranta–Lahti University of Technology LUT

Master's Programme in electrical engineering, master's thesis

2024

Anniina Sorvisto

Examiners: Professor Samuli Honkapuro and D.Sc. Ville Tikka

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

LUT School of Energy systems

Electrical Engineering

Anniina Sorvisto

USE CASES FOR V2X IMPLEMENTATION

Master's thesis

2024

66 pages, 13 figures and 7 tables

Examiners: Professor Samuli Honkapuro and D.Sc. Ville Tikka

Keywords: Use case, EV, bidirectional charging, V2X, V2G, V2B, EMSA

Abstract

Use of renewable energy sources (RES) has increased as response to climate change and the EU's goals for decreasing carbon dioxide (CO_2) emissions. Correspondently, the transportation sector has created solutions, and the use of e-mobility has increased. These changes bring challenges to the grid stabilization as uncontrolled electric vehicles (EVs) charging may increase grid's peak demand and renewable generation may be variable.

Bidirectional charging is a concept that can release the energy stored in EVs batteries to grid, buildings, homes, or loads. Such applications are called vehicle to X (V2X). Bidirectional charging can utilize growing e-mobility as an advantage in grid balancing supporting renewable energy integration. V2X can benefit monetary EV users and building owners with incentives and tariff optimization and grid operators as balancing and maintenance costs decrease.

Modelling of system architecture and use cases are essential for gaining understanding of the operation and interactions within a multidimensional system such as V2X. E-Mobility Systems Architecture (EMSA) model and use case descriptions are employed in the development of two V2X use cases. The first use case showcases vehicle to building (V2B) application in Porto airport where long-term charging of EVs in a parking lot is utilized in building energy optimization. The other use case presents vehicle to grid (V2G) scenario in which Terni city center EV chargers supply flexibility to RES congested grid.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

Energiajärjestelmät/LUT

Sähkötekniikka

Anniina Sorvisto

Käyttökohteita kaksisuuntaisen latauksen hyödyntämiseen

Sähkötekniikan maisteriohjelma, Diplomityö

2024

66 sivua, 13 kuvaa ja 7 taulukkoa

Tarkastajat: Professori Samuli Honkapuro ja tohtori Ville Tikka

Avainsanat: käyttötapaus, kaksisuuntainen lataus, sähköajoneuvot

Tiivistelmä

Uusiutuvien energialähteiden käyttö on lisääntynyt ratkaisuna ilmastonmuutokseen ja EU:n tavoitteisiin hiilidioksidipäästöjen vähentämiseksi. Vastaavasti liikennesektori on luonut ratkaisuja ja sähköinen liikenne on lisääntynyt. Nämä muutokset tuovat haasteita verkon tasapainon ylläpitämiseen, koska hallitsematon sähköautojen lataus voi lisätä verkon huippukysyntää ja uusiutuvan energian käyttö luo sähköntuotantoon arvaamattomuutta.

Kaksisuuntainen lataus on konsepti, joka voi vapauttaa sähköautojen akkuihin varastoitunutta energiaa verkkoon, rakennuksiin, koteihin tai kuormiin. Tällaisia sovelluksia kutsutaan nimellä ”vehicle to x” (V2X). Kaksisuuntainen lataus voi auttaa hyödyntämään kasvavaa sähköistä liikennettä apuna verkon tasapainon ylläpitämisessä ja uusiutuvan energian käytössä. V2X voi hyödyttää rahallisesti sähköajoneuvojen käyttäjiä ja rakennusten omistajia kannustimilla ja tariffioptimoinnilla sekä verkko-operaattoreja tasapainotus- ja ylläpitokustannusten pienentymisellä.

Järjestelmäarkkitehtuurin ja käyttötapausten mallintaminen on välttämätöntä, jotta saataisiin ymmärrystä moniulotteisen järjestelmän, kuten V2X:n, toiminnasta ja vuorovaikutuksista. Sähköisen liikkuvuuden systeemi arkkitehtuuri (EMSA) mallia ja käyttötapauskuvauksia hyödynnetään kahden V2X-käyttötapauksen kehittämisessä. Ensimmäinen käyttötapaus esittelee kaksisuuntaista latausta rakennukseen (V2B) Porton lentokentällä, jossa sähköautojen pitkäaikaista latausta parkkipaikalla hyödynnetään lentokentän energiaoptimoinnissa. Toinen käyttötapaus kuvaa kaksisuuntaista latausta verkkoon (V2G), jossa Ternin keskustan kaksisuuntaiset laturit tarjoavat joustavuutta uusiutuvan energian vuoksi ruuhkautuneeseen verkkoon.

ACKNOWLEDGEMENTS

This master's thesis was made as part of DriVe2X project in the Laboratory of electricity markets in LUT University in 2023-2024. I want to thank professor Samuli Honkapuro and Dr. Ville Tikka for examining this thesis and for the opportunity to work as research assistant and learn from this incredible project. I want to thank Hossein Aghamohammadloo for assistance with my work and for keeping me updated. Thanks to Dr. Goncalo Pinto Mendes for great guidance, insight, and humour. Thanks to everybody in LUT Laboratory of Electricity Markets for being welcoming and kind. I also want to thank Luiz Dias for expertise and general advice. I express my deepest gratitude for everyone in the DriVe2X project. It was an honour to learn from you and get to meet you all in GA Amsterdam. I wish you luck in all your future research and projects and cannot wait to see what DriVe2X can accomplish further.

Lastly, thank you to all my friends from LUT University for your support. I have had too much fun with you along these studying years. I wish they never ended. Thank you to my parents for motivating and supporting me. Thank you to my sister for always cheering me on and believing in me. Thank you to my loved Kuisma Saariaho for everything.

Anniina Sorvisto
25.4.2024
Lappeenranta

Abbreviations

aFRR	automatic frequency restoration reserve
BEMS	Building energy management system
CO_2	Carbon dioxide
CPO	Charging point operator
CS	Charging station
DAB	Dual active bridge
DER	Distributed energy resources
DSO	Distribution system operator
EMI	Electromagnetic interference
EMME	Electric mobility network management entity
EMS	Energy management system
EMSA	Electric mobility system architecture
EMSP	Electric mobility system provider
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
FCR	Frequency containment reserve
FCR-D	Frequency containment reserve for disturbances
FCR-N	Frequency containment reserves for normal operation
FFR	Fast Frequency Reserve
GDPR	General Data Protection Regulation
GHG	Greenhouse gas
HEMS	Home energy management system
HTTPS	Hypertext transfer protocol secure

LFC	Load frequency control
LFMP	Local flexibility market platform
MQTT	Message Queuing Telemetry Transport
OCPP	Open charge point protocol
PFC	Power factor correction
PV	Photovoltaic
RES	Renewable energy sources
REST	Representational state transfer
SGAM	Smart grid architecture model
SoC	State-of-charge
TCP	Transmission control protocol
TSO	Transmission system operator
UDP	User datagram protocol
UI	User interface
V2B	Vehicle to building
V2G	Vehicle to grid
V2H	Vehicle to home
V2L	Vehicle to load
V2X	Vehicle to anything

Table of contents

1 Introduction

Climate change and international agreements on greenhouse gas emissions reductions make sustainable smart energy system and e-mobility development essential. Transportation sector is responsible for about 25% of Europe's greenhouse gas (GHG) emissions and therefore transition to EVs plays significant role in decreasing GHG emissions (European Environment Agency, 2024). Still, increasing amount of EVs with non-controlled charging may not lead to emission reductions as energy production in many countries may still rely heavily on non-renewable energy generation (Bibak & Tekiner-Mogulkoc, 2021). This non-controlled charging where EV is charged when connected to charger is also referred as dumb charging. Large scale utilization of e-mobility such as EV combined with dumb charging increases the peak-demand of grid (Kene and Olwal, 2023) (Khalid et al, 2019). Simultaneously renewable energy integration causes grid congestions, deficits, and unpredictability to energy generation. With these challenges demand and supply of grid require more balancing to avoid grid malfunction, especially in peak load hours. Strategies for stabilization have been designed and implemented such as demand response, energy storages and reserve power plants (Zsiborács et al, 2021).

1.1 Bidirectional charging

E-mobility systems lack comprehensive use of EVs storage and flexibility potential. Most of the time EVs are not in active use. Bidirectional charging can utilize that time effectively and benefit both EV user and all stakeholders of the grid. Bidirectional charging is a concept where energy stored in EV batteries can be discharged back to grid or houses, homes, or loads. These applications that are enabled with bidirectional charging are referred as V2X.

When EVs are discharged to grid, it is called V2G. V2G can aid in preservation of grid's functionality various ways. When grid has peak demand EVs can supply energy and when grid is in low demand EVs can take energy from grid to charge. Therefore, bidirectional charging can moderate grid frequency and voltage decreasing grid malfunctions and offer back-up energy and reliability to the operation of grid. With its fast load balancing capabilities power quality of grid can be increased as well as energy efficiency as transmission losses are reduced by using EVs as distributed local resources. Bidirectional

charging and V2G can bring security to renewable energy use since they can mend the energy deficits when RES are not meeting the demand. (Lotfi et al, 2024) EVs can also store excess energy produced by renewable energy sources and reduce grid congestions caused by large scale RES use. Therefore, bidirectional charging can accelerate adaptation to higher share of renewable energy in power system. Bidirectional charging additionally reduces the demand for non-renewable reserve energy generation and the use of EVs instead of gasoline vehicles decrease CO_2 emissions (Bibak & Tekiner-Mogulkoc, 2021). It is studied that in best case scenario optimized bidirectional charging with V2G can reduce EVs CO_2 emissions per mile by 59%. Achieving emission reductions with charging scheme is highly dependent on discharging at peak demand periods. (Hoehne & Chester, 2016)

Bidirectional charging offers benefits to flexibility markets and tariff optimization. It reduces costs for grid operator as better stabilization of grid decrease malfunctions, breaking of components and need for grid upgrades. End-users and building owners can benefit by controlled charging in which charging is conducted at times when electricity is more affordable and discharging and selling energy when price is high. EVs can also store the energy of solar photovoltaics (PV) in commercial buildings or homes.

Interoperability and complexity of bidirectional charging limit its utilization. Estimating EV charging/discharging times and amount of discharge can pose challenges considering changing customer behaviours and preferences. Controlling of electric vehicle supply equipment (EVSE) and charging direction or aggregation of smaller loads or resources needs to take place. Information, monetary or energy exchange between different actors must be functional and reaction to grid requirements must be fast. Technical challenges in V2G system and control include cyber security, standardization, and integration of new smart applications to existing energy system. Wider adaptation of EVs that allow bidirectional charging is essential as well as decreasing user travel anxiety with better services and investment in new charging equipment and EVs that allow bidirectional charging. Development and deployment of bidirectional charging is widely dependent on customer interest and participation. Therefore, information must be available to general population about possibilities of bidirectional charging.

1.2 Electric vehicles in smart grid

Smart grid is defined as an electricity network that tries to balance demand and supply real time with smart communication technologies. Smart grids architecture of energy systems maximizes the energy efficiency with distributed energy resources (DERs) and energy storages. It measures energy need in real-time and distributes resources accordingly. Smart grid concept enhances grid reliability and sustainability. (Butt et al, 2020). Smart grid utilization requires measuring, bidirectional energy flow and communication between system actors. Bidirectional charging supports smart city development enabling EVs to serve as distributed energy storages and stabilization reserves for grid, buildings of varied sizes, homes, and loads. For effective use of bidirectional charging technology, the system architecture and its processes require research and modelling. Smaller energy resources or flexibility requires aggregation to gain efficient connecting of resources to the grid. Energy flow management needs algorithms, measurement, and fast communication between system actors for efficient operation. Charging services and e-mobility network demands constant management and monitoring. Complicated relations in energy system having bidirectional charging can be better understood with use case modelling and system architecture design.

1.3 V2X charging in recent studies

Bidirectional charging applications and their benefits have been recognized widely in studies. (Pearre & Ribberink, 2019) (Thompson & Perez, 2020) (Vadi et al, 2019) Also challenges regarding V2X have been assessed. (Gschwendtner et al, 2021) (Thompson, 2018) (Saxena et al, 2018) (Wan et al, 2024) (Noel et al, 2019) (Vadi et al, 2019) One prominent challenge is the negative effects V2X can have on battery life which has been studied by (Uddin et al, 2018), (Adegbohun et al, 2024) (Tchagang & Yoo, 2020) and (Gong et al, 2024).

Bidirectional charging technology such as converters, rectifiers and power factor correction has been studied and simulated. (Bridha & Annapoorani, 2023) (Bentalhik et al, 2022) (Chiang et al, 2012) (Firmansyah et al, 2010) (Jain et al, 2022) (Madhumitha et al, 2023) (Johannessen, 2018) (Altin & Sarp, 2020) (Islam et al, 2022). V2X business cases have been

assessed by (Zhou et al, 2021). They highlight the opportunity for light-duty EV owners to decrease EV life-time costs and opportunity of business cases for fleet managers of high-duty EVs such as school busses or utility tracks as well as building owners.

Modelling of successful V2G system that can be used in frequency and power regulation has been simulated by (Pavan et al, 2022). V2G deployment with an aggregator for load and frequency regulation has been simulated by (Amamra & Marco, 2019). The benefits for EV owner and aggregator have been studied and it is concluded that frequency regulation gives EV user benefit as charging cost degreases. Voltage regulation gives greater benefit to aggregator than frequency regulation as there are no service costs. Algorithms for V2G charging station placement and sizing have been studied by (Shareef et al, 2016) Optimal control and scheduling algorithms for V2G has been studied by (Castellanos et al, 2019), (Hu et al, 2016), (Evangelos et al, 2015), (Ota et al, 2011) and (Zhou et al, 2017).

V2B deployment have been simulated by (Yusuf et al, 2023) that create a cost optimization for bidirectional charging to a workplace microgrid with two buildings. It creates cost-benefit analysis according to charger configurations, payback periods, energy cost savings, and peak reductions. It concludes that high-duty electric vehicle (HDEV) is a better cost-effective solution in comparison to light-duty electric vehicle (LDEV) in terms of energy cost reduction and payback periods. Optimal number of EVs giving V2B services to building with solar PVs is studied by (He et al, 2022). It is concluded that available solar energy and season affect the optimal number of EVs for V2B.

V2H applications including renewable energy integration have been studied by (Mazzeo, 2022) which created smart charging algorithm and (Naghibi et al, 2018) that conducted optimization for the size of renewable resources and battery storage system for V2H integration. (Villante et al, 2022) have assessed the benefits of V2H charging through simulation. Control system for V2H has been also studied by (Kosinka et al, 2020). V2H implementation has been conducted by (Shemami & Sefid, 2022)

Vehicle to vehicle (V2V) has been recognized to decrease range anxiety for EV owners as vehicle can be charged with another vehicle if there is shortage of charge. Off-board DC V2V charger has been designed by (Mahure et al, 2020) for reducing power conversion stages and increasing efficiency. V2V technology is also studied by (Shafiqurrahman et al, 2023).

There has been assessment for V2X technologies, and many have conducted simulation, control methods or optimization for V2G and V2H applications but V2X concepts still lack large-scale utilization. There are also very few use case descriptions or architectural modelling of V2X applications in studies.

1.4 Objective and research questions

This master's thesis is a part of DriVe2X project. DriVe2X is an EU-funded project that aims to develop solutions, tools, and technology for mass V2X deployment in Europe (European Commission, 2023).

The purpose of this master's thesis is to describe bidirectional charging and its current state, applications, and possibilities. For more detailed description different use cases are constructed. Use cases demonstrate diverse ways to practise V2X technology. For better visualisation modelling of use cases system architecture is constructed. V2X is a multidimensional complex process, and the intention of this thesis is to simplify the understanding of its operation and requirements for better utilization. Obstacles or gaps of knowledge in various parts of the process are discussed as well as areas of improvement.

Research questions are:" *What applications does bidirectional charging have?" "What requirements and challenges does bidirectional charging applications have?" "What actors and interactions are required in use cases of bidirectional charging applications?" "How uses cases of bidirectional charging can be modelled?"*

1.5 Methods

Use cases are a method for analysing or reviewing a system. This methodology was created by Ivar Jacobson in 1960s (Cockburn, 2000). Use cases as a writing method try to explain how service or product operate and how it benefits stakeholders. Use cases are used to define requirements and objectives for a system (Schneider & Winters, 2006). Use case maps the system architecture. It offers detailed information how the process of a service or using of product proceed with simple steps and describes the interactions between different system actors. Actor is an active participant such as component, system, or market player in a use case. Use case explains the main success scenario as well as possible variables, alternative

paths, and issues in the process and how to overcome them. (Schneider & Winters, 2006) (Cockburn, 2000) They can be used for any type of system development.

