VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

FAKULTA ELEKTROTECHNIKY A KOMUNIKAČNÍCH TECHNOLOGIÍ

ÚSTAV JAZYKŮ

INTEGRACE NABÍJECÍ STANICE DO ENERGETICKÉHO SYSTÉMU RODINNÉHO DOMU S FVE

BAKALÁŘSKÁ PRÁCE

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BRNO 2021

BRNO FACULTY OF ELECTRICAL
UNIVERSITY ENGINEERING
OF TECHNOLOGY AND COMMUNICATION

Bachelor's Thesis

Bachelor's study field **English in Electrical Engineering and Informatics**

Department of Foreign Languages

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Year of study: 3
Academic year: 2021/22

TITLE OF THESIS:

Integration of a charging station into a family house photovoltaic system

RECOMMENDED LITERATURE:

Dle instrukcí odborného konzultanta (Ing. Michal Vrána)

Date of project specification: 10.2.2022   *Deadline for submission:* 31.5.2022

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Abstract

This bachelor's thesis deals with integrating a charging station into a family house photovoltaic system. The thesis is divided into two parts, the theoretical and the practical. The purpose of the theoretical part was to conduct research about current possibilities concerning charging stations and their integration into the household. In the practical part, there were created function designs to integrate the charging station into the intelligent household and there was realised the testing of the selected charging station.

Keywords

Charging station, wallbox, household, charging capacity, intelligent control unit, Modbus TCP/IP

Abstrakt

Tato bakalářská práce se zabývá integrací nabíjecí stanice do energetického systému rodinného domu s fotovoltaickým systémem. Tato práce je rozdělena na dvě části, teoretickou a praktickou. Účelem teoretické části bylo provézt výzkum o současných možnostech nabíjecích stanic a jejich integrací do domácnosti. V praktické části byly vytvořeny návrhy funkcí pro integraci nabíjecí stanice do chytré domácnosti a bylo provedeno testování vybrané nabíjecí stanice.

Klíčová slova

Nabíjecí stanice, wallbox, domácnost, nabíjecí výkon, inteligentní řídící jednotka, Modbus TCP/IP

Rozšířený abstrakt

Elektromobilita je v současné době perspektivní oblastí pro rozvoj dopravy. S rostoucími cenami ropy, a s tím souvisejícím zdražováním pohonných hmot obecně, přechází mnoho lidí právě na elektrická vozidla. Jelikož cena elektromobilů postupně klesá, kapacita baterií se zvyšuje a s ohledem na dotace, které Evropská unie poskytuje potencionálním zájemcům o elektrická vozidla, vlastní fotovoltaický systém a nabíjecí stanice, lze očekávat ještě větší nárůst zájmu o tento způsob dopravy. Na rozdíl od automobilů se spalovacími motory, které, podle zprávy agentury Reuters, způsobují natolik kritické znečištění ovzduší, že i některá města v Německu zakázala vjezd automobilům s naftovými motory.

Tato bakalářská práce se zabývá možnostmi integrace nabíjecí stanice do rodinného domu s vlastním fotovoltaickým systémem. Uvedený způsob výstavby rodinných domů, na kterých je přímo vybudována menší solární elektrárna, se stává častějším a častějším jevem. Práce je rozdělena na dvě části, teoretickou a praktickou. Cílem teoretické části bylo seznámit se s vlastnostmi různých nabíjecích stanic, jejich standardy a protokoly, prostřednictvím kterých jsou schopny komunikovat s ostatními zařízeními v domácnosti, nebo samotným vozidlem. Následně byly porovnány dvě inteligentní řídící jednotky, pro řízení různých spotřebičů v domácnosti, a devět nabíjecích stanic. Praktická část se zabývala návrhem základních funkcí v programovacích prostředích inteligentních řídících jednotek a samotným testováním jedné vybrané nabíjecí stanice, jak rychle je schopna reagovat na jakékoliv neočekávané události, které se v domácnosti mohou objevit.

Mezi vlastnosti nabíjecích stanic, které jsou rozebrány v textu, se řadí nabíjecí výkon, RFID (Radio Frequency Identification) identifikace, komunikace prostřednictvím PLC (Power Line Communication), stupeň krytí IP (Ingress Protection), certifikace MID (Measuring Instruments Directive), různé stupně ochrany (proti unikajícímu proudu, proti přepětí a nadproudová ochrana) a různé typy nabíjecích konektorů vyskytujících se ve světě. Protokolem pro komunikaci s nabíjecí stanicí je například OCPP (Open Charge Point Protocol) protokol, který zprostředkovává komunikaci mezi jednotlivými nabíjecími stanicemi a centrálním systémem, nebo ISO 15118 protokol, který slouží ke

komunikaci mezi nabíjecí stanicí a vozidlem. Standard IEC 61851 definuje čtyři různé režimy nabíjení a Modbus komunikační protokoly slouží pro komunikaci nabíjecí stanice s ostatními zařízeními v domácnosti.

Jako inteligentní řídící jednotky chytré domácnosti byly vybrány a porovnány ty od české společnosti Teco a.s. (Tecomat TC700 a Tecomat Foxtrot) a Loxone Miniserver. Do rozsáhlého porovnání devíti nabíjecích stanic byly zvoleny nabíjecí stanice Fronius Wattpilot Go 22 J, ČEZ SMART, Etrel INCH Home, Alfen Eve Single Pro-line (3f), Circontrol eHome Link, go-eCharger HOME+, Heidelberg Wallbox Home Eco Europe, Webasto live Wallbox a Schneider Electric EVlink Smart Wallbox.

V praktické části byly vytvořeny základní návrhy funkcí v prostředích Mosaic a Loxone Config, konkrétně šlo o vytvoření jednoduchého ovládání nabíjecí stanice, za účelem nabíjení připojeného vozidla pouze v nočních hodinách mezi 22:00 a 6:00.
V jednodušším programovacím prostředí Loxone Config bylo přidáno i nabíjení z přebytků z fotovoltaického sytému.

Na základě komunikace s dodavateli a splnění požadavků, které byly stanoveny, aby nabíjecí stanice byla schopna nabíjet nabíjecím výkonem až 22kW a komunikovat prostřednictvím Modbus TCP/IP komunikačního protokolu, byla pro testování vybrána nabíjecí stanice Etrel INCH Home. Testovala se rychlost reakce nabíjecí stanice na změnu nabíjecího výkonu v průběhu nabíjení. Testování proběhlo se zapůjčeným vozidlem Tesla Model S v internetovém rozhraní Etrel, za pomoci Modbus Master aplikace a za pomoci jednoduché LabVIEW aplikace. Ukázalo se, že nabíjecí stanice je schopna omezit nabíjecí výkon během 1 sekundy, a tak rychle reagovat na jakékoliv neočekávané události.

Bibliographic citation

LIŠKA, Martin. Integrace nabíjecí stanice do energetického systému rodinného domu s FVE. Brno, 2021. Dostupné také z: https://www.vutbr.cz/studenti/zav-prace/detail/139456. Semestrální práce. Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, Ústav jazyků. Vedoucí práce Magdalena Šedrlová.

Author's Declaration

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Paper type: Bachelor's Thesis

Academic year: 2021/22

Topic: Integration of a charging station into a
family house photovoltaic system

I declare that I have written this paper independently, under the guidance of the advisor and using exclusively the technical references and other sources of information cited in the project and listed in the comprehensive bibliography at the end of the project.

As the author, I furthermore declare that, with respect to the creation of this paper, I have not infringed any copyright or violated anyone's personal and/or ownership rights. In this context, I am fully aware of the consequences of breaking Regulation S 11 of the Copyright Act No. 121/2000 Coll. of the Czech Republic, as amended, and of any breach of rights related to intellectual property or introduced within amendments to relevant Acts such as the Intellectual Property Act or the Criminal Code, Act No. 40/2009 Coll., Section 2, Head VI, Part 4.

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Brno, ------------------------------   ---------------------------------------
           date   author's signature

Acknowledgement

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INTRODUCTION

Electromobility is a promising area for the development of mobility and transportation. The history of electric vehicles dates back to the end of the 18th century when Alessandro Volta invented the voltaic pile, leading to the first electric vehicle on the road. The first electric vehicle for practical use was produced in the 1880s. As electric vehicles appeared on the market, so did another type of car, the gasoline-powered vehicles. Back then the horse was still used as the primary type of transportation. The mass-produced vehicles with combustion engines became more available and affordable than electric vehicles, which were not very efficient at that time.

The constantly increasing number of automobiles causes plenty of problems around the world whether it means traffic jams, lack of free parking spaces and last but not least, air pollution. Nowadays, the majority of automobiles are produced with a combustion engine, either with a petrol engine or with a diesel engine. These engines are currently sufficient. However, according to Reuters, the pollution that is caused by diesel engines is so critical that even some cities in Germany banned the entry of certain older diesel automobiles. [1]

Furthermore, the petroleum supplies in the world are thinning, and no one knows how much petroleum remains below the Earth's surface. These thinning supplies of oil cause its sharply rising price, and petroleum will be needed for more important things than replaceable automobiles with the combustion engine in the future. Therefore, it is assumed that electric vehicles are our future due to the long-term declining price and increasing capacity of lithium-ion batteries. To prepare ourselves for this rising trend of electromobility, it is necessary to build up a functional network of electric vehicle charging stations, either public or private. Alternatively, electric vehicles can be charged from excess electricity from solar panels.

This thesis will introduce the possibilities of intelligent charging at home and the elementary properties of the domestic charging stations. These charging stations offer users to adjust the charging options entirely according to their needs and to the household's needs. The thesis will analyse the comparison of different intelligent control units that may be utilised in the household to control energy consumption as charging stations are energy intensive in general. Besides, the intelligent control units may serve to control not only the energy consumption but also the management of all connected devices that can cooperate with each other.

In this thesis, it will be possible to see the comparison of the specific charging stations that are suitable for the integration into the intelligent household and the testing of one selected charging station. The elementary function designs will be introduced in the programming interface of intelligent control units.

1. INTELLIGENT CHARGING

According to the official NRDC (Natural Resources Defense Council) website, up to 80% of electric vehicles are recharged at home. [2] There are two possibilities for charging up the vehicle at home; the first is using the charger commonly included with the car. The second possibility is to have a wallbox installed. In both cases of the AC charging, the charger, otherwise called the on-board system, is located directly in the vehicle. The AC charger sends alternating current to the on-board charger, and the on-board charger then converts alternating current into direct current and stores it in the battery. [3] The significant difference between the two methods is the speed of the charging, safety, and the possibility of communication with the wallbox. The only advantage of the charger supplied by the manufacturer of the vehicle is that the charger can be plugged into any regular single-phase 230V socket.

