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The Implementation of HMI Technology for a Charging Station

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The Implementation of HMI Technology for a Charging Station

Bachelor Thesis

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Abstract

English:

This TFG will provide human-machine interface capabilities to a power charging station, for BEV (battery electric vehicles). In order to do so the process of charging will be designed. Customers will be able to arrive at the charging station and through the screen manage to take all the necessary steps for charging their electric vehicle.

Castellano:

En este TFG se dotará de capacidades de interfaz hombre-máquina a una estación de carga de energía para BEV (vehículos eléctricos de batería). Para ello se diseñará el proceso de carga en su totalidad. Los clientes que lleguen a la estación de carga podrán realizar todos los pasos necesarios para cargar su vehículo eléctrico a través de una pantalla.

PALABARAS CLAVE/KEY WORDS

HMI, vehículos eléctricos, electric vehicles, charging station, estación de carga

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List of Abbreviations

HMI	Human Machine Interface
EV	Electric Vehicle
BEV	Battery Electric Vehicle
TFG	"Trabajo Final de Grado"
SoC	State of Charge
DoD	Depth of Discharge
CC	Constant Current
CV	Constant Voltage
ECS	Electric Charging Station
EVSE	Electric Vehicle Supply Equipment
V2G	Vehicle to Grid
EMOCH	E-Mobility Operator Clearing House
EVCC	Electric Vehicle Communication Controller
PWM	Pulse Width Modulation
SECC	Supply Equipment Communication Controller

1. Introduction

This TFG will provide human-machine interface capabilities to a power charging station, for BEV (battery electric vehicles). In order to do so, the complete charging process will be designed bearing in mind different use cases or possible situations and following the ISO 15118 standard charging steps and the corresponding regulations for each use case. Customers will be able to arrive at the charging station and through the screen manage to take all the necessary steps for charging their electric vehicle. Therefore, the HMI interface has been designed for enhancing the user's experience when charging an electric vehicle at a charging station with an interface implemented. Thus, the user is the main target of this thesis and the whole design focuses on how to adapt the iso charging steps so they can be performed on an HMI interface, while at the same time the interface displays key information for the user and guides the user through the charging process in a clear and fast as possible way. By having an interface for performing the charging process, new features are unlocked. Therefore, apart from designing an interface for applying HMI technology to a charging station, in this thesis it has been briefly studied if an added feature such as Vehicle to Grid capabilities have a positive outcome on both the grid and the user. First, an explanation on Vehicle to Grid capabilities will be made, as to how smart grids work and which implications it has. Then, we will talk about the benefits for the grid and by analysing different published papers on the matter, we will study possible outcomes for users and requirements/limitations for maximizing their profit. Finally, for different use cases, a complete walkthrough of the interface design will be displayed.

2. Background & state of the art

In this chapter topics such as charging theory and HMI design theory are discussed.

2.1 Charging Theory

BATTERY CHARGING PROCESS:

As seen on the graph below [1], when charging a battery the current starts with a value equal or less than the nominal battery's current. While the current remains constant, the voltage increases as time goes by and the battery gets charged. This period is called as the constant current or "CC" region. Once the battery has achieved an 80% storage of energy, the charger shifts from a constant current region to a constant voltage region, also called as "CV". During the constant current region, the charge current gets decreased little by little until 0. Therefore, we can clearly define two different states when charging, CC and CV. Fast charging usually focuses on the CC region as the current value is high, it charges a lot quicker than in the CV region, where current gets decreased until 0.

An important detail to take into account when charging EV is the C-rate (the rate at which a battery is discharged or charged), as a high C-rate indicates high battery losses and a higher battery temperature, resulting in a reduction of the battery's lifetime. We can calculate the C-rate by:

$$C - rate = \frac{Pch}{Enom}$$

Where:

P_{ch}= Charging Power (kW)

E_{nom} = Nominal capacity of the battery (kW)

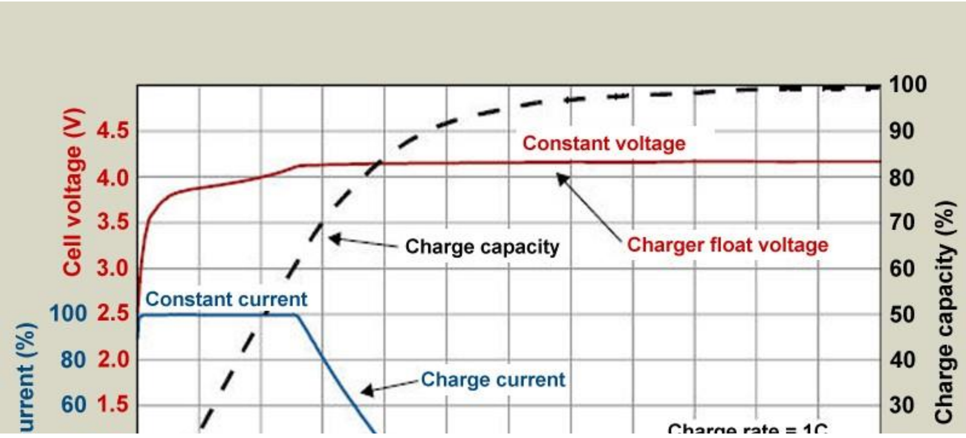

Figure 1: Charging Process. Source: [1]

Figure 2: Future network structure as defined by the European Technology Platform SmartGrids, with a focus on virtual power plants and distributed resources. Source: [6]Figure 3: Charging Process. Source: [1]

2.2 Human-Machine Interaction Design

While designing the program in order to enhance EV Charging Stations and providing them with HMI capabilities, the next 9 rules have been strictly followed for achieving the easiest, simplest and fastest design. Therefore, as every HMI design, a human must be able to interact with it, no matter its technological background/education. The process must be as fast as possible. [2], [3].

The 9 rules followed are:

1. Knowledge about the user, task and environment

EV charging stations can be used by anyone. Therefore, the design must be as simple as possible and require low technological knowledge background. Every step of the charging process must be clear, understandable and possible to perform by any given user. The main task is to charge the EV, therefore the design is focused on guiding the user through the charging process, making it as simple as possible whilst providing the user with the key information needed. Bearing in mind environment knowledge, appropriate colours and fonts have been used so the touch screen can be used either during the day or at night.

2. Patterns

The design and symbols [4] used are similar to others found in other apps, programs and real-life metaphors. Therefore, the user is familiar with these UI patterns, making it easier and faster the first time is used.

3. Consistency

The design must be as consistent as possible, especially aspects as layout. Otherwise, an inconsistent design leads to wasting time of the user, as every different screen the user must reanalyse the design and figure out how to continue, whereas consistent designs help the user in advancing much faster, resulting in lower usage times, increasing the efficiency.

4. Visual hierarchy

The interface has been designed in a way that allows the user to focus on what is most important. The colour, placement, and size of each element work together, creating a clear path to understanding the interface, resulting in a design easy to understand by the user. Thus, avoiding any ambiguities.

5. Feedback

The interface speaks at all time to the user. Users are always informed of their actions. At any given time the expected input action and the result is displayed clearly, successfully delivering the information to the user and informing them at any given time of their current step of the process and if the user's input is being processed successfully or not.

6. Flexibility

The design always includes an action undo functionality, as users could make a mistake while navigating through the process or simply change their mind on one of the choices. Therefore, it has been design as forgiving as possible and avoiding start overs from the beginning, users are able to go one step back from any given point of the process, permitting easy reversal of actions.

7. Language

The interface has kept messaging as simple and concise as possible, guiding the user through the charging process. Furthermore, in order to reach as many users as possible, language barriers have not been set. Users can select their preferred language between English, German or Spanish.

8. Simplicity & Intuitiveness

The interface has been designed bearing in mind simplicity and displaying the information as clear as possible, following a minimalist design. It does not contain unnecessary elements, therefore not bloating the interface and saturating the user with unnecessary information. Instead, key elements are succinct and make sense. Every function included in the design has been tested as to if it is necessary or not, using the following question, “Does the user really need this?”

9. Test

When designing the interface, the User Centred Design Process has been followed, improving previous versions of the design after performing usability tests and determine weak points which require improvement.

The User Cantered Design Process consists of four phases, which are:

1- Analyse:

The first phase performs the analysis of the usage context, collecting important information of the potential users, the task they will perform, the environment in which the task is performed.

2- Interaction Concept & Visual Design:

A creative interface is designed following the information acquired in the previous step.

3- Prototyping

In order to perform Usability Tests, an interactive prototype must be built.

4- Evaluation & Test

Once the prototype has been built, the concepts can be evaluated from the user’s point of view, therefore finding any weak points that require an improvement.

These tests analysed the five main usability components:

- **Learnability:** How hard is it to use it the first time ever.
- **Efficiency:** After getting used to the design, do users increase their usage speed?
- **Memorability:** Is it hard to remember the design? Can users navigate through the program easily after not using it for some time?
- **Errors:** Can users recover from errors?

- **Satisfaction:** Is it a satysfing design?

USAGE CONTEXT ANALYSIS

An analysis of the environment, task and stakeholders is performed.

RESEARCH ON ENVIRONMENT

Description:

The implementation of Human-Machine Interaction (HMI) capabilities will enhance the experience whilst opening up new paths when using an Electric Vehicle Charging Station. The main objective of providing HMI capabilities to an EV Charging Station is to guide the user through the charging process, making it easier and providing a wider range of possible choices.

The program will display the different charging speeds (charging power) available, payment methods and status of the current charging process. Furthermore, the user will be informed of error messages such as unsuccessful connection between the charging station and the EV, enabling the user to correct this situation and continuing with the charging process. The users have been granted the possibility of performing shortcuts when using the interface. Such shortcuts are implemented by storing the user's latest charging process chosen.

Disturbance parameters:

As the Charging Station can be used by anyone, the design must be as simple and easy to use as possible, without any limiting factors, such as technological background.

Correct choice of shapes and colours must be chosen in order to display key information clearly, accelerating the needed time to perform the task, as user do not have to spend a lot of time figuring out what their next action is.

In order to minimize incompatibilities between the charging station and the connected vehicle, the standard and most used configuration, as to power output, has been chosen.

Time aspects:

The user must be able to go through the charging process as quick as possible, enhancing the user's experience as it is not a dull and lengthy process, just a fast selection of parameters and the charging process is finished! There are no big-time constraints, as the process can be done quickly. The possibility of time constraints can appear if there are any error messages. For example, on the HMI design possible errors messages have been added, such as EV to charging station connection issues or payment errors, either due to the card reader or the connection between the charging station and the servers in order to perform the transaction. Therefore, the user will receive feedback in relation to these errors.

Tools involved:

Software: In order to perform the HMI design, EB Guide Studio will be used. Then, the software interface will run on a RaspberryPi, therefore the Operating System Raspbian is used.

Hardware: A complete and functional Electric Charging Station (ECS) is needed, which must include a touch screen. Plus, eventually a keypad, card reader, and a Raspberry Pi in order to run the software.

Social/organizational milieu:

Target User: Any user that drives an Electric Vehicle. Therefore, users must be older than 17 years old as it is the minimum age at which a driving license can be obtained in Germany or UK. For other countries, users must be minimum 18 years old for obtaining a driving licence. A simple and intuitive design "easy to use" was chosen so anyone with low tech knowledge can access it successfully.

Technical constraints

There could be incompatibilities between the Electric Vehicle and the Charging Station, as to the charging connector type or the power output. Therefore, the standard and most common connector and power outputs (depending on the charging speed) in Europe have been used.

Therefore, the charging station should run a verification/test in order to determine if the car that has been plugged in has capabilities of full iso options, as high level of communication enabled, which would allow a higher control over the charging process and in car payment options.

RESEARCH ON STAKEHOLDERS/USERS

Stakeholders:

There are multiple stakeholders for the interface, which are the following:

-**Design engineers**: They oversee the main work related to the layout and technical aspects of the software. Therefore, in order to provide an appropriate design where key information is displayed clearly and provides a smooth usage to the user, the HMI design rules stated previously were precisely followed.

-**Quality control**: The quality control stakeholders are in charge of performing any testing necessary for receiving feedback as to the design of the interface and the several actions made through the interface. Therefore, the target is to spot any bugs, errors, glitches or any needed improvements in order to achieve a smoother usage by the user.

-***End-user:*** The target user of the HMI interface for the charging station is any user that owns an Electric Vehicle willing to charge their car at the charging station. Therefore, these users must be older than the legal age to have a driving license.

-**Marketing team:** They are in charge of making the HMI interface known to potential companies willing to include it to their charging stations. Therefore, they plan publicity strategies and contact key companies. Furthermore, they are in charge of doing research so the design engineers can increase their accuracy regarding the potential user's desired functions should be able to perform via the interface and how is the information displayed.

-**Domain experts:** These experts will oversee designing a website for displaying all needed information by potential customers. As to technical requirements to run the software at the charging station, compatibility issues, tasks performed by the interface, pricing.

-**Accounting:** All financing issues are taken care by the accounting team, plus planning future investments, working closely with the marketing team, in order to invest on any areas that require an improvement.

RESEARCH ON TASK

Use cases:

The following use cases can be performed:

- Show target price

- Optimize settings

- Slow Charging Speed (3 – 6 kW)

- Fast Charging Speed (7 – 22 kW)

- Ultra-Fast Charging Speed (50 – 100 kW)

- In-car Payment

- Contactless Payment

- V2G capabilities (Smart Charging)

- SoC visualization

- Store previous charging options chosen

Use Case Groups:

Charging speed choice: Slow Charging Speed (3 – 6 kW), Fast Charging Speed (7 – 22 kW)

, Ultra-Fast Charging Speed (50 – 100 kW)

Type of payment: In-car Payment, Contactless Payment.

EV providing electricity to the grid: V2G capabilities (Smart Charging)

Battery Level: SoC visualization

Objective of the user:

The objective of the user is to charge their electric vehicle at their desired power output, depending on their needs and restrictions, which are usually timewise. For example, a user that requires their car to be charged in a short time, must choose the ultra-fast charging method.

Task performed via the Interface

The interface has been designed in order to guide the user through the charging process, enhancing the experience compared with a simple charging station. Thus, the interface will perform the task associated to the several use cases defined previously. From the beginning of the charging process, selecting the charging speed (charging power) to the payment method, perform payment and start charging. Other functions can be done through the interface, such as displaying error messages, enabling Vehicle to Grid (V2G) capabilities, accessing an information screen where the pricing, V2G, and type of connector are explained. Furthermore, once the car has started charging, from the interface we can view for how long the charging process has been active, amount of energy charged, charging speed selected and if the V2G function has been enabled or not. Finally, the possibility of storing the last chosen options for the previous charging process done by the user has been added. Thus, for repetitive user that access the charging station on a daily basis (for example, a charging station at work), the charging station will suggest the user if they would like to carry out the same charging process as the previous time, reducing the time the user spends whilst interacting with the interface.

REQUIREMENTS AND SYSTEM SPECIFICATION

The interface requirements are set.

1. Purpose:

The objective of the system is to provide HMI capabilities to a Charging Station, guiding the user through the charging process and enhancing their experience, plus enabling the user to choose the best fitting charging process settings (power output - charging time) to their needs.

2. Product perspective

The program's different view screens are based on all use case groups, keeping it simple and not displaying too much information, just key information concisely, making it easier for the users. When any warning messages are activated, a new window will pop up with a text message explaining the problem and what actions the user should perform.

3. Functional perspective

The main functions of the program are:

- **Choice of charging speed:** Users decide which charging speed fits best to their needs, if it is pricing (lower power output has cheaper pricing) or time restrictions.
- **Choice of payment method:** The payment action can be performed either via a contactless card or in-car payment (if high level of communication is possible)
- **V2G capabilities:** When the two key parameters are fulfilled (in order to increase the user's benefit), which are time period (between 08:00 and 20:00) and slow charging mode chosen, user's will be able to enable or not the vehicle to grid function, setting a minimum battery level. If it is enabled, the user's EV will be

able to provide electricity at peak level demand situations, where electricity prices are more expensive. Therefore, the user will benefit pricing reductions.

- **Battery level status:** Users can visualize the amount of energy charged, amount of time the EV has been charging for, and the remaining time depending on which charging speed has been chosen.

4. General stakeholder perspective

The main stakeholders of this product are the designers of the HMI Interface, Aaron Ujaque Hurley and Mr. Meroth.

3. Description of scope/problem/different scenarios

The design of an HMI interface for a Charging Station involves many different requirements and setting for different scenarios. Before working on the design, a brainstorming exercise was performed for determining as many different scenarios as possible, so we can set several use cases of the interface. Some of these scenarios are:

- **Scenario 1**: Charging at a public parking space when spending leisure time at a shopping centre. In this scenario, the predefined variables/settings were set depending on the average time spent at a shopping centre, which can go from 1 hour if it is a short visit until 4 or 5 hours for a longer visit with including perhaps having a meal at the shopping centre. Therefore, for this scenario the user might or might have a time constraint as to the necessity of using the car in a short time span. For that reason, in this case the user should be able to choose between different charging speeds depending on how much time the user is going to spend at the shopping centre and how soon they need to use the EV. As it would be located at a leisure centre, perhaps the payment could be done via a "membership card" of the shopping centre, but in order to simplify the design, it has been determined the payment should be done via normal card payment or via in car payment if the EV is able to achieve a High Level Communication with the Charging Station. As to value added capabilities and extra functionalities, the HMI interface would display the current charging status, with information such as for how long has the charging process been enabled plus the amount of energy transferred to the EV, and as extra functionalities, if the EV fulfils the requirements to perform Vehicle to Grid support, the user shall be able to choose if it wants to accept it or not.

