



Development of AC electric vehicle charging systems

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Escola Superior de Tecnologia e de Gestao (EsTIG) and Université Libre de Tunis (ULT) are not responsible for the opinions expressed in this report.

I declare that the work described in this report is my authorship and is of my wish that the same be submitted for evaluation.

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Dedication

To my dear father Hadi and my dear mother Naima, for their love, sacrifices and support in the most difficult moments, which are at the origin of my success, may God keep and protect them.

To my sister Oumaima, for here continuous encouragement and support since my birth, I wish you a life full of happiness and success.

To all the people who, actively or not, participated and helped in the accomplishment of this work.

It is with great pleasure, I dedicate this modest work to you.

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Abstract

Electric vehicles have been gaining more and more acceptance in recent years. With the development of battery technology, the range on a single charge has evolved to values that make them credible options in a market still dominated by combustion vehicles.

An important issue for electric vehicles is the charging system, currently even in fast charging they still have high times, but when it is possible to charge slowly at home, this process not only becomes comfortable but also more economical.

This thesis report presents a system for charging electric vehicles at home. The system presents the basic functionalities for charging electric vehicles. It forms the basis for future integration into an energy management system that, without user intervention, can maximize the use of energy produced in the house itself, through photovoltaic solar panels.

Keywords : EVSE, GFCI, Micro controller esp32, J1772, Pilot signal, Power split, Electric car

Résumé

Les véhicules électriques sont de plus en plus acceptés ces dernières années. Avec le développement de la technologie des batteries, l'autonomie sur une seule charge a évolué vers des valeurs qui en font des options crédibles sur un marché encore dominé par les véhicules thermiques.

Un problème important pour les véhicules électriques est le système de charge, actuellement même en charge rapide, ils ont encore des temps élevés, mais lorsqu'il est possible de charger lentement à la maison, ce processus devient non seulement confortable mais aussi plus économique.

Ce rapport de thèse présente un système de recharge de véhicules électriques à domicile. Le système présente les fonctionnalités de base pour la recharge des véhicules électriques. Il constitue la base d'une intégration future dans un système de gestion de l'énergie qui, sans intervention de l'utilisateur, peut maximiser l'utilisation de l'énergie produite dans la maison elle-même, grâce à des panneaux solaires photovoltaïques.

Mots clés: EVSE, GFCI, microcontrôleur esp32, J1772, signal pilote, Puissance Divisé, voiture électrique

Resumo

Os veículos elétricos vêm ganhando cada vez mais aceitação nos últimos anos. Com o desenvolvimento da tecnologia das baterias, a autonomia com um único carregamento evoluiu para valores que as tornam opções credíveis num mercado ainda dominado pelos veículos a combustão.

Uma questão importante para os veículos elétricos é o sistema de carregamento, atualmente mesmo em carregamento rápido eles ainda apresentam tempos altos, mas quando é possível carregar lentamente em casa, esse processo não só se torna confortável como também mais econômico.

Este relatório de tese apresenta um sistema de carregamento de veículos elétricos em casa. O sistema apresenta as funcionalidades básicas para carregar veículos elétricos. Constitui a base para uma futura integração num sistema de gestão de energia que, sem intervenção do utilizador, permite maximizar a utilização da energia produzida na própria casa, através de painéis solares fotovoltaicos.

Palavras-chave : EVSE, GFCI, Microcontrolador esp32, J1772, Sinal piloto, Power split, Carro eléctrico

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Acronyms

This document contains some abbreviations which are defined here.

AC	Alternating Current
BEV	Battery Electric Vehicle
CCS	Combination Charging System
DC	Direct Current
EVs	Electric Vehicles
EVSE	Electric Vehicle Supply Equipment
EREVs	Extended Range Electric Vehicles
FCVs	Fuel Cell Vehicles
GHG	Greenhouse Gas
GFCI	Ground-fault circuit interrupters
HEVs	Hybrid Electric Vehicles
IC	Internal Combustion
ICE	Internal Combustion Engine
MPPT	maximum power point tracking
OS	Operating Systems
PV	Photovoltaic
PHEVs	Plug-in Hybrid Electric Vehicles
PWM	Puls Width Modulation
PDM	Pulse Duration Modulation
RTOS	Real-Time Operating Systems
SoC	State of Charge
WPT	wireless power transfer

Chapter 1

Introduction

In recent years, interest in electric cars has increased due to concerns about climate change and global warming. Public opinion on electric cars has evolved as producers like NISSAN, RENAULT, TESLA and others have developed low-cost, practical automotive solutions. Manufacturers' focus on non-commercial vehicles has contributed to the delayed adoption of electric vans and delivery trucks. As a result, electric van technology has mostly fallen behind.

The number of Electric and Hybrid Vehicles (HEVs) that use on-board electrochemical energy storage devices (batteries) that must be fully or partially recharged by connection to a low-voltage electrical grid supplying domestic or light industrial users will increase significantly over the next few years. A battery charger consisting of a unidirectional or bidirectional power electronic converter that transforms the Alternating Current (AC) power supply into Direct Current (DC) or vice versa is required for the grid connection.

Future automotive power electronic converters are expected to have a lifespan of at least ten years and be capable of operating at extreme temperatures - factors that compromise current power converter topologies, especially those that use electrolytic capacitors [1].

1.1 Objectives

The main objective of this work is to develop a system that allows to recharge the battery of an electric vehicle.

1.2 Document structure

The document structure is presented as follows :

- **Chapter 1:** Gives an introduction to the subject of study and a presentation of the objective of the Master's Thesis.
- **Chapter 2:** Presents the state of the art, history, Electric vehicle, types, technologies and difference.
- **Chapter 3:** Presents the statement of the problem and the proposed solution, an overview of the used hardwares and and a description of the monitoring system.
- **Chapter 4:** Presents the algorithm discussions and results obtained according to the implementation.
- **Chapter 5:** Brings the conclusions of this work and mention proposals for the future work.

Chapter 2

Electric Vehicle Technology

Overview

The aim of this chapter is to define some notions of history, Electric vehicle, types, technologies, difference.

2.1 Introduction

Electric Vehicles (EVs) had a range of 120 to 150 Km in their early iterations. Mid-range EVs now boast a range of 500 KM. Regardless of the generation of electric vehicles, a well-distributed charging infrastructure is required to overcome their usage constraints and to provide consumers with peace of mind. When assessing the sales data of EV, the psychological aspect among users (i.e. the fear of being left without a means of recharging) must be considered. AC/DC chargers that may be used for single-phase recharging from AC power outlets and/or three-phase recharging on specialized terminals increase recharging availability for customers while lowering infrastructure costs. As a result, several automakers, including as Renault and BMW, have built their own AC/DC chargers for their electric vehicles [1].

2.2 Overview

To achieve zero-emissions standards, there has been a movement toward electrification of fleets. Companies all around the world have shown interest in and commitment to speeding up the transition to electric mobility by converting their conventional fleets to electric vehicles (EVs). Walmart, for example, has pledged to electrify its entire fleet by 2040. By 2025, IKEA will have zero-emission delivery in all cities. Leading corporations such as DHL Group and FedEx have already committed to achieving net-zero emissions logistics by 2050. As a result, workplace charging infrastructure, also known as electric vehicle supply equipment (EVSE), is progressively expanding.