1.1 Wallbox properties

1.1.1 Charging capacity

The charging capacity of the wallbox depends on whether it is single-phase, two-phase, or three-phase connected and on the nominal current flowing. According to the formula

$P = phase \cdot 230V \cdot I_\mathrm{n}$,

when the maximal nominal current is 32A, as it is mentioned below in chapter 1.2.3, it is possible to calculate that the maximal charging capacity for the single-phase connection is 7,4kW and for the three-phase connection is the typical charging capacity 22kW. For the three-phase connection, it is necessary for the property to have a three-phase electricity supply. [4]

1.1.2 RFID identification

Radio Frequency Identification (RFID) is used in the form of an identification card that works via a radio signal and is used to protect the charging station from unauthorized use. The RFID reader is built into the wallbox or any other charging station, and the users must identify themselves by attaching an identification card before use. [5]

1.1.3 *PLC* communication

Power Line Communication (*PLC*) is a form of digital communication between the electric vehicle and the charging station. The data is sent via the charging cable. The *PLC*'s purpose is to create a powerful data connection for authorization, charge control, and negotiation of charging sessions. It uses the HomePlug Green PHY standard for *PLC* signals when charging vehicles according to ISO 15118. The attenuation levels make it possible to differentiate *PLC* signals and avoid signal crossing. The *PLC* communication is further depicted in the ISO 15118-3 protocol. [6]

1.1.4 IP code

Most of the charging stations are suitable for outdoor usage. The Ingress Protection code (IP code), developed by the International Electrotechnical Commission (IEC), states the grade of protection against solid particles and liquids. An example of IP protection is IP 54, the first number states the protection against solid particles, and the second number states the level of protection against liquids; the higher the number is, the higher is the degree of protection. [7] In accordance with the DEM web page, which is the company that also produces enclosures for electronic devices, the IP 44 is satisfactory for outdoor usage and standard weather since the rain is marked as the low-pressure spray and thus on the IP scale as a number 4. The number 4 that indicates the protection against solid particles means that the device is protected against objects greater than 1mm. [8]

1.1.5 MID Approval

The Measuring Instruments Directive is a directive of the European Union presented in 2004 to replace national directives about measuring instruments. It applies to measuring equipment and systems in connection with commercial transactions. Besides, when the measuring device is used for billing, it must be calibrated to determine and reduce the error. The MID covers ten categories of measuring equipment, including active electrical energy meters, water meters, thermal energy meters, etc.

The MID approved meter in the charging station serves to record the energy consumption and allows more precise control of the energy consumption of the charging process. [9], [10]

1.1.6 Protection

Another important feature when selecting a wallbox should be if the protection devices are implemented. These devices may be costly, and thus it is necessary to trace if the charging station includes any. There are three major types of protection related to charging stations; these are differential protection, surge/overvoltage protection and overcurrent protection.

The Residual-Current Devices (RCDs) are used to detect any leakage current and then break an electrical circuit for differential protection. This device protects equipment against damage and people to reduce the potential harm from an ongoing electric shock that may lead to electrocution. There are several types of RCDs, depending on the type of the current (AC or DC), on how extensive the leakage current is, and alternatively, on the frequency. [11]

The surge protection utilizes a device that is designed to prevent voltage spikes in alternating current circuits and heavy damage to electrical appliances. The surge protector works on the principle that if the spike rises above the accepted level (usually about double the typical value of the voltage), the surge protector redirects the extra electricity into the grounding wire. On the other hand, overvoltage protection is a protection that refers to a continuous voltage that is above a specification. Four categories characterize the overvoltage; the higher category, the higher protection against overvoltage. [12], [13]
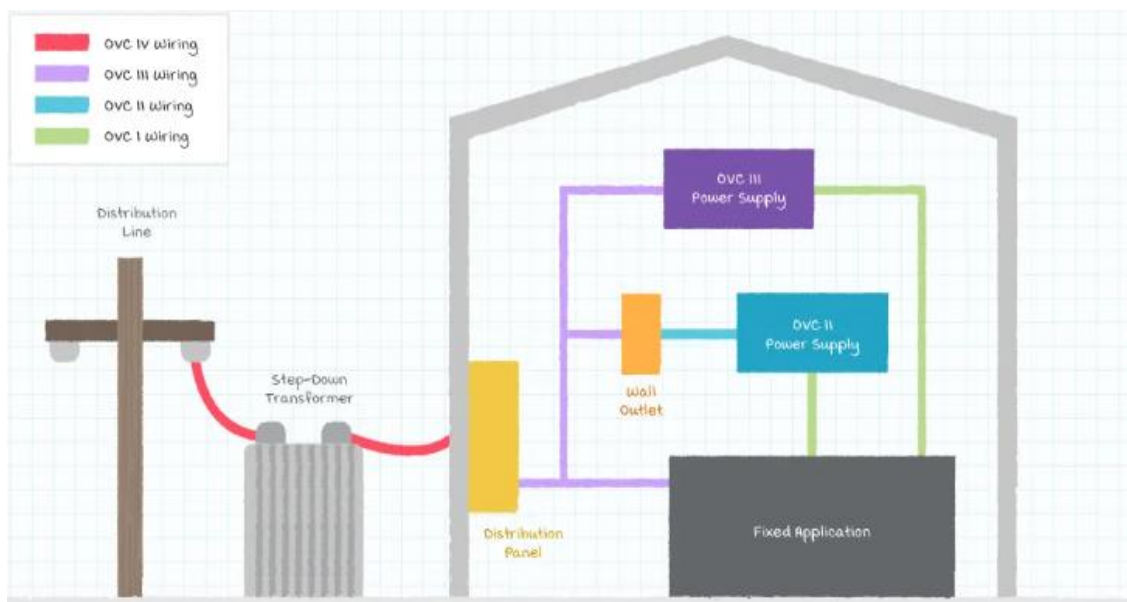

Figure 1: Overvoltage categories [12]

Overcurrent protection is the type of protection that uses devices called circuit breakers, fuses and fusible links. These devices behave as a conductor and are connected in series with the circuit, while they add an insignificant amount of the resistance to the circuit. The circuit breakers trip, fuses, and fusible links blow when the overcurrent event appears. It means that these devices stop the current flow to protect the circuit. [14]

1.1.7 Types of charging connectors

Nowadays, there exist several types of connectors, and it is necessary to find a charging station with an outlet that matches the socket of the car that is supposed to be charged. The types of connectors differ according to the current. There are two main types of alternating current (AC) and two main types of direct current (DC). In addition, these types may also vary depending on the region where the manufacturer of the vehicle is located and on the charging speed.

For example, China developed its own standard of connector types for AC and DC charging, the GB/T. It has the opposite gender layout to the rest of the world. [15] There is a separate connector also in Japan, the CHAdeMO, initially developed by five Japanese vehicle manufacturers. It is a type of DC connector that can charge up electric vehicle batteries with power up to 100kW. They are currently cooperating with the Standardization Administration of China, which developed the GB/T standard, on developing the third generation of the ultra-fast connector with a power of up to 900 kW. [15], [16]

Tesla uses an utterly different type of connector than any other manufacturer in the world. It means that the extensive network of DC charging stations built up by Tesla serves especially the Tesla customers and cannot be used by any other vehicle. However, in Europe, Tesla's Supercharger stations use the European standard, the CCS Type 2. [16]

The most widely used connectors worldwide are the SAE J1772, otherwise called the Type 1 connector and the Mennekes, otherwise known as the Type 2 connector. The Type 1 connector is a single-phase AC charging connector that is used primarily in North America and Japan. It can provide a maximum charging capacity of 19.2kW. [15] In 2003 a German manufacturer of industrial plugs and connectors, Mennekes, introduced a three-phase Type 2 connector, and it quickly became the new European standard for AC charging. There is only Level 2 (240V), and higher charging in Europe since the standard for household electricity is 230 V. The Type 2 connector offers charging power up to 43 kW, depending on the grid capability.

This type of connector was adopted as a recommendation in Europe and, for instance, in Australia and New Zealand. [15]

The Combined Charging System is a solution for DC charging. It is an improved version of Type 1 and Type 2 connectors with additional two direct current contacts at the bottom for the purposes of quick charging. The CCS Type 1 and CCS Type 2 allow to charge up the vehicle with power up to 350 kW. Presently, it is the most popular DC connector globally, used nearly everywhere except in Japan and China. [15], [16]
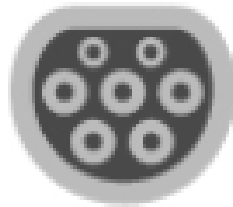
Figure 2: The Mennekes - Type 2 connector [16]
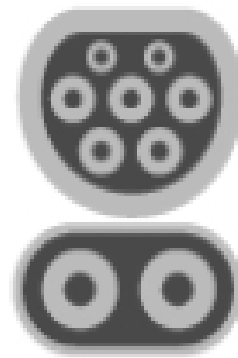
Figure 3: The CCS Type 2 connector [16]

1.2 Wallbox protocols and standards

1.2.1 OCPP protocol

The Open Charge Point Protocol (OCPP) serves to communicate between individual charging stations and a central system focusing on monitoring, billing, and authorisation of who is allowed to charge. Besides, the OCPP enables communication between the charging stations themselves. It can be used both at the local level to limit the power taken from the network or at the global level so that the power consumption from the grid does not exceed the network's ability to generate electricity.[17], [18]
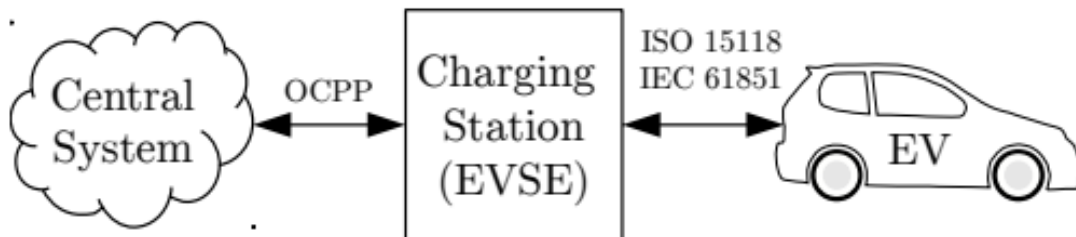
Figure 4: The OCPP communication protocol [18]