Business use cases focus on business perspective and technical use cases in technical perspective. Use case can be casual or dressed. Casual use case is one written in simple style and do not get into details as dressed. Use cases can be from business perspective or system perspective. Business perspective describes business operation and system perspective more technical system operation. Use cases can have corporate, computer system or system innards scope. Corporate use case is from the perspective of corporate operation, while computer system takes computer system model scope and innards style discusses parts or components in the system in detail. It can be also white-box or black-box style of writing. White box use cases try to define a system and all its internal interactions well. Black box use case does not describe the internal parts of a system but focus more on requirements. Use cases can be in strategic, user-goal, or subfunction level. Strategic goals involve multiple user-task level goals. User-goals use cases greatest interest is user goal. Subfunction use case have goals that are needed to achieve user goal. Use case may have different features such as a brief that is a one sentence summary of a use case. Preconditions are conditions happening before and after a use case. Triggers are factors that cause the use case to begin. Use cases have actors that are participants of process that perform tasks. A primary actor is the main beneficiary of the process described in use case. (Cockburn, 2000)

IEC standard 62559 defines use case framework in four parts in which include use case template, management repository and harmonization between use cases, XML import/export format and practises for use cases. It defines that use cases can be described most accurately by steps in which information exchange is defined. Common knowledge about use case such as name, description, main actors, and narrative must be explained. IEC standard gives standardization to use cases as a methodology for the development of smart grid systems. (IEC, 2024)

This master’s thesis describes two use cases in detail which demonstrate different ways to utilize EVs in V2X concepts. Use cases are written from system scope as they describe the V2X system and system innards scope since different parts of the system are discussed. Use

cases are dressed since details such as preconditions and technical actors of the use cases are described. They also have white box scope and cooperation of different components in V2X process are displayed. They have user-goal level as the use case execute the user goal. The use cases follow the requirements of IEC 62559 standard.

1.6 Structure

In chapter 2, Modelling styles for e-mobility and energy system is introduced. V2G concept is explained in chapter 3 and in chapter 4, various actors, roles, and market players involved in V2X applications with bidirectional charging are explained. In chapter 5 different applications for bidirectional charging are described and in chapters 5.1 - 5.4 these applications are discussed more precisely. In chapter 5.5 challenges of bidirectional charging are discussed. Chapter 6 introduces two V2X use cases with descriptions and architectural models. Conclusions are made in chapter 7.

2 Modelling system architecture

Modelling of a system architecture is an efficient way to tackle complexity and achieve interoperable system including multiple types of engineering and operators. Complexity in this context means changing, multidisciplinary or incompatible variables, technologies, or actors. Interoperability means effective communication and interaction ability between actors or components. There are different models that can be used in explaining V2G use cases system architecture which are introduced in this chapter. (Kirpes et al, 2019)

2.1 SGAM

The smart grid architecture model (SGAM) was created to facilitate the designing of smart grid systems. SGAM has three dimensions to describe an energy system and parts of it to gain comprehensive understanding of its operation; Interoperability layers, zones, and domains. Interoperability layers include business, function, information, communication, and component layer that provide different perspectives to view system. Every layer has the same zones and domains and therefore layers can be viewed on top of each other for better understanding of affiliating factors. The zones compromise market, enterprise, operation, station, field, and process. The domains involve generation, transmission, distribution, DER, and Customer Premise. SGAM model created by (CEN-CENELEC-ETSI Smart Grid Coordination Group, 2012) is introduced in figure 1.

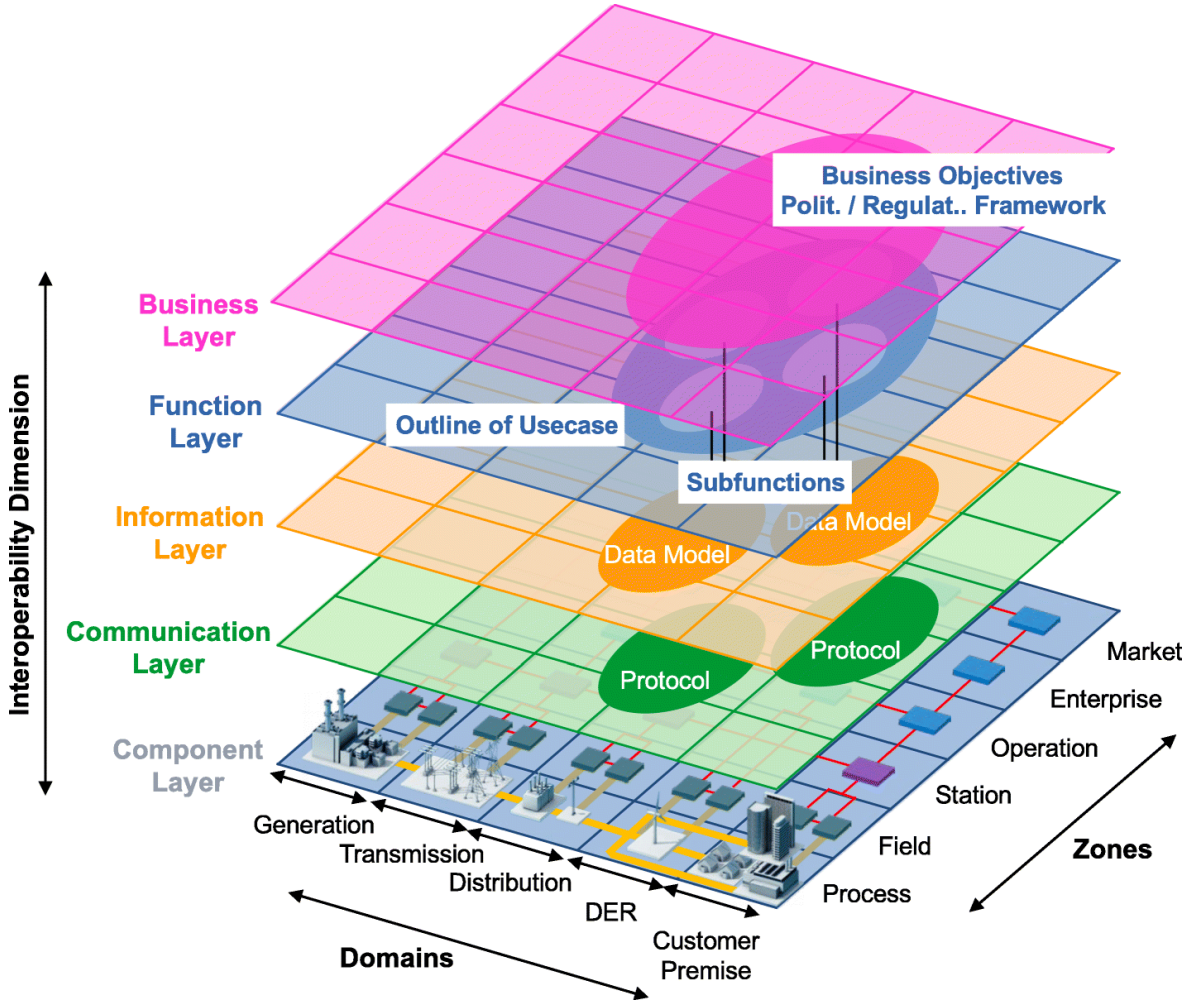

Figure 1. Smart Grid Architecture Model (CEN-CENELEC-ETSI Smart Grid Coordination Group, 2012)

SGAM model business layer holds the system stakeholders and their business relations. It contains business models, services, and processes as well as economic or regulatory framework. This includes actors that participate in payment actions, incentives, information exchange or trades. Function layer shows the direct actions or services between different stakeholders or components. Information layer defines what information is exchanged between stakeholders and aligns with functions. Communication layer shows communication protocols or technologies which enable communication between different components or stakeholders. Component layer encompasses the relevant physical components, hardware, or network infrastructure of system. (Kirpes et al, 2019)

Domains explain in which part of conversion chain is actions or actors placed, generation, transmission, distribution, DER, or customer premise. The generation domain contains any production of energy or actions/actors in the production facility. The transmission domain covers the stage of energy transfer from generation to local distribution. The distribution

domain denotes sharing of energy that is maintained locally. DER means all distributed energy sources such as distributed solar or wind energy production. The customer premise domain contains customer home and its appliances such as EV, HEMS, or home charger. (Kirpes et al, 2019)

The zones describe the extent of management within smart grid that is observed. Process contains energy transformation and physical equipment involved. Field has equipment monitoring, metering, and controlling a process of e-mobility. Station zone holds aggregation of field activities and concentrating data from multiple local sensors. Operation holds management service combining or processing aggregated data. Enterprise includes utility management or service providing and other organizational areas. Market zone encompasses the range of market operations feasible within the e-mobility ecosystem, including services related to charging networks, e-mobility providers, EV sharing, energy trading, and platforms facilitating the exchange of user data. (Kirpes et al, 2019)

2.2 EMSA

E-mobility Systems Architecture (EMSA) Model is a modification of SGAM model having the same interoperability layers with same dimensions and zones, but domains differentiate. The domains include energy conversion, energy transfer from/to EV, EV, and EV user premises. Energy conversion domain contains all energy generation, transmission, distribution, and DERs. Energy transfer from/to EV domain compromise transferring activities of energy to electric vehicle such as charging station functions or components. EV domain has e-mobility vehicles and their parts and actions considering them. EV user premises contains interfaces such as application, services and devices which have user interaction. (Kirpes et al, 2019) Visualization of the E-mobility Systems Architecture model from Kirpes is introduced in figure 2.

V2X system architecture can be applied to E-mobility systems architecture model so it is used for use case modelling in this thesis.

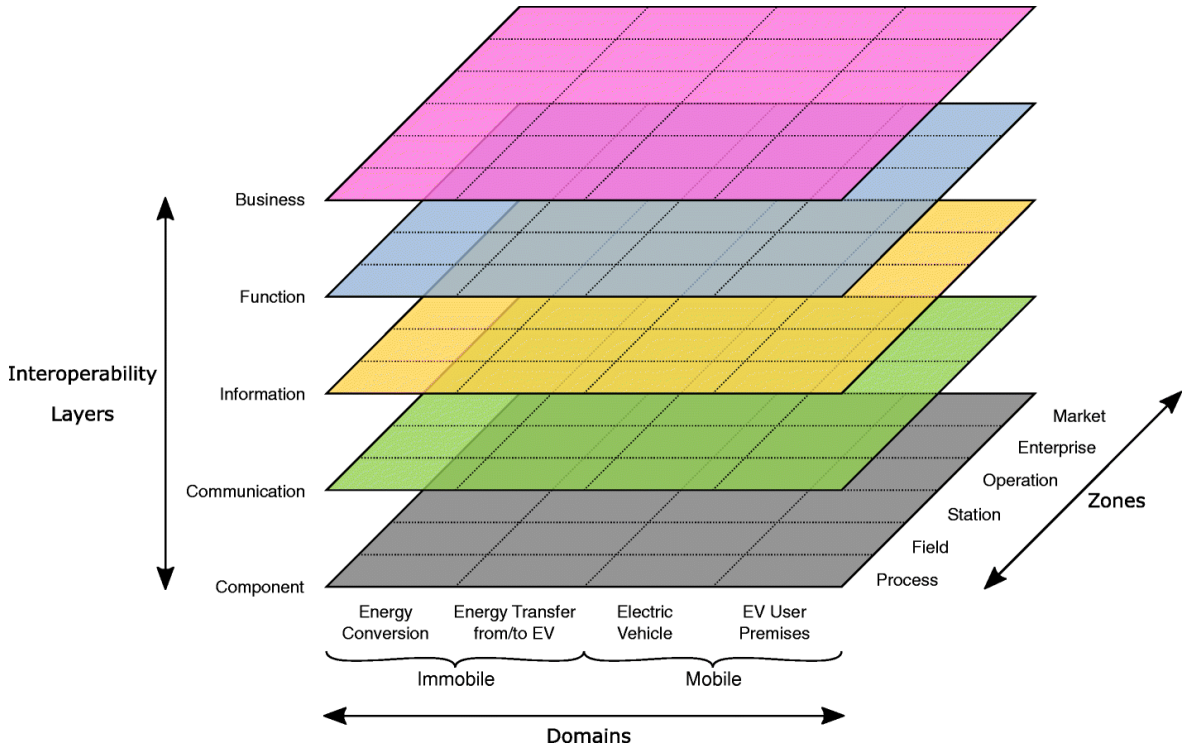

Figure 2. Visualization of the E-Mobility Systems Architecture (EMSA) model (Kirpes et al, 2019)

3 Bidirectional charging technology

V2G means that in addition to charging battery with energy from grid, power from EV battery can be discharged back to grid or loads. EV charging process first alternates AC current to DC with rectifier. Then DC current is alternated to acceptable level for EV battery with DC-DC step-down converter. Bidirectional charging has same two conversion processes but both ways. Bidirectional charging also requires a control unit for switching direction and input filter is needed at supply before rectifier/inverter as well as power factor correction (PFC). (Chiang et al, 2012) (Altin & Sarp, 2020)

Bidirectional EV charging can be implemented as on-board or off-board charging. In off-board charging AC-DC and DC-DC conversion is implemented inside charging point and the EV charger feeds EV the right level DC-current. In on-board charging the AC-DC rectification and DC-DC conversion is implemented in the EV and charger feeds EV AC-current. The most common type of charging currently is on-board charging. (Jain et al, 2022)

AC-DC rectifiers can have power delivered in one phase or three phase AC. One phase AC power supply is used for lower input power and three phase power supply for higher levels of power supply. Off-board charging is usually conducted with higher power level. (Jain et al, 2022) On-board charging can be classified to level one two and three chargers based on supply power. Levels one and two have single phase supply as level three has three phase supply and fast charging capabilities. (Islam et al, 2022) AC-DC or DC-DC converters can be isolated or non-isolated. Isolation in converters mean that the input of a converter is not directly connected to the output. This is usually achieved by placing a transformer between them. (Vadi et al, 2019) Non-isolated DC-DC converters offer better efficiency and lower cost and therefore are more preferred than isolated. Isolated DC-DC converter is more expensive but provides higher power density and ability for fast control. (Habte, 2020)

Bidirectional AC-DC converter function as a rectifier when EV battery is charged with grid power, and it can switch mode to be an DC-AC inverter when EV battery is discharged to grid. For bidirectional AC-DC converter can be bridgeless, half-bridge, or full bridge. Full bridge converters are most used bidirectional AC-DC converters, and they can be used in vehicle to home (V2H) mode in addition to normal charging and V2G. (Panchanathan et al,

2023) Rectifiers can also have multiple levels. Higher power systems require more levels to topologies. (Altin & Sarp, 2020)

Rectifiers distort current phase and therefore PFC is needed. It means shifting the current to same phase as voltage for efficiency improvement. (Chiang et al, 2012) PFC can be implemented passive or active way. Passive PFC refers to use of passive components such as inductor or capacitor that will manage the current to same phase as voltage. With passive PFC low total harmonic distortion cannot be usually achieved. Therefore, active power factor correction is preferred. Active power factor correction refers to active circuit controlling with feedback to reshape the current waveform. Bidirectional PFC can be obtained for example with bridgeless interleaved boost converter (Chiang et al, 2012), bridgeless totem-pole (Bentalhik, 2022) (Yu et al, 2020) or AC-DC dual active bridge (DAB) converter. (Johannessen, 2018)

Bidirectional DC-DC converters can operate in step-up or step-down mode. In step-down mode converter decreases voltage and increases current. Step-up mode converter increases voltage while decreasing current. (Madhumitha et al, 2023) For bidirectional DC-DC converter type buck-boost converters, dual converters such as dual-Cuk, dual-flyback and DAB, as well as half-bridge, half full bridge, full-bridge and forward-flyback converters have been researched. (Altin & Sarp, 2020) (Yu et al, 2020) (Vadi et al, 2019) (Habte, 2020) Interleaved topologies increases converter efficiency and decreases current and voltage ripple. It also decreases switching losses. (Madhumitha et al, 2023) Cascaded converters offer lower conduction losses and therefore higher efficiency. Also, resonant converters can be considered. Resonant converters have capacitors and inductors which resonate in certain frequencies. This offers enhanced efficiency to converter. (Bridha & Iyswarya Annapoorani, 2023)

4 V2X operators and terminology

V2X have various operators that enable the complex process. All operators and their roles in V2X process are explained in this chapter. These roles may differ among e-mobility applications and in variable use cases. Tasks involved in e-mobility system operation include the estimation and controlling of bidirectional charging, distribution of energy, upkeeping the e-mobility stations and services, energy market operations, providing of EVs, billing and parking management as well as energy system management.