By 2020, the number of global private and public charging EVSE units will have surpassed 10 million, with a total charging capacity of 55 GW. The most important impediments to EV expansion at work are a shortage of charging infrastructure and demand charges in commercial and industrial rates associated with peak demand from charging loads. Some utilities have suggested EV-specific tariffs to bypass the demand charge hurdle. The demand meter is bypassed in this unique solution, which necessitates the installation of a separate meter for charging station loads alone. While the goal is to move charging loads away from the peak during hours of midday solar over-generation, smart charging and scheduling are required for the EV fleet owner to fully benefit from the rates in terms of cost savings. To keep EV fleet charging demand up, workplace Electric Vehicle Supply Equipment (EVSEs) have been the key emphasis. Keeping the expense of the project to a minimum [2] The general idea of the co-simulation of optimal EVSE can be expressed by the following figure 2.1.

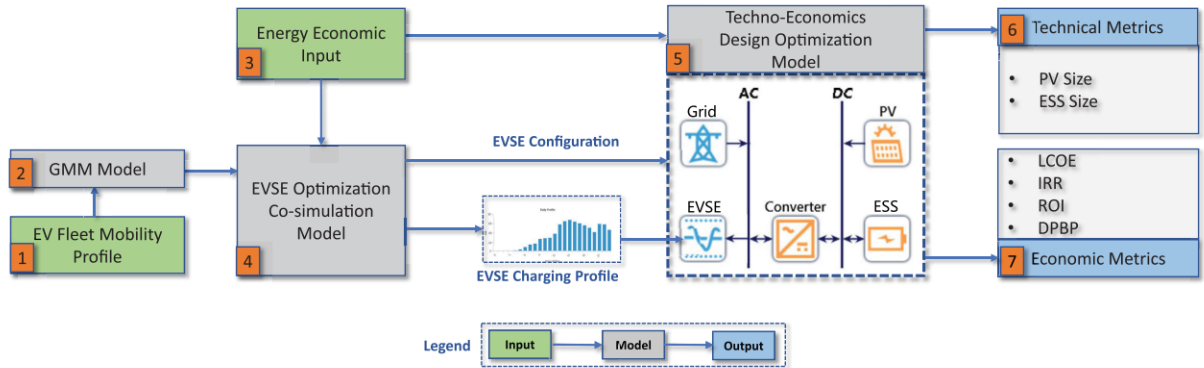


Figure 2.1: A proposed approach for co-simulation of optimal EVSE and techno-economic system design model [2].

2.3 History

First and foremost, it is critical to emphasize that electric vehicles are not a new or newly developed technology. Battery Electric Vehicle (BEVs) have a lengthy history, and they formerly held a large market share around a century ago. As a result, it's crucial to figure out why electric vehicles have lost their allure and then devise measures to boost their market share. Various scholars have analyzed the history of electric vehicles, which may be divided into three broad phases:

- **1890– 1920:** Rising popularity,
- **1920 - 1970:** Diminishing popularity,
- **After 1970:** Efforts to resurrect popularity.

The first experimental light-weight EVs were built in the united States, the united kingdom, and the netherlands in the 1830s. This was around ten years after the electric motor's principles were initially proven. In the years that followed, further battery research was carried out, culminating in the groundbreaking presentation of the first lead-acid battery cell in 1859. The 'golden age' of electric vehicles occurred in the United

States from 1880 and 1920, when the electric passenger automobile was significantly more popular than in Europe. There were three sorts of automobiles available at the time: steam-powered vehicles, gasoline ICE vehicles, and electric vehicles. In 1900, electric cars overtook gasoline-powered vehicles as the most popular road vehicles in the United States, accounting for 28% of the market. By 1900, 936 gasoline cars, 1575 electric vehicles, and 1681 steam vehicles had been registered throughout the country. EVs were dominating in large metropolitan locations (New York, Boston, and Chicago), with around two EVs for every one fuel vehicle.

There was no obvious indication of which kind would dominate the market. Each technology had its own set of benefits and limitations, and they were all competing in terms of performance and price on the free market. Steam-powered vehicles were quicker and less costly, but they took a long time to start and needed frequent water breaks. The ICEs were dirtier, more difficult to start, and a little more costly, but they could go greater distances without stopping. Electric vehicles were clean and quiet, but they were sluggish and costly.

The lack of vibrations, smell, and noise associated with gasoline automobiles was one of BEV's key benefits over their competitors. Because decent roads were only available in cities at the time, and most traffic was caused by urban commuting, the range problem was not a major concern. As a result, between the 1890s and the 1920s, EVs mostly serviced metropolitan regions rather than rural families. ¹⁹ This was an ideal scenario for electric vehicles, given their restricted range. However, BEV manufacturers realized this limitation as early as the early 1900s and attempted to discover practical ways to make the electric vehicle more competitive for longer journeys outside of cities. To accomplish this, three major measures were implemented: (1) easily replaceable battery systems were developed to overcome range limitations; (2) the principle of regenerative braking was implemented, which utilized the electric motor's ability to act as a generator, recharging the battery when driving downhill; and (3) hybrid technology was developed. At the time, HEVs were touted as combining the best of two technologies: noiseless driving in city areas and no constraints to the car's range outside of cities. However, mostly owing

to financial concerns, the hybrid idea faded away, never to be seriously considered again until the early 1970s.

The worldwide stock of electric vehicles reached a record high of 30,000 in 1912, but this was followed by a drop that began in the 1920s owing to a number of key technological and economic issues. These changes happened between 1900 and 1920, and were largely related to improvements in the gasoline automobile. The technical reasons were as follows: (1) After 1920, a better network of roads outside of cities was established, necessitating the use of longer-range vehicles and creating increasingly unfavorable conditions for EVs; (2) Furthermore, Internal Combustion Engine (ICE) vehicles were technologically improved while the electric car remained stagnant. The manual crank, for example, was obsolete by 1912 thanks to the introduction of the electric starter. Furthermore, the fuel consumption per kilometer driven was significantly lowered[1].