1.2.2 ISO/IEC 15118 protocol

On the contrary, ISO 15118, or Vehicle-to-Grid (V2G), is a protocol for the communication between the charging station and the electric vehicle. Even the OCPP 2.0 protocol communicates with the ISO 15118 protocol and was developed to support intelligent charging requirements from the electric vehicle. The ISO 15118 specifies requirements for charging management, billing, and metering. In addition, it is safer than its counterparts considering it uses encrypted data. Therefore, the unique identity of each electric vehicle cannot be tracked. The ISO 15118 protocol allows a more advanced form of communication than the current most widely used standard, IEC 61851. [18], [19]
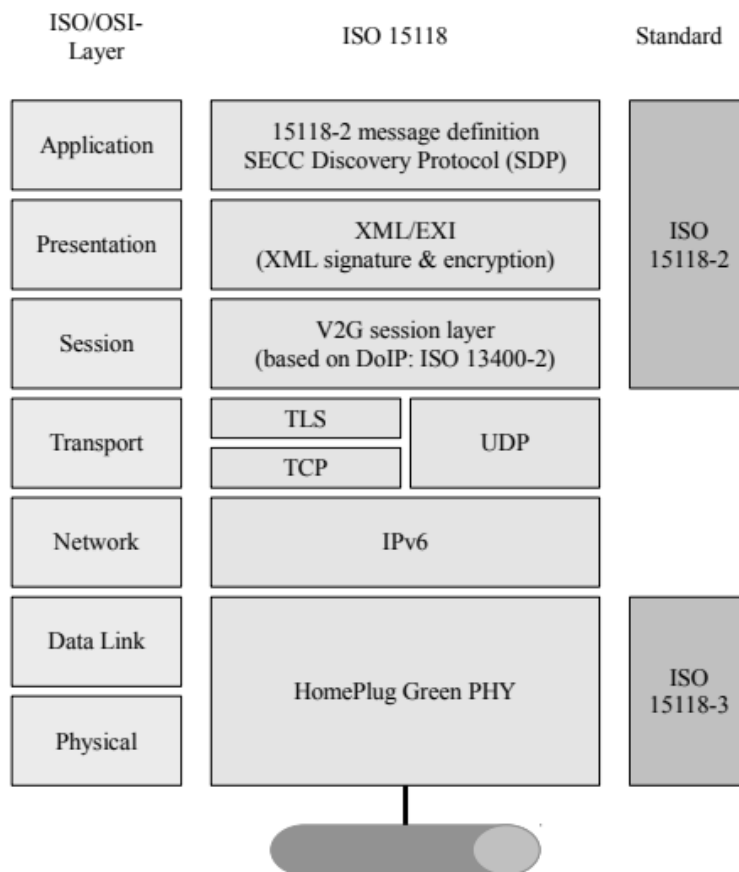
Figure 5: The structure of the ISO 15118 protocol [18]

1.2.3 IEC 61851 standard

The IEC 61851 defines four modes of connection. Mode 1 and Mode 2 are connections to the household socket. The difference between these two modes is that Mode 2 is equipped with an in-cable control and protection device (IC-CPD). Mode 3 defines that the electric vehicle uses a dedicated charging station. It is characterized by the limitation of the maximal current to 32A for both single-phase and three-phase charging. Mode 4 utilizes the fixed charging cable to the charging station with a DC output. [20]
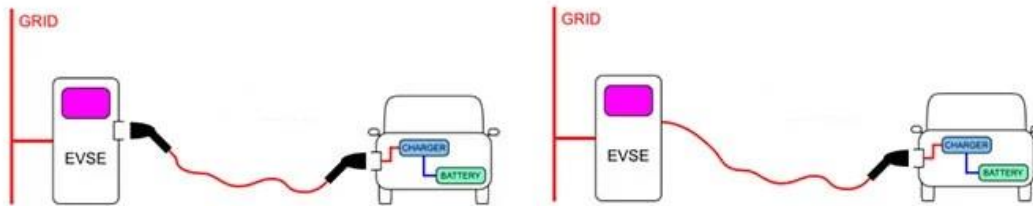
Figure 6: The Mode 3 connection [20]

1.2.4 Modbus TCP/IP

As it is mentioned in the Modbus application protocol specification, the Modbus protocol is a communication protocol based on master/slave or server/client architecture that allows communication between devices within all types of network architectures. It means that one master (usually PLC or PC) can realise a remote operation for an unlimited number of slaves (automation devices). [21]
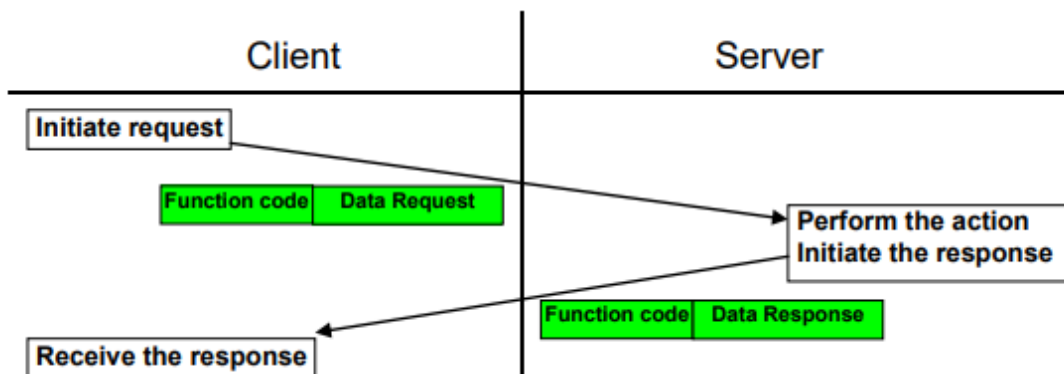
Figure 7: The Modbus TCP/IP message [21]

1.2.5   RS485 Modbus

The RS485 Modbus communication protocol is a serial communication standard. It means that devices are connected directly in series with one trunk cable. The trunk cable length should be maximally 1.2km without using a repeater. The major disadvantage of the RS485 communication protocol is that there is a limited number of connected devices in one segment, precisely 32 devices. [22]

2. INTELLIGENT CONTROL UNITS

Intelligent control units are an integral part of smart households. It is a complex system capable of controlling the flow of electricity in the household, saving energy by the clever redistribution of the electric power between appliances, and controlling the devices, for both low-voltage and high-voltage appliances. These are centralized systems whose central units are so-called programmable logic controllers (PLC), which means that they are customizable to the household and the customer. Several factors depend on the choice of the intelligent control unit, for instance, how the system will be used, the possibilities to edit something in the system, the price of the system, and the replacement possibilities in the case of failure. According to the official Loxone website (one of the intelligent control unit manufacturers, see below chapter 2.2), the price of intelligent wiring for home automation is approximately double of standard household wiring. [23]

2.1 Teco a.s.

Teco a.s., the Czech manufacturer of industrial control systems and systems for intelligent building control and automation, has developed and offers two series of programmable logic controllers (PLCs), the PLC Tecomat TC700 and the PLC Tecomat Foxtrot.

2.1.1 Tecomat TC700

Tecomat TC700 offers the series of units CP-700x, whose basic models differ in the number and types of inputs and outputs, subsequently by the size of the Random Access Memory (RAM). The differing number of inputs and outputs allows users to choose the model according to the property's needs. This unit is suitable for both complex systems and small systems with several inputs and outputs. In households, it is possible to utilize it for integration of heating, ventilation, and air conditioning (HVAC), building security features and access systems, and for energy management and coordination of building processes. The Tecomat TC700 is not suitable exclusively for households, it can be used in the field of mechanical engineering, traffic management and tunnel management. The configuration of the unit is performed via the Mosaic software. [24], [25]

Figure 8: Tecomat TC700 [24]

2.1.2 Tecomat Foxtrot

The first generation of the Tecomat Foxtrot offers a series of units CP-100x and CP-10xx. As in the case of Tecomat TC700, it differs according to the number and type of inputs and outputs and may be equipped with an LCD display. In 2019 the second generation, the Tecomat Foxtrot 2, was introduced. The second generation is fully compatible with all existing expansion modules with TCL2 and CIB (Common Installation Bus) and with application programs of the first generation of the Foxtrot. The number of manufacturers of various modules is expanding as well as the number of types of interconnected devices, a novelty in the second generation is, for example, voice control. The configuration of the unit and thus of the entire system is performed via the FoxTool software. The programming takes place in the Mosaic software as well. [26], [27]

The Tecomat Foxtrot system can ideally coordinate building processes and therefore ensure higher energy savings. As an example, which is mentioned on the official Teco a.s. website, one basic Foxtrot module serves all 36 underground parking spaces equipped with a wall box and a charger at the headquarters of Moneta Money Bank in Prague. In this case, the Foxtrot system is capable of indicating the immediate consumption of the building and thus redistributing energy to the wallboxes. As a result of this, the local limits of the building are not exceeded. Besides, each wallbox is equipped with the RFID reader to ensure priority charging; alternatively, the RFID reader charges additional fees for priority charging. [28]
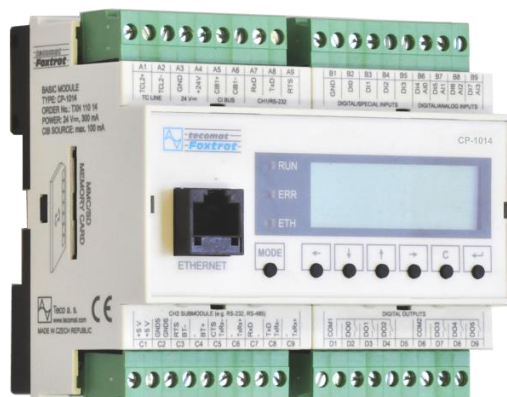
Figure 9: Tecomat Foxtrot [26]

2.2 Loxone

Loxone is a European manufacturer of intelligent wiring and building automation systems originating in Austria. The Loxone system has two variants of the mini-server, the Miniserver and the Miniserver Go, with the Miniserver Go being characterized as wireless. While the wired variant is more suitable for new buildings, the wireless variant is the best option for renovations and for the places where the current interior cannot be damaged. Due to a large number of accessories and extensions that can be purchased, the Miniserver Go is as powerful and capable as the Miniserver, but it does not have to be installed in a switchboard. The configuration of the unit is performed via the Loxone Config software. [29], [30], [31]

As it is reported on the official Loxone website, the Miniserver has a 400 MHz processor and 64 MB of RAM memory. About 10 MB of this memory is used to run the operating system, and another approximately 10 MB should be available for tasks such as web requests. [32]

The Loxone Tree and the Loxone Air Base extensions allow clever and uncomplicated connection of peripherals. As the name suggests, the Air Base extension extends Miniserver or Miniserver Go using wireless technology by up to 128 Air devices. The Tree extension offers two Tree branches, and up to 50 Tree devices can be connected to both of its branches. [29]

Figure 10: Loxone environment extensions [29]