- **Scenario 2:** Charging at a charging station on the Highway. For this use case, the main requirement is time. Therefore, potential users should be able to charge their electric vehicle in a short time span if necessary, as if it is either a long journey or a few kilometres from final destination, the user should not spend a long time at the charging station. Thus, high output power charging methods should be prioritized over slow charging methods. On the other hand, the added functionality of providing

Vehicle to Grid support is discarded as the main priority is to charge the electric vehicle as fast as possible. Payment should take place the same way as in the previous scenario, where users pay via a card payment or in car payment If possible.

- **Scenario 3:** Charging at home. This use case covers the requirements for charging from home. Consequently, users should be able to choose between different charging speeds (power output) depending on their time constraints. One functionality that is not necessary in this scenario, as the user is at the same time the owner of the charging device, is the payment function. Nevertheless, value added functionalities such as Vehicle to Grid support and Displaying charging information should be included, although the Vehicle to Grid support would be only useful if the car is being charged during the day, which for households does not usually happen as EV are mostly charged at night.

- **Scenario 4**: Charging at the workplace. This scenario is the most interesting one as covers several different possibilities, from charging speed (time constraints) to value added capabilities. On one hand, usually electric vehicles being charged at the workplace would not have a time constraint as usual working hours span from 6 to 9 hours. Therefore, the car would have enough time to charge at a slow charging speed. On the other hand, if perhaps on some specific days the user/worker must drive to another location because of a business meeting or another matter related to the job. In this case, the user should be able to choose a higher charging speed. Payment should be done either by card payment or in car payment if possible. Furthermore, as this charging process take place on a daily basis, a "memory" function has been added to the charging station interface where if you repeatedly charge your car at the charging station, it will remember the charging setting chosen the previous day (charging power, payment method, V2G) and suggest this chosen charging process once the car is connected and the charging station detects a previous charging settings is stored for such vehicle, the interface will display the information of such choice and the user has the possibility to accept this charging settings or reject it and create a new one. The aim of this functionality is to reduce the usage time by the user, as time is money. Furthermore, there is a high chance the Vehicle to Grid functionality is eligible as most working hours take place during the day (where electricity demand is higher) and as charging at a slow rate (less power output) is usually cheaper, therefore many user would select these settings and they would be able to support the grid via V2G functionalities. Users would benefit from fees discounts when using their EV as a battery for the electrical grid when electricity is needed, at peak demands as the frequency suffers a sudden drop.

All things considered, the design of the HMI interface was done taking into account the requirements of charging speed/power output selection, payment rate, payment method, V2G for different scenarios/uses , but mostly focusing on Scenario 4-Charging at the workplace as it covers most requirements at once and it is helpful to set a more concise target where the usage of such interface would be extremely beneficial.

The HMI interface guides the user through the charging process as fast as possible, displaying clearly key information with an intuitive layout, making easy to understand and quickly to use and go through the charging setting for starting the charging process. Furthermore, an information screen was added were some basic concepts related to the charging station are explained, in case first time users need some information about the connector type at the charging station, how is pricing performed, and what does V2G consist of plus the benefits and drawbacks for the user when enabling such functionality.

4. ISO Charging steps

Following the ISO 15118 [5] description of the charging process, we will analyse the different steps needed in order to achieve a successful communication between EVSE and EV for charging. The ISO 15118 encompasses the different regulations for each step of the charging process. These different regulations for each step depend on parameters such as if high level of communication is enabled, AC or DC charging type, if it is possible to postpone the start of the charging process, V2G capabilities, etc. Although the ISO 15118 includes all different charging types, in this chapter we will focus on the needed steps for our desired application, which is adding an HMI interface to a charging station used at the workplace. Therefore, bearing in mind the environment of the main target, a summary of the ISO 15118 normative for the charging steps regarding the previously stated initial conditions will be displayed.

The design of the HMI interface has strictly followed the charging steps included in the ISO 15118 that match the application and target of the interface.

The steps for completing the charging process are:

A- Start of the Charging Process.
B- Communication setup.
C- Certificate Handling.
D- Identification and Authorization.
E- Target setting and charging scheduling.
F- Charging controlling and re-scheduling.
G- Value-added services.
H- End of Charging Process.

A- START OF THE CHARGING PROCESS

Initiation of the process between vehicle and EVSE after the physical plug-in of the vehicle. It sets the basis for the on-going charging process.

- **A1)**

Use case element name: Start AC/DC charging process with forced High Level Communication.

Objectives: Establish High Level Communication.

Description: This use case covers the first PWM signals from the EVSE, which has a 5% duty cycle in order to require a High Level of Communication.

- Primary actors: EV, EVSE, EVCC, SECC.

Prerequisites:

- EV must be connected physically to EVSE.
- EV and EVSE require pilot function and basic signalling.
- EV and EVSE must have a higher level communication device (ISO 15118-2 and ISO 15118-3)

Requirements:

- Successful set-up of High Level Communication at the data link layer.
- Timing for the initialization process must be according to ISO 15118-3
- Triggers:
  - For EVSE: EV must be connected properly to the EVSE
  - For EV: Plug is connected and PWM duty cycle indicates a High Level of Communication.

End Conditions:

- Success end conditions:
  - Successful set-up of the High Level Communication at the data link.
- Failure end conditions:
  - Unsuccessful establishment of the High Level of Communication at the data link.
  - Uncorrect association between the SECC and EVCC or timeout in the binding process.

B- COMMUNICATION SETUP

Establishes the association and relevant connection between EVCC and SECC.

- **B1)**

Use case element name: EVCC and SECC communication set-up.

Objectives: The aim is to establish a communication link between the EVCC and the SECC.

Description: At application layer, there is no information exchange between the EVCC and the SECC.

- Primary actors: EVCC, SECC.

Prerequisites:

- Plug in process detailed in use case elements A1 and A2 must have been established successfully.

Requirements:

- Successful The SECC and the EVCC must be capable of being associated one to one.
- The EVCC must be bound to SECC by using the protocol described in ISO 15118-2. Timing of the binding must be acceptable within the requirements in ISO 15118-2.

End Conditions:

- Success end conditions:
  - SECC and EVCC are associated and connected successfully.
- Failure end conditions:
  - Unsuccessful negotiation of the ISO 15118-2 protocol.

C- CERTIFICATE HANDLING

Everything related to certificates during the Charging Process. Two different Use case elements are designed: Certificate update and certificate installation.

- **C1)**

Use case element name: Certificate update.

Objectives: The aim is to establish a communication link between the EVCC and the SECC.

Description: This use case element covers the update of a valid certificate in the EV. The EVCC will initialise a certificate update process using the High Level Communication with SECC.

- Primary actors: EVCC, SECC.
- Secondary actors: EMOCH, FO, E-Mobility Operator.

Prerequisites:

- Communication set-up according to the use case element previously displayed, B1, must have been established successfully.
- The EV must posses a valid certificate for an energy contract.

Requirements:

- The EV must be able to support the process of updating the certificate.
- The SECC must be able to support the process of updating the certificate.
- Triggers:
  - For EVSE: SECC/EVCC detect that the certificate of the EV has a limited remaining lifetime.

End Conditions:

- Success end conditions:
  - Valid certificate (the Contract Certificate) from the secondary actor must be saved in the EVCC.
- Failure end conditions:
  - Certificate update failed because of communication problems.
  - Certificate update rejected by the secondary actor.

D- IDENTIFICATION AND AUTHORIZATION

In this step the required method for identification and authorization is explained. The EVSE will identify itself to the Electric Vehicle and will check if the EV is allowed to start charging. Usually, an EV can start to charge once the EV or User has provided the payment information after receiving the Contract Certificate.

- **D1)**

Use case element name: Authorization by Contract Certificate.

Objectives: Verification of the certificate's validity.

Description: This use case element covers the process using the contract certificate at the Electric Charging Station.

- Primary actors: EVCC, SECC, EV, EVSE, HMI.
- Secondary actors: EMOCH, FO, E-Mobility Operator.

Prerequisites:

- Communication set-up according to the use case element previously displayed in B1.

Requirements:

- Exchange of IDs between EVCC and SECC.
- Triggers:
- Initialization of the process for authentication from the EVCC.

End Conditions:

- Success end conditions:
  - Successful process of authentication.
- Failure end conditions:
  - Process of authentication fails.

E- TARGET SETTING AND CHARGING SCHEDULING

It includes the information needed from the EV as well as from SECC and the secondary actor to start the charging process.

- **E1)**

Use case element name: AC charging with load levelling on High Level of Communication.

Objectives: The use case only covers charging with local infrastructure.

Description: EVCC and SECC will exchange information as to the AC current limits. This is done via High Level Communication.

- Primary actors: USER, SECC, EVSE.

Prerequisites:

- Successful authorization according to use case element D.

Requirements:

- The EVCC must ask about the maximum AC current limit and the SECC must reply.
- EV must no exceed the maximum AC current.
- Trigger:
- The charging authorization must be completed.

End Conditions:

- Success end conditions:
  - The EV charges within the AC current limits.
- Failure end conditions:
  - Delivery failure.

F- CHARGING CONTROLLING AND RE-SCHEDULING

The start of the charging loop is explained plus added functionalities such as Vehicle to Grid capabilities.

- **F1)**

Use case element name: Charging loop with metering information.

Objectives: Perform the charging process until successful conditions are reached.

Description: This use case covers the basic charging loop plus a meter readout. In order to have a reliable billing of the amount of energy that has been transferred, the utility must prove the energy was delivered to a specific EV. The EVCC must send to the SECC the EV's status plus signed meter reading. The SECC must send to the EVCC the EVSE status plus meter reading.

- Primary actors: EV, EVCC, SECC, EVSE.

Prerequisites:

- Already set a charging schedule according to use case E2.
- The charging loop must be active.

Requirements:

- The EVCC must send to the SECC the current status at a given time during a determine time frame.
- The SECC must no reply with an interrupt command.
- The SECC must provide the EVCC with a meter readout for signing.
- The SECC must send the signed readout to the MO.

End Conditions:

- Success end conditions:
  - Charging loop continious .
  - The EVCC receives its metering readout and then it send it back signed to the SECC.
- Failure end conditions:
  - Charging loop is interrupted.
  - Wrong metering.

- **F5)**

<u>Use case element name</u>: Vehicle to grid support.

<u>Objectives</u>: The EV can provide energy to the grid.

<u>Description</u>: This use case covers the possibility of sending power from the EV to the Grid. Thus, the EV must inform it is capable of sending energy back to the grid and it shall indicate how much power it can provide. The SECC must send to the EVCC the possibility to perform vehicle to grid operation. The EVCC must send to the SECC the confirmation of possibility to perform the vehicle to grid operation, the maximum supported value.

- <u>Primary actors</u>: EV, EVCC, SECC, EVSE, User.
- <u>Secondary actors</u>: DSO,DCH,EMOCH.

<u>Prerequisites:</u>

- Already set a charging schedule according to use case E2.
- Active charging loop.
- EVSE must be able to support V2G capabilities.
- The secondary actors must be able to request vehicle to grid support.

<u>Requirements</u>:

- The SECC must indicate the EVCC that vehicle to grid operations are requested.

<u>End Conditions:</u>

- <u>Success end conditions:</u>
  - The EV provides energy to the grid.
- <u>Failure end conditions:</u>
  - The EV does not provide energy to the grid..

G- VALUE ADDED SERVICES

It consists of elements that are not needed for pure charging of electric vehicles but enhance the experience of the user by providing them more information.

- **G2)**

Use case element name: Charging details.

Objectives: Provide information regarding the current supply of energy to the EV..

Description: This use case covers the information exchanged about the charging process. Such parameters could be: Battery status, SoC. The SECC must send to the EVCC the possibility request charging details. The EVCC must send to the SECC the requested charging details.

- Primary actors: EV, EVCC, SECC, EVSE, User.
- Secondary actors: DSO,DCH,EMOCH.

Prerequisites:

- Already set a charging schedule according to use case E2.
- Active charging loop.
- EV must be able to send charging details.

Requirements:

- Any secondary actor has requested for information.

End Conditions:

- Success end conditions:
  - Any secondary actor receives the requested details.
- Failure end conditions:
  - Any secondary actor does not receive the requested details.

H- END OF CHARGING PROCESS

It includes the needed information in order to trigger the end of the charging process.

- **H1)**

Use case element name: End charging process.

Objectives: Safely ending the charging process.

Description: This use case covers a simple ending process.

- Primary actors: EV, EVCC, SECC, EVSE, User.

Prerequisites:

- The charging setup must be set according to use case F2 or F3.

Requirements:

- Trigger: Charing loop must have finished or the User/EV/EVSE starts the ending process.

End Conditions:

- Success end conditions:
  - Successful biling process.
- Failure end conditions:
  - The charging process is not terminated successfully and there is a loss of information.

5. Smart Charging

In this chapter the Smart Charging concept will be discussed. First, we will have a look at it meaning and how it works, then we will focus on the benefits for both the user and the electrical grid. Finally, we will have a look at how it has been implemented in the HMI design.

5.1 Meaning

Smart Charging refers to a system where an electric vehicle and a charging device share a data connection, and the charging device shares a data connection with a charging operator.

As opposed to traditional charging where data connection between the user and the provider is not enabled, with smart charging as devices are connected to the cloud it allows charging stations to monitor, manage and restrict the use of their devices to optimize energy consumption.

Smart Charging provides endless possibilities as it is based on a cloud system, it can be modified easily, being able to add and update new features as new requirements appear as time goes by.

Smart EV charging works by implementing an intelligent back-end solution, which brings real-time data from all connected devices to the smart grid to the charging station. Therefore, as charging stations are connected to this intelligent cloud, they can be managed depending on different parameters, such as electrical energy production, electricity consumption/demand, quantity of other EVs being charged or in general what is the grid's load on real time.

One of the biggest advantages of Smart Charging, apart from grid stress relief, is working along with renewable energies in order to maximize the profits of their unstable production. An example of this feature is if there is at any given time a low production of electricity from renewable energies, in order to lower electricity demand to avoid using Peak Load Power Stations (which usually work with fossil fuels), Smart Charging Stations would cut the charging process for some EVs. The unloading procedure would be predefined depending on different parameters. These parameters can be found by creating a tree type case scenario when a user starts the charging process, as when selecting the different options at the charging station it will create a charging profile. For example, when the peak unloading process is needed, the Smart Charging Station would look through its EV charging profiles which are eligible to cut the charging process. The predefined charging profile which is eligible for Vehicle to Grid operations is when Slow charging method is enabled and the charging process takes place between 08:00 and 20:00, in order to maximize the benefits for the user, as it is between this timeframe when the majority of peak loads take place.

SMART GRID:

The European definition [6] of what a Smart Grid is defined as a system which includes and links intelligent devices that generate electricity, storage appliances and network equipment ICT. The objective is a cost-efficient, robust, safe system, and sustainable supply of electric energy. It can also be perceived by the definition in the US as a fully automated power delivery network that controls and monitors every customer, enabling a two-way flow of electricity and information between the power plant and the appliance, and all points in between. Its distributed intelligence, coupled with broadband communications and automated control systems, enables real-time market transactions and seamless interfaces among people, buildings, industrial plants, generation facilities, and the electric network.

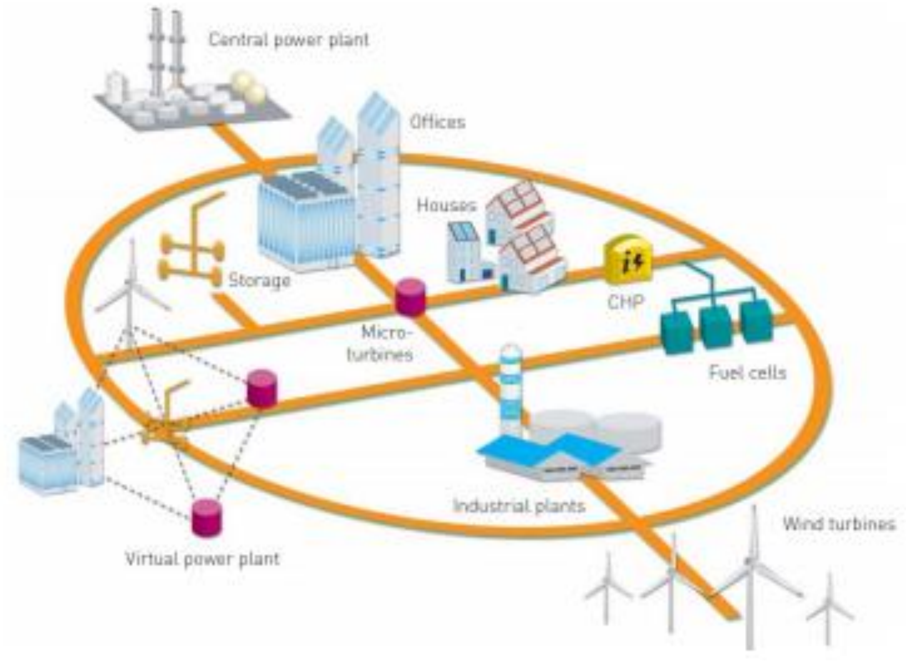

Figure 4: Future network structure as defined by the European Technology Platform SmartGrids, with a focusFigure 5: Uncontrolled Charging Process. Source: [7]EQFigure 6: Uncontrolled vs Controlled Charging. Source: [8]a Figure 7: Comparison of

The **main benefits** of this grid distribution are: **Demand flexibility, higher reliability and efficient use of renewable energies.**

These benefits are achieved thanks to the grid’s high level of automation, which can autonomously detect faults, increase of demand, and other extraordinary situations.

Demand flexibility occurs by balancing intermittent supply and demand, as we can not only control the production of electricity but also the consumption, therefore loads can be postponed to other times when power demand is lower, creating a less resource intensive grid system. Thus, we can “flatten” as much as possible our demand graph, shifting to a more constant system, increasing its efficiency.