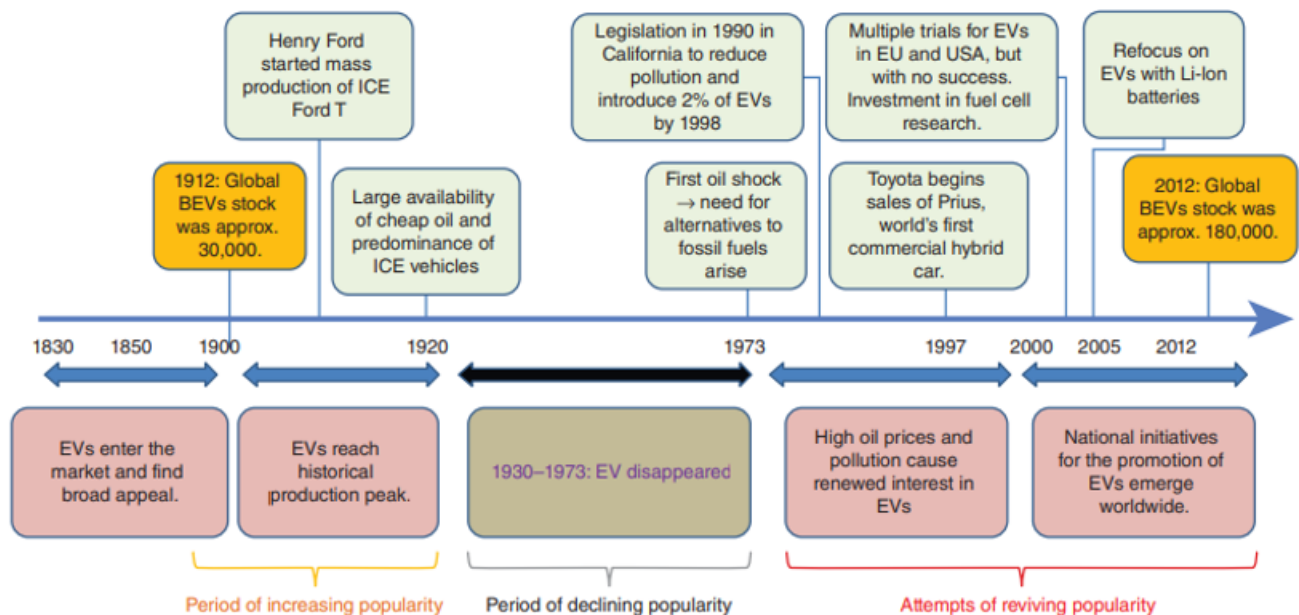


Figure 2.2: Major milestones in the history of EVs [1].

THE ELECTRIC CAR PAST AND FUTURE

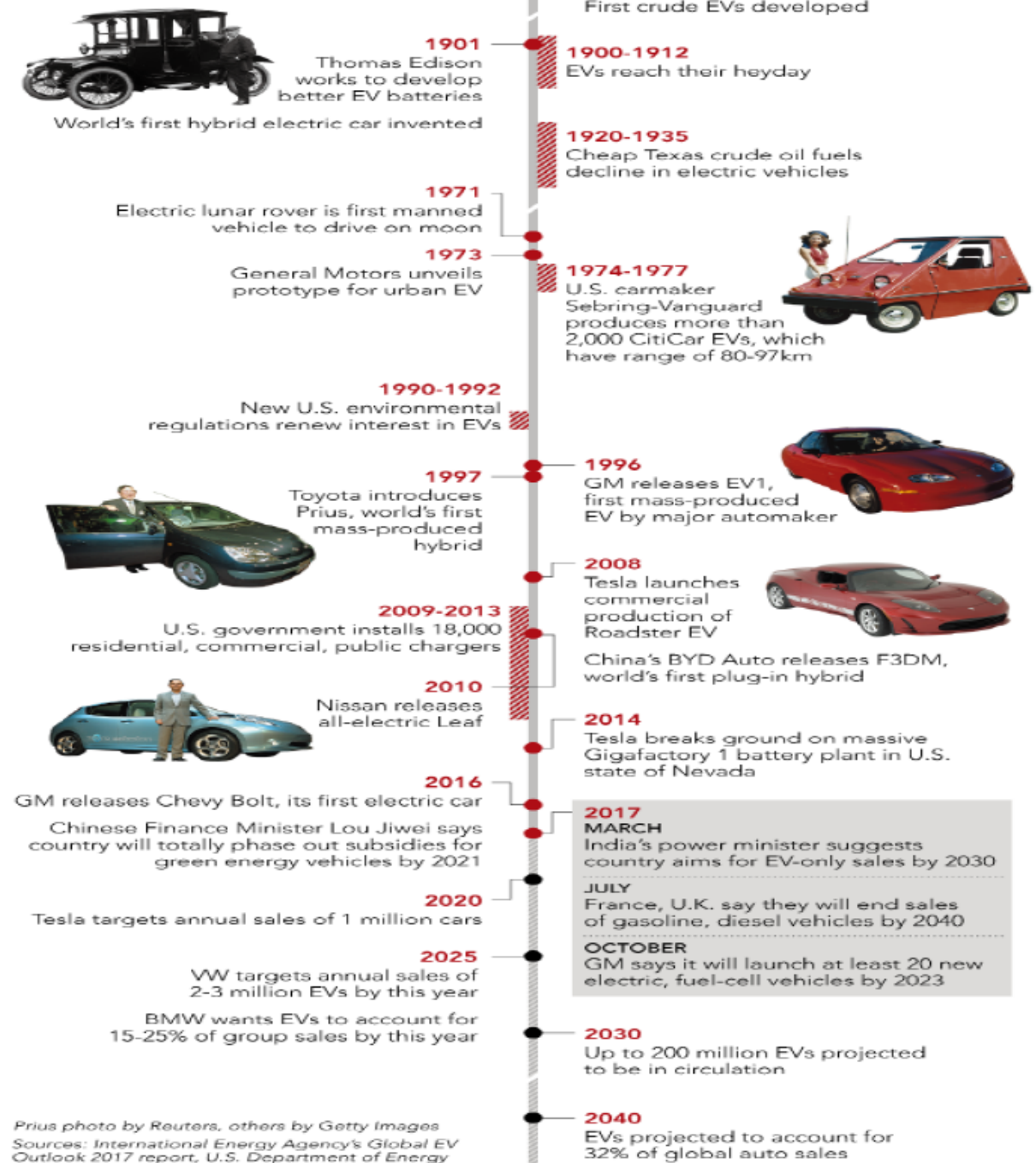


Figure 2.3: Timeline of EVs [3].

2.4 Electric vehicles

Electrical system infrastructure has been built to meet the maximum expected demand, which occurs at most at 5% of the year overall [4]. However, electrical systems should deliver energy for other sectors and utilize their infrastructure, especially during off-peak times. That, as mentioned earlier, makes the electrical energy sector the best alternative for feeding the transportation sector. Greenhouse Gas (GHG) emissions and oil prices are the biggest reasons to electrify the transportation sector. According to the Oregon Department of Energy, oregonians drive over 60 billion kilometers per year, with more than 70% of these kilometers being driven in private cars [5]. Hence, electrifying private vehicles will be a cornerstone for energy switching. Electric vehicles are not a new invention; they go back to the 1830s when the first electric vehicle, with no rechargeable battery, was driven [6]. Electricity was one of the preferred methods for motor vehicle propulsion; however, electric vehicles have not achieved the vast success of Internal Combustion (IC) vehicles, which normally have much longer ranges and are easy to refuel. Lately, due to the environmental impact of petroleum-based vehicles along with the price of oil, EVs have received increased attention over the traditional IC-engine vehicles. Therefore, different types of EV have been developed in conjunction with the development of batteries, electronics, and control technologies.