The Loxone Config software offers three predefined charging stations as peripherals, Keba KeContact P20 Wallbox, Keba KeContact P30 Wallbox and BMW Pro Wallbox. These charging stations usually offer charging in the range between 4.1kW up to 22kW, following the standard IEC 61851 Mode 3, where the maximum current is limited to 32A. [20] It is still possible to implement any other charging station within the Loxone environment, whet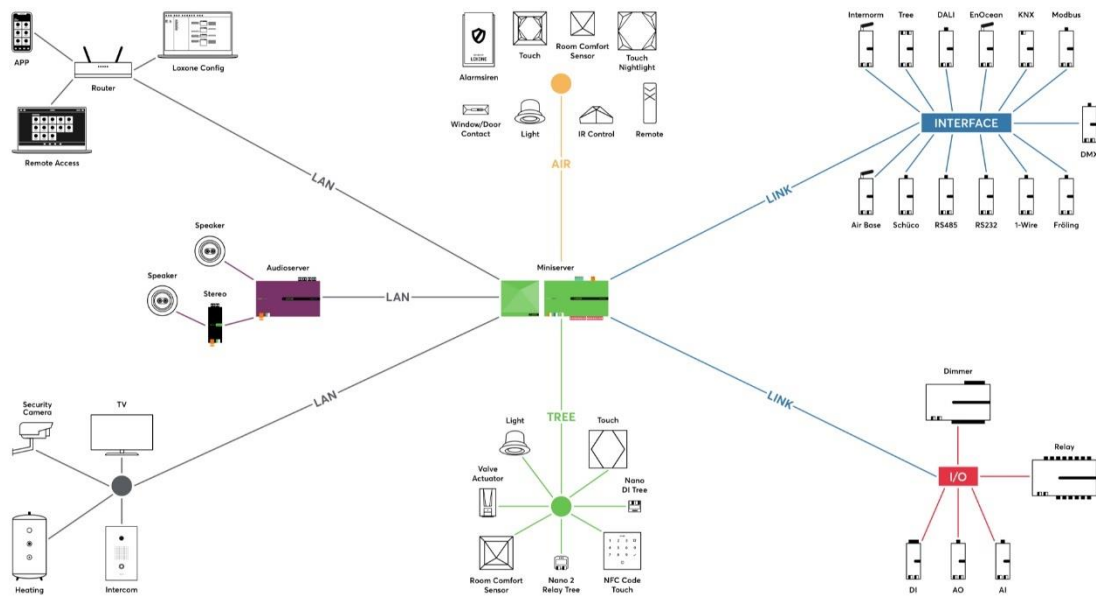her it is a station that cannot communicate over the network or the station is not predefined in the Loxone Config software. The charging stations communicating with Loxone mini-servers via Local Area Network (LAN) are comfortable to use and provide the possibility of controlling, monitoring and visualisation of the electricity flow in the household. Moreover, the charging station supplies all the necessary information via LAN, including whether the vehicle is currently connected to the charging station, the actual charging capacity, measurement of energy consumption and the vehicle's statistics. It is possible to create additional profiles in the controlling mobile or desktop application to have separate statistics for each vehicle. [33], [34]

The energy management and the Loxone system operate hand in hand with the Photovoltaic system (PV system). As a consequence of the Loxone mini-server capabilities, it is feasible to charge a vehicle with solar energy produced on the roof and manage intelligent energy distribution depending on the production, needs and set priorities. The consumption of electric power is the lowest during the day; on the contrary, the production by the PV system is the highest. The batteries are commonly installed with the PV system, and these allow to store excess energy and its usage after the sunset or during the power cut. The Loxone system recognises the current energy consumption and, in the event of surplus energy, can run up to 12 loads according to set priorities; therefore, the energy produced is not sent back into the electrical grid. [35], [36]
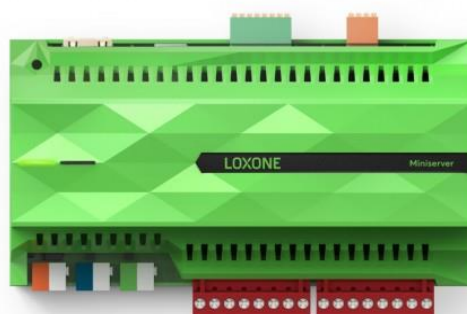
Figure 11: Loxone Miniserver [30]

3. FUNCTION DESIGNS

For the purposes of integrating the charging station into a family house with the photovoltaic system is the most satisfactory solution to utilise something that can manage both the charging station and the photovoltaic system. For instance, in this case, the elementary function designs were initiated in the programming software of each PLC, thus for the Loxone Miniserver in Loxone Config and Tecomat Foxtrot in Mosaic.

3.1 Mosaic

The cooperation between the Tecomat and Axomer s.r.o companies resulted in the development of the module C-EV-0302M for the controlling and integration of the charging of electric vehicles into households with the programmable logic controller Tecomat Foxtrot. They developed a function block to control this module. [37] Based on this function block for the handling of the C-EV-0302M module, the function block for the wallbox was recreated to integrate it into the Tecomat environment. Since the programming in the Mosaic software is rather complicated, unlike, for example, in the Loxone Config software, it is necessary to create and define your own function blocks. For this purpose, there are six possible programming languages to choose from. In this case, the ST (Structured Text) for the specification of different values and the graphical programming language CFC (Continuous Function Chart) for the main program were used.
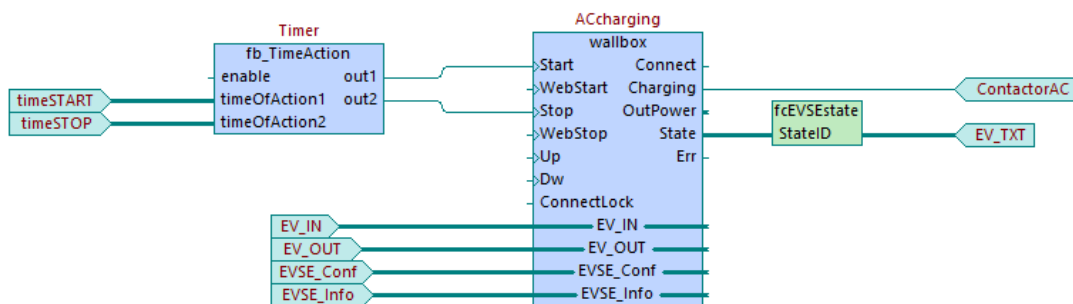
Figure 12: Mosaic schema for AC charging

This schema (see figure 12) is designed for overnight charging, specifically from 10 PM to 6 AM. This is achieved by using a simple timer function block, where inputs **timeSTART** (10 PM) and **timeSTOP** (6 AM) are brought, then the output **out1** is directly connected to the start of the charging and **out2** is connected to the **Stop** input of the wallbox function block.

The two inputs entering the wallbox function block at the bottom of the figure 12 indicate the specification of the values and information about the charging itself. Specifically, the **EVSE_Info** input provides information about the charging status and settings of the charging station. In the **EVSE_Conf** input is possible to configure the values of the maximum charging capacity, the steps by which the charging current is increased or decreased, or the delay of the charging.

The inputs **EV_IN** and **EV_OUT** specify the way in which the charging station is connected; in this case, the ethernet connection between the Tecomat Foxtrot and the charging station is used, with the specification of the IP address of the charging station and the TCP protocol is selected for the communication between these two.
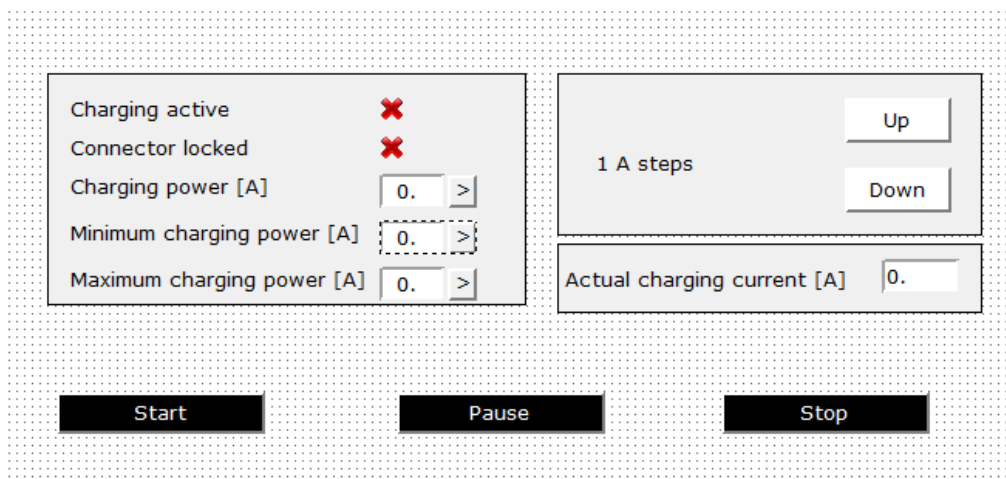
Figure 13: Example of the WebMaker tool

The Mosaic programming interface allows the user to create a simple web application with the help of the WebMaker tool. As it is possible to see above in figure 13, there is a possibility of tracking of the charging status, setting of the maximum and minimum charging capacity, the charging power itself, or setting of the charging capacity by 1A steps.

3.2 Loxone Config

The programming in the Loxone Config software is straightforward and intuitive. As it is possible to see in the picture below, there are predefined function blocks for the controlling of the supported peripherals. For this particular example of the integration possibility in an intelligent household, the Timer, the Energy manager, and the Wallbox function blocks were used. In addition, the Loxone Config software allows the user a simple simulation to test the program's functionality.
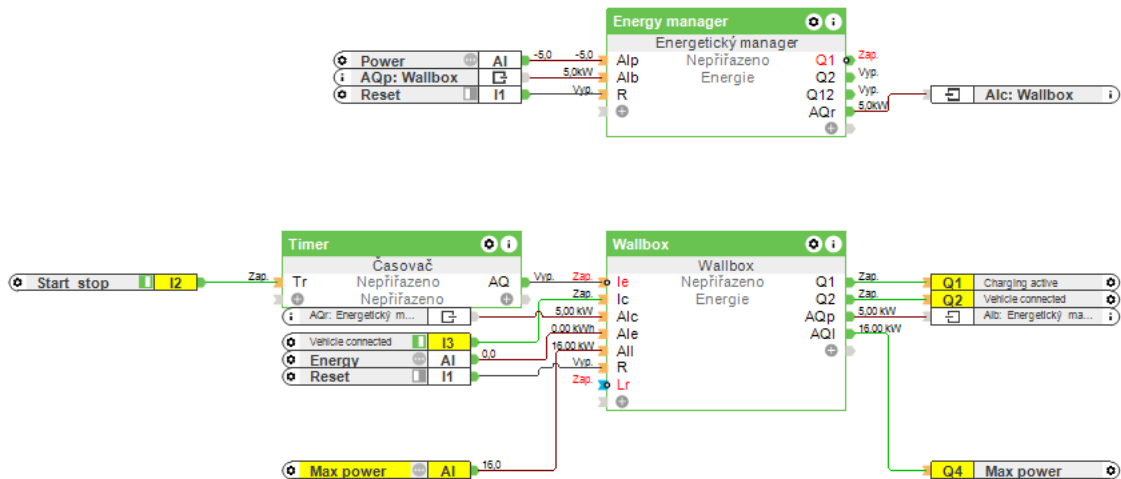
Figure 14: Loxone Config schema for AC charging

The Timer is an utterly uncomplicated time function block with freely adjustable switching times. Double-click on the function block opens an editing window that can define switching times. According to the input, the Timer is used digitally only to start or stop the activity of the Timer. It is connected to the **Ie** input of the wallbox function block that starts or stops the charging. The Timer is set for activation at night between 10 PM and 6 AM to have the vehicle fully charged in the morning.