An aggregator acts as handler of multiple EVs to comply their resources for supplying flexibility to the grid. Aggregator sells and buys energy when its beneficial and makes predictions of energy demand for EVs and benefit EV owners by managing the electricity buying/selling and electricity demand estimations. Aggregator usually must follow a load frequency control (LFC) signal in providing flexibility to grid. (Cai & Matsuhashi, 2022)

Charging point operator (CPO) controls the operation of charging point chargers in a parking lot and manage and upkeep the charging infrastructure. Charging point can support grid or building with the energy balancing gained with EVs. If building is supported CPO is communicating about energy requirements with building energy management system (BEMS) or if the grid is supported CPO may receive signals from local flexibility market platform (LFMP), aggregator, DSO, or other entity for energy exchange.

Distribution system operator (DSO) manages local grid distribution and its interactions, optimization, and forecasting and compensating actors offering resources. DSO engineers the distribution system most beneficial way for gaining, storing, and distributing the resources. This also includes the responsibility to integrate the flexibility resources to the distribution system and guide the CPOs for efficient spots for charging stations. DSO supplies the energy to charging station or home.

E-mobility system provider (EMSP) provides charging service such as applications for customers. These applications are easily accessible payment platforms that get customer information and provide information about charging point availability and charging process. EMSP usually also receives payment from customers through user interface and compensate CPO for management of charging infrastructure.

Electric mobility network management entity (EMME) operates the charging stations network. The network gives EV user the access to e-mobility energy markets. With the operation of this actor the interoperability between CPO and EMSP can be ensured. EMME monitors the energy and financial transactions in e-mobility network making decisions about charging station locating based on the information. EMME informs the energy markets company about the energy volume available by each bidirectional charging operator. (Redes, 2024) (Mobi.e, 2024) This entity operates in Portugal in which the other use case from this thesis locates.

Parking manager handles reservations and billing related to parking. Parking manager assigns the parking spaces to EV users and retains the information regarding parking session. Parking manager may give building manager or CPO information about available EVs in advance. Building manager is an actor that operates building's energy system. It monitors the loads and communicates with CPO or handles the charging operations by itself for optimizing the building energy system.

BEMS is a computational energy control system that manages buildings different parts and devices' energy consumption. This could include lighting, EV chargers, heating, or cooling. Home energy management system (HEMS) manages the home energy optimization. HEMS can control home EV charger and consumption of home electronics for tariff optimization. It can store the renewable energy from solar PVs to EV or optimize the energy consumption of home applications according to available energy. The operation of BEMS and HEMS enable the efficient use of renewable resources and increase the energy efficiency.

EV fleets are EVs used as a service to gain money for a company. Bidirectional charging can be utilized in EV fleets as it decreases the life cycle costs for those vehicles. EV Fleet operator manages EV fleet's operation, billing of customers and maintenance.

Clearing house is an entity moderating between other entities. It can monitor the e-mobility network and financial flows between EMSP and CPO for ensuring fair and interoperable transactions.

Local flexibility market platform (LFMP) is operator that aggregates flexibility resources to grid operator. It receives flexibility bids from grid operator and offers from local generation or flexibility resources and match them accordingly to location and price for efficient distribution. Local flexibility market platform manager operates the LFMP.

5 Applications

Bidirectional charging has multiple applications including V2G, V2H, vehicle to building (V2B) and vehicle to load (V2L). This chapter explores the possibilities, requirements, and challenges with these use scenarios. Figure 3 demonstrates smart grid with V2X applications.

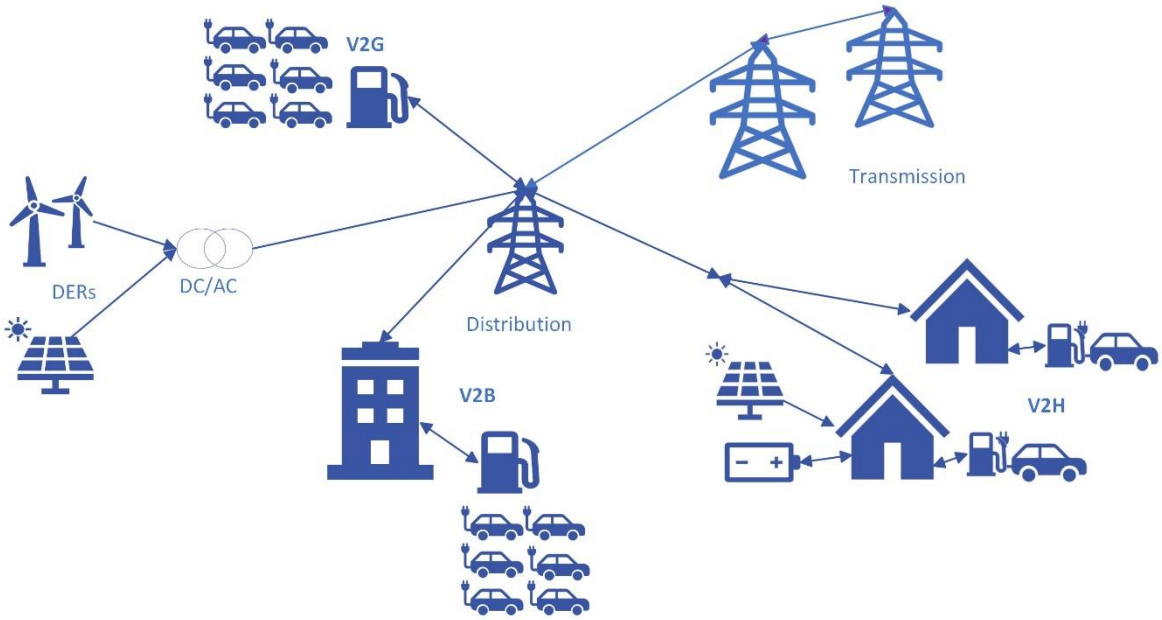

Figure 3. Smart grid with bidirectional charging applications.

5.1 V2G

In V2G scenario EVs act as a distributed energy storage for grid that can be used when vehicle is connected to charging point at home or parking station. Electric vehicles can be utilized in ancillary services such as spinning reserves or in peak power shaving, frequency regulation, or demand response. (Amamra & Marco, 2005) All these scenarios have the same purpose of grid balancing and ensuring its function. Frequency regulation and load shaving can be achieved with the active power gained from EVs and voltage support with reactive power. (Zhang et al, 2023)

Demand response means adjusting power consumption to times of grid low demand. This can be easily achieved with EVs since most of the time they usually are not in use. Charging

with demand response principal can be achieved in daily basis to gain lower electricity expenses for EV owners since the price of electricity is lower when grid is experiencing low demand. Demand response itself does not require V2G capabilities but can be utilized more effectively including adjusted discharging as well.

Frequency regulation is V2G application where constant frequency balancing is the main objective. (Nour et al, 2020) When grid is in high demand, electric vehicles can give needed energy to grid and when demand is lower electric vehicles can charge. This balancing helps to stabilize the voltage and frequency of grid. Frequency balancing of grid is essential since frequency deviation may harm electric equipment and disconnection from grid is done in that scenario causing a blackout. (Amamra & Marco, 2019) V2G can prevent events of grid malfunction and blackouts. Regulation could take place hundreds of times a day and reaction would be required in less than a minute and last some minutes which is more rapid use compared to spinning reserve application. With V2G frequency regulation better power quality is achieved, and need for stabilization capacity is reduced.

In Finland, the transmission system operator (TSO) Fingrid has frequency containment reserves (FCR) in which participation is possible through reserve markets. FCR are grid services created to ensure that the frequency of grid stays as near 50Hz as possible. FCR is divided to containment reserve for disturbances (FCR-D) and containment reserves for normal operation (FCR-N). FCR-N operates when frequency is in normal range and tries to keep frequency between 49.9 Hz to 50.1 Hz. FCR-D stabilizes the frequency in case of disturbances when frequency passes limits of normal range and the objective is to keep frequency over 49.5 Hz or under 50.5 Hz. Requirements for joining to FCR-N include minimum bid size of 0.1MW. FCR-D has minimum bid size of 1 MW. Participation can be achieved with smaller resources if various smaller resources are aggregated to pass the limit. Participation to FCR requires prequalification testing to prove the fulfilment of necessary features. (Fingrid, 2024) Fast Frequency Reserve (FFR) market is an application in which frequency containment reserves are activated in case of large frequency deviations. FFR can be activated as fast as in under seconds. Different reserve options include activation in 49.7 Hz within 1.3s, 49.6 Hz within 1s and 49.5 Hz within 0.7s. Participation to FCR and FFR must be achieved with automatic local control as Fingrid does not give controlling signals. (Fingrid, 2024)

Spinning reserve application refers to EV use as backup power for times when there is loss of generation. Spinning reserve should take requests from grid operator in case of generation deficit and provide energy in within minutes to hour. Vehicle owners could be compensated of the time in which EV is available for use as spinning reserve. (Wan et al, 2024) Typically requests for spinning reserve power are made about 20-50 times a year. (Ehsani et al, 2012) The duration of the spinning reserve need is typically hours. (Hu et al, 2016) For spinning reserve application, the Finnish TSO Fingrid has automatic frequency restoration reserve (aFRR). The reserves operate according to activation request send by TSO sent every ten seconds. The aFRR is acquired for specific hours in which frequency tends to vary the most. (Fingrid, 2024)

Peak shaving / Valley filling is an application in which power from electric vehicles is supplied in times of peak demand and charged during valley demand to achieve balanced supply and demand. Times of peak and valley demand depend on in which part of the world, day of the week and time of the year is but usually peak hours occur at evenings. Peak demand can overload network components as the grid experiences voltage drop and power losses. V2G in peak or valley demand can further reduce the need for additional power balancing capacity at those times and the cost for grid stabilization is reduced. (Nour et al, 2020) This benefits grid operator as demand for balancing capacity and new component upgrades decrease. EV owners can benefit by monetary compensation or decreased electricity bills.

V2G system requires charging stations and EVs allowing bidirectional charging and power conversion to both ways. It also requires intelligent controlling system to determine direction of energy flow in charging stations or at home charging point. V2G requires an aggregator to supply many EVs to grid since minimum bid size is in balancing reserve markets can be regulated. In Finland minimum capacity for FCR-N is 0.1 MW and for FCR-D, FFR and aFRR 1 MW. (Fingrid, 2024) These capacities cannot be gained from one vehicle and therefore aggregation of vehicle capacities is required. Also, billing of customers and customer preference and interface management is required. Large scale adaptation to V2G depends on customers approval to participate in bidirectional charging. Using EVs in grid stabilization could give EV owners monetary compensations so that large scale EV participation is achieved.

5.2 V2H

V2H involves utilizing EVs to support the energy demands of EV owners' homes. EV owners can benefit from dynamic electricity pricing more efficiently if EVs are used as energy storages. During low demand and low price of electricity, EV owners can store electricity in EVs. And respectively during peak demand and high electricity price, EV owners can use the energy stored in their EV batteries to power their homes or sell it in energy markets. Additionally, EV batteries can serve as backup power sources during grid blackouts, providing better energy stability to homes. (Vadi et al, 2019)

Prosumers, individuals who both consume and produce energy, can leverage EVs as renewable energy storage units. They can store excess energy generated from sources such as solar PVs in their EV batteries and later use it to meet their home energy requirements.

Implementing V2H applications requires a home management system equipped with smart energy management algorithms to efficiently manage the flow of electricity. Alternatively, an aggregator can also facilitate this process by coordinating energy usage between the EV and the home.

5.3 V2B

V2B is a concept in which EVs are used to power a building with bidirectional charging. It operates similarly to V2H but with more storage capacity as it could involve a whole parking lot full of chargers and EVs. V2B application can be used in building energy optimization and serve as renewable energy store and as backup power reserve. V2B can be also used in energy tariff optimization as V2B charging can be activated in times of peak demand and high price of electricity. (Zhou et al, 2021) If V2B is used in peak demand times it can also benefit more than just the building and EV owner. Large scale V2B integration can reduce peak loads in distribution system and even in the whole grid. (Nour et al, 2020) (Dagdougui et al, 2019)

Management of multiple chargers requires more complex monitoring and controlling. The management of multiple chargers can be achieved by operational entity such as CPO, building manager or an aggregator. V2B application must have information from building’s

energy system and entity to control bidirectional charging for energy optimization for which BEMS or building manager is required.

5.4 V2L

Electric vehicles can power just about any appliance or device if equipped with on-board converter for adaptation from DC to AC current. V2L brings possibilities to off-grid loads and security of supply to loads during grid blackouts. AC current offered by EV can be used in powering other EVs or any type of home electronics. (Bridha & Iyswarya Annapoorani, 2023) V2L can be taken advantage of as backup power for critical loads such as hospital equipment, elevators, power tools, military bases, and servers in times of energy shortage. (Islam et al, 2022) V2V applications can reduce range anxiety and bring sense of security to travelling. EV owner could set a limit to the discharging at which it would stop so that adequate level of charge is still left in EV.

V2L application requires adapter to the EV's charging port and an on-board charger that enables the control of charging/discharging operations. This requires manufacturers to recognize the benefit of V2L feature in EVs.

5.5 Challenges of bidirectional charging applications

For the technical constraints, all bidirectional charging scenarios include battery degrading due to more charging and discharging compared to situation where vehicle is not used in these applications. Control scheme for bidirectional charging has the most effect on battery degradation. Degradation is less significant in V2G application where charge and discharge cycles are more shallow and rapid. V2B, V2H and V2L applications require a larger energy throughput which leads to more battery degradation. Battery degradation can be decreased by minimizing time in high state of charge and average charge power as well as constraining temperature rise. (Thompson, 2018) It has been also studied that proper control of V2G could also extend battery life (Uddin et al, 2018) (Wei et al, 2022) Control scheme of bidirectional charging should consider the battery aging and offer remuneration accordingly to the degradation effects the control scheme causes. Uncertainty of degradation effects may diminish participation to V2X and therefore it should be discussed openly.

The increased integration of EVs to the power system and especially V2G application impact on supply and short circuit levels of the grid that can lead to safety and reliability issues since protection coordination schemes are affected. (Saldarriaga-Zuluaga et al, 2022) The safety aspects of V2G scenario require further consideration. Charger control topology and filter type will determine the level of impact the EV has on grid. (Clarke et al, 2014)

Aggregation of vehicles energy flow requires user information and control access to car charger which can evoke cyber security and privacy concerns. Threat of unauthorized access and data stealing must be considered. Privacy of personal data about location and user patterns must be ensured. (Vadi et al, 2019) Resent studies have assessed cybersecurity threats and safety mechanisms for V2X applications with promising solutions. (Sedar et al, 2023) (Saxena, 2017) (Wan et al, 2016)

Regulations and standardization for bidirectional charging applications is necessary for its safe and efficient operation. If there are many different types of charging scenarios, components, applications, and compensation methods participation can be challenging. Standardization can ensure that technological decisions are compatible and profitable and support the understanding and adaptation in any type of technological process. Also, customer portfolios need to be determined and considering and minimizing risks of changing customer behaviour. (Gschwendtner et al, 2021)

Bidirectional charging data management and controlling of multiple charging points is a complex task. V2G applications may have contradiction between the distribution grid needs, economic benefit of V2G and technical potential of EVs. (Gschwendtner et al, 2021) EV owners' preferences and EVs technical potential should be considered as well as proper incentives while still supporting grid needs. Electricity taxation may not be optimal in all countries to V2G utilization and double taxation may be an issue. (Noel et al, 2019) Smart charging algorithms are required for energy estimations and charging time optimization. (Zhang et al, 2023)

Investment in new innovative technology is indispensable for achieving large scale V2X utilization and benefits from it. EVs with bidirectional charging must be purchased to an extent that investing in new charging stations is profitable. EV prices play a big part in the large-scale customer participation. Information about bidirectional technology may not have reached the general population and therefore informative promotion of the topic and

addressing customer concerns could aid in embracing V2G concept. Participation to V2X concepts should be made simple and accessible. (Gschwendtner et al, 2021)

V2X utilization requires cooperation among multiple system operators. Entities included in parking of vehicles, charging control, network management, market operating, supplying of vehicles and billing must work together to gain an efficient and approachable e-mobility system. For proper understanding and engineering of the system architecture and technology of e-mobility use case description or system modelling is necessary.