2.4.1 Electric vehicle technology

In electric vehicles, the electrical energy that drives the motor is stored in a battery pack. By connecting the vehicle to a power source at a charging station, the batteries are charged. When braking, the electric motor operates like a generator and charges the batteries.

2.4.2 Electric vehicles types

Any vehicle that uses an electric motor for propulsion is referred to as a "electric vehicle" [6]. Electric vehicles include electric trains, electric boats, and electric automobiles. The

term "electric vehicle" will be used in this study to refer to only electric cars or automobiles that feature an electric motor and are powered entirely or partially by electricity. There are numerous varieties of electric vehicles; however, until recently, five of them have dominated research: Hybrid Electric Vehicles (HEVs), Fuel Cell Vehicles (FCVs), Plug-in Hybrid Electric Vehicles (PHEVs), Battery Electric Vehicles (BEVs), and Extended Range Electric Vehicles (EREVs). Because EV innovation has received greater attention recently, additional varieties other than these five are likely to emerge in the near future[7].

Hybrid electric vehicle

Hybrid Electric Vehicle refers to vehicles powered by a combination of an (IC) engine and an electric motor. With nearly half the fuel consumption of internal combustion vehicles, the HEV is more energy efficient. Furthermore, the regenerative braking system reduces CO₂ emissions significantly. With a large number of variations, the design could even have more than two power sources [6]. HEVs operate in the same way that internal combustion engines do, but with better fuel economy due to the electric motor. Figure 2.4 shows the HEV.

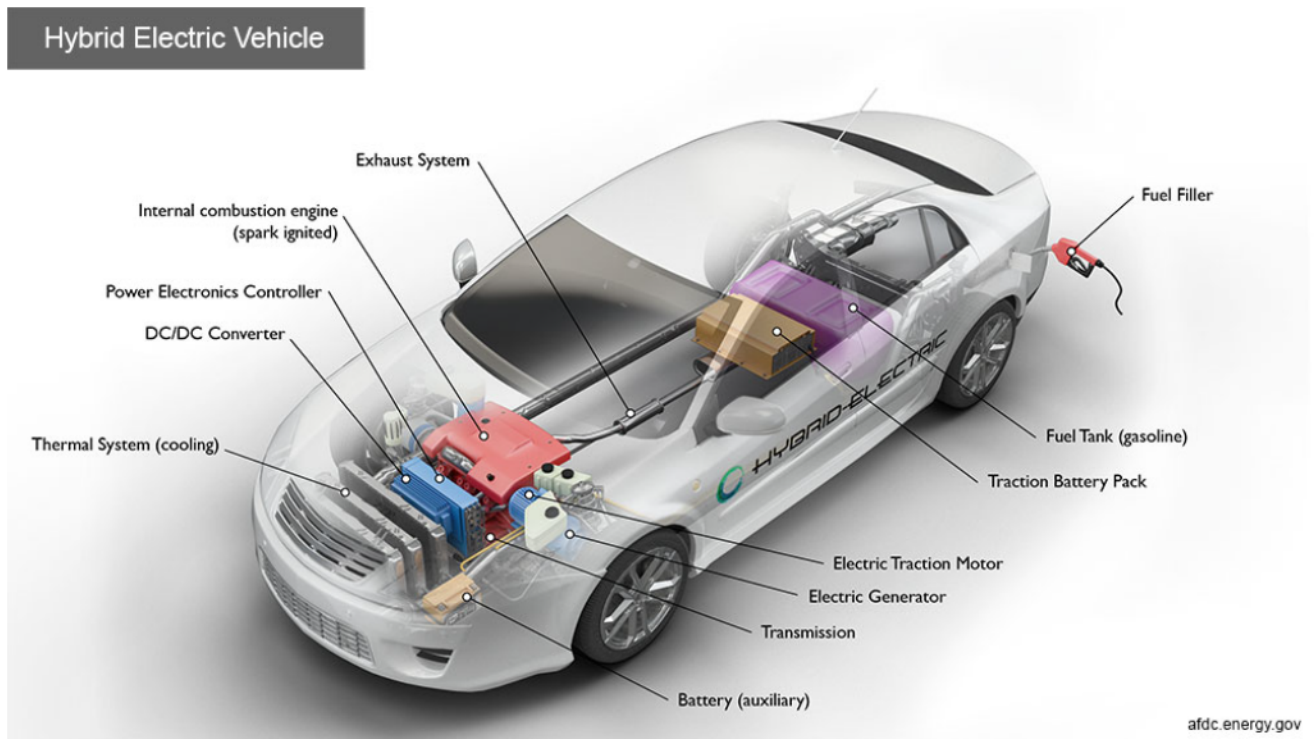


Figure 2.4: Hybrid electric vehicle [8].

Battery electric vehicle

Vehicles with electric motors that are powered solely by chemical energy stored in battery packs are known as battery electric vehicles. The basic concept of a BEV is that it is propelled by electric motors and controllers. The electric motor is powered by the energy stored in rechargeable batteries, and the controller regulates the vehicle's speed by controlling the power supplied to the motor. BEVs have a shorter driving range than conventional cars due to their complete reliance on a limited battery capacity. figure 2.5 present this type.

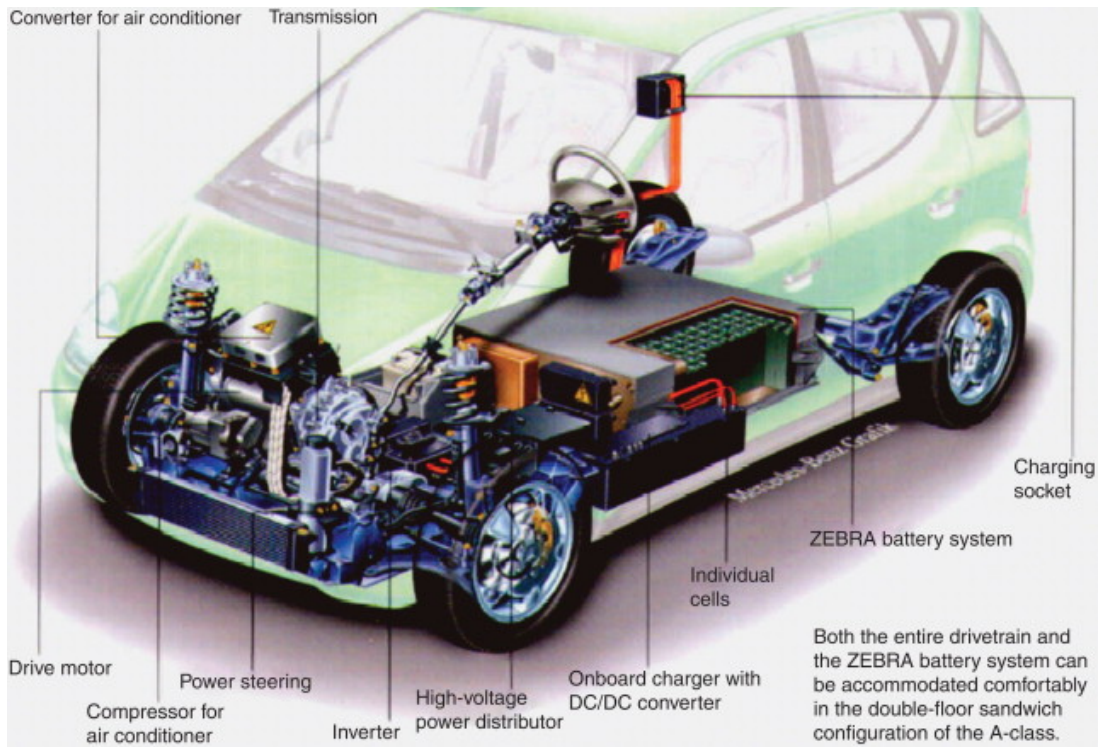


Figure 2.5: Battery electric vehicle [9].