In accordance with the Loxone Config help window, which describes individual function blocks, the Energy manager is a module that allows the connection of up to 12 appliances. It optimally uses excess energy, which is otherwise discharged into the grid. The **Alp** input indicates the current power of the domestic grid; when the value is negative, the production of the household's photovoltaic system is higher than it is possible to consume for the household; on the other hand, the positive value expresses the consumption from the grid.

Connected appliances have assigned priorities, the output **Q1** has the highest priority, and the **Q12** has the lowest priority, then there is an output **AQr** that shows excess energy. On the **AQr** output, the wallbox function block is connected since the charging of the vehicle is not the first priority in the majority of households. If there is excessive power at the **AIp** input, the Energy manager will turn on as many devices as possible, starting with the highest priority. The loads are active during the time when the appliances are switched on; when they are switched off, the other devices may be turned on, regardless of priorities. [38]

The Wallbox function block is used for the management of the charging station. As it was mentioned above in chapter 2.2, there are three predefined charging stations in the Loxone environment, Keba KeContact P20 Wallbox, Keba KeContact P30 Wallbox and BMW Pro Wallbox; the others must be defined by inputs and outputs. The **Ic** input indicates whether the vehicle is connected to the charging station. While the **Alc** shows the current value of the charging capacity, the input **All** can set the maximum charging capacity. The **Ale** serves for the counting of all the energy transmitted to the vehicle, and the R resets this value. Besides, there are the blue marked values on the left side of the function block, which are parameters for different profiles and their statistics. In this particular schema, it is not necessary to set them. The outputs on the right side of the function block reveal the information about charging itself. The output **Q1** shows whether the charging is active, and the **Q2** if the vehicle is connected. The **AQp** indicates the current power consumption of the vehicle. The **AQl** is the value of the maximum charging limit. The letter **E** indicates a possible error code. [38]

This specific schema is created for charging from excess energy from the photovoltaic system at night, starting at 10 PM and ending at 6 AM. As it is possible to see from the simple simulation, the production of the household is set to 5kW, and the wallbox function block is connected to the output that charges from excess energy. The previous outputs with higher priority are not connected since it is necessary to demonstrate that all the produced energy is utilised to charge the vehicle. When the connection of the vehicle and the start of the timer are simulated, the charging begins. As can be seen, the maximal power at the bottom of the figure 14, is set for the value of 16kW. This is the way in which the maximum charging capacity may be limited in the Loxone environment.

4. CHARGING STATION SELECTION

For ordinary household purposes, choosing one of the slower charging stations is occasionally preferable because a three-phase connected charging station with 32A per phase may cause a significant load on the grid. The intelligent household needs the charging station to be manageable. It could be done using the manageable charging station, or the intelligent control unit can control the charging. The most satisfactory solution is likely to be the combination of both. The controllable charging station allows setting the charging time when the prices are at their minimum, to charge primarily with the excess energy from the photovoltaic system, and switch between single-phase and three-phase charging. The intelligent control unit serves to control the smart household as a whole. Several manageable charging stations were chosen in this research and comparison to prove their suitability for integration of a charging station into a family house with the photovoltaic system.

The leading requirements for the charging station to integrate it into a family house with a photovoltaic system are to be able to charge with the maximum charging capacity of 22kW and to have the possibility of communication via the Modbus TCP/IP communication protocol.

4.1 Fronius Wattpilot Go 22 J

Fronius International GmbH is a company originating in Austria specialising in developing and manufacturing welding technologies, solar energy technologies, and electromobility. This company has developed the first possible charging station for domestic usage, the Fronius Wattpilot. It is an intelligent and autonomous charging station that offers two mounting solutions: the Wattpilot Home (stationary charging station); and the Wattpilot Go (the device is hanging upright and then can be removed and transported). [39] This chapter will be focused on the version Wattpilot Go 22 J. The Wattpilot Go 22 J is offered in one performance version, specifically with the nominal current of up to 32A per one phase and the nominal current can be configured along with the phases, or automatic switching between single-phase and three-phase connections can be used for the optimal usage of the excess solar energy. [40] It means that the maximal charging capacity is 22kW, according to the formula for calculating the charging capacity in chapter 1.1.1.

From table available in Appendix A, it can be seen that the price of this charging station seems favourable, but there is a difficulty. For the connection of the charging station to the intelligent household, it is necessary for the charging station to communicate with the programmable logic controller via some communication protocol, such as Modbus TCP/IP, RS485 Modbus, or Modbus RTU. As reported by Petr Kotrba in the e-mail conversation (on March 7, 2022), the Fronius Wattpilot itself has no such communication protocol integrated. Instead, it is crucial to own the Fronius power inverter that includes the Datamanager 2.0 or purchase the Datamanager 2.0 Box, which can communicate through the Modbus TCP/IP or Modbus RTU communication protocol. The charging station can communicate with Datamanager 2.0 only through the WLAN connection. [41] This means that the total price can be almost doubled.

The advantage of this charging station may be that it has its own application *Fronius Solar.wattpilot*, where the commissioning, settings, and charging mode selection occur; alternatively, the data about charging may be seen here. There are two charging modes available in this application, the Eco Mode and the Next Trip Mode. The Eco Mode is suitable for the owners of the households with own photovoltaic system. The Eco Mode utilizes the excess electric energy produced by solar panels, and the flexible electricity tariffs are used for the remaining required power for the charging. In this way, the peak loads in the electrical grid can be entirely avoided when electricity is the most expensive.

The Next Trip Mode, the second mode of this charging station, offers the ability to plan the next trip at a fixed time set in the *Solar.wattpilot* application from where the charging station is configured. The charging station will use the maximum available solar energy when planning the charging, alternatively the flexible electricity tariffs. [39], [42]

4.2 ČEZ Group

The ČEZ Group is the largest electricity producer in the Czech Republic, and it follows a sustainable development strategy with new technologies and energy efficiency. They offer a wide range of manageable charging stations, from the simplest single-phase connected wallboxes with a maximum charging capacity of 7.4kW to the three-phase supplying the maximal nominal current of 32A with numerous features. The BASIC Wallbox is a compact charging station that allows manual reduction of charging power. [43] The SMART and PROFI wallboxes enable users to connect them via the ethernet cable, alternatively wirelessly using Wi-Fi or LTE, to the intelligent household environment. The charging station itself can be controlled via a web application; this application allows the power regulation, charging speed control and reporting option. It is possible to manage the charging on the LCD display too. [44], [45], [46]

This chapter will be focused predominantly on the charging station ČEZ SMART. Unlike the Fronius Wattpilot, this charging station uses an integrated communication protocol, the Modbus TCP/IP, for communication with the programmable logic controller. The maximum charging capacity is 22kW with the nominal current 32A and three-phase connection. However, it is possible to connect the charging station only with one phase, thereby reducing the maximal charging capacity to 7,4kW. The SMART wallbox was preferred before the PROFI wallbox because the PROFI wallbox has for a considerable amount of extra money in its standard equipment only the possibilities of SMS logging in, RFID identification, and PIN authentication. [46] The SMART wallbox has plenty of optional equipment and is customisable according to needs. Even the protection devices, which can cause a significant rise in costs, if they are not implemented in the household's wiring, can be supplied with this charging station. [46]

4.3 Etrel INCH Home

Etrel is a manufacturer of charging stations and charging equipment in general. It also provides its own IT platform for charging management. Their charging stations are basically very similar, if not the same, both in terms of appearance and parameters to the charging stations offered by the ČEZ Group. For example, Etrel INCH LITE is the same as the ČEZ LITE wallbox, according to data sheets of both. However, the ČEZ SMART differs in some aspects from Etrel INCH Home, such as the type of optional mobile internet connection or the IP code. [47]

Similarly to the ČEZ SMART wallbox, this charging station offers a maximum charging capacity of 22kW with a three-phase connection. Alternatively, it is possible to connect it only using one phase. The Etrel INCH Home can be integrated into the intelligent household using the Modbus TCP/IP protocol. The power regulation, charging speed control and reporting option is carried out in the Etrel web interface, or LCD display may be used. Moreover, it is customisable as a consequence of the optional equipment that may be supplied with the charging station. [47]

4.4 Alfen Eve Single Pro-line (3f)

Alfen is a Dutch company that offers intelligent energy solutions such as transformer stations, energy storage systems, charging stations, etc. The marking of this charging station as *(3f)* at the end of the name is essential because this charging station provides only a three-phase connection. This means that the maximal charging power is limited to charging between 11kW and 22kW. The charging station itself can be controlled only through the LCD display. However, it is equipped with the ethernet port and with that associated communication via the Modbus TCP/IP protocol to connect it with the intelligent household. The Alfen Eve Single Pro-line is one of the more expensive charging stations in this comparison. On the other hand, it offers several authentication and protection devices in its standard equipment. These devices include the OCPP protocol, RFID reader, protection against 6mA DC fault, and overcurrent protection that is integrated into the firmware. [48]

4.5 Circontrol eHome Link

Circontrol eHome Link is one of the cheaper charging stations, and its equipment corresponds to that. There are various possible connections, but for this solution would be the most suitable the one with a three-phase connection and with maximal nominal current 16A meaning 11kW of maximum charging capacity. This charging station would bring difficulty in the form of the RS485 Modbus communication protocol. For all the programmable logical controllers mentioned above, it would mean that it would be necessary to purchase an additional submodule for the communication via the RS485 Modbus and the intelligent household itself. The simplicity of this charging station is ensured by the Plug & Charge function, which falls under the ISO 15118 protocol. There is no need for the RFID identification, OCPP protocol, or mobile application; this function ensures that the charging happens with encryption, decryption, and two-way authentication. The only thing needed is to connect the vehicle to the charging station. [49] Furthermore, for the Circontrol eHome Link, it is important to emphasise the degree of protection against overvoltage in the household; in the case of excessive electrical voltage, it is disconnected from the network and then reconnected, thus protecting the vehicle and the charger. [50]

4.6 go-eCharger HOME+

The Austrian company go-e GmbH is an international manufacturer of AC charging stations that developed the go-eCharger HOME+ wallbox. There are two versions of this wallbox, with a maximal charging capacity of 11kW and 22kW. It is a very interesting charging station, especially in terms of price and what it offers. It can be either stationary or portable; it weighs only 4kg, which allows the user many possible placing solutions. Furthermore, an adapter exists as an accessory that can be connected to any regular socket, not only to the CEE three-phase socket. [51]
This charging station is able to communicate through the Modbus TCP/IP protocol when connected to the Wi-Fi hotspot or Wi-Fi, and it grants the possibility of connection to the smart household. Furthermore, the go-e company has developed its own application where all the settings take place, the charging data can be shown, or it is possible to monitor the energy consumption, as this charging station is equipped with a built-in electricity meter as well. The electricity meter can measure the total consumption of kWh or limit the total amount of kWh per one RFID card.