6 V2X Use cases

This master's thesis introduces two V2X use cases from DriVe2X. The relevant market players, functions, components, information, and communication protocols are mapped in EMSA layers. Step-by-step description of use case operation is conducted. Therefore, the functionality and requirements of use cases are represented. In chapter 6.1 a V2B use case is introduced. It is demonstrated by Porto Airport in Maia, Portugal. The chapter 6.2. introduces a V2G use case demonstrated by Terni City Centre.

6.1 V2B at Porto airport

This use case studies the process of long-term V2B charging in an airport parking lot. This long-term charging could last from 12 hours to several days which offers great advantage for load balancing. The EVs support the airport's energy optimization and benefit building owner with decreased energy tariffs as EVs can operate as energy storages for renewable energy or low-price energy. Monitoring and management of airport's V2B activities require many entities including building manager, parking manager, EMME, EMSP and CPO. In this use case one entity plays the role of building manager, CPO, and parking manager but for clarity and repeatability of this use case these roles are kept apart many times.

6.1.1 Modelling of use case

The relevant market players of Porto airport V2B use case and their interactions are mapped in EMSA business layer found in figure 4. EV users utilize the parking services offered by parking manager and get information about available parking spaces and pay for the parking to them. EV users also give user information and pay EMSP for the provided charging electricity.

EMSP gains charging information from CPO to determine payments for customers and offers compensation to CPO from charging services. EMSP buys energy from market agent or acts as a market agent and pays network tariffs to DSO. EMME monitors the charging information and payments between CPO and EMSP as they use the e-mobility network.

Building manager purchases information needed in energy optimization for example energy price from energy markets and purchases energy for building. It receives charging information from CPO and give information of needed bidirectional charging actions. Building manager gets information of reservations and V2B capacity from parking manager. EMME exchange information with DSO for efficient charging station placement and building manager pays network tariffs to DSO.

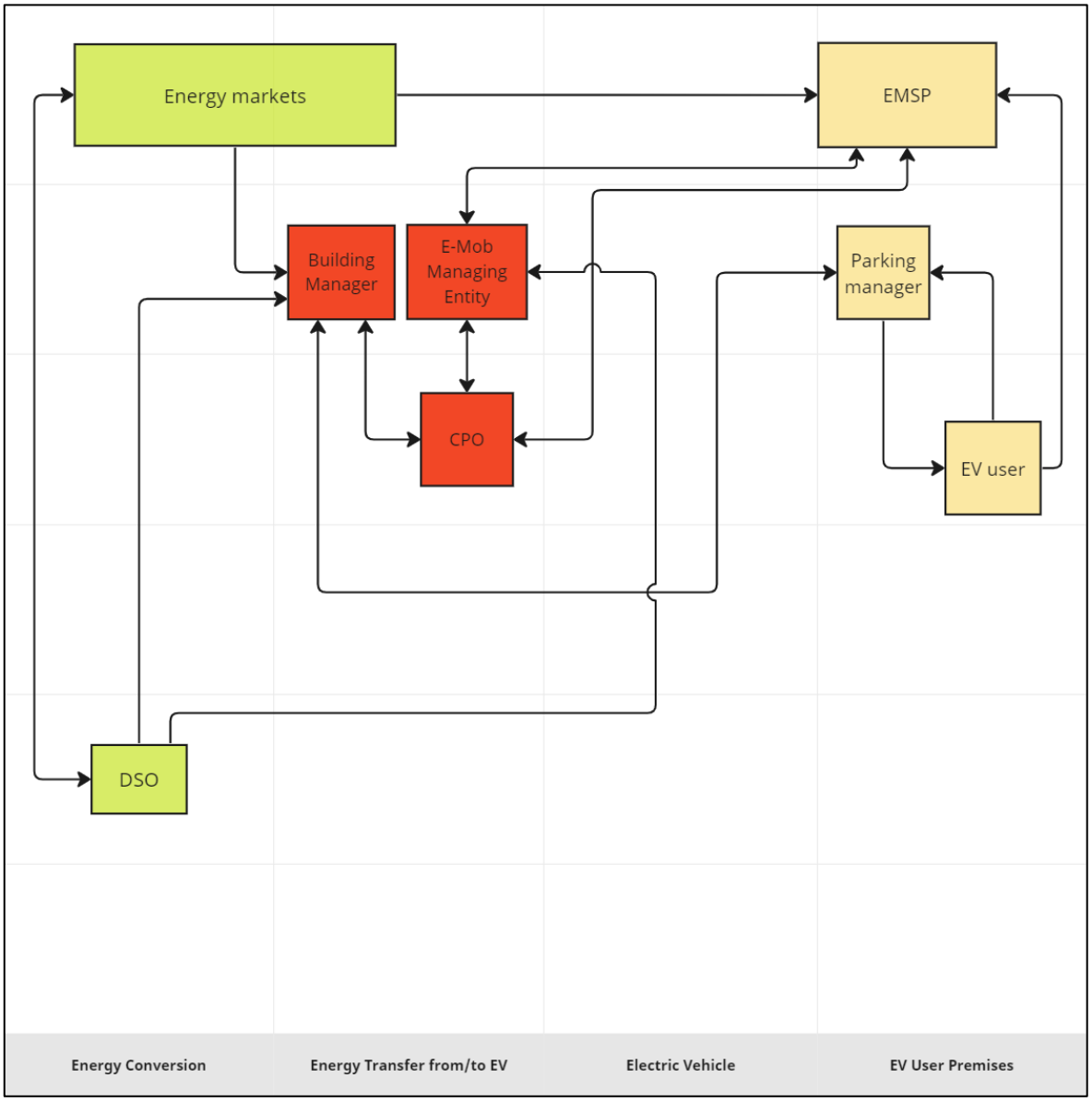

Figure 4. EMSA business layer for the V2B use case of Porto Airport. The colours represent different domains.

The functions of this use case are depicted in EMSA function layer found in figure 5. EV user services include functions occurring in applications and user interfaces such as parking

services offered by parking manager and charging services offered by EMSP. Parking management includes the parking reservations containment and management as well as billing for parking services. Charging slot management comprise the slot scheduling for EV users according to building and EV user preferences. Charging station (CS) management includes the maintaining operations of charging station ensuring the functionality. Smart EV charging control encompasses the controlling of charging operations including bidirectional charging. By EV management is meant EV's own system's functionalities such as measuring state of charge. Building automation means the automatic energy optimization of the building that the BEMS is conducting. Energy management refers to the optimization of energy usage or load balancing operations with V2B. Metering is a measurement of grid's, building's or charging station's energy state and transactions.

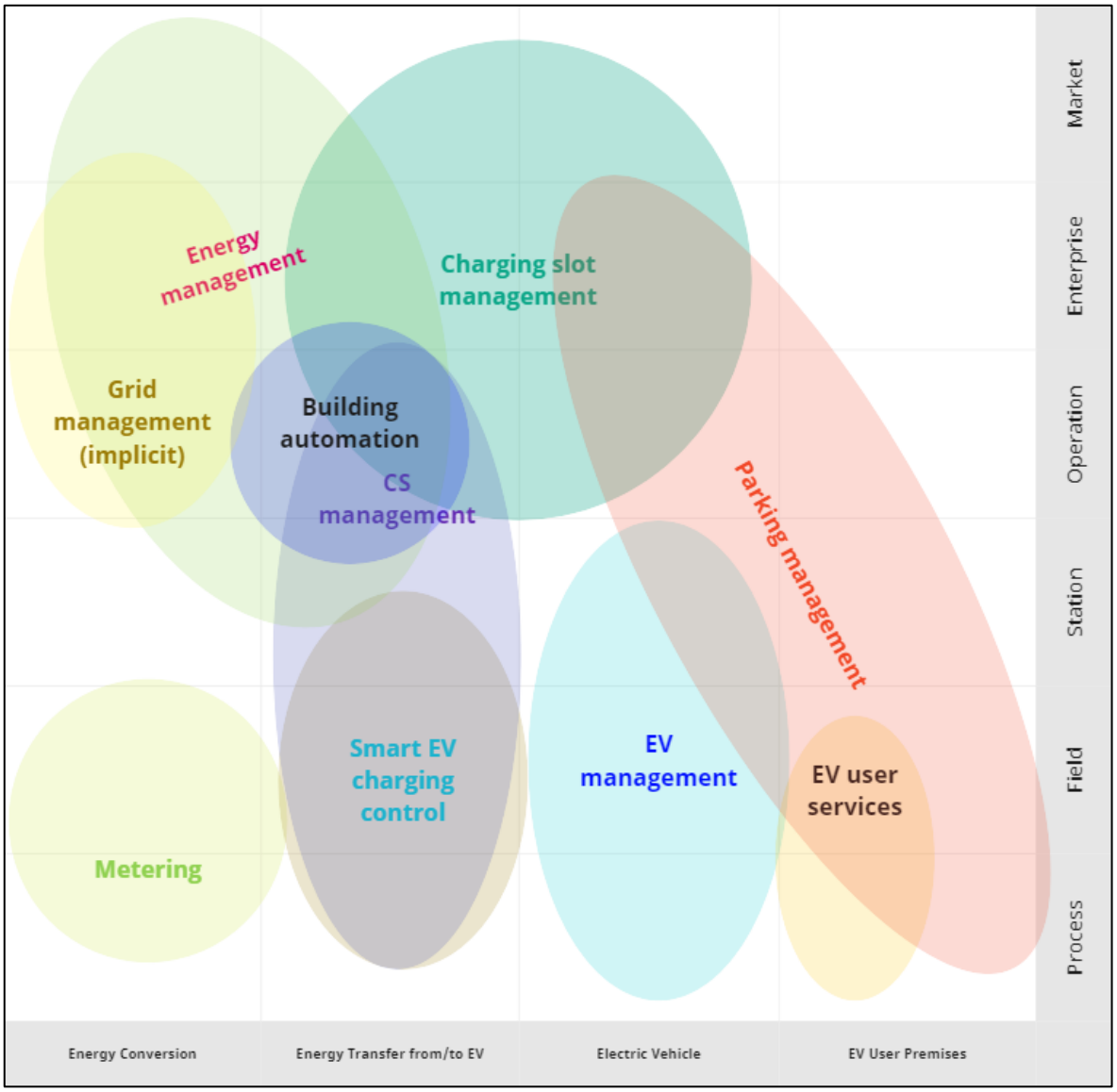

Figure 5. EMSA function layer for the V2B use case of Porto airport.

Necessary components for this use case are mapped in EMSA component layer in figure 6. In market layer EMME system monitors e-mobility market and data exchange as energy market system maintains the platform for energy trading. Enterprise level compromises CS operator system and parking management system. Parking management system preserves parking information and reservations and gets information from online booking user interface (UI). CS operator system upkeeps the charging infrastructure.

CS management system gains information from CS controller about charging operations in charging station. CS controller sends commands to the EVSE controller for charging operations. EVSE charging controller supplies EV with energy. EV systems include EV charging controller, battery management system and sensors and controllers for gaining

information about state of charge (SOC) and ending charging when battery is at minimum required state of charge.

Parking management system informs smart charging session web app about made reservation and Smart charging session web app informs parking management system about end of reservation. Smart charging session web app offers information about charging to EV user in ad hoc UI and receives user preferences and information of participation to V2B from there. Smart charging session web app communicates user information and stop/start of charging to CS energy management system (EMS).

CS EMS operates the bidirectional charging of EVs. CS EMS signals start/stop of charging to CS controller and which in turn communicates to specific EVSE controllers these commands. CS controller sends charging information to CS management system and CS EMS which in turn sends the information to BEMS for energy optimization. CS EMS receives information of reservation times from parking manager.

BEMS receives information from grid management system and energy market system about information needed for energy optimization such as energy prices. BEMS informs the CS EMS about energy demand for V2B discharging. Sensors and controllers measure bidirectional energy flow from vehicles to building and building energy consumption. Measurement devices send information about generation and consumption of energy to grid management system.

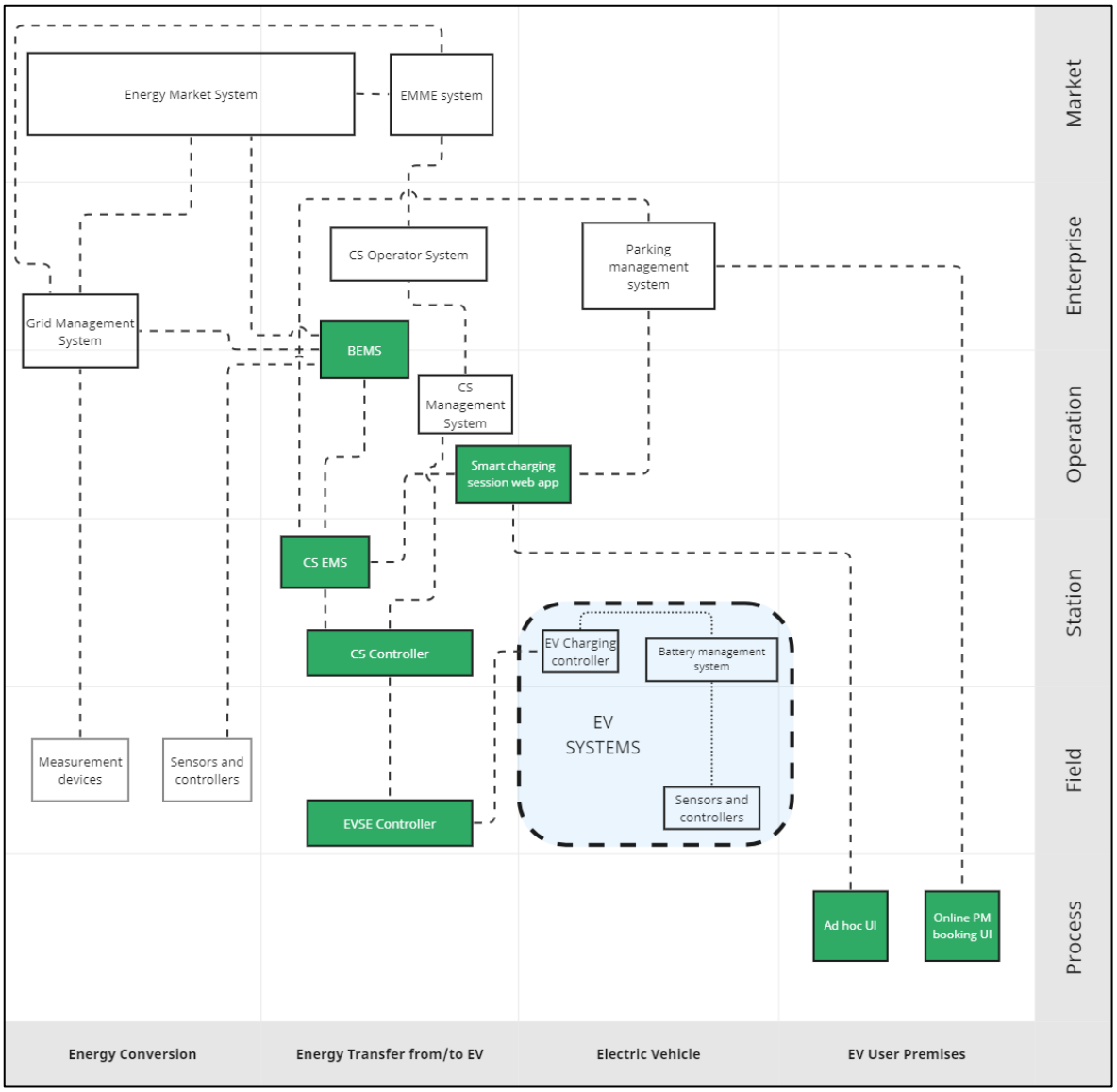

Figure 6. EMSA component layer for the V2B use case of Porto airport. The green coloured components are relevant for V2B functionality.