- **Reactive regulation:** In order to be able to inject reactive power to the grid, there should be a bidirectional charger. According to “Examination of a PHEV bidirectional charger for V2G reactive power compensation by Kisacikoglu, M.C.; Ozpineci, B.; Tolbert, L.M, reactive power regulation does not cause any degradation on the EV’s battery life.
- **Peak Shaving:** When enabled, the EV can supply electricity back to the grid. Therefore, as “slow charging” method has been selected, we expect the car to be connected +6 hours and when peak demand occurs, where electricity demand grows drastically, the car can supply electricity back shifting from being a client to a provider. Thus, transforming the daily electricity demand into a stable horizontal line, where demand/supply remains as constant as possible as we are supplying the grid with electricity at peak load moments. Therefore EVSE with Smart charging/Grid support capabilities can be considered as battery storage systems, a much needed functionality with Renewable Energies. At peak load moments, electricity price grows drastically, enabling EVSE to have a two-way benefit, by charging cars and by resupplying the grid. Electric Vehicle customers that enable the Smart Charging/ Grid supply option, will benefit of a discount on the kWh charging price. Limits must be set as to what minimum percentage does the EV need to have in order to supply the grid and once it is supplying the grid, how much % of its battery charge can it supply, which must be decided by the user, choosing the minimum battery % required at any given time.

ELECTRIC VEHICLES AS FREQUENCY CONTAINMENT RESERVES

Electric vehicles have the potential to become an additional service for the power grid. This capability is called Vehicle-to-Grid (V2G).

As day by day the quantity of renewable installed capacity is growing, the need for stabilizing components in the electric power grid becomes greater. Therefore, as the number of Electric Vehicles is increasing, and this process is expected to accelerate as auto industry manufacturers shift to full production of electric vehicles, these become a perfect solution for stabilizing the grid's frequency, as they are basically energy storage capacity on wheels.

There are two main ways of using electric vehicles for demand response, one is by reducing the power input while charging or extracting electricity out of the battery using a bidirectional system for charging. These two responses would be run by the EVSE, which being a smart charging station alongside the smart grid, it would be able to decide which response is better. In order to decide which action to take, as explained before the smart charging station creates charging profiles depending on the user's options chosen, as to time needed for charging, whether they want to subscribe to this plan, etc…

THE GRID FREQUENCY

By analysing the grid's frequency, we can retrieve information such as supply and demand in real-time. The frequency of the grid is the nominal frequency of alternating current changes (AC) in the electric grid. Nominal frequency in Europe and Asia is 50 Hz, whereas in the United Sates it is 60 Hz.

Although there is a nominal value for the frequency, it is not always stable and exactly that value, as the real-time frequency varies. We can experience a drop of the frequency when there is a high demand of electricity (or low supply), and an increase of frequency when there is low demand (or high supply). Therefore, by analysing the grid's frequency, we can determine the supply/demand balance in real-time. It is extremely important to maintain frequency as stable as possible around its nominal value as if we experience big shifts (either a high increase of frequency or big drop) we can suffer from power outages.

With smart charging stations and smart grids, we can use EVs as energy storage systems for demand response. The need to use these supply systems can be easily determined by looking at the frequency. For example. If we have a drop of frequency, which means we have a higher demand than supply, if we have at any given time 10.000 EVs charging at a speed of 22 kW (Power = 3 phase * 32 A * 220 V). Then, as we want to decrease grid demand, we reduce the charging power from 22 kW to 3 kW (3 Phase * 4.5 A * 220 V) (from fast charging to slow charging). Thus, calculating the difference of power: [(22 kW - 3 kW) * 10 000 EVs], resulting in a reduction of demand by 190 MW. It is a considerable power reduction without having to cut the charging process. If we experience a massive drop of frequency, more extreme measures can be taken in order to reduce the demand, from cutting the charging process to extracting electricity from the EVs. Following the same starting conditions as stated before, if we cut the charging process it would free up 220 MW of power supply. In the worst-case scenario where EVs must provide electrical energy to the grid with bidirectional charging, if we declare the power output from the EVs as 10 kW * 10.000 EVs, electric vehicles would be providing 100 MW of power.

Therefore, when there is an overload of the grid and the frequency drops, we can use EVs to stabilize it and balance the supply/demand. This process can be done automatically as smart charging stations are connected with smart grids on the cloud.

Before such measures are taken, the charging station must decide the maximum time these measures are applied and the minimum battery percentage (State of Charge) set by the user just in case the charging process must be finished before scheduled so the user can always have a decent amount of energy on its EV, as the User's charging experience must not be compromised.

It is possible to stabilize either for a situation of an increase of frequency or a sudden drop of frequency. The simplest way is if there is a drop of frequency (high demand) we can either reduce the charging power, completely stope the charging process or extract energy from the battery. On the other hand, if we have an increase of frequency (higher supply than demand), we can increase the charging power output to increase the demand and balance the demand/supply, thus balancing the grid's frequency.

5.2 Benefits for the grid

Smart Charging works by optimizing the charging process and spreading the load, reducing peak loads when there is high demand. Smart charging is enabled by having EVs and the Power Grids communicate to each other through the EVSE, so at times of high electricity demand the EVSE can cut the charging process or even EVs can provide energy to the grid in order to stabilize the Supply/demand, keeping them as constant as possible and avoiding peaks.

With conventional charging as it is not possible to efficiently modify the loads connected to the Power Grid, we experience demand peaks which result in having to oversize electric installations so the grid can stand these fluctuations.

Another positive aspect about Smart Charging is the efficient usage of electricity produced by renewable sources, as at times of low electricity production from renewable sources EVSEs can stop charging EVs in order to decrease the demand of electricity and not having to depend on Peaking Power Plants, as they are usually fossil fuel plants, thus reducing CO_2 emissions. [7]

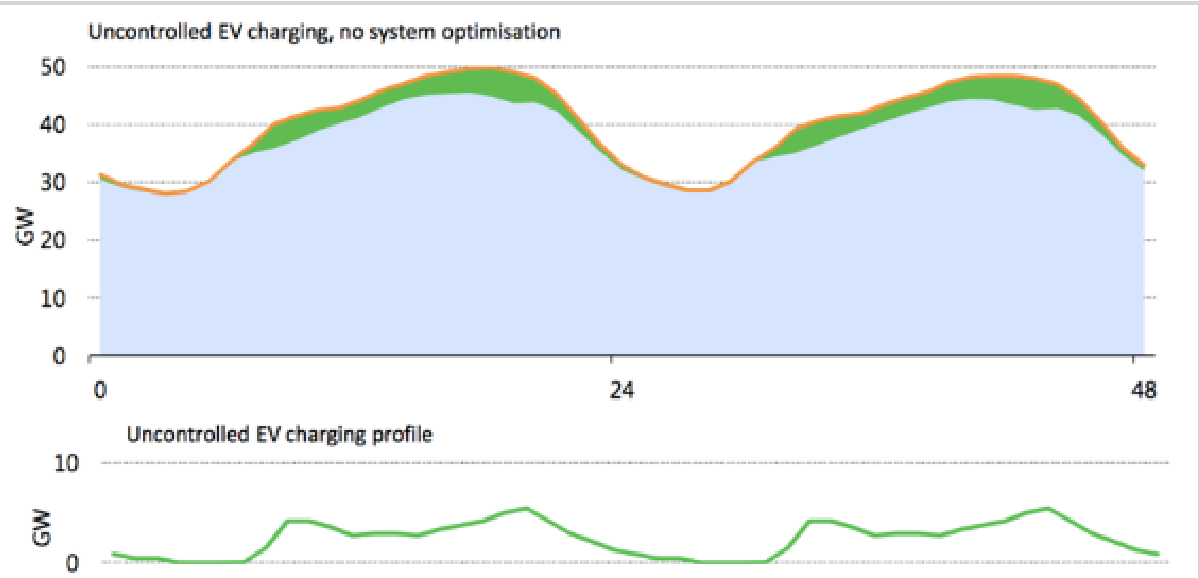

Figure 8: Uncontrolled Charging Process. Source: [7]

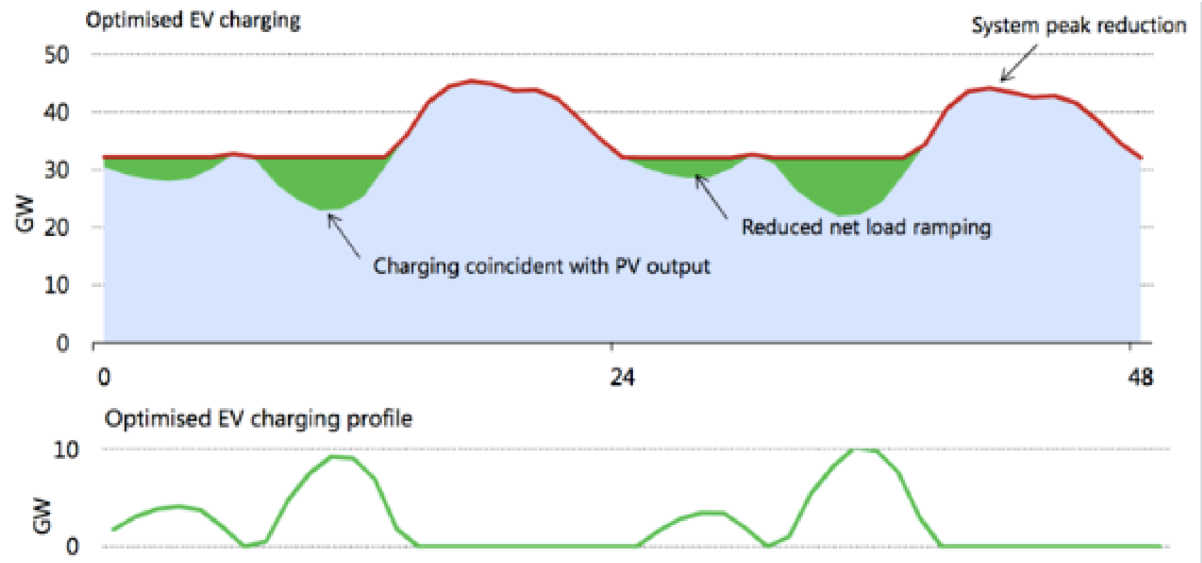

Figure 9: Controlled Charging Process. Source: [7]

As we can see on both figures, Uncontrolled EV charging vs Controlled EV charging, whilst the former has a highly irregular electricity demand, the latter has a more constant power demand, resulting in a higher efficient system.

In the next graph [8] we can see another example of the impact smart charging can make, drastically reducing demand peaks and maintaining this demand as constant as possible.

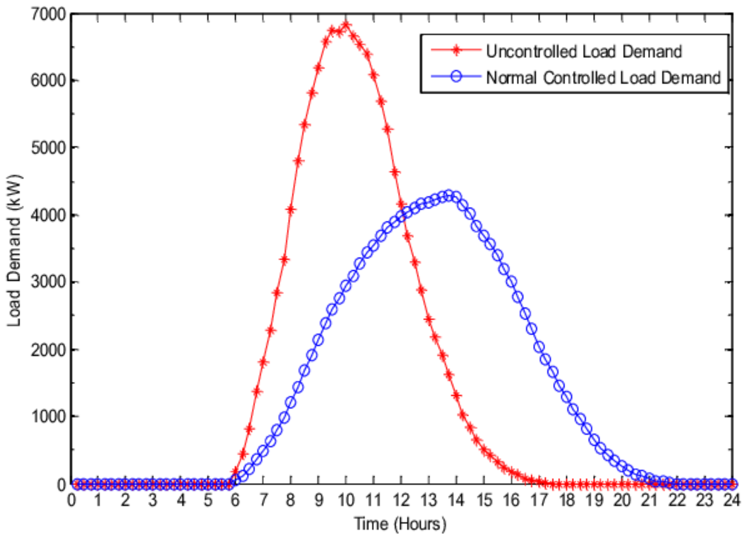

Figure 10: Uncontrolled vs Controlled Charging. Source: [8]

Smart Charging will also help relief sudden increases of EVs getting plugged in. As we can see on the following graph [9], statistically there is an increasing demand of power for charging EV's from 06:00 until 9:00 and from 18:00 until 19:00. Therefore, it would be more efficient to spread the loads as much as possible, avoiding demand peaks.

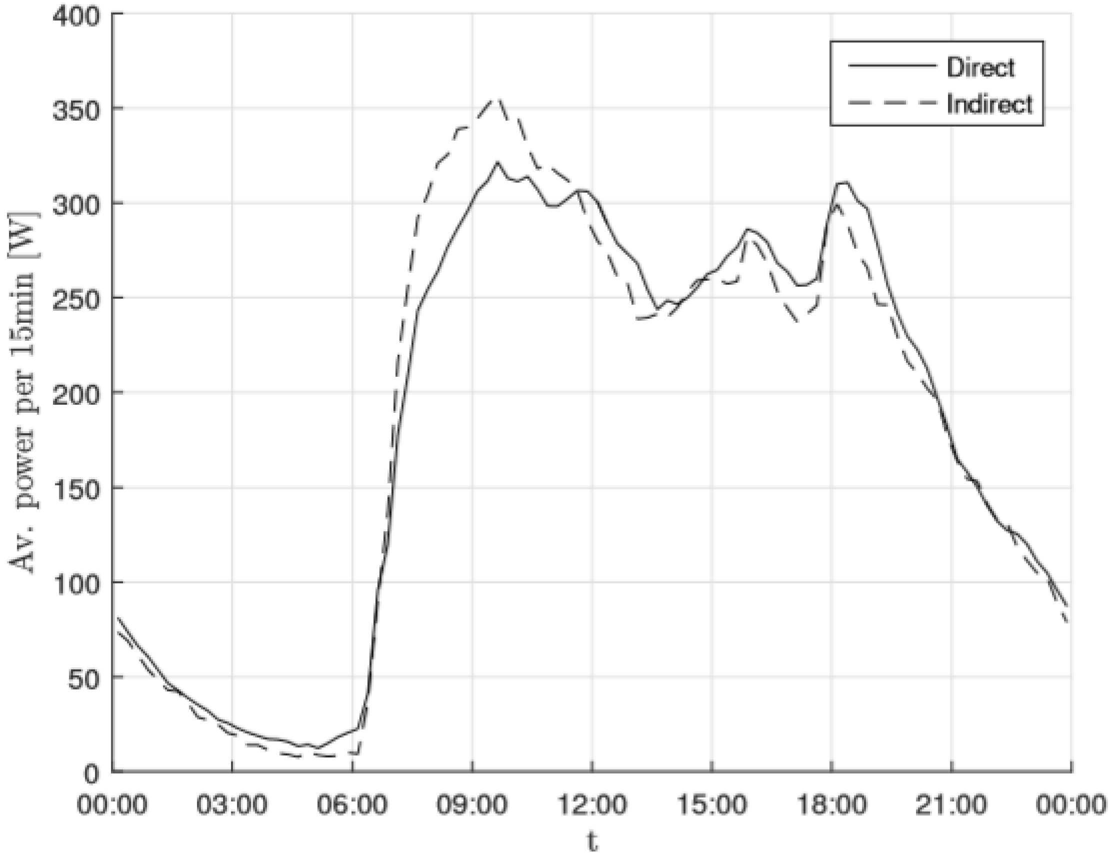

Figure 11: Comparison of standardized load profiles. Source: [9]

5.3 Benefits for the user

The user could benefit from cheaper charging fees or discounts. Therefore, we will now have a look at the possible Business Models based on V2G capabilities. Furthermore, we will analyse some research papers where the potential benefit for the user has been studied for different situations, such as electricity price, grid stability, etc…

BUILDIG A BUSINESS FROM V2G SYSTEMS

There is a business opportunity to implement these capabilities, as the smart EVSE are reserve pools which can sell the energy to a Transmission System Operator, also called TSO as Frequency Containment Reserves (FCR).

The company Virta has developed a Proof of Concept together with TSO Fingrid, which is a Finnish Transmission System Operator, implementing this business model.

Furthermore, a win-win-win scenario can be envisioned, as the grid benefits of frequency stabilizing systems at a low cost (without having to install peaking load power plants), the smart charging station can make a profit by pumping electricity from EVs to the grid and the end user can get fee discount on the charging price.

Another benefit from implementing this system is helping to tackle the renewable energies main problem, which is inconsistency as they fluctuate easily from producing to not producing because they rely on external factors (wind, sun…). Therefore, Smart Charging Stations can apply for subsidies as they would be helping tackle Climate Change by being an electricity storage service. Currently in order to tackle this main problem with renewable energies, battery storage facilities are being installed, which are very expensive. But with this system, we would achieve a similar effect at a much lower cost, as the storage system becomes private electric vehicles.

BUSINESS MODELS CASE STUDIES

There are several published papers studying the economic viability on this topic, therefore we will on focus on the paper published by R. Rezania, and W. Prüggle [10]: *"Business models for the integration of electric vehicles into the Austrian energy system*", as well as the research paper "*Assessment of economic benefits for EV owners participating in the primary frequency regulation markets*" published by Nataly Bañol Arias, Seyedmostafa Hashemi, Peter Bach Andersen, Chresten Træholt, and Rubén Romero [11]. The whole procedure and method used for calculating the business potential of using Smart Charging will be stated. The aim of stating these research papers is to find whether such business model has the potential to result in a positive outcome for EV users.

DOCUMENT 1: Business models for the integration of electric vehicles into the Austrian energy system. R. Rezania, and W. Prüggle. [10]

This research paper will define and to economically analyse the use of electric vehicles in the Austrian energy system as a Business Model (BM), from the energy sector's point of view. The chosen timeframe is 2020 and beyond. The business model consists of Vehicle to Grid (V2G) and Grid to Vehicle (G2V) capabilities.