Additionally, it has its own surge protection and the residual-current device protecting the charging station from 30mA of AC and 6mA of DC current. [51]

4.7 Heidelberg Wallbox Home Eco Europe

The Heidelberg company has recently expanded its services to charging stations as well; besides being the largest manufacturer of offset printing presses [52], one of those charging stations is Heidelberg Wallbox Home Eco Europe. This is the cheapest charging station in this comparison, and the equipment it offers corresponds to that. One of the disadvantages is that this charging station is offered only with the maximal charging power of 11kW. Furthermore, communication is not really feasible with this charging station, as it has not any possibility to connect it to the internet network. The Heidelberg company provides the service Heidelberg Wallbox Energy Control Europe that costs an extra 815 euros and permits the communication via the RS485 Modbus. This service is used for the linking of wallboxes and their management. The only possible way to control this charging station on its own is by using the LCD display, where the condition of the charging can be seen, and the restart button is located there. [53]

4.8 Webasto live Wallbox

The Webasto live Wallbox is the most advanced charging station in this comparison. It was developed by the manufacturer of innovative roof systems, heating and cooling solutions, and charging stations, Webasto Group. The price of this charging station is slightly higher, but the offered properties and equipment may justify that. The charging station is made for a single-phase or three-phase connection with a maximal charging capacity of 22kW. The Modbus TCP/IP for the implementation into the intelligent household is present, and to a greater extent, there is the RS485 Modbus for reading external power meters. The application Webasto Charging grants the possibility to control the charging, to access the charging station remotely, and to see the charging data report. The charging station provides various authentication systems, communication protocols, and the possibilities for communication, including an RFID reader, OCPP protocol, MID approved meter, ethernet, WLAN and mobile connection. This means that it is made for the grid connection of the more significant number of these wallboxes in a larger parking lot, but these properties would also apply to a family house. [54]

4.9 Schneider Electric EVlink Smart Wallbox

Schneider Electric brings digital automation solutions that are the basis of integrated solutions for households, buildings, data centres, infrastructure and industry, including the development of charging stations. One of those is the Schneider Electric EVlink Smart Wallbox, which is a relatively affordable charging station with many features. It offers the possibility of a single-phase or three-phase connection with the maximal charging capacity of 22kW and the RS485 Modbus for communication with the intelligent household. However, as mentioned above in chapter 4.5, there is a need to purchase an additional submodule for the programmable logic controller. Schneider Electric has developed an application, EcoStruxure^{TM} Facility Expert, where it is possible to track reports about the history of charging, create reports and organise the maintenance records; besides, the basic settings of the station are done here. There are three available ethernet ports for the connection to other devices, and they can communicate via a mobile internet connection either. The residual-current device type B with the protection against 30mA of AC and overcurrent protection are both present. [55]

4.10 Result

In this comparison, six out of nine charging stations met the requirements mentioned above in the introduction of this chapter, precisely the charging capacity of 22kW and communication through the Modbus TCP/IP protocol. However, there was discovered a difficulty with the communication via the Modbus TCP/IP protocol in the case of Fronius Wattpilot. Alfen Eve Single Pro-line (3f) can charge only using the three-phase connection, and additionally, it is one of the more expensive charging stations. The go-eCharger HOME+ wallbox seems to be designed for more portable than domestic usage.

Of the remaining suitable charging stations (ČEZ SMART, Etrel INCH Home, and Webasto live Wallbox), the Etrel INCH Home was selected for the testing based on the communication with suppliers.

The whole comparison table is available in Appendix A at the end of this paper. The data for the comparison were extracted from the data sheets of the individual charging stations.

5. TESTING

Based on the previous comparison of charging stations in chapter 4, the Etrel INCH Home was selected for the testing. However, the company sent us the Etrel INCH Pro, which is used to serve more electric vehicles, according to the official Etrel website. It has more functions than the Home version and smart clustering and power management that help with operational costs. [56] The demanded features for the charging station were to be able to charge at 22 kW and to communicate via the Modbus TCP/IP communication protocol.

The goal of the measurement was to set the desired value of the charging capacity during the charging process without stopping the charging or disconnecting the vehicle and to find out how the vehicle and charging station would react. For example, to find out how fast it is possible to limit the charging capacity when the household's grid is overloaded or when the photovoltaic system is unable to produce the required amount of electric energy.

The electric vehicle used in this test was the Tesla Model S. The exciting feature, concerning the vehicle, was that after connecting the vehicle to the charging station, the vehicle automatically set the maximum input current to 25A for the AC charging. At the beginning of the testing, the Tesla Model S had a battery charged to about 40%.

Figure 15: Tesla Modes S connected to the charging station

5.1 Web interface

The first tested option to limit the charging capacity was done in the web interface developed directly by the Etrel company. The user gets into the web interface by typing the IP address of the charging station, which must be connected to the local network, into any web browser. On the homepage of the web interface, it is possible to see the progress of the current charging session, the charging duration, the energy consumed during the charging, and the presumed time when the vehicle will be fully charged. The web interface allows the user only the fundamental but sufficient settings to manage the charging station.

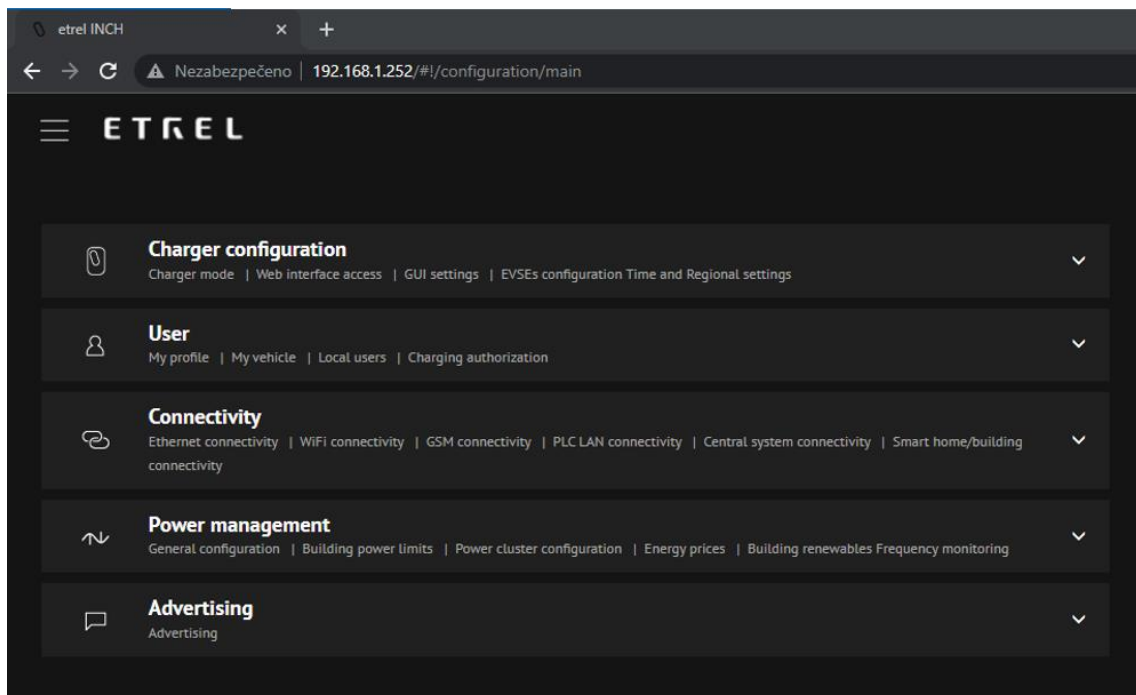Figure 16: The web interface menu

The most important sections of this menu are the charge configuration, specifically the EVSEs (Electric Vehicle Supply Equipment) configuration, and the power management. The power management allows to connect the device to an intelligent household by typing the IP address of the selected PLC, and thus, the PLC takes control over the power management in the household.

In the EVSEs configuration, it is possible to set the desired number of phases and consequently limit the charging capacity between the maximum of 7.4kW and 22kW. However, this statement is valid only theoretically for the reason that, as was mentioned above in chapter 5, this specific vehicle used for the testing limits its AC charging capacity on 25A; thus, the real value of maximal charging capacity, according to the formula in chapter 1.1.1, ranges between 5.75kW and 17.25kW. The testing was performed using the three-phase connection.

The physical quantity for changing the maximal charging capacity used in all tests was the maximal charging current in the range of 0A and 32A, as it is possible to see below in the figure 17.

Figure 17: EVSEs configuration

According to the telephone conversation (on April 29, 2022) with the technical support employee of Etrel in Slovenia, it should be realisable to change the maximal charging current during the charging session. Unfortunately, this information did not prove to be right when tested. When the maximal charging current was replaced by another value, the vehicle did not accept this information. Instead, it continued in the charging with the previous pre-set value of the charging current. Therefore, the only option for entering a

new charging current setpoint into the vehicle was to disconnect both the vehicle and the charging station and reconnect again. This option is not too time-consuming but cannot be done remotely.

On the other hand, the web interface offers the possibility of setting a departure time that tells the charging station when the vehicle should be fully charged. The departure time automatically switches the maximal charging current according to the vehicle's needs. It can be set by using the unix time, or it can be left on the charging station, which decides when to stop the charging based on previous charging sessions. The previous charging sessions may be seen in the reporting.