Plug-in hybrid electric vehicle

Vehicles that use both gas and electricity are referred to as plug-in hybrid electric vehicles. PHEVs are a technology that sits somewhere between HEVs and BEVs. A plug-in hybrid electric vehicle is a type of HEV with larger batteries that can be charged directly from the electrical grid, allowing the vehicle to travel further. PHEVs have a high degree of energy resilience because they use two different power sources. figure 2.6 present PHEVs type.

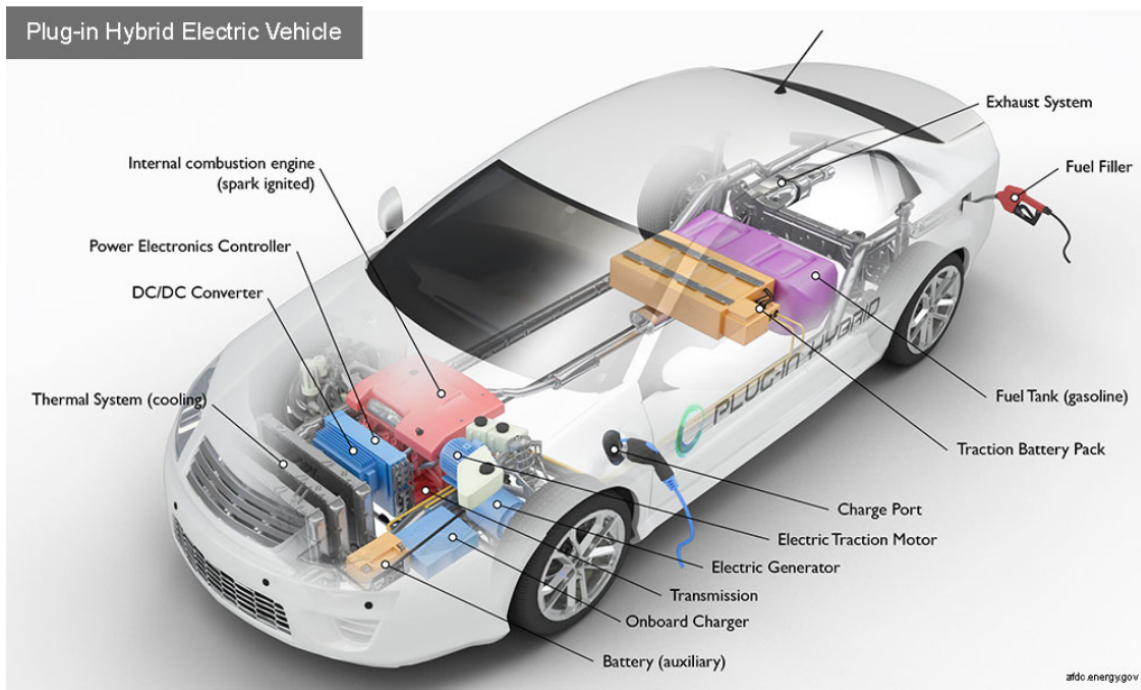


Figure 2.6: Plug-in hybrid electric vehicle [10].

Fuel cell vehicle

Vehicles powered by fuel cells are referred to as fuel cell vehicles. The basic principle of the FCV is similar to that of the BEV, but instead of batteries, the chemical driving force comes from combining a fuel, usually hydrogen, with oxygen. Hydrogen is most commonly derived from methane or other fossil fuels; however, hydrogen is classified as an energy carrier rather than a source of energy.

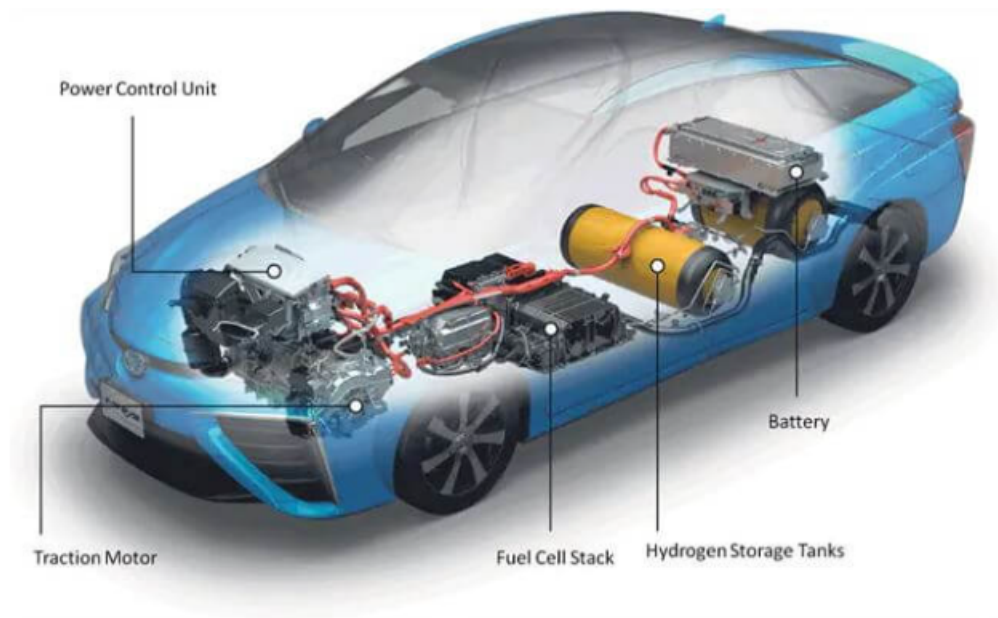


Figure 2.7: Fuel cell vehicle[11].

Extended range electric vehicle

Extended Range Electric Vehicles are vehicles that are powered by batteries and a small generator, similar to BEVs. To improve on the limited range of BEVs, the small onboard generator is used to recharge the batteries and extend the range of the vehicle. Various fuels, including gasoline, diesel, ethanol, and even fuel cells, can be used to power the generator [6].