There have been several studies in which the economic potential of using EVs for providing control energy has been evaluated for different areas of control, reaching different assumptions. For instance, in the paper "*Plug-in hybrid electric vehicles as regulating power providers: Case studies of Sweden and Germany",* this EVs providing control energy Business model was studied for using plug-in hybrid vehicles in both Sweden and Germany, using historical data on control energy demands. With the method applied, they obtained a positive profit margin ranging from 30 to 80 €/Vehicle/Month (taking into account the cost of battery degradation) for vehicles in Germany. On the other hand, the same method was applied for the Swedish energy market, the results were negative profit margins. These distinct results for Germany and Sweden come from many market characteristics. For example, in Sweden there is not a power price for providing control energy. Another characteristic difference in both energy markets is generation capacity mixtures. There are more papers that have studied this topic: *"Electric vehicles and the electricity sector regulatory framework: The Portuguese example, Conference EVS24, Stavanger"* the results were that plug-in hybrid vehicles could qualify for positive margins of around 18 €/Vehicle/Month by providing the energy market with secondary and tertiary control energy in Portugal. Another paper about this same topic: *"E. Larsen, D.K. Chandrashekhara, J. Østergård (2008):.Electric vehicles for improved operation of power systems with high wind power penetration. IEEE Energy 2030"* calculated a positive profit margin raging from 6 to 160 €/Vehicle/Month in Denmark. In general, the previously stated results depend on charging and discharging capacities, without considering additional costs such as communication infrastructure.

This paper focuses on the definition and assessment of vehicle to grid (**V2G, controlled charging and discharging)** and grid to vehicle (**G2V, controlled charging**) possible business models including the description of stakeholders that are involved. The V2G and G2V business models are studied for the participation of EVs in the Austrian control energy markets.

CHAPTER 1: BUSINESS MODELS FOR V2G AND G2V APPLICATIONS

The authors describe in this chapter the Business Model bearing in mind the participation of EVs in the energy control market. In order to have a more precise result, the BMs are divided using two different criteria. On one hand, they are divided in three different use cases depending on the location of the charging station and on the other hand they are divided depending on if they provide a positive or a negative control energy. The difference between positive and negative control energy is that from the point of view of the EV, positive control energy happens when the EV provides energy to the grid and negative when the EV absorbs energy from the grid.

CHAPTER 2: ANALYSIS EXPLANATION

The analysis performed refers to specific battery electric vehicle groups of 94, 36 and 28 vehicles which have installed a battery capacity of 16, 24 and 48 kWh. The driving patterns have been declared using the Austrian travel survey for the federal state of Salzburg in 2004. The main charging strategy used is based on a linear optimization having the target function to minimize the costs of charging taking into account the several Li-ion battery charging characteristics. As there are different daily price curves for electricity during the whole year, two main curves have been declared (winter and summer periods), assigning low cost charging points (when electricity is cheaper). Thus, by using price curves from 2009, an average price was calculated and adapted for 2020. The obtained average price of electricity is 80.82 €/MWh. The constraints declared for the optimization consists of a maximum charging/discharging power of 10.5 kW, with a charging and discharging efficiency of around 95 %. With these values, the battery is operated between a 10 and 90 % of its normal capacity in order to reduce negative impacts from performing deep discharges or overloading, resulting in loss of capacity.

In order to simulate the control energy demands (calls), historical data of the APG (Electrical Grid company in Austria) control area and an add-on modelling of daily control energy has been used. This data is based on the outcomes of descriptive statistical analyses of historical data from 2006 to 2010. The modelling performed consists of 3 steps:

- **Step 1: Analysis of control energy demand**. This step focuses in assigning an appropriate probability density function to each time interval within a day. The database consists of called control energy in the APG control area from 2006 to 2010, with a 15 minutes resolution

- **Step 2: Amount of control energy calls within a day:** For the number of control energy calls within a day, a normal distribution function is assumed. Accordingly, an average value and a standard deviation of the mentioned normal distribution function have been derived based on various historical data.

- **Step 3:** Use of **a random generator for selecting exact times and their associated amounts of control energy calls**. An acceptance-rejection method [12] is chosen to derive total amounts of control energy calls. Combining different driving patterns (number of vehicles) with the control energy scenarios it will build up a result range for each vehicle category for the economic assessment of the V2G and G2V application. Explicitly, the **comparison between the charging costs of a low cost charging optimization approach** on the one hand and the **charging costs of the G2V business models** on the other hand, will be performed.

CHAPTER 3: DATA

The determined price curves for low cost charging station for V2G/ G2V use cases are shown below. The energy price curves during the summer periods are characterized with a maximum energy price at 12:00. On the other hand, winter prices during a day show a trend of having 2 peaks, on in the early morning (08:00) and evening (19:00).

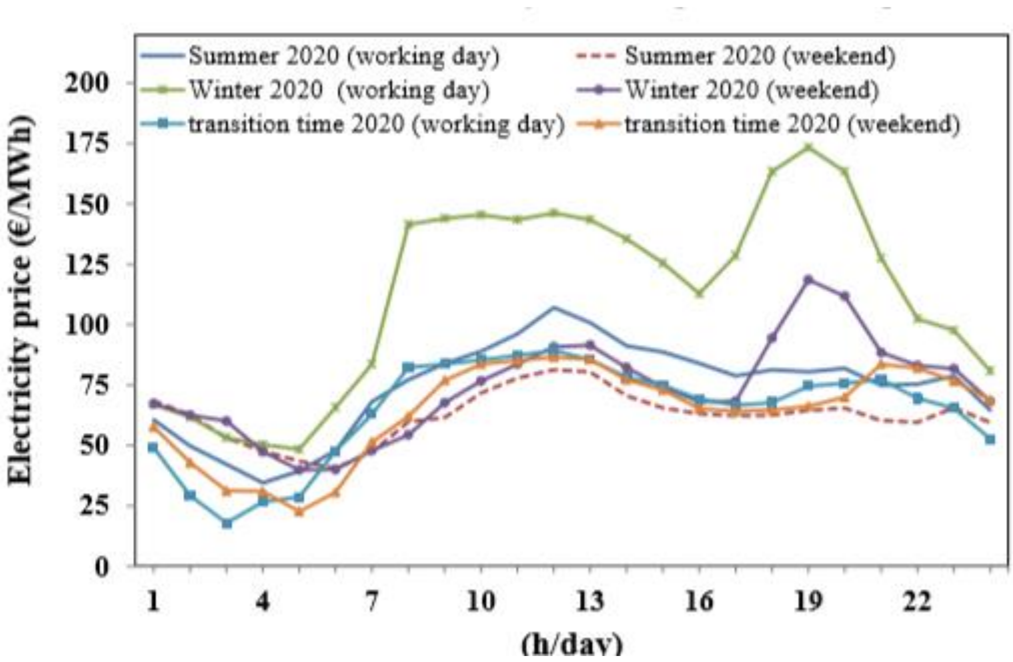

Figure 12: Assumed electricity prices for 2020 based on 2009 price curves. Business models for the integration of electric vehicles into the Austrian energy system. Source: [10]

The Table below shows the used power and energy prices for the Austrian control energy market in 2020, which have been calculated based on historical control energy market conditions.

	Positive (V2G)		Negative (G2V)	
	Power price €/MW/h	Energy price €/MWh	Power price €/MW/h	Energy price €/MWh
Primary control	53.6		53.6	
Secondary control	26	116.90	26	73.1
Tertiary control	2	176.75	10	73.1

Table 1: Average Value of Energy and Power Price for the Austrian Control Market 2020. Business models for the integration of electric vehicles into the Austrian energy system. Source: [10]

CHAPTER 4: RESULTS

EVs participation in control energy market in the APG- control area

The charging costs in the G2V use case (within the tertiary market) are higher than the low cost charging strategy on the point 100 % (power price = 10 €/MW/h, energy price = 73.10 €/MWh). The main reason is the high concentration of tertiary energy between 06:00 and

20:00. Consequently, the electric vehicle must be charged using higher energy costs compared to the so-called low-cost charging strategy (which consists of charging in the early morning or late evening, when there is a lower demand resulting in cheaper prices). The power price cannot compensate the mentioned difference (maintaining a negative contribution margin). A positive gap can be achieved by reducing the energy price by about 30 % from the main point with an energy price of 73.10 €/MWh. This energy price will be paid by the aggregator due to EV charging. Therefore, charging electric vehicles on the secondary market results in lower charging costs and therefore positive margins compared to the low-cost charging strategy can be achieved due to a higher number of secondary calls, their distribution over all time periods and higher prices. Based on the discussed main point in Fig. 8, the contribution margins due to participation of EVs on negative control market (tertiary and secondary) obtain a spread of margins between -87.6 and 70.80 €/vehicle/yr. (-7.32 and 5.9 €/vehicle/month).

It is possible to obtain positive margins with battery investment costs lower or equal to 500 €/kWh due to lower battery degradation costs. The margins for providing positive secondary power ranges between 270.72 to 767.28 €/vehicle/yr (22.56 and 63.94 €/vehicle/month) (when considering battery investment cost of **500** €/kWh). The same analysis has been conducted for providing positive tertiary control, resulting in margins ranging from 63.49 to 198.1 €/vehicle/yr (5.29 to 16.51 €/vehicle/month) (with a battery investment cost of 500 €/kWh). The disclosed margins indicate the maximum contribution margins for each vehicle because of ignoring the dispatch probability in Austrian control area. The control power reserves in Austria are about +/-200 MW for secondary and +280/ -125 MW for tertiary control. The control power data, which will be provided by the balancing group coordinator, indicates dispatch probabilities of about 17 % (18 %) for positive (negative) secondary and 0.4 % (1.35 %) for positive (negative) tertiary control energy in 2010. The same probabilities are found in control markets in Germany. However, considering dispatch probabilities (see Fig. 9) reduces the contribution margins for V2G application (secondary control) raging between 46.02 to 130.44 €/vehicle/yr. Fig. 10 illustrates battery capacity losses due to automotive use for all analysed vehicle categories, assuming an automotive lifetime of 10 years. The 16, 24 and 48 kWh battery packs show average capacity losses of about 12 %, 9% and 6 % of their capacity.

CHAPTER 5: CONCLUSION DOCUMENT 1

The previous calculation of G2V and V2G profit margins does not consider secondary costs like the communication infrastructure or a V2G inverter. Consequently, an economic realization of V2G and G2V (participating in the control energy market in Austria) with a maximum margin from -87.6 to 767.28 €/vehicle/yr (without consideration other costs and dispatched probability) cannot be recommended. The G2V application for participation on the negative secondary control market has a better economic potential compared to the V2G application. The reasons lie in a higher number of control energy calls and non-existing battery degradation costs.

COMMENT ON DOCUMENT 1

Although the paper concludes it is not highly profitable, profit margins are highly dependent on electricity cost and battery pack cost. Therefore, with the increasing electricity price and cheaper battery pack trends, such business model can become more profitable with higher margins in future years. Consequently, although it is not highly profitable nowadays, it is a BM to keep an eye on as electricity prices are soaring whereas battery packs are getting cheaper and cheaper. As we can see in the following graphs, the former [12] depicts the evolution of electricity prices in Germany and the latter [13] depicts the evolution of battery cost per kWh.

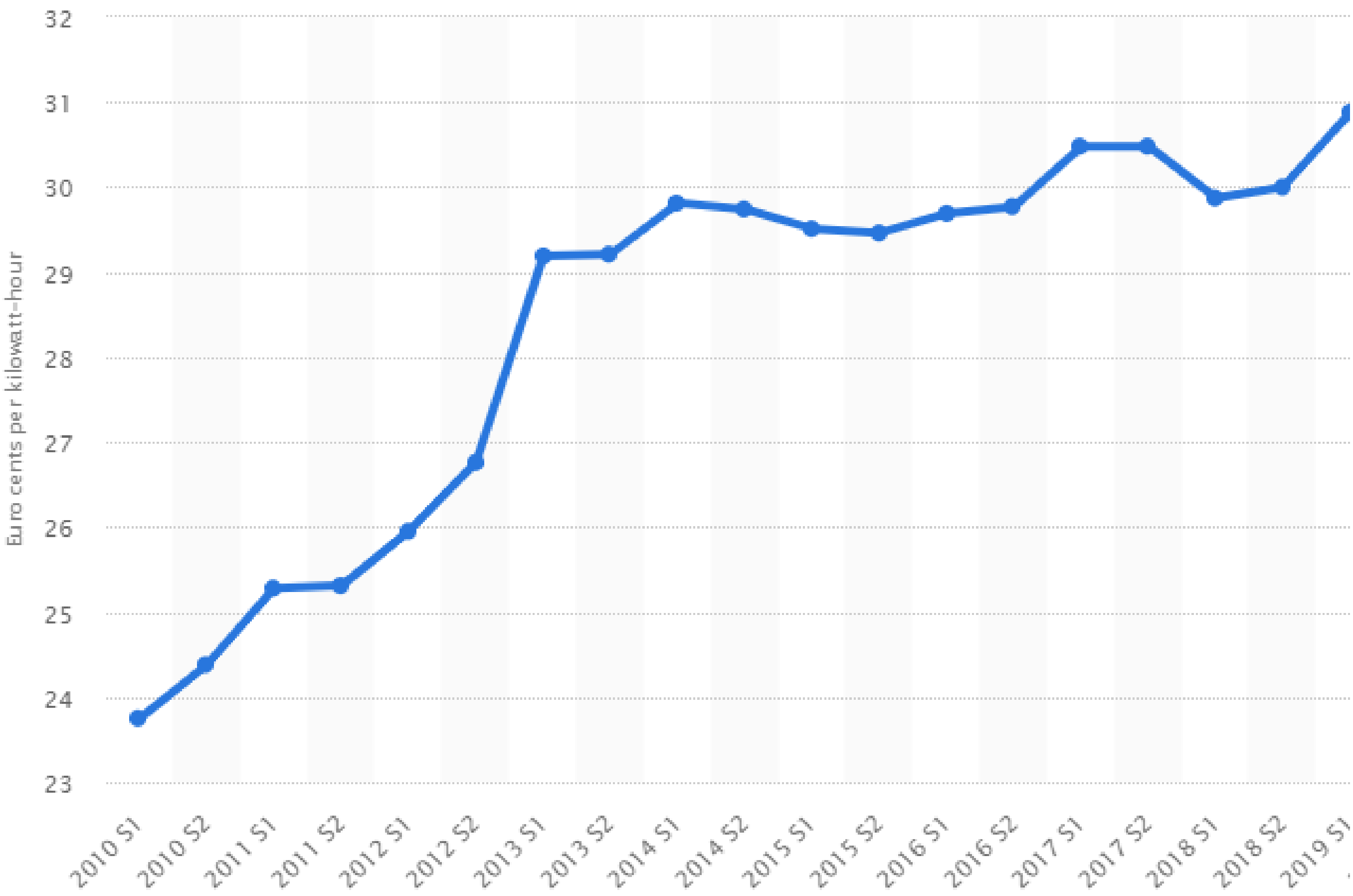

Figure 14: Electricity price in Germany for households. Time period from 2010 until 2019. Source: [12]

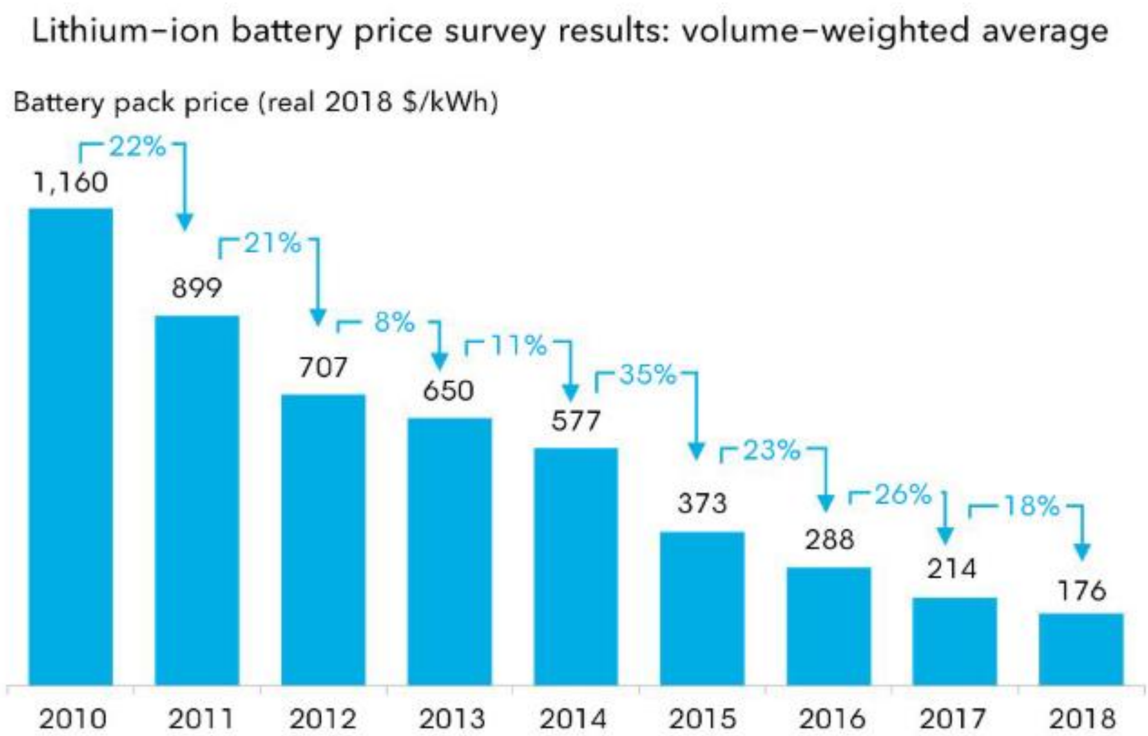

Figure 13: Lithium-ion battery pack price evolution per kWh. Source: [13]

Therefore, as we have seen on the last two graphs, Electricity price and battery packs will follow their trends, with electricity getting more expensive and battery packs cheaper. Another trend that could increase the profit margin in the upcoming years is the higher percentage of installed capacity of renewable energy, mainly solar and wind. These renewable energies are highly unstable and requires stabilizing systems, fitting perfectly in this Business Model.