The information protocols used in exchange of data between different operating systems is mapped in EMSA information layer presented in figure 7. The information layer is mapped on top of component layer to visualize between which components the information protocols are used. In market level the energy market trading information and monitoring between EMME system, energy market system, CS operator system, BEMS, and grid management system and is exchanged with Representational state transfer (REST) protocol. It is also used in information exchange with UI. REST defines the type of architecture used for software interfaces in the web. Open charge point protocol (OCPP) defines communication standards between charging station and charging station network. IEC 61850 standardizes electrical

substation communication, and it is used in information exchange between grid management system and measurement devices. IEC 62196-3 gives standardization to EV connectors requirements and therefore it is used with CS controller and EVSE controller. IEC/ISO 15118 is standard used in EV and charging station communication. Information protocols of this use case are mapped in EMSA information layer in figure 7.

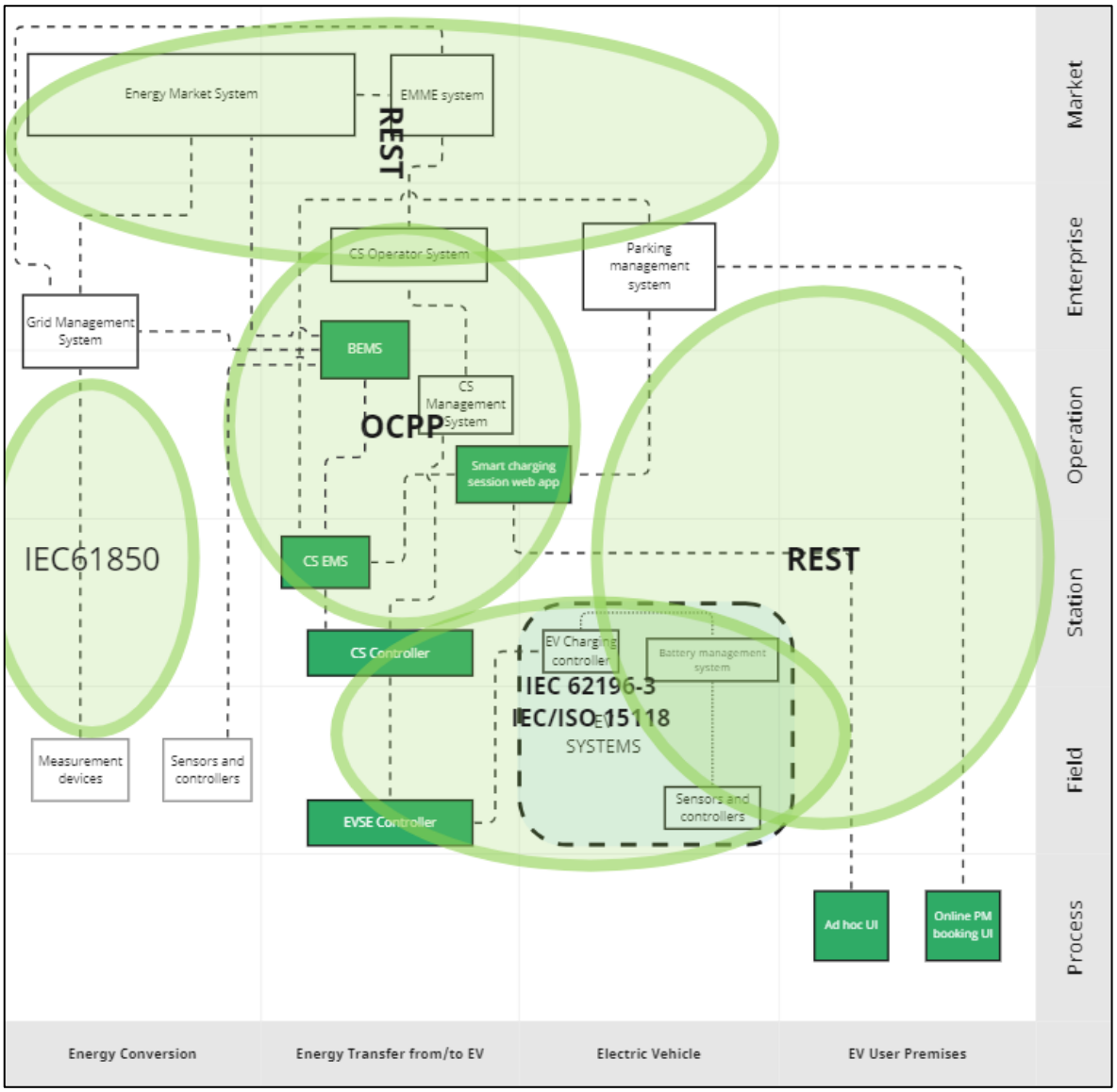

Figure 7. EMSA information layer mapped on top of component layer for the V2B use case of Porto airport.

The EMSA communication layer provides the communication protocols required for this use case and it is presented in figure 8. Communication standard used in energy market information exchange could be transmission control protocol (TCP) or user datagram protocol (UDP). TCP and UDP are communication protocols that defines information

exchange in network between applications. The difference is that TCP requires a connection between source and destination as UDP does not. These protocols are used in charging station information exchange between system operators and management systems and applications as well as between energy management, measuring devices, parking management and EMME. Hypertext transfer protocol secure (HTTPS) is a protocol for safe transfer of information on the web. It is addition to HTTP protocol to ensure that the data transfer is encrypted both to and from the server. In this use case it is used in information exchange to/from user interfaces.

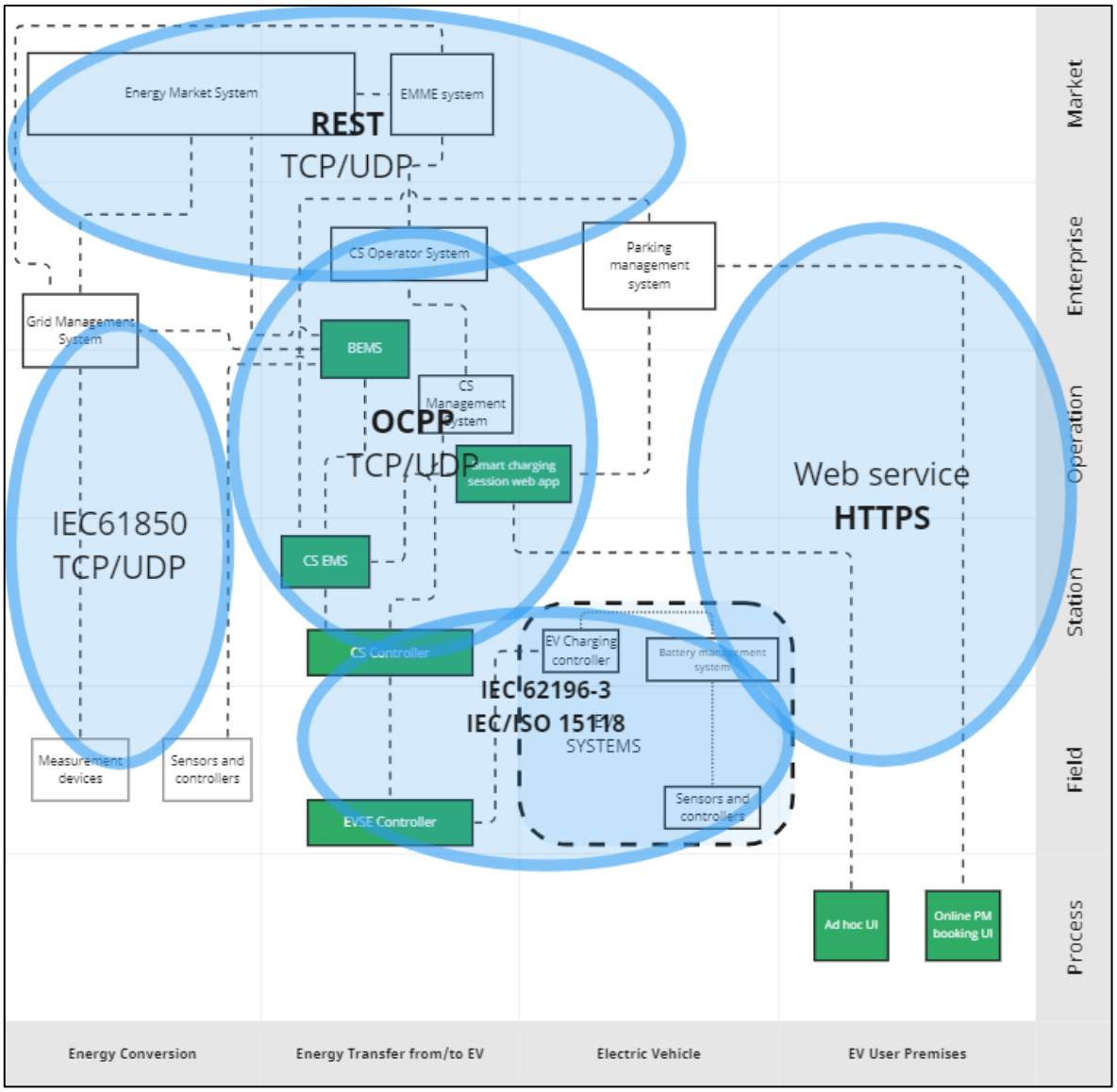

Figure 8. EMSA communication layer mapped on top of the component layer for the V2B use case of Porto airport.

6.1.2 Description of use case

This chapter explains the use case steps and operation more detailed and chronologically. Information about use case including main success scenario is given in table 1 and use case steps are in table 2. Use case summary is given below.

Use case summary
EV user books parking lot space from online booking UI operated by parking manager. Parking manager reserves the space for EV user. EV user accepts the V2B participation and starts charging in ad hoc UI. Smart charging session web app sends the charging command to CS EMS which sends it to CS controller. CS controller commands EVSE to start charging and gains charging information from it. CS controller sends this information upstream. CS EMS informs BEMS to start energy optimization. BEMS receives information from DSO and energy markets required for energy optimization. BEMS controls the bidirectional charging through CS EMS. When charging session ends CS EMS sends charging session data to smart charging session web app which transfers it to UI.

Table 1. Use case details of Porto airport V2B.

Use Case name	Long-term V2B charging with load aggregation in parking lots for dynamic load balancing and BEMS integration
Primary actor	EV User
Goal of primary actor	- Charging of EV, with designated SOC at disconnection time to ensure mobility needs. - Offset EV upfront costs by capturing additional value streams from V2B strategies.
Technical actors	Parking management system, smart charging session web app, CS EMS, CS controller, EVSE controller, BEMS, ad hoc UI, online PM booking UI
Main success scenario	EV user prebooks parking or arrives spontaneously to the airports parking area equipped with bidirectional

	chargers. Car driver plugs car in to the charger and triggers bidirectional charging event using ad-hoc user interface. During the charging event car's battery together with charging equipment contributes to buildings energy balance in harmony with other possible energy resources. When the charging event is terminated the car's battery is at full charge or at the predefined target state-of-charge to ensure effortless operation of the car by the driver. The EV user leaves the airport.
Prerequisites	- Regulatory sandbox from Regulator entity - Pre-installation of infrastructure - Commercial partners collaboration and Integration - Charging port compatibility

Table 2. Porto airport use case steps.

Step	Action	Linked information exchange	Linked components' use
1	User accesses online parking reservation system from ANA and books (and pays) parking slot, accessing the airport parking lot	Reservation confirmation, payment details	Online Parking Management Booking UI, Parking Management System
2	EV driver plugs car into the bidirectional charger, beginning charging event	ISO 15118-20 information of the plug-in event	EV charging controller, EVSE controller
3	EV user interacts with UI to initiate V2B services, accessing online EV charging web app	Service availability, smart charging session creation	Smart charging session WebApp, Ad-hoc UI
3.1	For enrolment with DriVe2X, EV driver accepts General Data Protection Regulation (GDPR) and registers user account (if not done earlier)	Acceptance of GDPR and registration of user credentials	Smart charging session WebApp

Step	Action	Linked information exchange	Linked components' use
4	EV driver inputs smart charging session information	Input of estimated departure time and minimum SOC preference at that time	Ad-hoc UI, Smart Charging Session WebApp
5	EV driver confirms all the inputs, which sends signal to initiate charging session	Start of charging command	Ad-hoc UI, Smart Charging Session WebApp
6	Online charging app sends messaging with data input to CS EMS	Relay of charging requirements, and user preferences' data	Smart charging session WebApp, CS EMS
7	CS EMS in turn signals specifically allocated charger to initiate charging	Charger selection and scheduling, start command	CS EMS, CS Controller
8	Charger and EV Handshake: A communication handshake occurs between the EV and the charging station, initiating the charging session using ISO 15118-20	Handshake confirmation, protocol agreement, vehicle data streams	CS Controller, EVSE Controller, EV Charging controller, EV BMS
9	CS controller sends session information upstream and starts relaying OCPP messaging on charging event	Session information sent upstream, continual OCPP messaging	CS Controller, CS EMS, CS Management System, CS Operator System, Energy Market System
10	CS EMS sends charging session information to BEMS, which initiates optimization of charging session within the boundary conditions to meet building's energy balance targets	Sends session info to BEMS for energy management optimization	CS EMS, BEMS
10.1	BEMS interacts with the energy markets and DSO to acquire data that supports optimization goals	Messaging between BEMS, Energy markets and DSO using OpenADR, OSCP	BEMS, Grid Management System (DSO), Energy market System
11	Event is stopped via user input to the EV charging web app or Ad-hoc UI	Session termination	Ad-hoc UI, Smart charging session WebApp, EV Charging controller

Step	Action	Linked information exchange	Linked components' use
12	The web app backend sends session end signal to CS EMS	Session end signal sent	Smart charging session WebApp, CS EMS
13	CS EMS terminates charging session and sends termination signal to CS controller	Session end signal sent	CS EMS, CS controller
14	CS controller sends charging session terminations signal to EVSE controller, which terminates EV smart charging session and results in unlatching of the charging port (locking mechanism)	Event termination signal sent	CS Controller, EVSE controller
15	CS controller sends signal upstream that charging session has ended	The session has ended	CS controller, CS EMS
16	CM EMS sends session statistics to Smart charging session WebApp server, which compiles charging statistics report for Ad-hoc UI	Receives session status	CM EMS sends session statistics to Smart charging session WebApp server, which compiles charging statistics report for Ad-hoc UI
17	CM EMS sends session statistics to Smart charging session WebApp server, which compiles charging statistics report for Ad-hoc UI	Receives session status	CS EMS, Smart Charging Session Web App, Ad-hoc UI
18	EV driver is offered possibility of seeing event statistics in UI, and is informed of billing (if applicable), after which vehicle is unplugged	Displaying of charging statistics and billing information to user (by user discretion)	Smart Charging Session WebApp, Ad-hoc UI
19	EV charging web app considers outcomes of smart charging session and informs parking management system of cleared up parking slot	Parking information sent to parking manager	Smart charging session WebApp, Parking Management System
20	User leaves airport	N.A.	N.A.

6.2 V2G at Terni city centre

This use case studies process of short-term bidirectional charging at Terni city centre. It aims to relieve reverse power flow issues caused by growing RES integration in distribution grid by deployment of V2G charging. V2G can help in balancing of grids demand and supply and decrease the balancing costs for grid operator. EV users can benefit from offering their EVs to flexibility campaign by permission. Participation offers EV user monetary gain compared to one way charging which creates an economic incentive for EV users to use V2G services. This use case can facilitate the growing renewable energy integration and decrease emissions as the need for reserve generation decreases and the efficiency of energy system increases. In chapter 6.2.1 the EMSA layers for this use case are presented and 6.2.2 offers step-by-step use case description.

6.1.3 Modelling of use case

The EMSA business layer contains the market players included in the use case of Terni city center. EMSP provides the EV user UI for monitoring and controlling the charging. EMSP also compensates and bills the EV user according to the charging and V2G services provided. EMSP buys energy from energy markets and gives flexibility offers to the market platform manager. EMSP compensates CPO for charging station management and CPO gives information to EMSP about charging operations.

Clearing house monitors transactions between EMSP and CPO and ensures interoperable and proper operation of payment systems. Market platform manager gains knowledge of available flexibility from EMSP and the demand for flexibility services from DSO. It also informs the accepted bids to these entities. DSO collaborates with CPO to design V2G charging places in beneficial places. This requires information about charging and discharging taking place in charging stations and information about other flexibility services and demand nearby. DSO also upkeeps the distribution grid feeding CS.

DSO share information with the energy markets. TSO collaborates with DSO in grid engineering and share information concerning grid congestion management and balancing of grid.