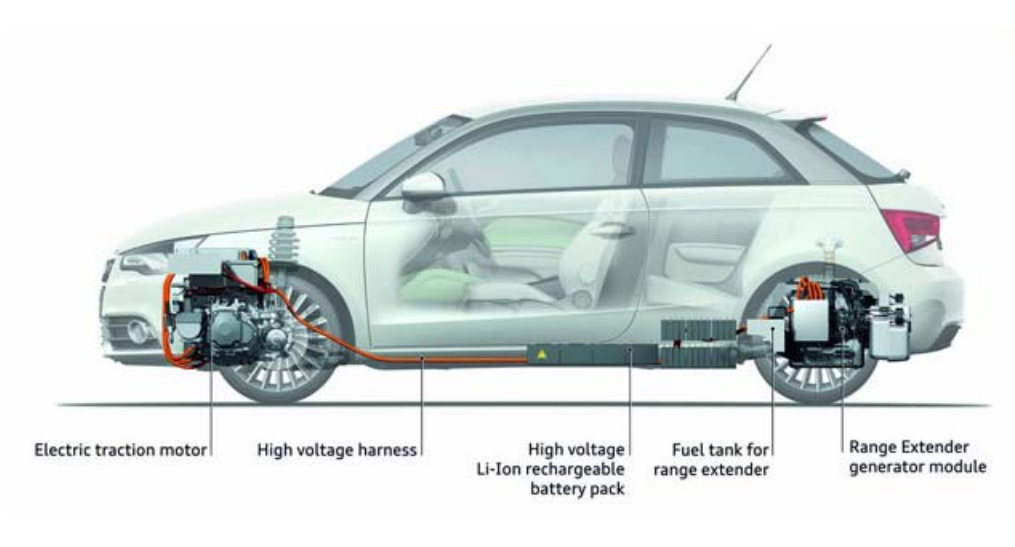


Figure 2.8: Extended range electric vehicle [12].

2.4.3 Difference between electric vehicles types

In brief, the system architecture of the four types of electric cars above can be seen in the following figure: 2.9

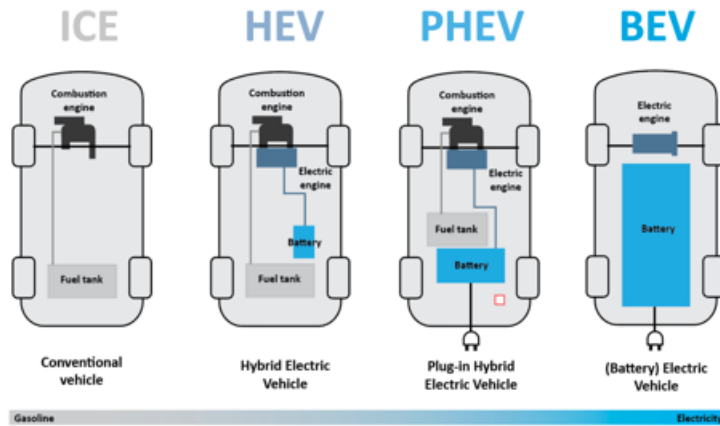


Figure 2.9: Deference between electric vehicles types [13].

2.4.4 Difference between gasoline and electric car

An electric car is powered by an electric motor. But, a gasoline car is powered by a petrol/diesel engine. Figure 2.10 presents the difference between electric cars and gasoline cars.

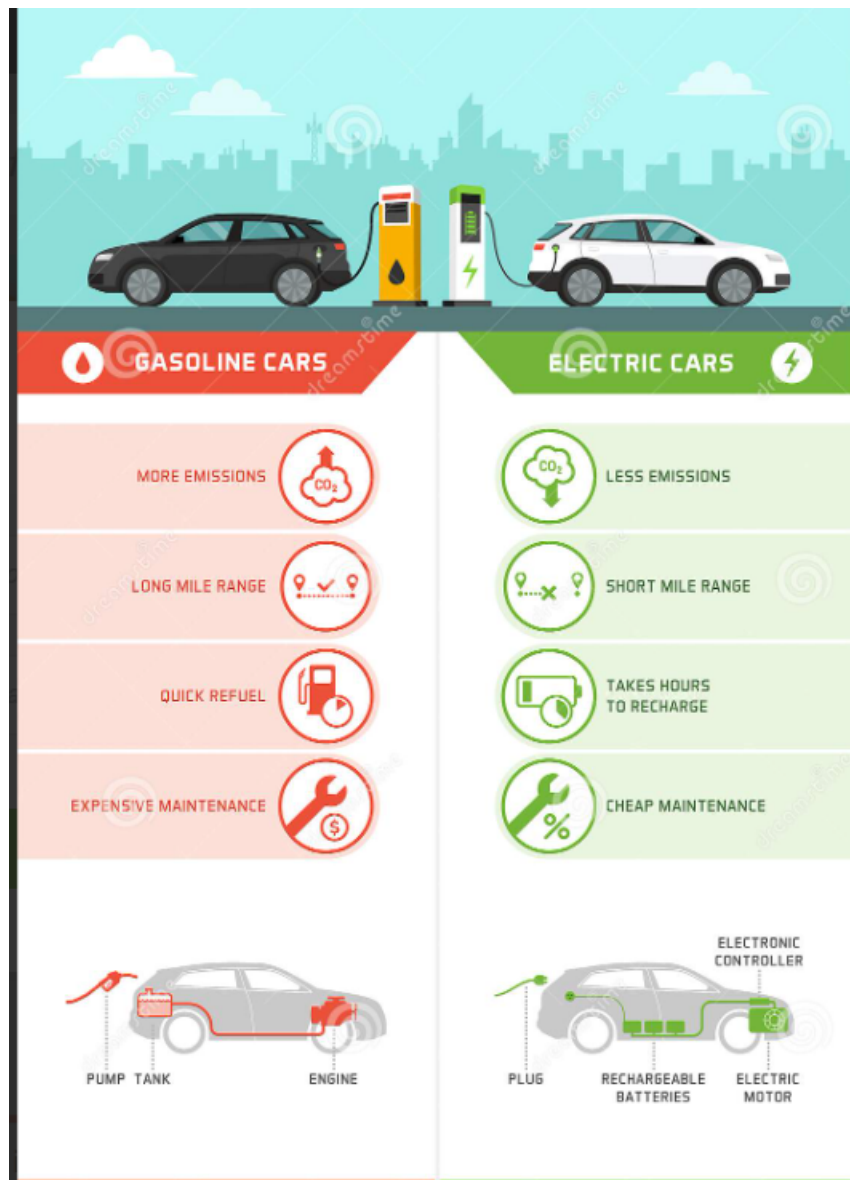


Figure 2.10: Main differences between gasoline vehicles and EVs [14].

2.5 Different charging points for electric cars

There are many places where you can load your car. we start by presenting :

2.5.1 Home charging stations

Figure 2.11 present the photoelectric effect refers to the creation of an electrical charge as a result of the absorption of light energy by a substance known as a semiconductor. The most popular semiconductor used by producers of Photovoltaics (PV) cells is silicon.