In order to provide extra information on the topic, a second paper on the matter has been analysed and studied in order to determine the economic benefits for EV users to participate in the frequency regulation markets

DOCUMENT 2: Assessment of economic benefits for EV owners participating in the primary frequency regulation markets. **Nataly Bañol Arias, Seyedmostafa Hashemi, Peter Bach Andersen, Chresten Træholt, and Rubén Romero. [11]**

In this paper, the authors design different methods in order to optimize the power bid that maximizes the benefit of Electric Vehicles owners by providing frequency controlled normal operation reserve (FCR-N), which is the primary frequency reserve in the Nord Pool market. A search algorithm that performs an exhaustive search of the power bid market is used in for maximizing EV owner's profits. The economic assessment performed in this paper address the profit margin from the EV owner's perspective.

The paper provides the following strategies for EVs providing frequency control:

In order to deal with battery degradation, caused by charging cycles and reaching the battery's maximum and minimum capacity, and to maximize the economic benefit of PFR, three operation strategies have been proposed: **complete pause**, a **preferred operating point** mechanism, and **over-fulfilment**. All these methods have been developed for being applied in real-time operation.

1) Complete Pause (CP)

This is the simplest strategy out of the three strategies developed by the authors, and basically when the battery has almost reached its maximum or minimum limits, this method allows predefined time periods to restore SOC. This method will happen either when the battery is fully charged or discharged. In those cases, when the battery has reached its maximum or minimum limit, a pause is activated and the EV is no longer able to provide service.

2) Over-fulfilment (OF)

The second strategy proposed consists of allowing modifications of $Preq$ in a predefined percentage σ. In case the SOC is less than the minimum allowed ($SOCOF$) and down-regulation is requested, the EV will be charged more than $Preq$. In case the SOC is higher than the maximum allowed ($\overline{SOCOF}$) and up-regulation is requested, the EV will be discharged more than $Preq$. Furthermore, once the battery is fully charged or discharged, the SOC is recovered as in the **complete pause strategy** described previously.

3) Preferred Operating Point (POP)

The last strategy designed by the authors of the article is Preferred Operating Point (POP), which is a mechanism used to ensure a safe EV's SOC and to be able to provide services at any given time. This strategy is based on defining a set point at which the EV will charge or discharge its battery based on the frequency signal using a flexible operating point. The POP can be calculated by using different policies/methods, and it should be activated as quick as possible and within short intervals.

PROBLEM FORMULATION AND OPTIMIZATION PROCESS

For Electric Vehicle owners participating in PFR markets, the economic benefit depends on different parameters. In this case, the benefit is calculated by considering costs and incomes of taking part in PFR markets. Incomes are calculated by capacity payment (ICP) and the amount of energy exchanged (IEE). Costs are calculated using several parameters, such as a penalty for the unavailability time (CUP), a penalty for causing congestion problems on the electrical grid (CGI), and the cost of battery degradation (CBD). All of them are calculated for a contracted regulation period (Π); for example, one year.

Cost of Battery Degradation

A main limiting factor for maximizing the benefit of participating in the PFR market is Battery Degradation. Calculating the exact battery degradation caused by taking part in the PFR market is highly challenging, as battery manufacturing companies provide very little information on degradation costs. On the other hand, a big chunk of battery degradation happens by using the EVs as its main function, transportation. Hence, total battery degradation (δ) is calculated from both daily use necessity ($\delta transp$) and service provision ($\delta sprov$). The authors only consider battery degradation produced by service provision. The battery degradation mainly depends on temperature, depth of discharge (DoD), the battery technology, SOC and the charging and discharging amount of power. In this paper, a battery cycle life method is used in order to calculate battery degradation caused by services provision, $\delta sprov$. The method, which uses a semi-logarithmic function, calculates the number of cycles in terms of the DoD ($CLDoD$), assuming at 80% the battery's end of life (EoL). This function provides the battery cycle life for a particular DoD, therefore it is extremely necessary to calculate the number of cycles that the battery will perform at a specific DoD (βDoD). βDoD depends on the SOC pattern, after the regulation period, and in order to calculate it, the authors use a rain flow-counting algorithm.

SIMULATION AND RESULTS

In this part of the paper, an adaptation of the method will be used for optimizing the power bid and the profit of EV owners taking part in the PFR market in **Denmark**.

1) Simulation Assumptions

The simulation findings congregate the expected annual benefit an EV owner could obtain by providing FCR-N. In order to do so, the simulating time period chosen is one year (i.e. equal to 8640 hours) by using historical data for frequency with one second resolution (Δs), besides the average 2017 price for availability payment and electricity price, 23.23 €/MWh/h and 31.95 €/MWh. Grid impact cost is considered only for downward regulation cases, since in those cases the EV should consume power from the grid (charge the battery). provoking a demand increase, where components may suffer from overloading or congestion. Each user has a maximum power consumption set as 7kW, in order to minimize congestion. T^- and φ^-

are defined as 1% and 5%, respectively. For the calculation of battery degradation, it has been considered 3000 cycles at 100% DoD, $\bar{\beta}$ is equal to 20%, $\bar{\Upsilon}$ is equal to 10 years and the replacement cost is determined as 158 €/kWh according to the cost projection of lithium-ion batteries for upcoming years.

The simulations are performed by using Four EV brands, which have different technical characteristics (range of miles, charge port, energy consumption, performance, dimensions, and weight) have been used in order to perform the simulation. These vehicles chosen are the same as the EV fleet used in the Parker project. These EVs are: Peugeot iOn, Nissan Leaf, Mitsubishi Outlander PHEV, Nissan e-NV200 Evalia, with a maximum battery capacities ($\bar{E}$) of 16, 30, 12 and 24kWh, respectively. The minimum energy required by the EV owner (E) is set to 30% of the maximum battery capacity. Moreover, an Enel V2G charger with maximum capacity ($Pmax$) of 10kW is chosen in order to run the simulation, assuming a charger efficiency (ηc). Next, the maximum bid is set as ±10 kW, considering a symmetric condition. Furthermore, $\Delta Pmax$ is equal to 1kW, $Pmax$ and $\bar{P}max$ are 0 kW and 10 kW, respectively, and the minimum bid condition is disregarded.

CONCLUSION DOCUMENT 2

The authors of this paper presented an assessment of the economic benefit for electric vehicle (EV) owners participating in the primary frequency regulation (PFR) market. A heuristic method was used to optimize the power bid that maximizes the EV owners' benefit along with a set of operational strategies that eases service provision. The **simulation results demonstrated that EV owners can obtain significant benefits by providing frequency-controlled normal operation reserves (FCR-N) in the Nord Pool market**.

It was determined that costs related to the unavailability of service and the electrical grid impact have a strong influence on the benefit, even more than the battery degradation. For example, results showed that EVs with less battery capacity present a high risk of unavailability fines or battery degradation costs when bidding high power bids (because the battery might be fully discharged or charged in a short span of time). Nevertheless, results also showed that using operation strategies helps reducing or even avoiding those costs.

Consequently, choosing a proper operational strategy can potentially increase profits by decreasing the unavailability of service as well as battery degradation.

Three different operation strategies were studied: complete pause, over-fulfilment, and the preferred operating point (POP) mechanism. The comparison among the three strategies proved that more sophisticated strategies such as POP, allows offering higher power bids and increasing the chance to obtain higher profits. It was demonstrated that even by bidding into the market with a low power capacity of 1 kW, EV owners are able to obtain an annual benefit of around €100. This 1 kW bid results in a profit for all operation strategies and avoids the risk of incurring fines because of service unavailability or grid impact. The application of **POP was the best operation strategy**, **decreasing both the unavailability period and battery degradation**. Under the **POP strategy**, EV owners are able to bid with the nominal capacity of the charger, which was 10 kW, and **obtain a yearly profit of up to €1100. This yearly profit can be achieved regardless of the EV battery capacity.**

Results also showed that **considering the daily operation of EVs** (customer preferences) significantly **reduces the benefit** that the EV owner could obtain (around 58% less), which demonstrates that the users' preferences play an important role within the economic calculations. In addition, results from the sensitivity analysis showed that the variations of the benefit highly depend on the operation strategy under analysis. The POP strategy proved to be less sensitive to variations of the maximum unavailability time and grid impact time, while the others showed significant variations of the benefit.

5.4 How included on the HMI Project. Explained and Restrictions

Bearing in mind the previously analysed papers, the implementation of V2G capabilities has strictly followed the findings of these papers. Therefore, some restrictions have been made in order to maximize the user's profits.

IMPLEMENTATION

After analysing the previous papers about the economic viability, although the authors on Document 1 conclude it is not recommended as it is not highly profitable, current trends show battery packs are getting cheaper whilst electricity cost is increasing. Therefore, there is a chance it becomes a more profitable business. Thus, it has been decided to include such feature in the HMI capabilities.

In order to increase profit margins, taking into account the data and methods used to analyse the economic viability the previous papers reviewed, a question tree scheme has been developed in order to identify possible users that can benefit from this V2G when using the charging station. These possible users will be selected if they match the requirements set for increasing the chances of having high profit margins. These requirements are set bearing in mind the charging speeds (ultra-fast, fast and slow) and at what time of the day is the charging process going to take place. The charging speed has been chosen as a determining factor as there is a clear relation between the required charging power and the EV's user available time for charging, as statistically when EV users choose ultra-fast and fast charging methods is because the available charging time is low and the EV user requires the EV charged as soon as possible. Therefore, Ultra-Fast and Fast are not applicable for V2G capabilities as in the situation where control energy for the electrical market is required, it would cut the charging process increasing charging time. That is why, only users that choose Slow charging method (low power required) are applicable for frequency stabilizing actions if needed. Apart from charging speed, at what time of the day the charging process is going to take place is also a requirement. Thus, for users charging at Slow speed, only those with the charging process happening between 07:00 and 20:00 are chosen for V2G capabilities. Such time period has been determined considering the typical daily demand graph for Germany. Therefore, overnight charging (usually at low speed/power) is not accepted as frequency stabilizer as electricity demand during night hours is constant, without any high demand peaks.

Therefore, if the user selects the slow charging speed and the charging process will take place inside the 07:00 until 20:00 time frame, the user will be informed about the possibility to activate Vehicle to Grid capabilities. Thus, the user will receive a fee reduction depending on the amount of energy sent to the electrical grid, helping to stabilize it.

An information screen has been included in case users need further information about V2G capabilities. At the V2G information screen, key information is displayed in order to successfully inform the user about the benefits and disadvantages of enabling such function.

If users meet the requirements and accept to enable V2G capabilities during their charging process, they will be asked to determine the minimum State of Charge (SoC) % of the battery required at any given time. Thus, in case the user ends the charging process sooner than expected, it ensures the user will have the desired amount specified of energy in their battery.

The implementation of V2G capabilities is done from a point of view where it is a win-win situation. By analysing the benefits for the electrical grid and the papers about possible business models (where if profitable it will benefit the user), we set the requirements and limitations as to making use of these capability.

6. Story telling: Different charging methods (use cases) and their complete program walkthrough

<u>USE CASE 1:</u> Slow charging method with card payment and V2G enabled.

This use case covers the HMI interface walkthrough for a user that selects a slow charging speed, with a power output ranging between 3 and 6 kW. Then, in order to be able to activate Vehicle-to-Grid capabilities, the user must fulfil two requirements, the slow charging speed must be chosen, and the charging process must take place between 08:00 and 20:00.

First of all, we have the main screen of the HMI Charging station [14]:

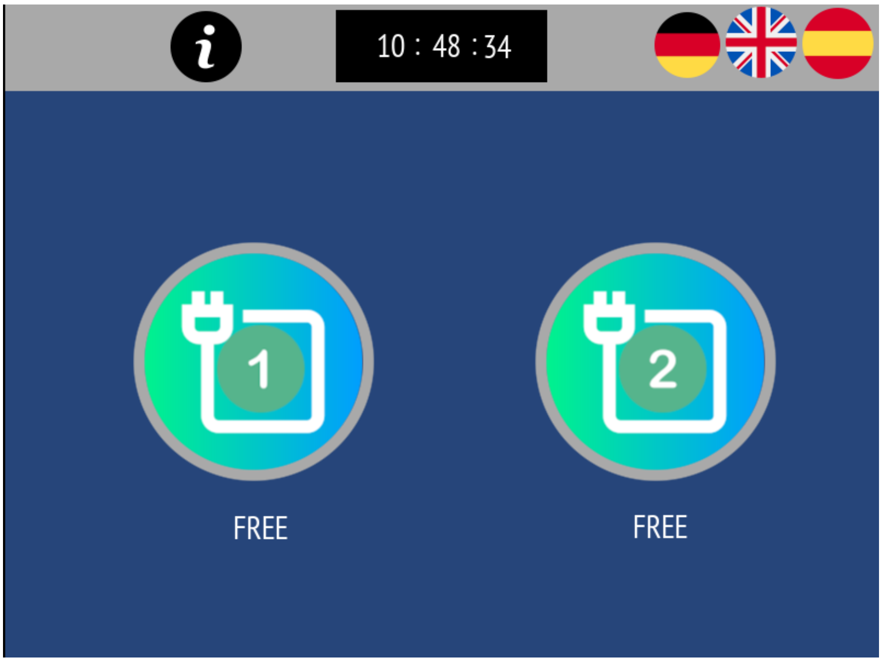

Figure 15: Interface main screen. Source: [14]

Then, the user can select whichever port is free in order to perform the charging process. In this case both ports are not being used and the user selects port 1.

The next screen is the charging speed selection:

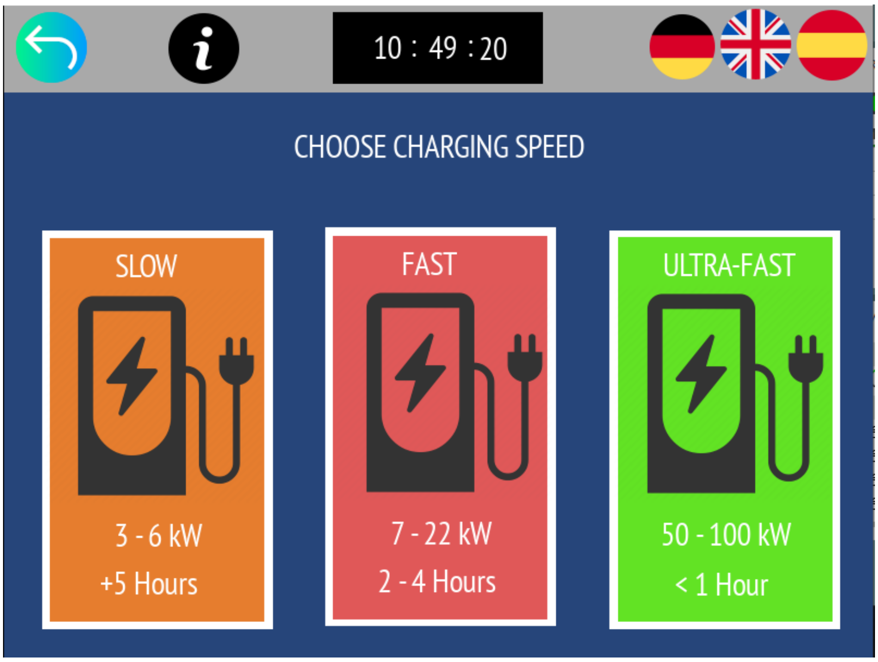

Figure 16: Charging speed selection screen. Source: [14]

Here the user can select between 3 charging speeds: Slow, Fast and Ultra-Fast. Depending on the user's need and the electric vehicle's physical capabilities, different charging speeds can be selected. Then, the user must choose the desired rate, ergo which pricing scheme fits best for their case.

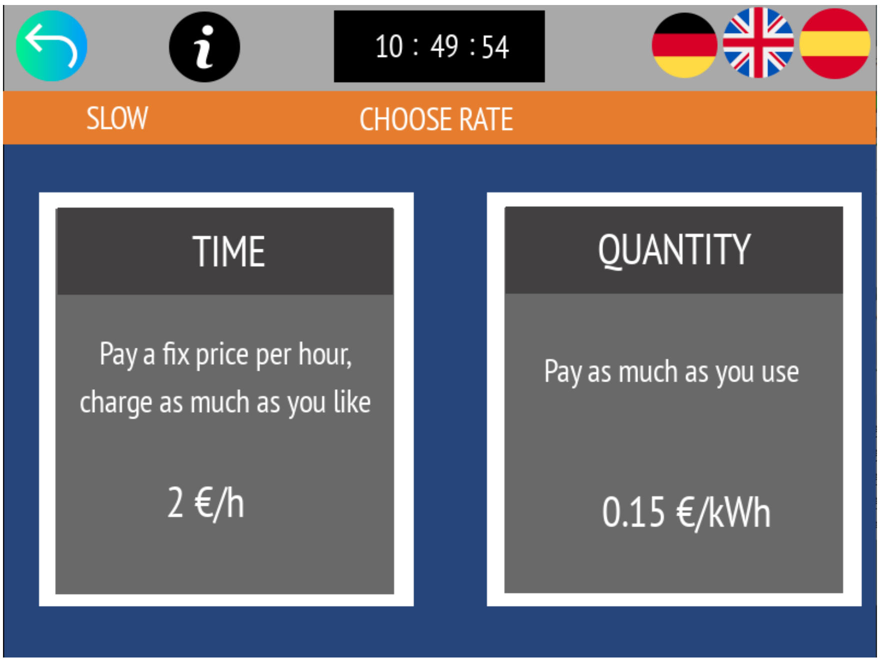

Figure 17: Pricing selection screen. Source: [14]

With the Time rate, users pay a fix price per hour. The faster the charging speed, the more expensive the time rate is, as with a higher charging speed more energy is transferred to the battery. On the other hand, with the quantity pricing scheme a price per kWh is set, therefore users just pay as much as they charge.