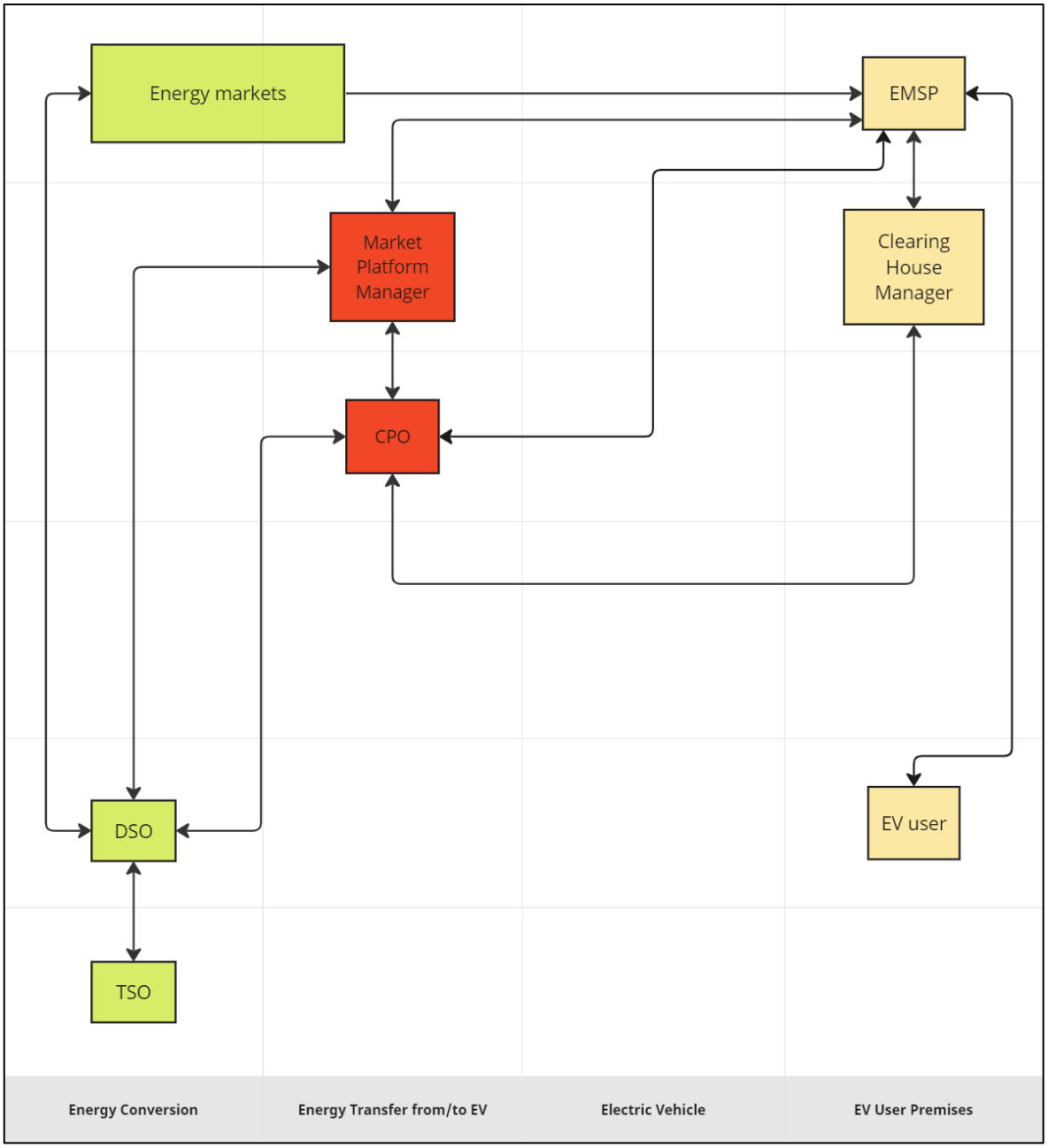

Figure 9. EMSA business layer for Terni city center V2G use case. The colors represent different domains.

The essential functions of the Terni city center V2G use case are mapped in EMSA function layer in figure 10. EV user services are application functionalities offered by EMSP such as commanding start of charging or accepting participation to V2G or payment actions. Charging slot management includes the allocation of charging slots to EV users. EV roaming allows smart charging to occur outside of service providers network. EV charging flexibility aggregation is a function that involves the local flexibility market platform to take advantage

of the flexibility from EVs and trade it to DSO. Energy management is operated by CS EMS as it optimizes CS energy usage for example by dynamic EV charging load management or voltage regulation. Grid management and reverse power flow management includes the balancing of grid generation, storages, and distribution capacities so that grid stability is achieved. Metering means the measurement of used and received energy so that accurate payments, compensations, and analysis can be made of trading activities. CS management refers to the upkeeping of charging stations. Smart EV charging control is the management of chargers and bidirectional charging actions. It is conducted by CS EMS, CS controller and EVSE controller. EV management is the measuring and operations occurring in EV and controlled by EVs components.

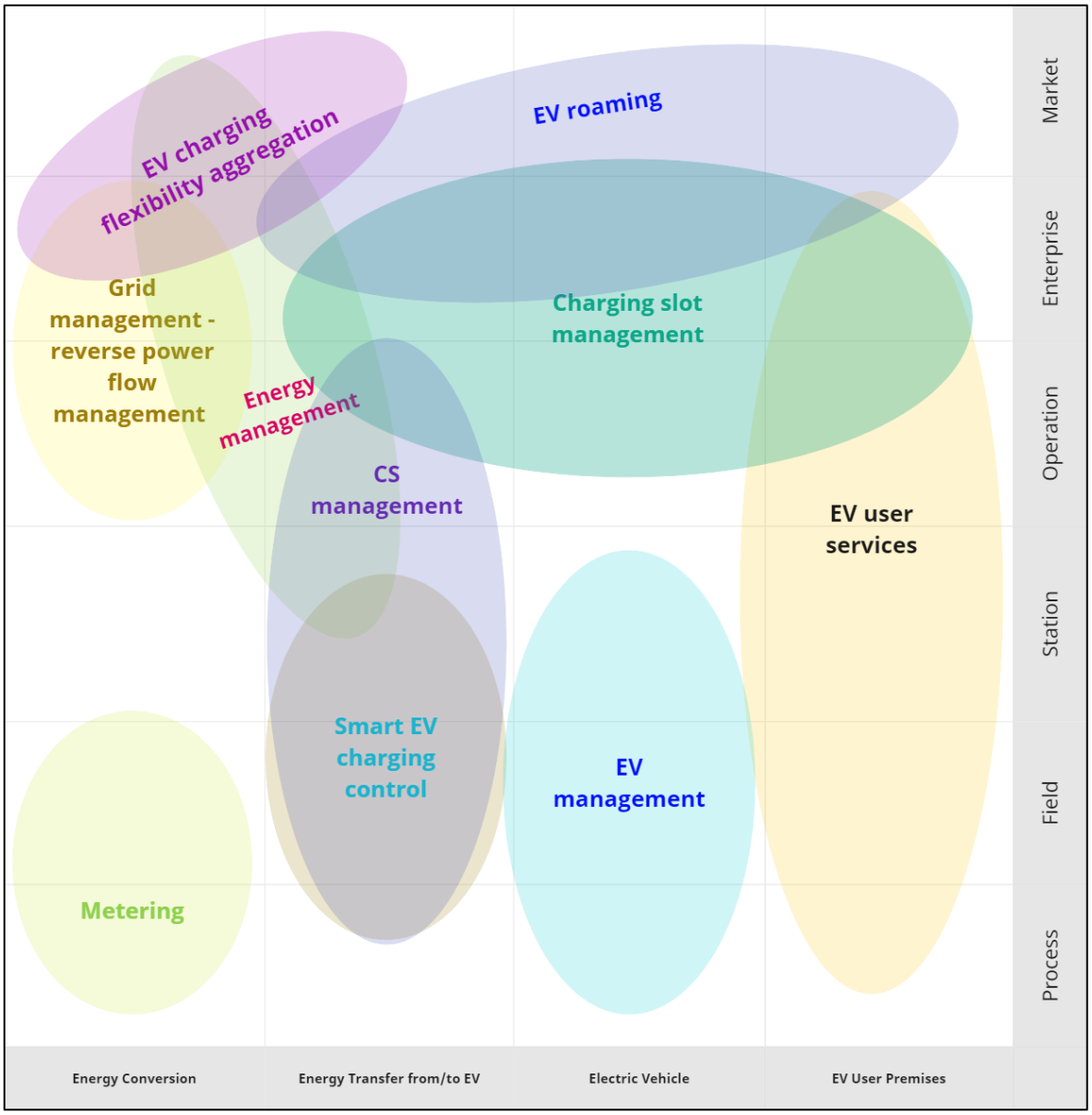

Figure 10. EMSA function layer for Terni city center V2G use case.

The EMSA component layer gives a demonstration of the relations of components in the use case's operation. Figure 11 illustrates the EMSA component layer for Terni city center use case. EMSP system gains user information, preferences, and permission for V2G charging through application for EV services. EMSP system receives command for start and end of charging from application for EV services. EMSP sends CS controller request to charge/discharge through CS EMS.

EMSP system gains information about EV SOC from sensors inside the EV and monitoring devices of charging station. EMSP purchases energy from energy market systems and offers

flexibility from EVs to LFMP. EMSP offers CS operator system compensation for charging services. Clearing house monitors the financial transactions between them.

LFMP receives requests from DSO dashboard and offers from EMSP system. Grid management system gets information from measurement devices about the grid energy transactions. Forecast service informs the forecast made according to measurements to DSO dashboard. The grid management system receives information from the energy market system about energy trading and gives DSO dashboard information about needed flexibility services.

CS EMS receives information for energy optimization from energy markets systems and receives information from EMSP about charging preferences. It commands the CS controller which in turn operates the EVSE controller to either supply or discharge energy from vehicles. CS controller also informs about charging actions upstream to the CS management system that informs the CS operator system. EVSE controllers gain information about the SOC from EV.

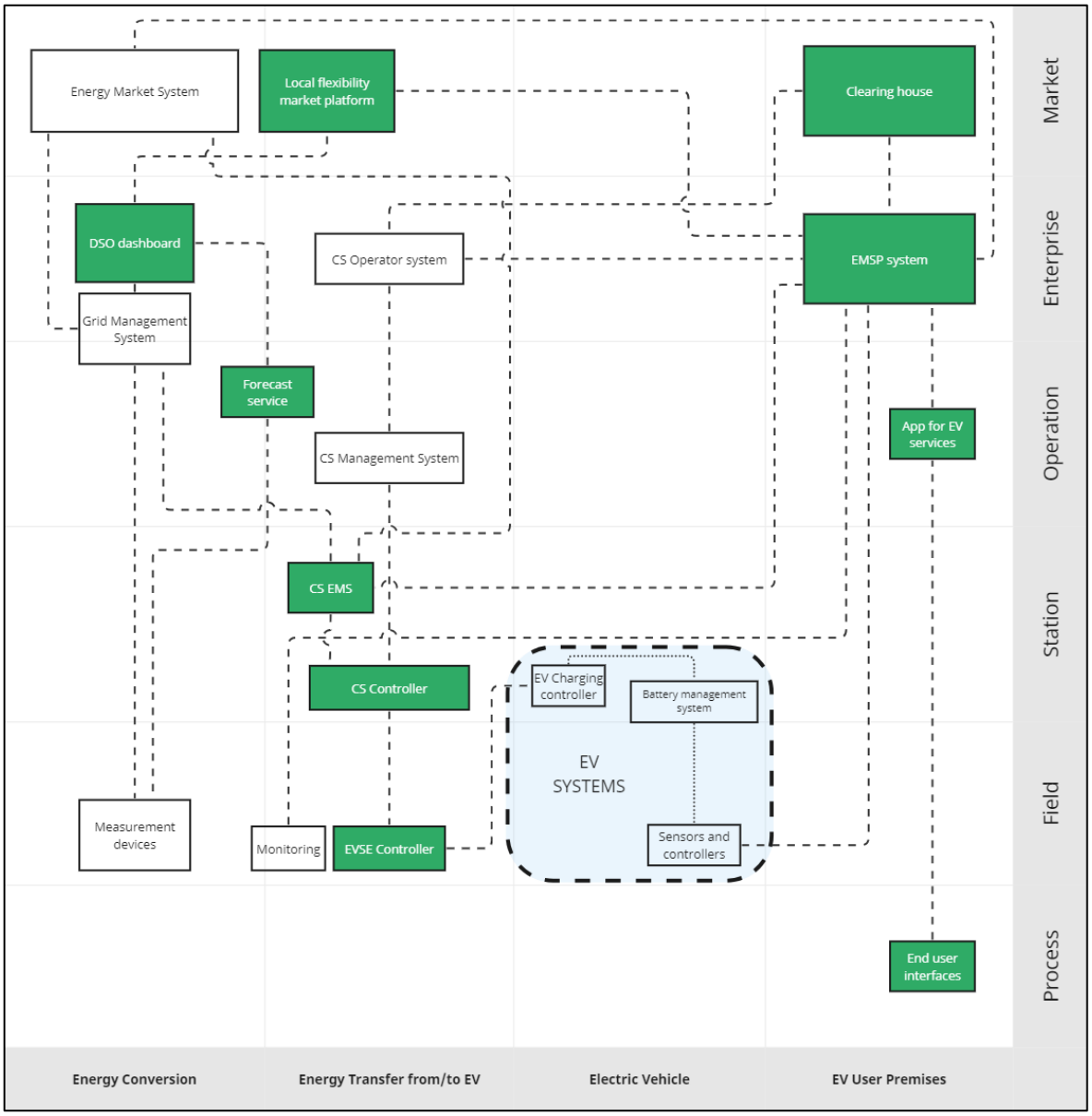

Figure 11. EMSA component layer for Terni city center V2G use case. The green colored components are relevant for V2G functionality.

The relevant information protocols of the use case are presented in figure 12. Rest API is an application programming interface that conforms to the REST principles of design. It is used in enterprise and market level communication between energy market systems, local flexibility market platform, CS operational system, EMSP system and clearing house. It is also utilized in communication between applications for EV services and end user interfaces.

OCPP can be used in charging station communication. Message Queuing Telemetry Transport (MQTT) is a communication protocol for network information exchange used in machine-to-machine messaging. MQTT can be used for this use case in information

receiving from sensors, monitoring, and measurement devices. IEC 62196-3 and IEC/ISO 15118 are used, as in Porto airport use case, for connector requirements and EV and charging station or EMSP interaction.

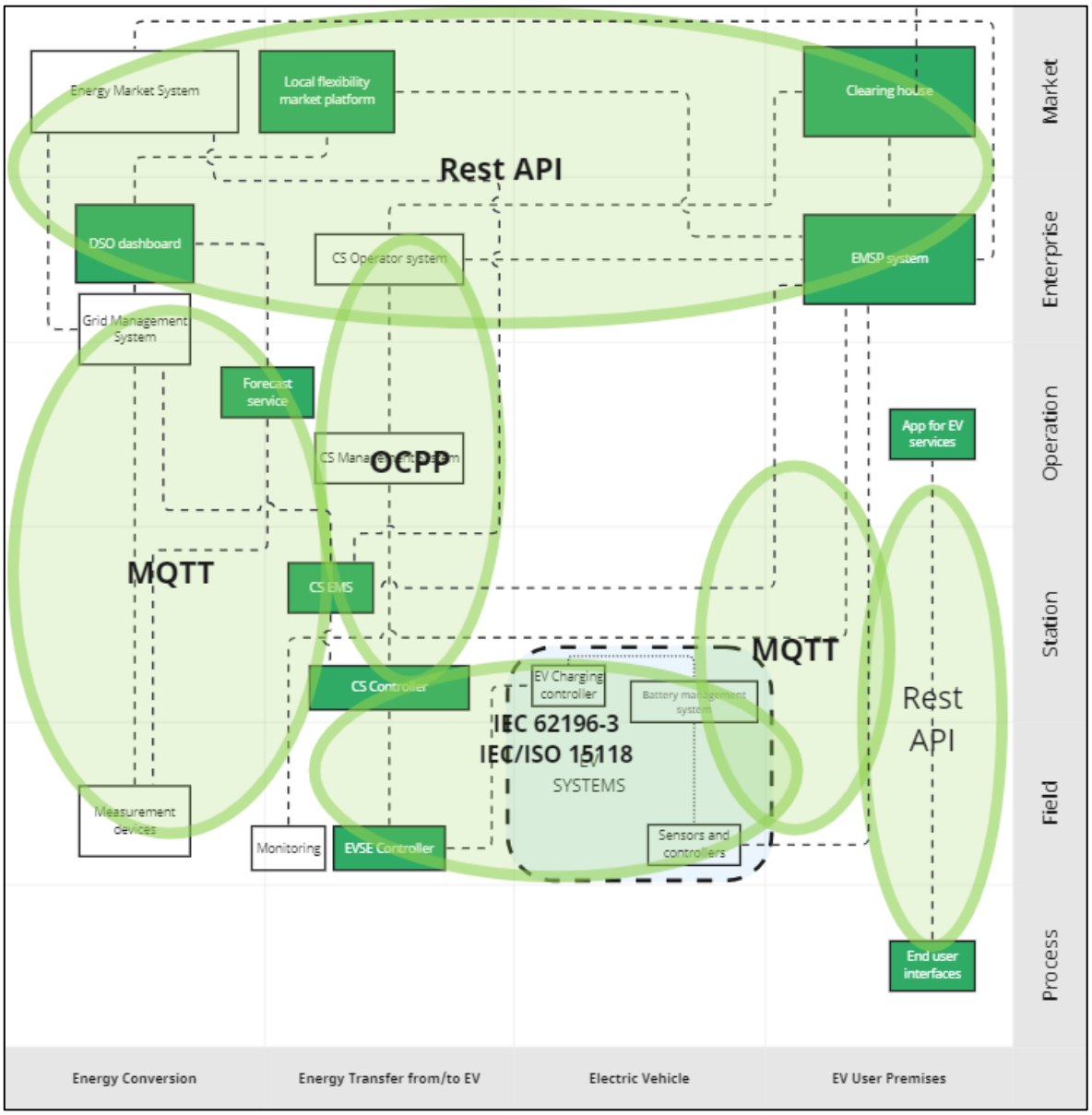

Figure 12. EMSA information layer mapped on component layer for Terni city center V2G use case.