Except for the limitation of the maximum charging capacity, it is feasible in the web interface, for example, to set different user profiles with their authorization and vehicles; alternatively, when the charging station is freely accessible by everyone, for instance, in front of the house, it is possible to share the costs by using the OCPP 1.6 JSON protocol.

5.2 Modbus Master application

The following alternative to limit the charging capacity already concerns the Modbus TCP/IP communication protocol. Primarily, it is necessary to obtain the list of reading and writing registers of the charging station. [57] For each device that is capable of communication via the Modbus TCP/IP protocol this list differs. A countless number of these applications exist for controlling the communication through the Modbus TCP/IP protocol. In this case, the QModMaster was used. In the options of this application, it is demanded to set the correct IP address of the charging station and the right TCP port that differs according to the registers that need to be either read or written. Specifically, for the limitation of the charging current, the TCP port is 502.

The parameters must be set after the connection between the Modbus master and the charging station. The unit ID should be ignored since the device is identified by the IP address. The function code differs on whether the registers should be read or written; the Etrel charging station supports the function codes 0x04 (Read Input Registers) and 0x10 (Write Multiple Registers). The starting address of the device ranges between 0 and 65 535 to have enough free positions to listen and receive messages. [58] The number of registers defines the message by its size; if the number of registers is 2, the message is extended into two positions in the range between 0 and 65 535.

The last parameter is the data format that varies according to the easiest way to write down the message. In this list of reading and writing registers are the data formats Float32, ASCII, and the Integer.

In the figure below, it is possible to see an example of the setting of the current setpoint to a value of 14A.
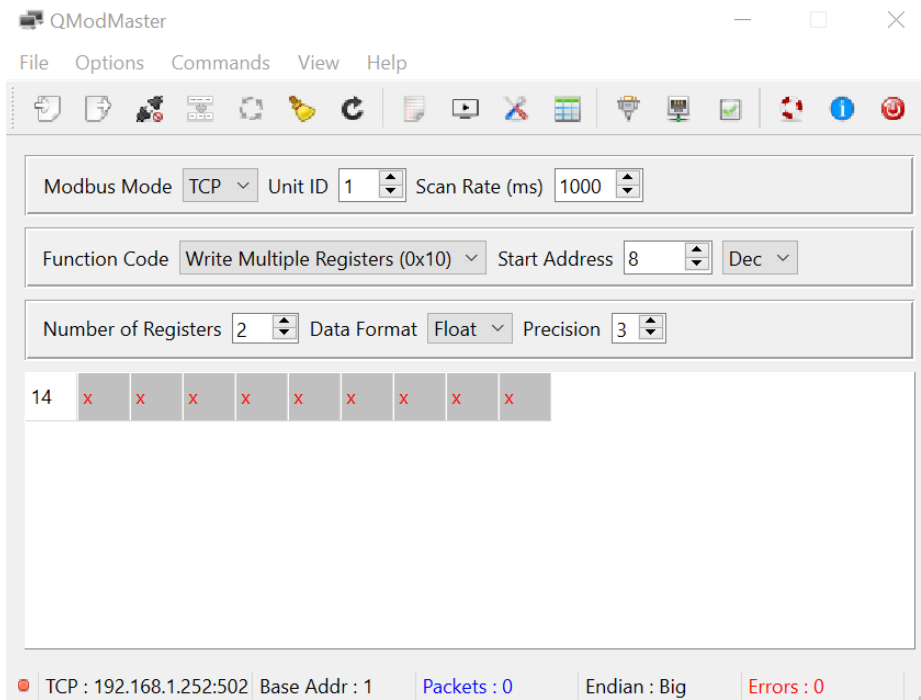
Figure 18: Modbus Master application

5.3 LabVIEW application

A simple LabVIEW application was developed based on the Modbus TCP/IP communication description. It worked on a similar basis as the Modbus master application, specifically with the usage of the list of reading and writing registers. The reading registers were used for the tracking of actual values, and thus the approximate accuracy of the measurement was examined without the necessity of checking on the measurement device. The same writing register for the setting of the current setpoint was used for the changing of the maximum charging current, as in the case of the Modbus master application. A simple waveform chart was added to facilitate the observation of the course of all three phases and the control signal. The LabVIEW chart monitored and recorded only the electric current data and its time.
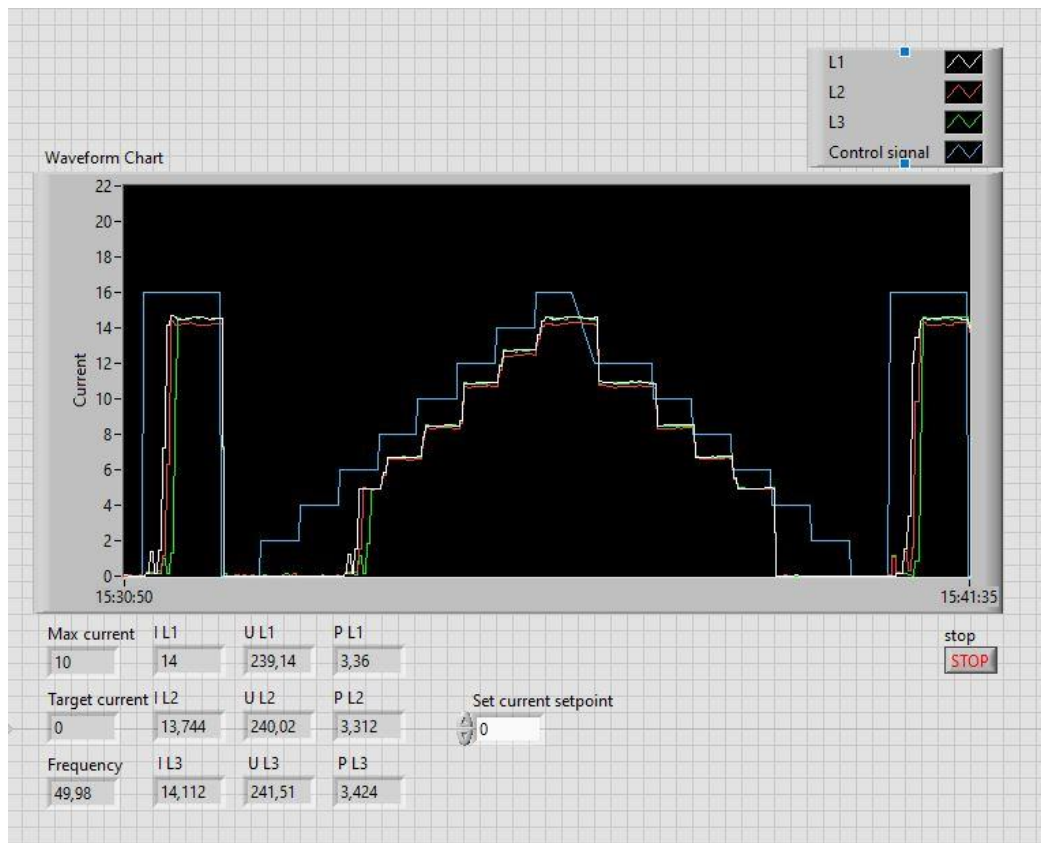
Figure 19: LabVIEW application

For a more accurate measurement, the Hioki 3390 Power Analyzer was directly connected to the phases of the charging station. As a result, the Hioki recorded the data of all different sorts, including the most important for this measurement, the root mean square (RMS) values of electric currents in each phase and the power transmitted via each phase.
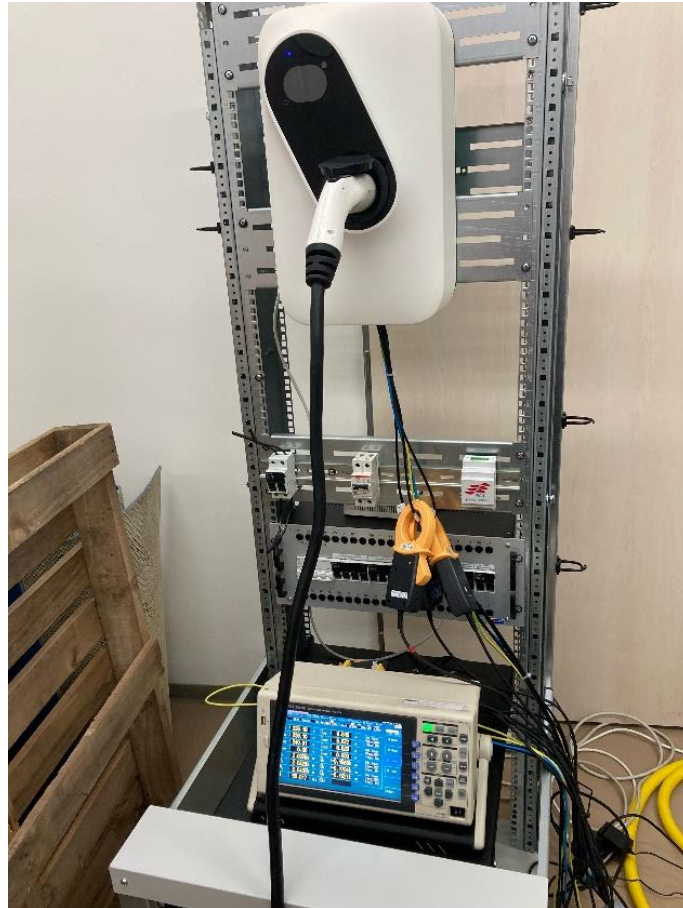
Figure 20: Hioki 3390 connected to the Etrel INCH Pro