In this use case, the user will select the Time pricing rate, thus through the touch screen the user must determine the number of hours the charging process will take place for.

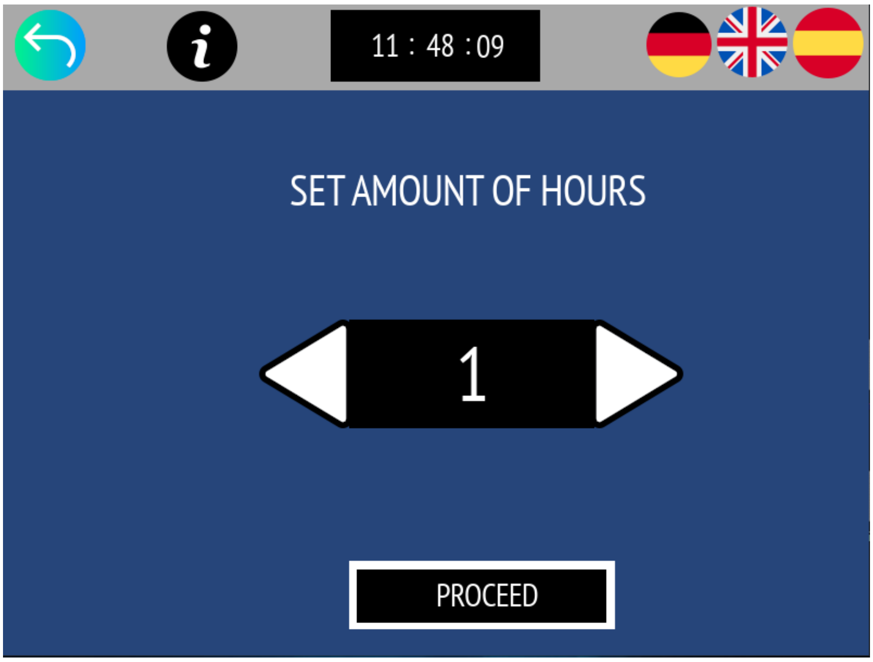

Figure 18: Amount of hours selection screen. Source: [14]

A minimum of 1 hour has been set and the user can choose up to 12 hours of time with this pricing rate.

After selecting the number of hours, the payment method must be chosen. It is possible to choose between in-car payment and contactless card payment. The in-car payment is only possible with EV which are capable of establishing a high level of communication with the Charging station, as the charging station will ask for the user's payment details (card number, billing address, etc…) and the EV will provide such information so the payment can take place. On the other hand, the user can choose the contactless payment method, which works with an RFID reader. It is the same system as found at supermarkets.

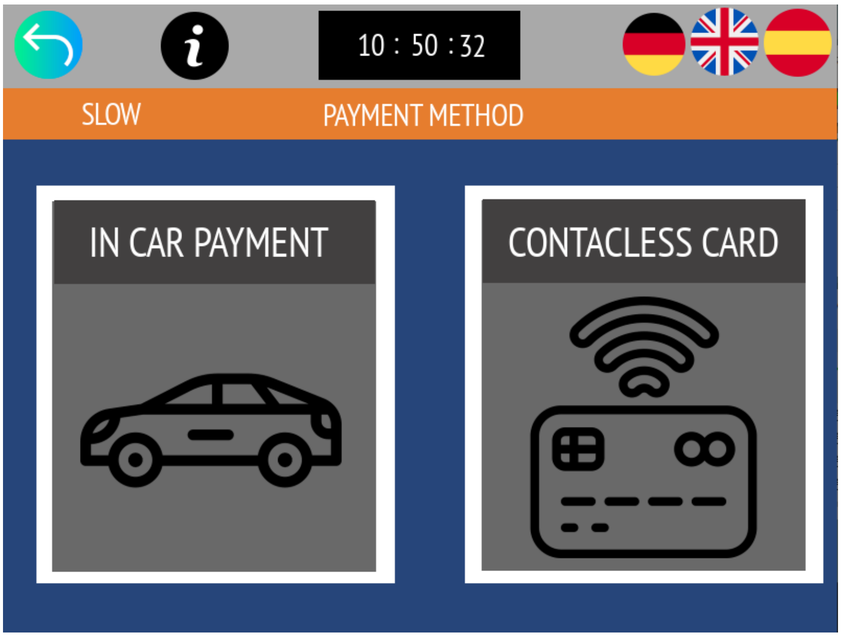

Figure 19: Payment method selection screen. Source: [14]

Once the payment method has been determined, the HMI interface will display the confirmation screen. On this screen, the user can view a summary of the chosen charging process, and either confirm or reject it. In any modifications should be made, the user can either completely reject the current choice and start with a fresh charging process or by pressing the back button (arrow) the user can go backwards and modify any of the inputs that were made.

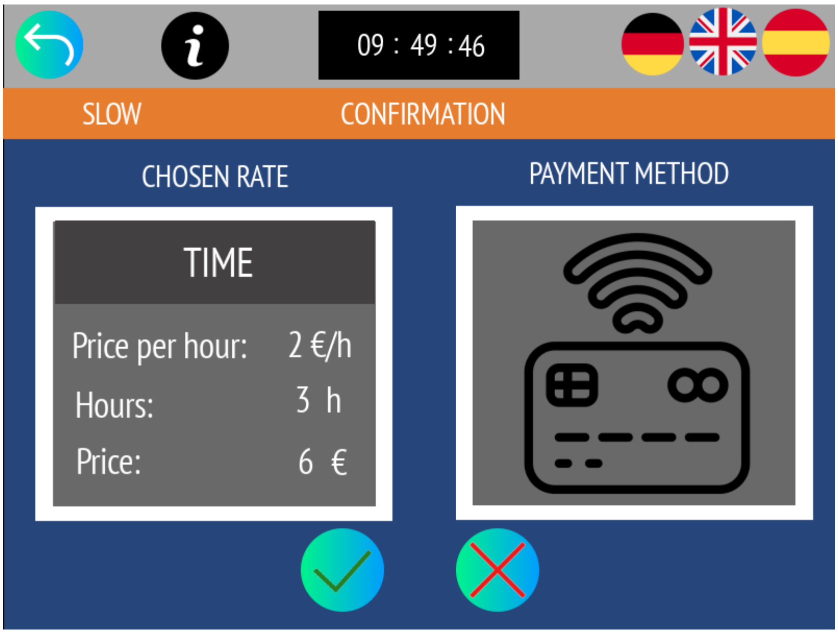

Figure 20 Confirmation Screen. Source: [14]

Apart from displaying the selected choices, the user will be informed about the total price.

If the user decides to accept the current election, the next screen will be displayed. In this case, as the charging speed has been set to “slow” and the charging process will take place between 08:00 and 20:00 , the user will be asked if they want to activate V2G capabilities, and if activated, they can experience price reductions. An information screen has been designed in order to provide key information to the user.

Figure 21: V2G activation screen. Source: [14]

If the user decides to activate V2G capabilities, the next screen will be displayed, where the user must choose the minimum battery percentage at any given time. Therefore, the user accepts to sell their energy at crucial times were peak demand takes place, but by setting the minimum battery percentage, the user will be certain that if the charging process must be finished before expected, they will have enough energy in the battery for making a normal use of the vehicle.

Therefore, in the next view screen the users will determine the minimum percentage of battery:

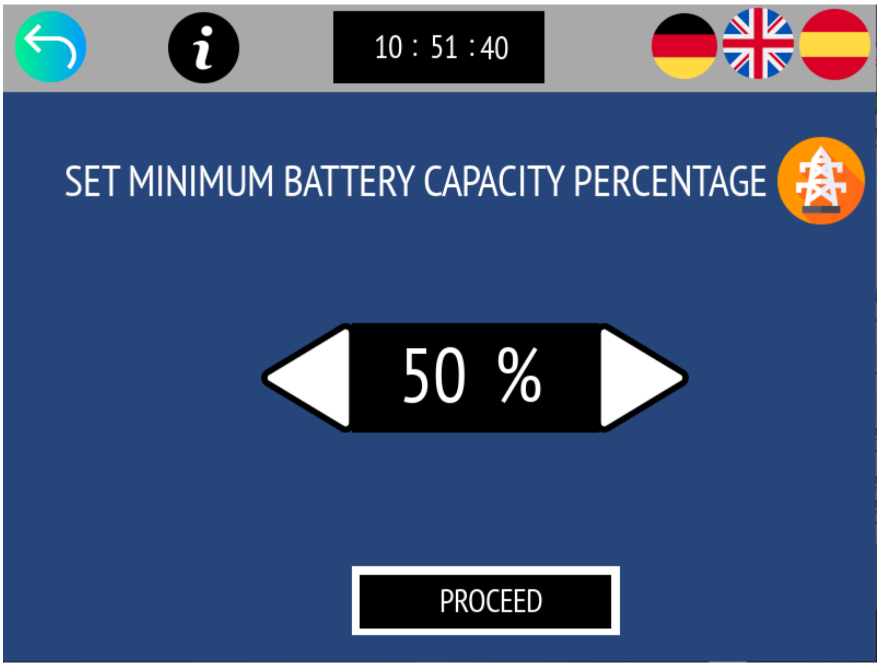

Figure 22: Minimum battery SoC. Source: [14]

Once the percentage has been set, the payment screen will appear. In this case, as the user selected contactless payment, the user must place the card on the contactless reader.

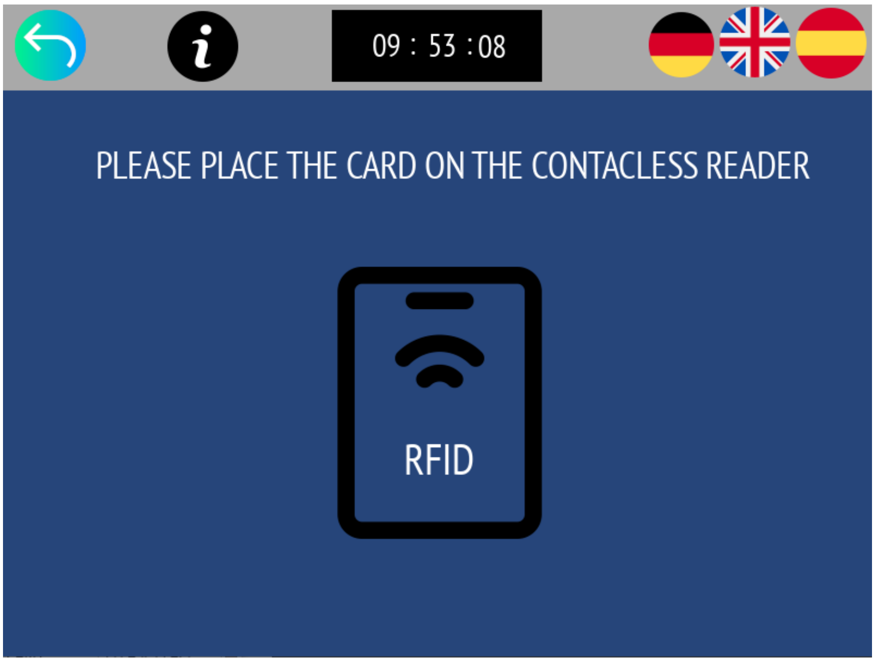

Figure 23: Card payment screen. Source: [14]

If there is not a satisfactory payment process, the next view screen will appear, where the user is informed that the payment process was unsuccessful, and they must try again.

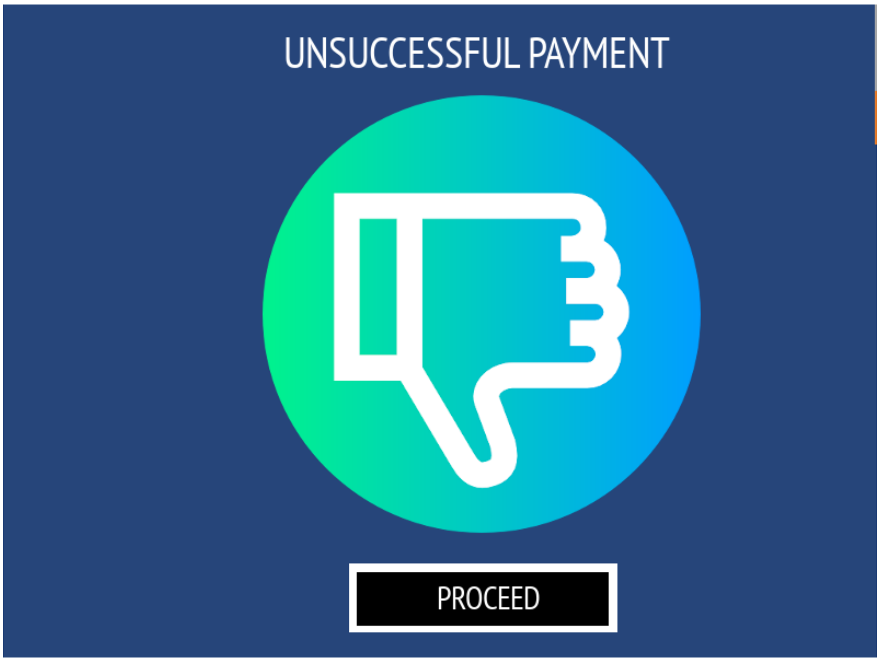

Figure 24: Unsuccessful payment screen. Source: [14]

If the payment process is successful, the user will view the next screen. Once the payment is successful and the user presses the "Proceed" button, the charging process will start.

Figure 25: Successful payment screen. Source: [14]

Once the payment is successful and the user presses the "Proceed" button, the charging process will start and the main screen will display the status of port 1, which is now charging.

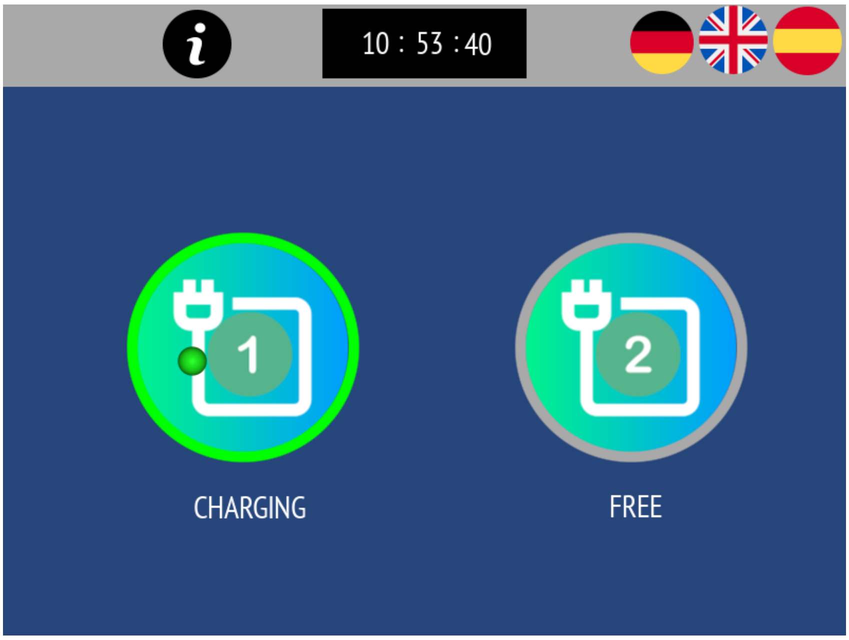

Figure 26: Interface main screen. Source: [14]

As Port 1 is charging now, if we press the button instead of opening the charging process selection menu, an information screen will be displayed. On this information screen we can see the charging speed selected, the amount of time the charging has taken place for, the amount of energy transferred to the vehicle and if V2G capabilities has been enabled.

The information screen for Port 1 can be seen below:

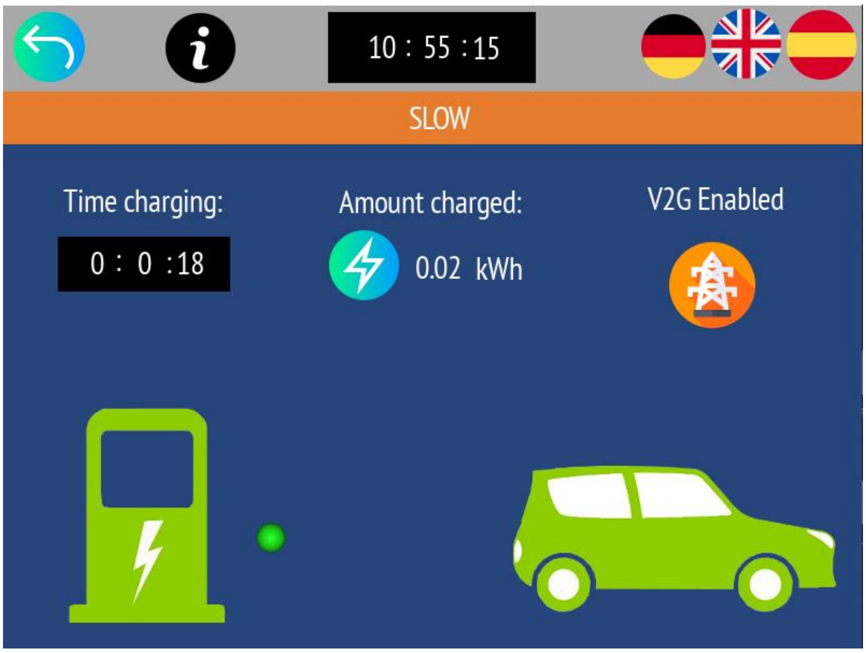

Figure 27: Charging process information screen. Source: [14]

<u>USE CASE 2:</u> Ultra-Fast charging method with in-car payment.