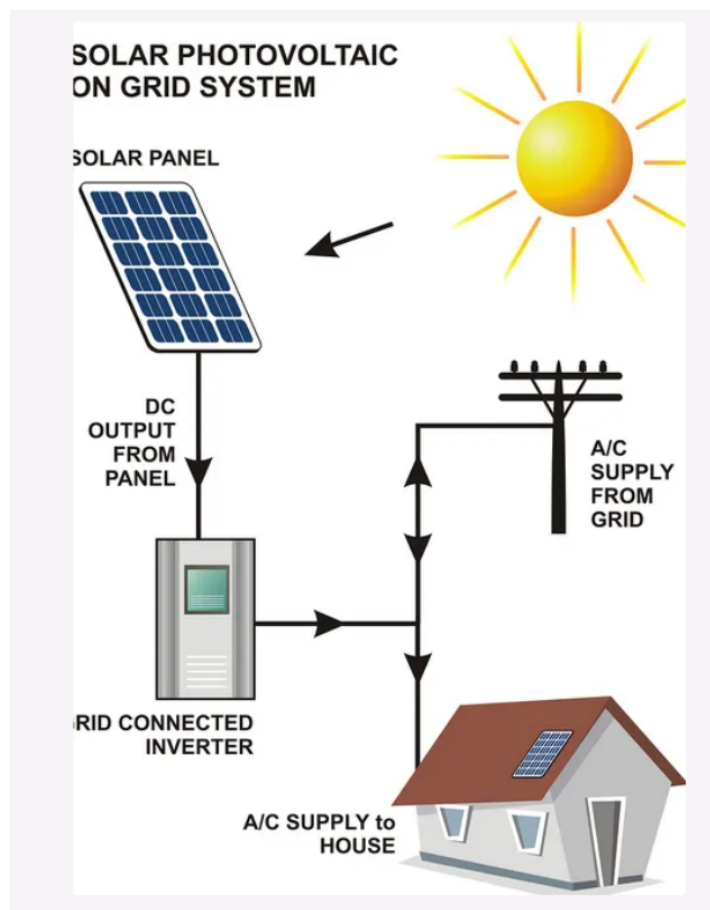


Figure 2.11: Sources of electrical loads.

A PV system that is connected to the electricity grid is referred to as such. The grid

receives the electricity that the PV system "exports" to it. The main benefit of using a grid-connected PV system is that it can be used to "store" electricity and then "re-purchase" it from the grid. When a payment is available for the electricity being exported to the grid, it makes sense to use a grid-tied system of this kind to reduce the cost of repurchasing electricity exported to the grid. Since physical storage systems (batteries) are not required for grid-connected PV systems, the investment cost is lower. An inverter receives power from the PV modules in a typical grid-connected PV system. The inverter transforms the DC electricity generated by the PV system into AC electricity for transmission to the power grid. The inverter is typically wired directly to the incoming grid cables from the grid or to the main circuit breaker or fuse box. Electricity from the grid is used if the PV system is not supplying enough electricity to power the loads in the building (for instance, at night, when there is no solar energy available). When the PV system's output of electricity exceeds the building's load requirements, the excess energy can be exported to the grid. In cases where there is a payment available for exporting electricity, this is an attractive option. Obviously it depends on the level of payment being offered[15].

2.5.2 Charging stations in public spaces

All charging stations are installed on roads and public sites. If they are still few in number, they are developing more and more, and see installations or renovations of car parks in urban areas, in shopping centers and supermarkets, on motorway areas. But often, it is necessary to have an access card to take advantage of it. also A large majority of terminals are in public car parks as show in the figure 2.12.



Figure 2.12: Charging stations [15].

2.6 AC-DC definition

2.6.1 Alternating current

AC stands for alternating current, which is a flow of electric charge that alternates on a regular basis. It begins at zero, increases to a maximum, declines to zero, reverses, reaches a maximum in the other direction, returns to the initial number, and so on. The period is the time interval between the achievement of a specific value on two consecutive cycles, the frequency is the number of cycles or periods per second, and the amplitude of the alternating current is the highest value in either direction [16].

2.6.2 Direct current

DC stands for direct current, which is an electric charge flow that does not change direction. Batteries, fuel cells, rectifiers, and generators with commutators all create direct

current. Because it was uneconomical to adapt direct current to the high voltages required for long-distance transmission in the late 1880s, it was replaced by alternating current (AC) [16].

2.7 Electric car cost

Once the vehicle has been purchased, the daily expenses will be linked to the purchase of the energy needed to run it. In the case of a thermal vehicle, going to the pump to refuel with fossil fuel. In the case of the electric car, the connection to the electrical network of the house, to a wallbox or a reinforced socket, or to a public charging station . Let's assume an average annual mileage of 20,000 kilometres. With the thermal vehicle, it will be necessary to count on a fuel envelope of around 2,500 € per year (for a full tank of unleaded 95 € to 50 € for 400 kilometres). With an electric car, the price of a full electricis on average 2 € for 100 kilometers using a home charging system. That is around 400 € for 20,000 kilometres, that is to say 2,100 € less than the thermal vehicle per year at annual iso-mileage. If you charge your car at home, you can also opt for electricity contracts suitable for charging electric cars, alternating between peak hours and off-peak hours, which will allow you to top up at the best time for your budget. Admittedly, the annual price of electric charging will increase if the user often resorts to public charging (generally more expensive than the home network) or fast charging (whose service is charged at a high price due to high technology used). But for most current customers (charging their vehicle almost all the time at home), the energy cost advantage is significant [17].

2.8 Conclusion

Electrical vehicles first appeared in the late 19th century, when electricity was one of the preferred methods for motor vehicle propulsion, however, there are many different engine types and sources of energy in the world, so the new generation of cars required different

charging stations as well as various types of EV chargers.

The process of creating an EV charger will be covered in more detail in the following chapter.

Chapter 3

Proposed Solution

The technical study of a project is a design expertise and represents a preliminary study for the realization of a prototype meeting the expectations defined for its realization. It mainly consists in presenting the information and the technical characteristics of the prototype.

3.1 Block diagram

Figure 3.1 shows the block diagram of our system .

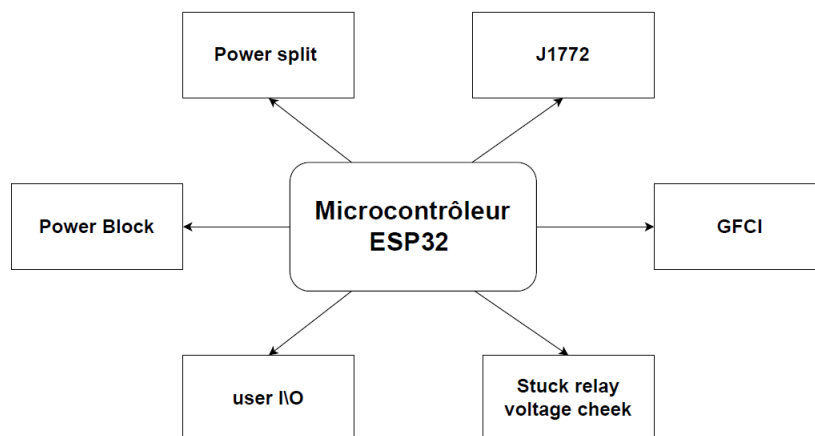


Figure 3.1: Block diagram.