The communication protocols used are defined in EMSA communication layer depicted in figure 13. HTTPS is utilized in market and enterprise level communication between energy market systems and clearing house, EMSP system, CS operator system, LFMP and DSO dashboard. It is also used in information exchange between application and user interface.

TCP/IP is used in communication to measurement and sensory devices and controllers. The same IEC standards are valid as in information layer (figure 12) between vehicle and EVSE controller or EVSE controller and CS controller.

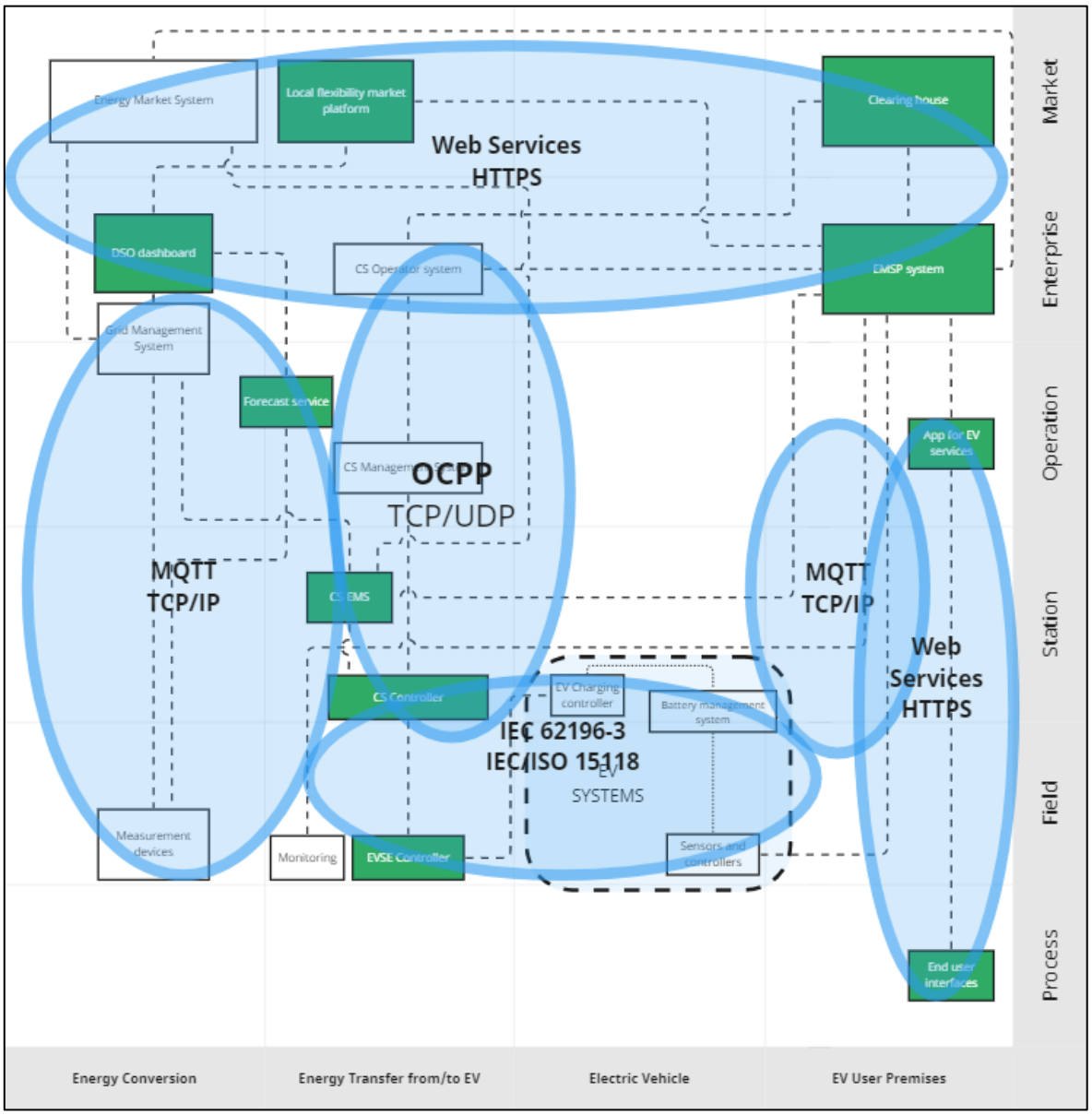

Figure 13. EMSA communication layer mapped on top of component layer for Terni city center V2G use case.

6.1.4 Description of use case

This chapter focuses on the detailed description of the operation of this use case. This approach explains the actions of each component involved and exchanged information in more detail and explain the operation more chronologically. Table 3 offers use case details and tables 4-7 present the Terni city center use case steps. Also, summary of the use case is given below.

Use case summary
User registers to application offered by EMSP. EV users get list of DSO flexibility requests through application from EMSP and EV user chooses participation conditions such as SOC and time of return and accepts to participate to bidirectional charging. User starts charging using UI. EMSP sends charging commands to CS controller which conveys it to EVSE controller that supplies the EV. EVSE controller collects the charging information. EMSP sends flexibility offers to LFMP according to user conditions. LFMP gets a list of bids and accepts the best bid. Information of accepted bid goes to EMSP that commands discharging through CS controller. User gets verification of trades to UI from EMSP. EMSP controls charging events accordingly until user returns and stops charging either from UI or from EVSE controller. EMSP receives charging information from EVSE controller and calculates payment. EV user pays the charging in UI.

Table 3. Terni city center V2G use case details.

Use Case name	V2G integration in public charging stations for addressing technical grid constraints
Primary actor	EV User
Goal of primary actor	- Charging of EV, with designated SOC at disconnection time to ensure mobility needs. - Offset EV upfront costs by capturing additional revenue streams from V2G services.

Technical actors	LFMP, clearing house, EMSP system, app for EV services, end-user interfaces, DSO dashboard, forecast service, CS EMS, CS controller, EVSE controller
Main success scenario	EV user uses an EMSP UI to identify an available charging point. EV user drives EV to that public charging station and plugs it into the charger. The UI invites EV user to participate in a DSO flexibility campaign, which suggests that revenues from V2G services could be attained. If EV user agrees to do so, a bidirectional charging session starts. During the smart charging event, the car's battery through the charging equipment offers demand/supply balancing to the distribution grid, with various charging/discharging cycles. When the charging event is terminated, EV user's car's battery is at full charge or at the predefined target SoC to ensure the least disruptive operation possible of the car and that mobility goals are reached. EV user is notified by the EMSP UI of how much revenue he made from V2G services. EV user leaves the charging station.
Prerequisites	- Application in place for user that has registered to it. - V2G compatible EV - Forecasting of energy demand by EMME - DSO evaluates future energy requirements

Table 4. Terni city center use case steps.

Step	Action	Linked information exchange	Linked component's use
1	EV driver arrives to the parking area.	N.A.	N.A.

2	EV driver plugs car in to the bi-directional charger to begin charging event.	ISO15118-20 information of the plug-in even	EV charger controller, EVSE controller
3	EV driver interacts with EMSP UI.	Session creation	EMSP UI, Smart charging session webapp
4	EV driver opts for bidirectional charging and DSO flexibility campaign and accepts GDPR notice (registers if not already registered).	Consent for data processing and registration details	EMSP UI, Smart charging session web app, potentially EMSP system for registration
5	EV driver sets estimated departure time and preferred SOC at the time of the departure.	Desired SOC and departure time	EMSP UI, Smart charging session web app
6	The EV driver starts charging event using EMSP UI (or event starts automatically after required data is inputted and campaign is approved)	Command to start the charging session	EMSP UI, Smart charging session web app, CS EMS
7	EMSP processes request and sends start signal to CS controller while also starting to interact with flexibility market.	signal for charging, energy usage data for billing	EMSP, CS controller, Local flexibility market platform
8	CS controller sends start signal to EVSE controller.	signal for charging session, session details	CS Controller, EVSE Controller
9	EVSE controller initializes session with the vehicle and subscribes real-time data streams according to ISO15118-20.	Real-time data stream subscription,	EVSE Controller, EV Systems

		session initialization	
10	EMSP continues interacting with the local flexibility market. EMSP triggers CS setpoint commands accordingly.	Bidding information, flexibility offers, CS controller setpoints	CS controller, Local flexibility market platform, EMSP
11	Event is stopped via user input to the EV charging control system, and communicates session termination to the EVSE controller, which subsequently informs CS EMS, and smart charging session web app. Alternatively, the charging event can be stopped via ad-hoc mobile app. Stop signal triggers final settlement of the session.	Stop signal for charging session, session termination data	EMSP UI, EVSE Controller, CS EMS, Smart charging session web app
12	EV charging web app summarizes the charging statistics and informs EV driver of the statistics and payments.	Charging statistics and payment statistics or information	Smart charging session web app
16	EV driver leaves the area.	N.A.	N.A.

Table 5 - User accepts to participate in the DSO flexibility campaign.

Step	**Action**	**Linked information exchange**	**Linked components' use**
1	User gets list of DSO requests	List flexibility requests	EMSP system UI

2	User sets preferences (price, minimum state of charge of EV)	User preferences	EMSP system UI
3	User requests to participate in a specific DSO flexibility campaign	Flexibility offer	EMSP system UI
4	The EMSP system puts flexibility offer in the marketplace	Flexibility offer	Marketplace
5	User gets confirmation	Flexibility offer	EMSP system UI

Table 6 - Requests and offers matching.

Step	**Action**	**Linked information exchange**	**Linked components' use**
1	The market session closes	N.A.	Local Flexibility Market Platform
2	The Marketplace gets the list of bids	Bids information	Local Flexibility Market Platform
3	The Marketplace determines the best bid in order to better respond to DSO's request	Bids information	Local Flexibility Market Platform

Table 7 - Verification and payment settlement.

Step	**Action**	**Linked information exchange**	**Linked components' use**
1	Real-time charging data provided by the EVSE is properly retrieved	Charging data	CPO system
2	The DSO unlocks payment for the flexibility request	Payment transaction	EMSP system

3	The EV owner gets the incentives for flexibility offered	Payment transaction	EMSP system
4	The EMSP gets economic benefits for providing service	Payment transaction	EMSP system

7 Conclusions

V2X is a way to utilize EVs as flexibility resources by bidirectional charging to grid or loads when EVs are not in use. V2G can be utilized in balancing peak demand and variable RES generation by management of charging and discharging according to grid requirements. V2B and V2H can be used for tariff optimization and V2L supply loads in times of need. V2B and V2H can benefit EV users and building owners by discounts and decreased energy costs as V2L with security of supply in off-grid solutions or grid malfunctions. Grid operator can benefit from V2G as demand for expensive reserve capacity decreases. Using EVs as distributed energy sources enhances the energy system efficiency and facilitates renewable energy and e-mobility integration while decreasing emissions.

V2X requires cooperation among system operators and interoperable communication. Use cases as a method for designing and explaining smart grid system architecture can foster coherent and interoperable systems and help in determining system requirements. Presented use cases display the V2G and V2B systems operation. Modelling these use cases with EMSA aids to visualise the communication, information, components, functions, and market participants in those systems' operation.

V2B use case of Porto airport uses EVs battery capacity to support building's energy system. Building manager is monitoring building's energy needs as charging point operator handles charging point operations in accordance with building manager's signals. EMSP is providing UI for EV users and handles the payments. V2B increases energy efficiency of building and decreases operational costs as well as CO_2 emissions.

Terni city centre V2G use case showcases how flexibility from EVs can be used to relieve grid congestions and support renewable energy use. EMSP operates charging according to customer preferences and communicates flexibility offers to LFMP. LFMP match flexibility offers and requirements and operates the market platform to bring flexibility resources, available to the DSO. EV users gain economically viable charging and support the sustainability and proper functioning of the grid.

Presented use cases offer clarity to V2B and V2G systems operation. The required standards and protocols are clarified as well as participants, components, and functions. This facilitates

the utilization of these use scenarios and V2X technology. Challenges for further research include the research of battery degradation and testing of V2G effects on grid protection schemes.

References

Saldarriaga, S., López-Lezama, J., Ríos, C., Jaramillo, A. 2022. Effects of the Incorporation of Electric Vehicles on Protection Coordination in Microgrids. World Electric Vehicle Journal. Vol. 13, no. 163. Available: https://doi.org/10.3390/wevj13090163

Kene, Raymond O., and Thomas O. Olwal. 2023. Energy Management and Optimization of Large-Scale Electric Vehicle Charging on the Grid. World Electric Vehicle Journal. Vol. 14, no. 4, pp. 95. Available: https://doi.org/10.3390/wevj14040095

Kirpes, B., Danner, P., Basmadjian, R., Meer, H., Becker, C. 2019. E-Mobility Systems Architecture: a model-based framework for managing complexity and interoperability. Energy Inform. Vol 2, no. 15. Available: https://doi.org/10.1186/s42162-019-0072-4

Amamra S. -A. & Marco J. 2019 Vehicle-to-Grid Aggregator to Support Power Grid and Reduce Electric Vehicle Charging Cost. IEEE Access, vol. 7, pp. 178528-178538. Available: https://doi.org/10.1109/ACCESS.2019.2958664

Vadi, S., Bayindir, R., Colak, A., Hossain, E. A. 2019. Review on Communication Standards and Charging Topologies of V2G and V2H Operation Strategies. Available: Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) Technologies - Google Books

Cockburn, A. 1999. Writing Effective Use Cases. Humans and technology. Addison-Wesley.

Schneider, G & Winters, J. 2001. Applying Use Cases: A Practical Guide. United Kindoms: Pearson Education. ISBN: 9780789745453, 0789745453.

Altin, N & Sarp, M. 2020. Review on Vehicle-to-Grid Systems: The Most Recent Trends and Smart Grid Interaction Technologies. GAZI UNIVERSITY JOURNAL OF SCIENCE, 33. 394-411. Available: https://doi.org/10.35378/gujs.554206.

Madhumitha, G., Rajesh, U., Priya, S. Comparative Analysis of Bidirectional Buck/Boost DC-DC Converter, and Interleaved Bidirectional Buck/Boost DC-DC Converter for EV applications. International Conference on Power, Control, and Sustainable Energy Systems (ICPCSES-2022). 2023. Article 8. Available: https://icpcses2022.org

Jain A, Gupta KK, Jain SK, Bhatnagar P, Vahedi H. 2022. A V2G Enabled Bidirectional Single/Three-Phase EV Charging Interface Using Modular Multilevel Buck PFC Rectifier. Electronics, 11(12):1891. Available: https://doi.org/10.3390/electronics11121891

Thompson, A. 2018. Economic implications of lithium ion battery degradation for Vehicle-to-Grid (V2X) services. Journal of Power Sources, volume 396, Pages 691-709, ISSN 0378-7753. Available: https://doi.org/10.1016/j.jpowsour.2018.06.053 .