Now we will see a complete walkthrough for a charging process completely different to the previous use case, number 1. In this Use case, number 2, the user will choose the maximum speed possible (Ultra-Fast), then the quantity pricing rate, in-car payment method. The user will not be offered to enable V2G capabilities because it does not fulfil the requirements, as the Ultra-Fast charging speed has been selected (the Slow charging speed is needed for enabling V2G capabilities, apart from charging between 08:00 and 20.00).

First of all, on the main screen, we will select the port number 2 for creating the use case 2 charging process.

Then we will select Ultra-Fast charging speed.

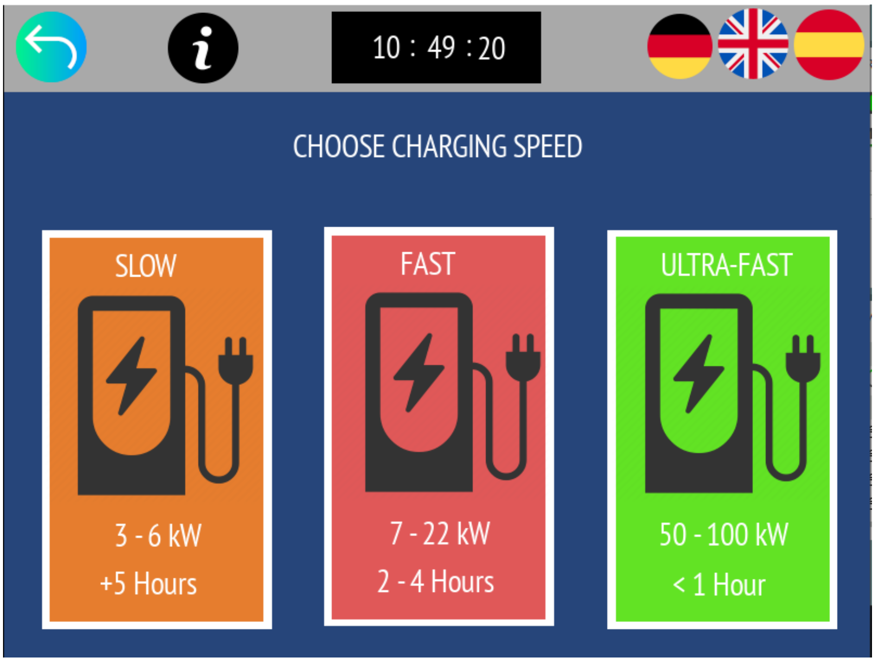

Figure 28:Charging speed selection screen. Source: [14]

Once Ultra-fast charging speed has been selected, the user will have to choose the pricing rate, either the time pricing rate or the quantity one.

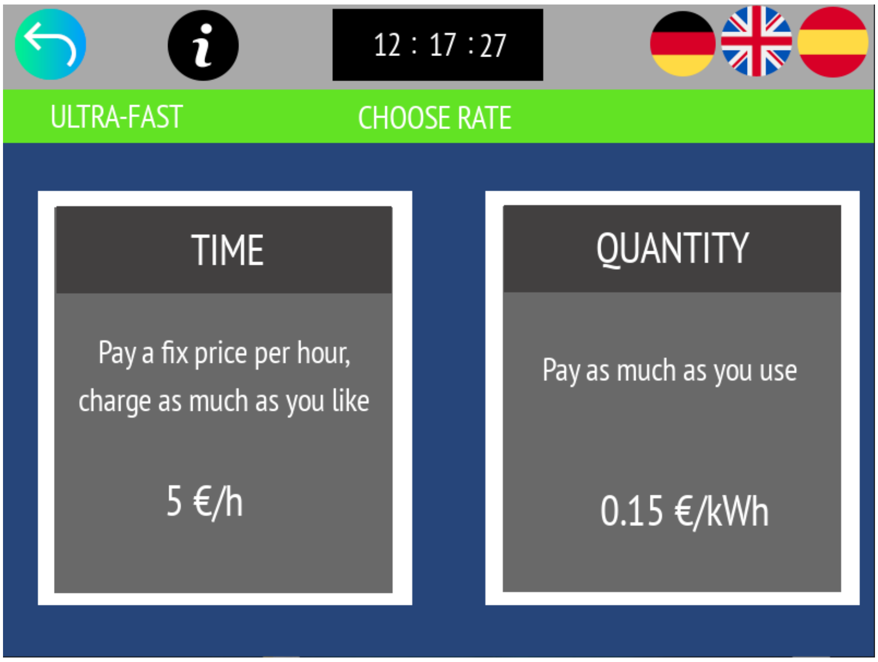

Figure 29: Pricing selection screen. Source: [14]

For this use case, we will select the quantity pricing scheme, we a fix price per kW charged is set. Therefore, users will only pay for as much energy as it has been transferred to the vehicle.

The next step on the charging process is to select the payment method.

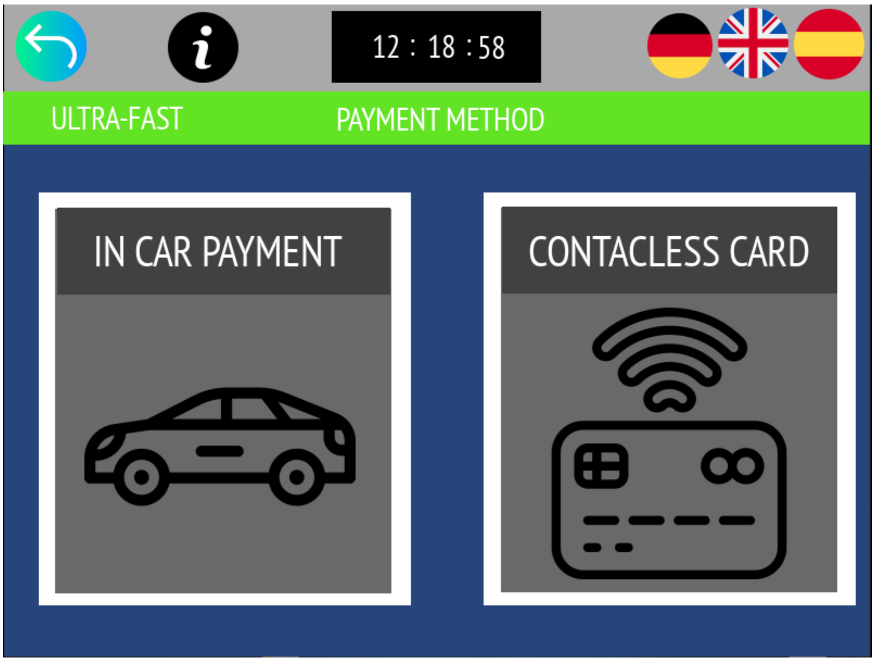

Figure 30: Payment method selection screen. Source: [14]

The in-car payment method is chosen for this use case. This payment method is only available for vehicles that are capable to establish a high level of communication between the vehicle and the charging station, as the charging station must be able to autonomously ask the electric vehicle for the user's billing information in order to perform the payment process.

Once the payment method is chosen, the confirmation screen will appear, with a summary of the current charging process for Port 2.

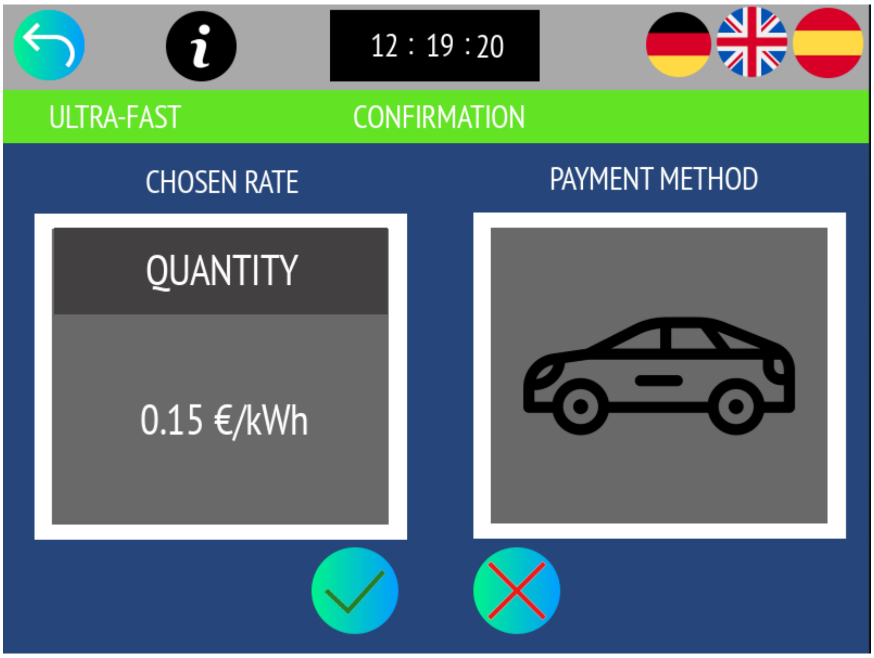

Figure 31: Confirmation screen. Source: [14]

On the one hand, if the user rejects the current charging process selection, the user will be redirected to the beginning of the charging process. On the other hand, if the user accepts the current selection, the payment screen will be displayed.

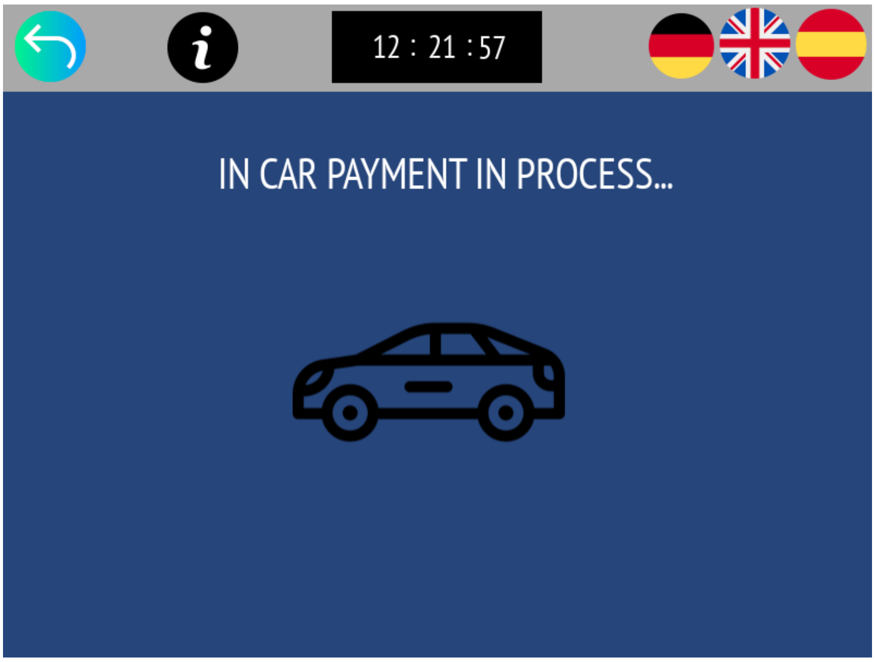

Figure 32: In-car payment method screen. Source: [14]

Once the payment process finalizes successfully, which means the electric vehicle was able to establish a high level communication protocol with the charging station and then carry out all the information exchange necessary for performing the in car payment, the interface will display the successful screen.

Figure 33: Successful payment screen. Source: [14]

By pressing the button “proceed”, the charging process will start, and the interface will display the main screen with the status of both charging ports.

If the payment process does not carry out successfully, the unsuccessful screen will be displayed, and the user will have to carry out the payment process again.

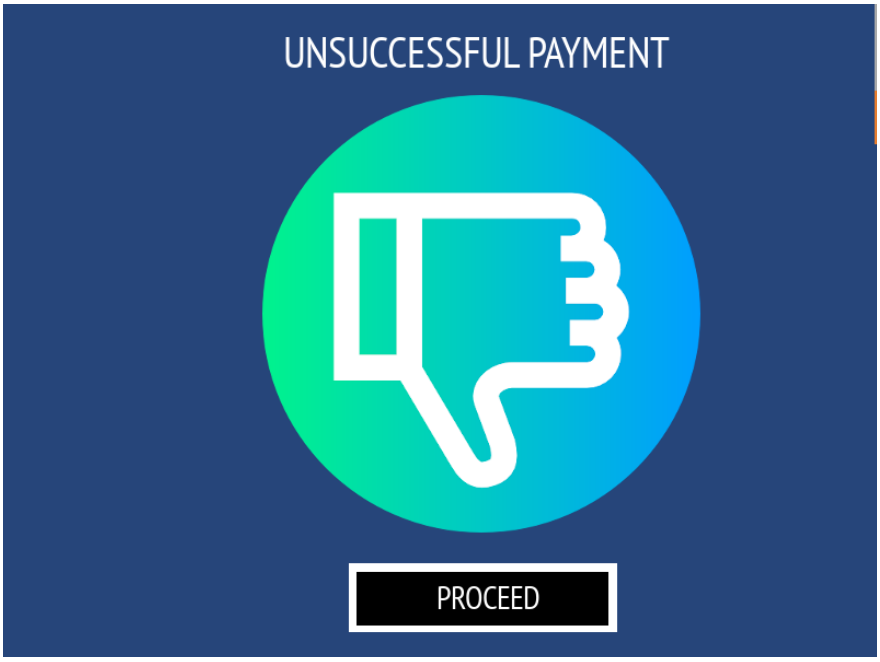

Figure 34: Unsuccessful payment screen. Source: [14]

Once the user is redirected to the main screen, after the payment process if finalized, the main screen will display the status of both charging ports 1 and 2. In this case, both ports appear as charging as the use case 1 was performed on port 1, and use case 2 on port 2.

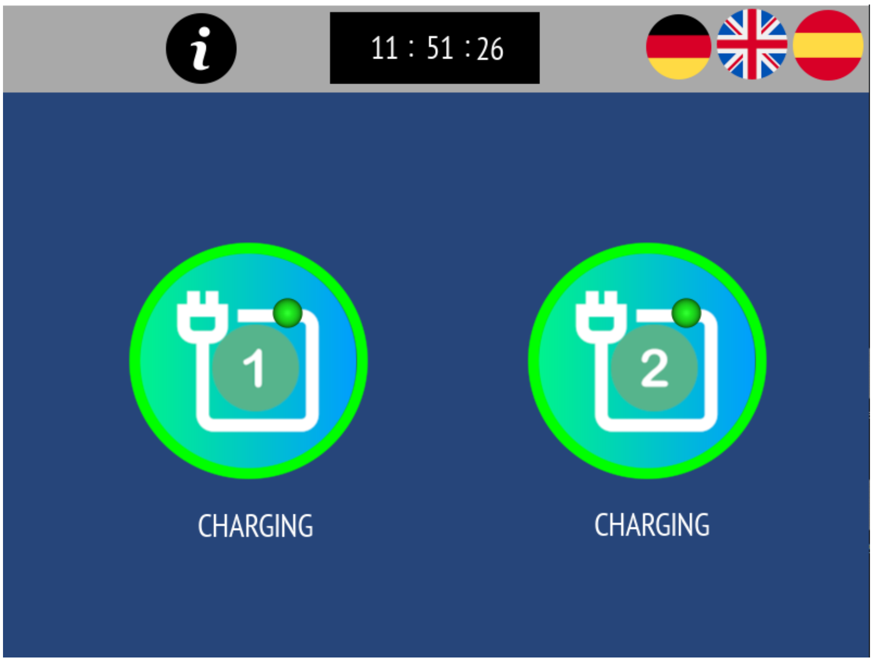

Figure 35: Interface main screen. Source: [14]

Thus, if we touch the port 2 button, the information on the current charging process will be shown:

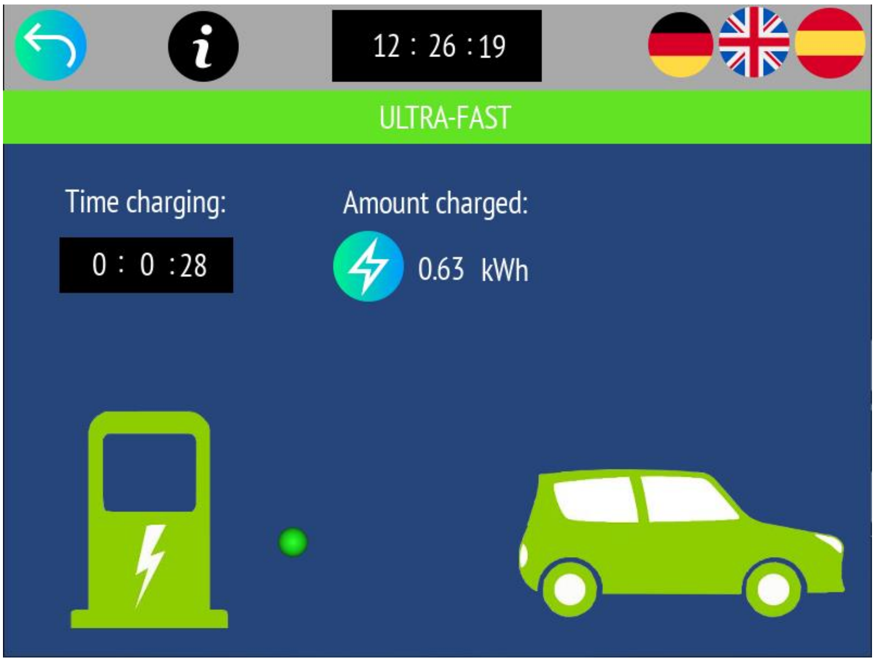

Figure 36: Charging process information screen. Source: [14]

<u>USE CASE 3:</u> Charging Process stored.