The measurement itself was performed by using 30 seconds steps between the switching of the current setpoints; only maximums in the beginning and at the end of the measurement lasted for 60 seconds. The 16A peak was selected as the maximum, with 2A steps upwards and downwards. It was needed to synchronise the times recorded by the Hioki measuring device and the LabVIEW software since there was a time shift that was equal to about 12 minutes between the Hioki and the Windows OS installed on the computer. The synchronisation was required for the reason that the control signal was recorded by the LabVIEW application, and the remaining data were used from a more accurate Hioki measuring device.
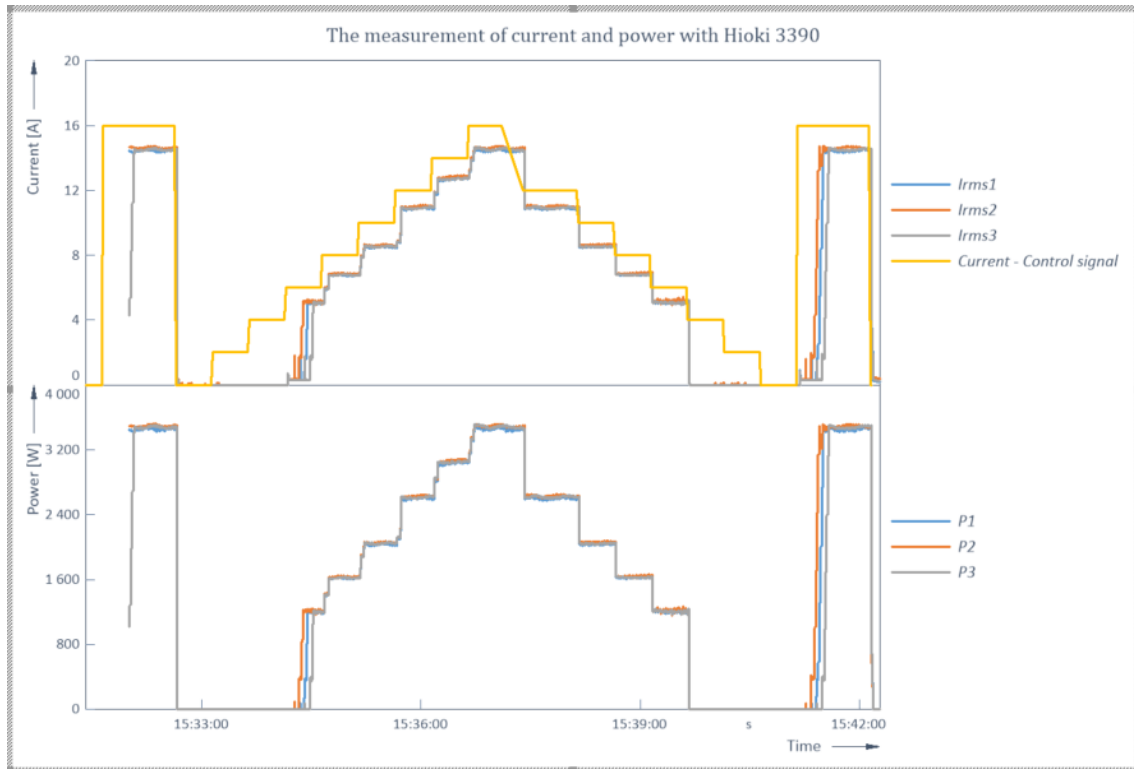
Figure 21: Measurement results

From the chart in the Figure 21, it is possible to see that the measuring device Hioki started to record slightly later than the LabVIEW application. However, this is advantageous in the distinct identification of acceleration of phases. It is still possible to recognise it from the later course of the chart, but the Hioki started to record when the third phase started to rise to about 14A. It is possible to see that the real RMS current is slightly lower than the current control signal, which represents the requested value. Interestingly, the phases gradually rose; the first that rose was the second phase, then the first phase, and the last one was the third phase. Specifically, in numbers, a more significant increment of the current, such as the transition between 0A and 6A or between 0A and 16A, caused a larger delay; the delay was computed from the start of the raising of the second phase till the third phase has reached the requested value. Both transitions lasted approximately 15 seconds. The 2A increasing steps were done within 1 second.

On the other hand, when descending, all three phases nearly immediately change their value to the requested one; all the transitions lasted less than 1 second. This feature may help with the integration of the charging station into the household. It means that it can react to any unexpected event that occurs during the charging session within seconds. These unexpected events include, for example, when the photovoltaic system is not able to provide enough electricity for the whole household, the charging station may quickly reduce the charging capacity.

Another essential characteristic of this charging station is that it did not respond to the gradual increase and decrease of the charging current until it reached the value of 6A. From the data set of the measurement, it is possible to see that when the control signal was set for the value of 6A, the RMS value of the current was roughly 5A and the charging capacity 1,2kW. These are the minimum values that the charging station can provide.

An error occurred with each attempt when descending from 16A to 0A with 2A steps. The error was in a LabVIEW application and occurred in the same place each time when the transition from 16A to 14A happened. From the chart, it is possible to see that this error caused the skipping of the 14A step and extended the duration of the 16A and 12A steps.

6. CONCLUSION

Electromobility is a promising area, and it is necessary to build up a functional charging station network. The private wallbox, which is simply said to be a manageable intermediator of the power for the vehicle, is one of the options since about 80% of electric vehicles are charged at home. It encounters numerous possibilities in customising the charging, unlike the charging from the regular 230V socket. Furthermore, it is appropriate to utilise one of the intelligent control units capable of the clever redistribution of the electric power between appliances to manage the household's electricity and not overload the grid. With the combination of both the manageable charging station and intelligent control unit, it is feasible to set the charging time for the most convenient charging, for instance, using the photovoltaic system.

This bachelor's thesis realized the exploration of the issue of the integration of a charging station into a family house with a photovoltaic system. In particular, the research was accomplished concerning the properties of different charging stations, their communication standards, the possibilities of charging electric vehicles at home and the most acceptable option for achieving it. One of the options was to use an intelligent control unit, and two of intelligent control units were selected and compared. Their programming interface was used to create a simple function dependent on the time when the vehicle is allowed to charge. A part of this thesis is composed of the extensive comparison of different charging stations, and the output of this comparison was the selection of the most suitable charging station for the testing. The testing took place using the selected charging station and borrowed electric vehicle; the testing focused on the limitation and gradual increase of the charging capacity during the charging session. It proved the possibility of a fast reaction to any unexpected event in the household.

To conclude this bachelor's thesis, this paper supports the idea of electromobility and the possibility of charging at home. Additionally, with the proper management of the electricity in the household, the integration of the charging station should not limit the household or the grid as a whole.

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SYMBOLS AND ABBREVIATIONS

Abbreviations:

NRDC	Natural Resources Defense Council
RFID	Radio Frequency Identification
PLC	Power Line Communication
IP code	Ingress Protection code
IEC	International Electrotechnical Commission
OCPP	Open Charge Point Protocol
V2G	Vehicle-to-Grid
ISO	International Organization for Standardization
TCP	Transmission Control Protocol
IP	Internet Protocol
UDP	User Datagram Protocol
IC-CPD	In-Cable Control and Protection Device
AC	Alternating Current
DC	Direct Current
CCS	Combined Charging System
PHEV	Plug-in Hybrid Electric Vehicle
PLC	Programmable Logic Controller
RAM	Random Access Memory
HVAC	Heating, Ventilation, and Air Conditioning
LCD	Liquid Crystal Display
CIB	Common installation Bus
LAN	Local Area Network
WLAN	Wireless Local Area Network
DIN	Deutsches Institut für Normung
PC	Personal Computer
PV system	Photovoltaic system
LTE	Long Term Evolution
Wi-Fi	Wireless Fidelity
EVSE	Electric Vehicle Supply Equipment
ST	Structured Text
CFC	Continuous Function Chart
RMS	Root Mean Square

Symbols:

P	charging capacity	(W)
I_n	nominal current	(A)

LIST OF APPENDICES

Appendix A - The charging station comparison

	Fronius Wattpilot Go 22 J	ČEZ SMART	Etrel INCH Home	Alfen Eve Single Pro-line (3f)	Circontrol eHome Link	go-eCharger HOME+	Heidelberg Wallbox Home Eco Europe	Webasto live Wallbox	Schneider Electric EVlink Smart Wallbox
Price	23.000,-	30.854,-	30.696,-	39.845,-	24.690,-	19.490,-	14.000,-	52.340,-	25.537,-
Maximum charging capacity	22kW	22kW	22kW	22kW	11kW	22kW	11kW	22kW	22kW
Phases	1/3 automatically switched	1, 3	1, 3	3	3	1, 3	1, 3	1, 3	1, 3
Communication protocol	Modbus TCP/IP, RTU	Modbus TCP/IP	Modbus TCP/IP	Modbus TCP/IP	RS485 Modbus	RS485 Modbus	Modbus RTU (+ € 815)	Modbus TCP/IP	RS485 Modbus
Web interface/app	App	Web interface	Web interface	×	×	App	×	App	Web interface
Connector type	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2
Mounting method	Hanging upright	On-wall mounted/pedestal mount	On-wall mounted/pedestal mount	On-wall mounted/pedestal mount	On-wall mounted	On-wall mounted	On-wall mounted/pedestal mount	On-wall mounted/pedestal mount	On-wall mounted/pedestal mount
Ethernet	×	✓	✓	✓	×	×	×	✓	✓
Mobile	×	optional (GSM, GPRS, EDGE, UMTS)	optional (LTE)	✓ (GPRS)	×	×	×	✓ (LTE)	✓ (GPRS)
WLAN	WEP, WPA, WPA2 and WPA3	optional (Wi-Fi)	optional (Wi-Fi)	×	×	✓ (Wi-Fi)	×	✓	×

	Fronius Wattpilot Go 22 J	ČEZ SMART	Etrel INCH Home	Alfen Eve Single Pro-line (3f)	Circontrol eHome Link	go-eCharger HOME+	Heidelberg Wallbox Home Eco Europe	Webasto live Wallbox	Schneider Electric EVlink Smart Wallbox
OCPP	×	OCPP 1.6 SOAP/JSON	OCPP 1.6 SOAP/JSON	OCPP 1.5, 1.6 (JSON)	×	×	×	OCPP 1.6 J	OCPP 1.6
RFID	√	optional	optional	√	×	√	optional	√	√
IP code	IP 54 (IP 44 with cable included)	IP 54 (IP 65 with cable included)	IP 56	IP 55	IP 54	IP 54	IP 54	IP 54	IP 55
Supports PLC	×	Optional (HomeGreenPHY PLC)	Optional (HomeGreenPHY PLC)	×	×	×	×	√	×
MID meter	×	optional	optional	√	optional	√	×	√	×
Communication interfaces (Standards)	IEC 61851-1, IEC 62196	IEC 61851, IEC 15118	IEC 61851-1:2017, ISO 15118:2015	IEC 61851-1:2017	×	×	IEC 61851-1:2010	ISO 15118-1, ISO 15118-2	IEC 61851-1, IEC 62196-2, IEC 61851-22, IEC 62196-1
Differential protection	6mA DC, 30mA AC	on request (RCD Type B, Type B+)	6mA DC fault, RCD Type A, Type A EV, Type B optional	6mA DC fault	RCD Type A (30mA) + 6mA DC, RCD Type B (30mA)	×	6mA DC	×	Type B (30mA)
Surge/overvoltage protection	×	√	×	×	×	√	√ (category III)	√ (category III)	×
Overcurrent protection	×	MCB 16A - 40A, characteristics C	MCB 16A - 40A, characteristics C	Integrated into firmware	×	×	×	×	40A characteristics C