Islam, S., Iqbal, A, Marzband, M., Khan, I., Al-Wahedi, A. 2022. State-of-the-art vehicle-to-everything mode of operation of electric vehicles and its future perspectives. Renewable and Sustainable Energy Reviews, Volume 166, 112574, ISSN 1364-0321. Available: https://doi.org/10.1016/j.rser.2022.112574 .

Zhang C., Sheinberg R., Gowda, S. N., Sherman, M., Ahmadian, A., Gadh, R. A novel large-scale EV charging scheduling algorithm considering V2G and reactive power management based on ADMM. 2023. Frontiers in Energy Research. volume 11. Available: https://doi.org/10.3389/fenrg.2023.1078027

Chiang, Y., Tseng, N., Chien, C. 2012. Bidirectional Power Factor Correction Converter Control of an EV On-board Charger for V2G Application. 26th Electric Vehicle Symposium. 2. 1210-1216. Available: https://www.researchgate.net/publication/289609484_Bidirectional_Power_Factor_Correction_converter_control_of_an_EV_on-board_charger_for_V2G_application

Bentalhik, I., El fadil, H., Lassioui, A., Koundi, M., El idrissi,, Z. Giri, F. 2022. Adaptive Observer Design for a Bidirectional AC/DC totem pole PFC Power Converter, IFAC-PapersOnLine, Volume 55, Issue 12, Pages 438-443, ISSN 2405-8963, Available: https://doi.org/10.1016/j.ifacol.2022.07.351 .

Yu, S., Gong, Xun., Wang, Gangyao., Bhardwaj, M. Designing a High-Power Bidirectional AC/DC Power Supply Using SiC FETs. 2020. Texas Instruments Power Supply Design Seminar SEM2400.

Butt, O. M., Zulqarnain, M., Butt, T. M. 2020. Recent advancement in smart grid technology: Future prospects in the electrical power network. Ain Shams Engineering Journal. 12. Available: https://doi.org/10.1016/j.asej.2020.05.004.

Zsiborács, H., Pintér, G., Vincze, A., Birkner, Z., Baranyai, N. H. 2021. Grid balancing challenges illustrated by two European examples: Interactions of electric grids, photovoltaic power generation, energy storage and power generation forecasting. Energy Reports. Volume 7. Pages 3805-3818, ISSN 2352-4847. Available: https://doi.org/10.1016/j.egyr.2021.06.007

Fast Frequency Reserve (FFR). Fingrid. Accessed 6.3.2024. Available: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/fast-frequency-reserve/#technical-requirements

Frequency containment reserves (FCR products). Fingrid. Accessed 6.3.2024. Available: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/frequency-containment-reserves/#technical-requirements

Automatic frequency restoration reserve (aFRR). Fingrid. accessed 24.4.2024. Available: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/automatic-frequency-restoration-reserve/

Nour, M., Chaves-Ávila, J. P., Magdy, G., Sánchez-Miralles, Á. 2020 Review of Positive and Negative Impacts of Electric Vehicles Charging on Electric Power Systems. *Energies*, *13*, 4675. Available: https://doi.org/10.3390/en13184675

Dagdougui, H., Ouammi A., Dessaint, L. A. 2019. Peak Load Reduction in a Smart Building Integrating Microgrid and V2B-Based Demand Response Scheme. *IEEE Systems Journal*. vol. 13, no. 3, pp. 3274-3282. Available: https://doi.org/10.1109/JSYST.2018.2880864.

Wan, M., Yu, H., Huo, Y., Yu, K., Jiang, Q., Geng, G. 2024. Feasibility and Challenges for Vehicle-to-Grid in Electricity Market: A Review. Energies, 17, 679. Available: https://doi.org/10.3390/en17030679

Ehsani, M., Falahi, M., Lotfifard, S. 2012. Vehicle to Grid Services: Potential and Applications. Energies, 5, 4076-4090. Available: https://doi.org/10.3390/en5104076

Lotfi, S., Sedighizadeh, M., Abbasi, R., Hosseinian, S. H. 2024. Vehicle-to-grid bidding for regulation and spinning reserve markets: A robust optimal coordinated charging approach. Energy Reports, Volume 11, Pages 925-936, ISSN 2352-4847. Available: https://doi.org/10.1016/j.egyr.2023.12.044.

Khalid, M. R., Alam, M. S., Sarwar, A., Asghar, J. M. S. 2019. A Comprehensive review on electric vehicles charging infrastructures and their impacts on power-quality of the utility grid. eTransportation, Volume 1, 100006, ISSN 2590-1168. Available: https://doi.org/10.1016/j.etran.2019.100006.

European Environment Agency. 2024. Transport and mobility. Accessed 14.3.2024. Available: https://www.eea.europa.eu/en/topics/in-depth/transport-and-mobility?activeAccordion=e53c3d45-3510-42da-bd18-cc72d0fb1a7b&activeTab=07e50b68-8bf2-4641-ba6b-eda1afd544be

Cai, S., Matsuhashi, R. 2022. Optimal dispatching control of EV aggregators for load frequency control with high efficiency of EV utilization. Applied Energy, Volume 319, 119233, ISSN 0306-2619. Available: https://doi.org/10.1016/j.apenergy.2022.119233.

Hu, J., Morais, H., Sousa, T., Lind, M. 2016. Electric vehicle fleet management in smart grids: A review of services, optimization and control aspects. Renewable and Sustainable Energy Reviews, Volume 56, Pages 1207-1226, ISSN 1364-0321. Available: https://doi.org/10.1016/j.rser.2015.12.014.

Mobi.e. THE FUTURE IS LIVED TODAY. Accessed 21.3.2024. Available: https://www.mobie.pt/en/quemsomos/a-mobi.e

Redes. Competensies. Accessed 21.3.2024. Available: https://www.e-redes.pt/en/managing-entity-electric-mobility-network-mobie-egme

Bibak, B & Tekiner-Mogulkoc, H. 2021. Influences of vehicle to grid (V2G) on power grid: An analysis by considering associated stochastic parameters explicitly, Sustainable Energy. Grids and Networks, Volume 26, 100429, ISSN 2352-4677. Available: https://doi.org/10.1016/j.segan.2020.100429.

Clarke, A., Bihani, H., Makram, E., and Corzine, K. 2014. Analysis of the Impact of Different PEV Battery Chargers during Faults. Journal of Power and Energy Engineering, 2, 31-44. Available: https://doi.org/10.4236/jpee.2014.28004.

Bridha, B & Iyswarya Annapoorani, K. 2023. Design of Bidirectional Resonant Converter For EV Application. Journal of Physics, Conference Series, 2601, 012037. Available: https://doi.org/10.1088/1742-6596/2601/1/012037

European Commission. 2023. Delivering Renewal and Innovation to mass Vehicle Electrification enabled by V2X technologies. Available: https://doi.org/10.3030/101056934

IEC. 2024. IEC 62559 – Use case methodology. Available: https://syc-se.iec.ch/deliveries/iec-62559-use-cases/

Yusuf, J., Jahid Hasan, A. S. M., Garrido, J., Ula, S., Barth, M. J. 2023. A comparative techno-economic assessment of bidirectional heavy duty and light duty plug-in electric vehicles operation: A case study, Sustainable Cities and Society, Volume 95, 104582, ISSN 2210-6707. Available: https://doi.org/10.1016/j.scs.2023.104582

Gschwendtner, C., Sinsel, S. R., Stephan, A. 2021. Vehicle-to-X (V2X) implementation: An overview of predominate trial configurations and technical, social and regulatory challenges. Renewable and Sustainable Energy Reviews, Volume 145, 110977, ISSN 1364-0321. Available: https://doi.org/10.1016/j.rser.2021.110977

Hoehne, C. G & Chester, M. V. 2016. Optimizing plug-in electric vehicle and vehicle-to-grid charge scheduling to minimize carbon emissions, Energy, Volume 115, Part 1, Pages 646-657, ISSN 0360-5442. Available: https://doi.org/10.1016/j.energy.2016.09.057

Noel, L., Rubens, G. Z., Kester, J., Sovacool, B. K. 2019. Navigating expert skepticism and consumer distrust: Rethinking the barriers to vehicle-to-grid (V2G) in the Nordic region, Transport Policy, Volume 76, Pages 67-77, ISSN 0967-070X. Available: https://doi.org/10.1016/j.tranpol.2019.02.002

Castellanos, J. D. A., Rajan, H. D. V., Rohde, A., Denhof, D., Freitag, M. 2019. Design and simulation of a control algorithm for peak-load shaving using vehicle to grid technology. SN Appl. Sci. 1, 951. Available: https://doi.org/10.1007/s42452-019-0999-x

Shareef, H., Md. Islam, M., Mohamed, A. 2016. A review of the stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles. Renewable and Sustainable Energy Reviews, Volume 64, Pages 403-420, ISSN 1364-0321, Available: https://doi.org/10.1016/j.rser.2016.06.033

Pavan, R., Naidu, K., Lakkavarapu, L. S, Sai, V., Sai V. A. 2022. SIMULATION AND ANALYSIS OF V2G AND G2V TECHNOLOGY IN ELECTRIC VEHICLES. Child Education Journal. Available: http://dx.doi.org/10.9756/INTJECSE/V14I5.151

Sedar, R., Kalalas, C., Vázquez-Gallego, F., Alonso, L., Alonso-Zarate, J. 2023. A Comprehensive Survey of V2X Cybersecurity Mechanisms and Future Research Paths. IEEE Open Journal of the Communications Society. PP. 1-1. Available: https://doi.org/10.1109/OJCOMS.2023.3239115 .

Hu, J., Morais, H., Sousa, T., Lind, M. 2016. Electric vehicle fleet management in smart grids: A review of services, optimization and control aspects. Renewable and Sustainable Energy Reviews, Volume 56, Pages 1207-1226, ISSN 1364-0321. Available: https://doi.org/10.1016/j.rser.2015.12.014.

Karfopoulos, E. L. & Hatziargyriou, N. D. 2016. Distributed Coordination of Electric Vehicles Providing V2G Services. IEEE Transactions on Power Systems, vol. 31, no. 1, pp. 329-338. Available: https://doi.org/10.1109/TPWRS.2015.2395723

Zhou, Z., Sun, C., Shi, R., Chang, Z., Zhou S., Li, Y. 2017. Robust Energy Scheduling in Vehicle-to-Grid Networks. IEEE Network, vol. 31, no. 2, pp. 30-37. Available: https://doi.org/10.1109/MNET.2017.1600220NM

Ota, Y., Taniguchi, H., Nakajima, T., Liyanage, K. M., Baba, J., Yokoyama, A. 2012. Autonomous Distributed V2G (Vehicle-to-Grid) Satisfying Scheduled Charging. IEEE Transactions on Smart Grid, vol. 3, no. 1, pp. 559-564. Available: https://doi.org/10.1109/TSG.2011.2167993

Saxena, N., Grijalva, S., Chukwuka V., Vasilakos, A. V. 2017. Network Security and Privacy Challenges in Smart Vehicle-to-Grid. IEEE Wireless Communications, vol. 24, no. 4, pp. 88-98. Available: https://doi.org/10.1109/MWC.2016

Naghibi, B., Masoum M. A. S., Deilami, S. 2018. Effects of V2H Integration on Optimal Sizing of Renewable Resources in Smart Home Based on Monte Carlo Simulations. IEEE Power and Energy Technology Systems Journal, vol. 5, no. 3, pp. 73-84. Available: https://doi.org/10.1109/JPETS.2018.2854709

Villante, C., Ranieri, S., Duronio, F., De Vita, A., Anatone, M. 2022. An Energy-Based Assessment of Expected Benefits for V2H Charging Systems through a Dedicated Dynamic Simulation and Optimization Tool. World Electr. Veh. J, 13, 99. Available: https://doi.org/10.3390/wevj13060099

Mazzeo, D., Matera, N., Luca, R., Musmanno, R. 2022. A smart algorithm to optimally manage the charging strategy of the Home to Vehicle (H2V) and Vehicle to Home (V2H) technologies in an off-grid home powered by renewable sources. Available: https://doi.org/10.21203/rs.3.rs-1685933/v1

Uddin, K., Dubarry, M., Glick, M. B. 2018. The viability of vehicle-to-grid operations from a battery technology and policy perspective. Energy Policy, Volume 113, Pages 342-347, ISSN 0301-4215. Available: https://doi.org/10.1016/j.enpol.2017.11.015.

Wei, Y., Yao, Y., Pang, K., Xu, C., Han, X., Lu, L., Li, Y., Qin, Y., Zheng, Y., Wang, H. 2022. A Comprehensive Study of Degradation Characteristics and Mechanisms of Commercial Li(NiMnCo)O2 EV Batteries under Vehicle-To-Grid (V2G) Services. Batteries, 8, 188. Available: https://doi.org/10.3390/batteries8100188

Thompson, A. W., Perez, Y. Vehicle-to-Everything (V2X) energy services, value streams, and regulatory policy implications. Energy Policy, Volume 137, 2020, 111136, ISSN 0301-4215. Available: https://doi.org/10.1016/j.enpol.2019.111136

Johannessen, S. W. 2018. Power factor correction for a bidirectional on-board charger for electric vehicles and plug-in hybrid electric vehicles-a fundamental study of the bidirectional totem-pole PFC (Master's thesis, NTNU).

Zhou, Y., Muehleisen, R. T., Zhou, Z., Macal, C., Oueid, R. 2021. "Considerations for Building the Business Cases for Bidirectional Electric Vehicle Charging". United States. Available: https://doi.org/10.2172/1817861. https://www.osti.gov/servlets/purl/1817861.

Habte, O. K. 2020. Bidirectional Power Transfer between Grid and Electric Vehicle Batteries (Master's thesis, University of South-Eastern Norway).

Mahure, P., Keshri, R. K., Abhyankar R., Buja, G. 2020. Bidirectional Conductive Charging of Electric Vehicles for V2V Energy Exchange. IECON 2020 The 46th Annual Conference of the IEEE Industrial Electronics Society, Singapore, pp. 2011-2016. Available: https://doi.org/10.1109/IECON43393.2020.9255386

Shafiqurrahman, A., Khadkikar V., Rathore, A. K. Vehicle-to-Vehicle (V2V) Power Transfer: Electrical and Communication Developments. IEEE Transactions on Transportation Electrification. Available: https://doi.org/10.1109/TTE.2023.3345738

Kosinka, M., Slanina, Z., Petruzela M., Blazek, V. 2020. Control system for V2H applications, 2020 20th International Conference on Control, Automation and Systems (ICCAS), Busan, Korea (South), pp. 916-921. Available: https://doi.org/10.23919/ICCAS50221.2020.9268383

Adegbohun F, von Jouanne A, Agamloh E, Yokochi A. 2024. A Review of Bidirectional Charging Grid Support Applications and Battery Degradation Considerations. Energies. 17(6):1320. Available: https://doi.org/10.3390/en17061320

Shafaati, S. M. & Sefid, M. 2022. Implementation and Demonstration of Electric Vehicle-to-Home (V2H) Application: A Case Study. In M. Alam, R. Pillai, & N. Murugesan (Eds.), Developing Charging Infrastructure and Technologies for Electric Vehicles (pp. 268-293). IGI Global. Available: https://doi.org/10.4018/978-1-7998-6858-3.ch015

Gong, J., Wasylowski, D., Figgener, J., Bihn, S., Rücker, F., Ringbeck, F., Sauer, D. U. 2024. Quantifying the impact of V2X operation on electric vehicle battery degradation: An experimental evaluation. eTransportation, Volume 20, 100316, ISSN 2590-1168. Available: https://doi.org/10.1016/j.etran.2024.100316

Tchagang A, Yoo, Y. 2020. V2B/V2G on Energy Cost and Battery Degradation under Different Driving Scenarios, Peak Shaving, and Frequency Regulations. World Electric Vehicle Journal. 11(1):14. Available: https://doi.org/10.3390/wevj11010014

CEN-CENELEC-ETSI Smart Grid Coordination Group. 2012. Smart Grid Reference Architecture. Accessed 24.4.2024. Available: https://ec.europa.eu/energy/sites/ener/files/documents/xpert_group1_reference_architecture.pdf