Once a user has set a charging process and this charging process has finished, the several parameters chosen are stored. Therefore, when the user returns to the charging station and plugs the electric vehicle to the charging station, the EVSE will detect the latest user's charging process and it will suggest the user if it wants to use the latest charging process.

As we can see below, once the user selects one of the ports, the next view screen will appear:

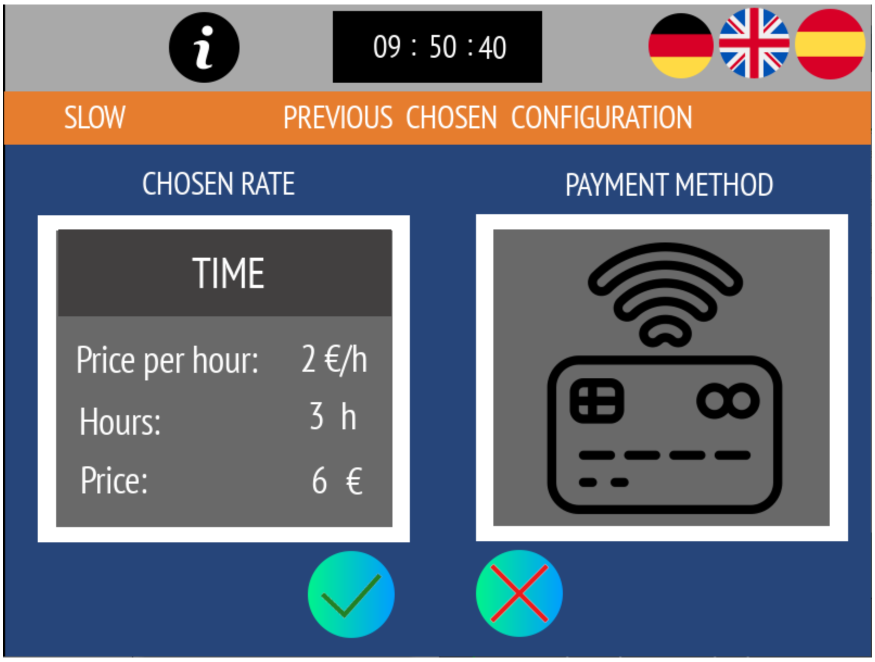

Figure 37: Previous chosen configuration screen. Source: [14]

This charging process configuration corresponds to Use Case 1. The user can either accept the latest charging process or reject it and create a new one.

If the user is eligible to activate V2G capabilities, the interface will display again the V2G screen, in case the user does or does not want to enable such function.

7. Proposed Solution

In this chapter we will discuss the technical part of the design, as to how the different functionalities have been programmed. The software used is EB Guide Studio [15] , a very useful tool that enables fast creation of user interfaces. Therefore, the state machines, variables, and functionalities in general will be briefly explained.

STATE MACHINES

Several state machines have been implemented for enabling different functionalities.

PAYMENT: The different payment methods for each port take place through a state machine, depending on which port the charging process will take place and the payment method chosen by the user. Once the user has confirmed its charging process selection, the corresponding dynamic state machine will pop up. Below we can see the code corresponding to the accept button on the confirmation screen:

```
function(v:touchId::int,v:x::int,v:y::int,v:fingerId::int)
{
   v:this.scalingX=100.0
   v:this.scalingY=100.0
   if(dp:card1==true)
{
f:pushDynamicStateMachine(popup_stack:Main,sm:Card,0)
}
else
{
f:pushDynamicStateMachine(popup_stack:Main,sm:Incar,0)
}

letv:vhour=f:string2int(dp:time_hour)
 in
if(v:vhour>8&&v:vhour<21)

   if(dp:slowon==true)
   {
      f:pushDynamicStateMachine(popup_stack:Main,sm:V2G,0)
   }
}
   false
}
```

As we can see on the code, depending on which method has been chosen, either the card payment method dynamic state machine or the in-car payment method will appear.

VEHICLE TO GRID (V2G): The V2G display screens are also embedded in dynamic states machines, one for each port. Thus, only if the user fulfils the requirements for enabling such capabilities will the dynamic state machine pop up. We can see how these requirements are checked in the previous lines of code displayed for the payment state machine. Therefore, when the user accepts the charging process on the confirmation screen, if the requirements are fulfilled the V2G state machine will be triggered. These conditions are: The charging speed chosen must be the slow mode and the charging process must take place between 08:00 and 20:00. The state machine is closed either by rejecting to enable such capabilities or if accepted, by indicating the minimum percentage of the battery.

CONNECTION WARNING: A dynamic state machine has been created in case the electric vehicle is disconnected or there are problems with the plug, the state machine will be triggered, and the HMI screen will display a warning message.

INFORMATION: An information screen has been added as a dynamic state machine, therefore from any stage of the charging process selection, if the user presses the information button, the state machine will display the information menu, where several aspects concerning the charging process are explained.

TIME SELECTION: A time selection menu (number of charging hours the user selects when choosing the time price rate).

LATEST CHOICE STORED: The latest choice performed by the user has been added as a view screen embedded in a state machine. It is triggered by pressing the port where previously a charging process was started but it has been finalized.

ANIMATIONS

Several animations have been designed in order to give real-time feedback to the user. For example, once the charging process has started, on the main screen there is an animation for each port which clearly informs the user if the port is being used or not. In addition, an animation has been added in the charging information screens for each port when they are being used, so the user can easily visualize if the charging process is taking place or not.

INPUTS

There are several inputs throughout the complete charging selection. Most of these inputs are fulfilled via Boolean variables, therefore, depending on which parameter the user selects, the corresponding Boolean variable for the parameter is set to true. As the HMI interface has a "forgiveness" design, users can go one step backwards of the charging selection process in order to modify their input, all variables corresponding to that view screen/stage are set to false so the user can input/choose a new option.

Apart from having inputs as Boolean variables, some other input variables are integers. These are used for determining the number of hours the user wants to charge the electric vehicle and it is also used when enabling V2G capabilities, for setting the minimum battery percentage.

All inputs are performed via the touchscreen.

PORT SELECTION: When pressing on the main screen either the port 1 or port 2, depending on the state of three different variables, three different view screens will appear. Below we can see the code corresponding to the port 1:

```
  if(dp:charging1==true)
{
  fire_delayed150,ev:"P11charging"();
}
elseif(dp:charging1==false&&dp:lastchoice==false)
{
  fire_delayed150,ev:P11NOTcharging();
}

elseif(dp:lastchoice==true&&dp:chargingstopped==true)
{
f:pushDynamicStateMachine(popup_stack:Main,sm:Lastchoice,0)
}
  false
}
```

As we can see on the code, the value of three Boolean variables are checked, which are *charging1*, *lastchoic*e and *chargingstopped*. Therefore, if charging1 is set to false, it means there is not a charging process taking place on port1 so the user can access the charging selection menu. The *lastchoice* variable is set to true whenever a charging process has finished, triggering a dynamic state machine which displays the user its latest charging process selected. The *chargingstopped* variable lets the software know that the charging process has finished, so if there is a *lastchoice* stored, the state machine will be displayed. On the other hand, if the *chargingstopped* variable is set to false, it means the charging process is still taking place so the user will visualize the current charging process information on the interface screen.

CHARGING SPEED SELECTION: Once the user selects the port where the charging process will take place, a charging speed must be chosen. In this case, we will use the code for choosing the slow charging speed, thus the software will run through this code when choosing the slow charging speed:

```
function(v:touchId::int,v:x::int,v:y::int,v:fingerId::int)
{
  v:this.scalingX=100.0
  v:this.scalingY=100.0
  fire_delayed150,ev:slow1()
  //Set the respective datapool as true and the rest as false
  dp:slowon=true;
  dp:faston=false;
  dp:ufaston=false;
  false
}
```

First, the scaling size is set. These lines of code correspond to the "touch released" function. Before these lines of code are run, the "touch pressed" function will be run, where the size of the button is reduced. Therefore, by first shrinking and then expanding the size of the button to its initial value, the user receives immediate feedback that the button has been pressed. Once the size has been rescaled, the next view screen will be fired, but with a 150ms delay as if it happened immediately, we would not be able to see the rescaling effect. Apart from firing the event that links to the next view screen, the value of three Boolean data pools are set. These variables will store the current charging speed chosen. Thus, the slow variable is set to true and as a safety measure, the other two charging speeds are set to false. These variables will be used to display the charging speed on the following view screens, as each charging speed corresponds to a different colour and only the variable that is set to true will be displayed on the screen.

CHOICE OF RATE: In this view screen users must choose the pricing rate, which is either a time rate or a quantity rate. The code written below corresponds to selecting the Time rate:

```
function(v:touchId::int,v:x::int,v:y::int,v:fingerId::int)
{
  v:this.scalingX=100.0
  v:this.scalingY=100.0
  dp:timerate1=true;
  fire_delayed150,ev:topaymentmethod();
f:pushDynamicStateMachine(popup_stack:Main,sm:time1,0)
  false
}
```

As we can see, the shrinking function (scaling) has been included in all touch button for giving immediate feedback to the users. Then we set the corresponding Boolean data pool variable to true, so in the confirmation screen such pricing rate will be displayed. The next view screen will be displayed as we fire the event to this screen. Finally, we pop up the state machine for selecting the number of hours, which has been explained previously in the state machines section of this chapter.

PAYMENT METHOD SELECTION: The user must select between the in-car payment method or the contactless card. In this example, we will have a look at the contactless card payment method:

```
function(v:touchId::int,v:x::int,v:y::int,v:fingerId::int)
{
  v:this.scalingX=100.0
  v:this.scalingY=100.0
  dp:card1=true;
  fire_delayed150,ev:toconfirmation1();
  false
}
```

First, the Boolean data pool is set corresponding to the card payment method to true, so such information is displayed on the confirmation screen at the end of the charging process. Then, we fire the event that will display the next view screen, the confirmation screen.

CONFIRMATION SCREEN: The user must accept or reject the current charging process selection. On this screen on the variables that were set as true in the previous steps will be displayed. By accepting the current selection, the next lines of code will be executed:

```
function(v:touchId::int,v:x::int,v:y::int,v:fingerId::int)
{
   v:this.scalingX=100.0
   v:this.scalingY=100.0
   if(dp:card1==true)
{
f:pushDynamicStateMachine(popup_stack:Main,sm:Card,0)
}
else
{
f:pushDynamicStateMachine(popup_stack:Main,sm:Incar,0)
}
letv:vhour=f:string2int(dp:time_hour)
 in
if(v:vhour>8&&v:vhour<21)
{
   if(dp:slowon==true)
   {
      f:pushDynamicStateMachine(popup_stack:Main,sm:V2G,0)
   }
}
   false
}
```

First, which payment method has been chosen is checked in order to trigger the corresponding dynamic state machine, which have been explained in the state machines section of this chapter. Then, in order to trigger the vehicle to grid state machine, it will be checked if the user fulfils the requirements by checking if the charging process will take place between 08:00 and 21:00. If such statement is true, then it will be checked if the charging speed selected is the slow mode.

On the other hand, if the user decides to reject the current selection by pressing the corresponding button, the following code will be executed:

```
function(v:touchId::int,v:x::int,v:y::int,v:fingerId::int)
{
  v:this.scalingX=100.0
  v:this.scalingY=100.0
  dp:card1=false;
  dp:incarpayment1=false;
  dp:timerate1=false;
  dp:quantityrate1=false;
  fireev:cancel1();
  false
}
```

As we can see, all buttons have been fitted with the shrinking (scaling) animation. Then, as the user has rejected the current charging process selection, all corresponding variables have been set to false and finally an event has been fired, which will take the user to the beginning of the charging process.

BACK BUTTON: Users have been given the possibility to undo single selected choices, so they do not have to start a new charging process again. Therefore, a "go backwards" button has been included in the design. In this example, we will see how the back button works on the confirmation screen:

```
function(v:touchId::int,v:x::int,v:y::int,v:fingerId::int)
{
  v:this.scalingX=100.0
  v:this.scalingY=100.0
 fireev:backfromconfirmation1();
  //we set the datapools to false as we need to choose again
  dp:card1=false;
  dp:incarpayment1=false;
  false
}
```

Once the back button is pressed, the event for going back to the previous screen is fired and the variable that must be chosen on the previous screen are set to false, so the user can input a new choice.

__**OUTPUTS**__

The dynamic information displayed to the user has been done via output variables, mostly strings. Via these string variables key information such as price, amount of energy charged or for how long has the current charging process has been taking place for, are shown on the screen for informing the user of such relevant information.

AMOUNT CHARGED: In order to display the amount charged by the vehicle, an internal transition was added for updating such value every second. The code below corresponds to the internal transition:

```
function()
{
if(dp:startcounter==true)
{
if(dp:slowon==true)
{
  dp:amount=dp:amount+0.00166;
}
if(dp:faston==true)
{
  dp:amount=dp:amount+0.00611;
}
if(dp:ufaston==true)
{
  dp:amount=dp:amount+0.02777;
}
}
else
{
  dp:amount=0.00;
}
dp:AMOUNT=f:float2string(dp:amount)
fire_delayed1000,ev:startcounter();
}
```

First, the code will check if the charging process has started, by looking at the value of the Boolean variable "startcounter". Then, if such variable is set to true, the code will read which charging speed has been selected in order to perform the corresponding calculation. Such calculation will increase every second the needed amount charged, stored as a floating-point variable. Then, the floating-point value is saved as a string, so it is displayed on the HMI interface.

CHOSEN SPEED HEADER: When going through the charging selection, at the top section of the screen, the selected charging speed and its corresponding colour displayed. The following code will display the needed colour depending on the speed:

3 triggers are added:

```
dp:faston
dp:slowon
dp:ufaston
```

When the value of one of these variables changes, the following conditional script will be run:

```
function(v:arg0::bool)
{
  if(dp:slowon==true)
  {
    v:this.fillColor=dp:speed1[1];
  }
  if(dp:faston==true)
  {
    v:this.fillColor=dp:speed1[2];
  }
  if(dp:ufaston==true)
  {
    v:this.fillColor=dp:speed1[3];
  }
  false
}
```

Depending on which Boolean variable is set to true, the colour of the rectangle will be set to the corresponding colour stored in a colour list.

CHARGING TIMER: A timer has been added which will display the amount of time the charging process has been going on for. This timer is displayed on the charging speed information screen, which is only accessible when the charging process is taking place. The following code updates the timer every second. Such code has been written in an internal transition:

```
function()
{
if(dp:charging1==true)
{
  if(dp:SEC<60)
{
```

```
    dp:SEC=dp:SEC+1;
}
else
{
    dp:SEC=0;
    dp:MIN=dp:MIN+1;
}
 if(dp:MIN==60)
{
    dp:MIN=0;
    dp:HOUR=dp:HOUR+1;
}
}
else    //Whennotcharging,settimerto0
{
    dp:SEC=0;
    dp:MIN=0;
    dp:HOUR=0;
}
dp:sec=f:int2string(dp:SEC);
dp:min=f:int2string(dp:MIN);
dp:hour=f:int2string(dp:HOUR);
    fire_delayed1000,ev:updatetimer();
}
```

First, the code will check if the charging process has started. If the Boolean variable "charging1" is set to true, it means the charging process has started and we can start counting. Thus, as this code is run every second, the value of the seconds data pool will be increased every time it is run. Once the seconds integer data pool reaches a value of 60, the value of the integer data pool that corresponds to the minutes counter will be increased by 1 and set the seconds variable to 0. Then, once the minutes variable reaches a value of 60, the value of the integer data pool corresponding to the hours counter will be increased by 1 and set the minutes counter to 0. Finally, the integer values are transformed into strings so it can be displayed, and the event "updatetimer" is fired once 1000ms have gone by. This event will trigger again this internal transition, so the timer is updated.

TEMPLATE

A template was designed where some common functions to all view screens were added, simplifying the design. This template includes a real time clock, the information button, and the three buttons which are used to change the language of the texts displayed on the interface. The needed code for changing the language can be seen below, in this case it is the code for setting the language to English.

```
function(v:touchId::int,v:x::int,v:y::int,v:fingerId::int)
{
   f:setLanguage(l:English,true);
   false
```

8. Conclusion

This thesis aimed to provide charging stations with HMI technology for guiding users through the whole charging process, enhancing their experience. Furthermore, extra capabilities were added, such as the possibility to the enable vehicle to grid capabilities and performed grid support activities, helping to balance the demand.

All things considered, the design of the HMI interface was performed using a user-centred design process, as the goal of this interface is to help the user to start a charging process in the smallest amount of time possible, by displaying only key information and in a clear way. During the design of the interface, several usability tests were performed for determining flaws and needed improvements. The target user was set in order to have a clear aim as to how to design the interface and which limitations such users could have. Apart from setting a target user, different use cases of the HMI interface were discussed, thus, the different possibilities were explained and finally a target use case was determined in order to focus most of the design to this desired use case. A shortcut was added to the design by storing the user's latest charging process selection, so the usage time of the interface is reduced. Concerning the extra functions, such as the vehicle-to-grid capabilities, it was studied if such capability is beneficial for the user. Several research papers were analysed about the matter and possible business models. Finally, a complete walkthrough for different users was performed for reflecting the different possibilities and the design of the interface.

Further investigation can be carried out in order to include membership capabilities. For example, if the charging station, where the interface is implemented is owned by a charging company and such company has a membership scheme (common within electric charging stations) then such capabilities could be included. Another possible further investigation is to add a touchscreen keyboard, enabling extra capabilities.

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