3.2 Types of charge

3.2.1 Level 1 charging: slowest AC charging method.

All EVs are equipped with a Level 1 on-board AC/DC charger that simply plugs into a standard power outlet (CSA 5-20R (20A bypass)) outlet is required if it is dedicated to EV charging). Level 1 charging does not require a charging station per se. It requires a Level 1 charging cable (CSA 5-15R) [18].

3.2.2 Level 2 charging: faster AC charging method than level 1

This level is also based on the use of the AC/DC charger on board the EV, but designed for higher powers. higher power ratings. Tesla and Renault, for example, offer on-board chargers from 10 to 20 kW and 22 to 43 kW, respectively. It should be noted that the charging time does not only depend on the characteristics of the of the charger but also on the power of the charging station . Level 2 charging requires a fixed charging station powered by a separate 208 or 240 V branch circuit. 208 or 240 V branch circuit. All electric vehicles sold in North America include an SAE J1777 charging pad. All electric vehicles sold in North America incorporate an SAE J1772 charging cradle, with the exception of Tesla vehicles, which require an adapter [18].

3.2.3 Level 3 charging : DC fast charging with an external charger to the EV

The main differences between DC charging and AC charging are the use of a charger in the charging station instead of the inverter on board the EV and the and the higher charging power. The charging station passes a direct current directly to the vehicle's battery and must therefore adapt the battery and must therefore adapt the voltage and intensity of the charging current to the characteristics of the EV. DC fast charging is governed by the North American SAE J1772 "Combo" and Japanese JEVS G105-1993 standards. DC fast-charging stations are usually compatible with both standards. DC fast-charging stations

are usually compatible with these two standards. All car manufacturers adhere to one of these All car manufacturers adhere to one of these standards, with the exception of Tesla, which has developed a more powerful All car manufacturers adhere to one of these standards, except Tesla, which has developed a more capable charging station, but offers CHAdeMO adapters on request [18].

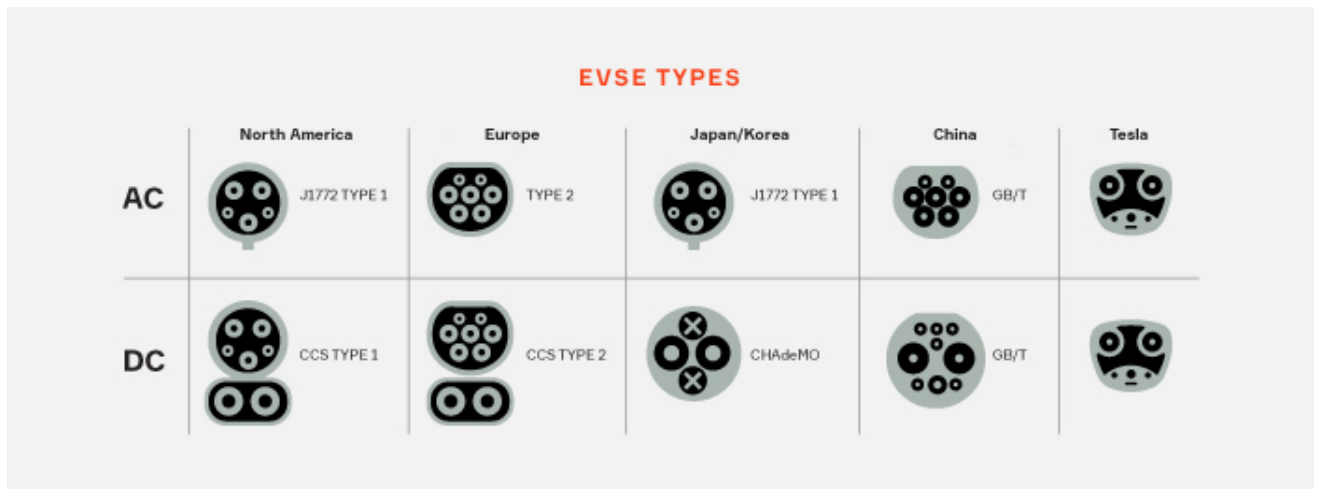


Figure 3.2: Types of evse.

3.2.4 Comparison of EV Charging Levels

The upgraded SAE J1772-v6 coupler contains variants that integrate AC and DC charging functionalities in one coupler, similar to the original SAE J1772-v0 charging standard from the early 1990s. This enables automobiles to have just one AC and DC charging inlet instead of two. The J1772 Combination Charging System (CCS) specifies three current levels: Level 1 DC (up to 80A/500Vdc), Level 2 DC (up to 200A/500Vdc), and Level 3 DC (up to 400A/500Vdc) [19]. Figure 3.3 depicts a comparison of different charging levels and their potential use as part of the EV charging infrastructure.







Charging Level	Setting	Supply Power	Representative Example
 AC Level 1	Residential/ Parking Lot 5 mi/hour @ 1.7 kW	120vac/20A (16A continuous)	
 AC Level 2 (minimum) AC Level 2 (maximum)	Residential/ Commercial 10 mi/hour @ 3.4 kW	208/240vac/20A (16A continuous)	
	Commercial (up to) 60 mi/hour @ 19.2 kW	208/240vac/100A (80A continuous)	
 DC Level 1 DC Level 2	Commercial up to 500v @ 80A dc (up to) 120 mi/hour @ 40 kW	208vac/480vac 3-phase (input current proportional to output power; ~20A-200A AC)	
	Commercial up to 500v @ 200A dc (up to) 300 mi/hour @ 100 kW	208vac/480vac 3-phase (input current proportional to output power; ~20A-400A AC)	

Figure 3.3: Comparison of EV charging levels.

3.3 System concept

Figure 3.5 illustrates the concept behind the complete system in terms of regulated charging for electric cars in areas with inadequate electrical infrastructure. Figure 3.4 illustrates the charge controller's fundamental architecture. Whenever the charge control pilot is intercepted, the module creates a new signal that complies with the J1772 protocol criteria. The J1772 protocol operates at a nominal frequency of 1 kHz using a changing voltage level signal. Without a linked car, the signal is a steady +12V DC signal. When a car is attached, this signal is routed via a sequence of latched resistors that are based on the vehicle's EV status. When the EV is connected but not ready to charge, the control pilot detects a 2.74 k resistance. This reduces the voltage to +9V DC and begins a Puls Width Modulation (PWM) signal through an opt isolator and microcontroller. This informs the module that the EV is attached but not ready to charge. When the car is ready to charge, a 1.3 k resistor is connected in parallel with the 2.74 k, resulting in an overall resistance of 882 and a voltage drop to +6V DC, triggering the controller to transmit power to the vehicle for charging. With the vehicle currently charging, the control pilot's PWM duty

may be changed to adjust the charging rate in accordance with Equation 1. This control allows for the downgrading of a Level 2 charger (duty cycle range of 10% to 50% for 6 to 30 A) to a Level 1 charger (duty cycle range 10-26 percent for 6 to 16A). Level 2 charging can be upgraded to 50A if the charger and car allow a greater current than 30A. This enables the gadget to be charged at both Level 1 and Level 2 [20].

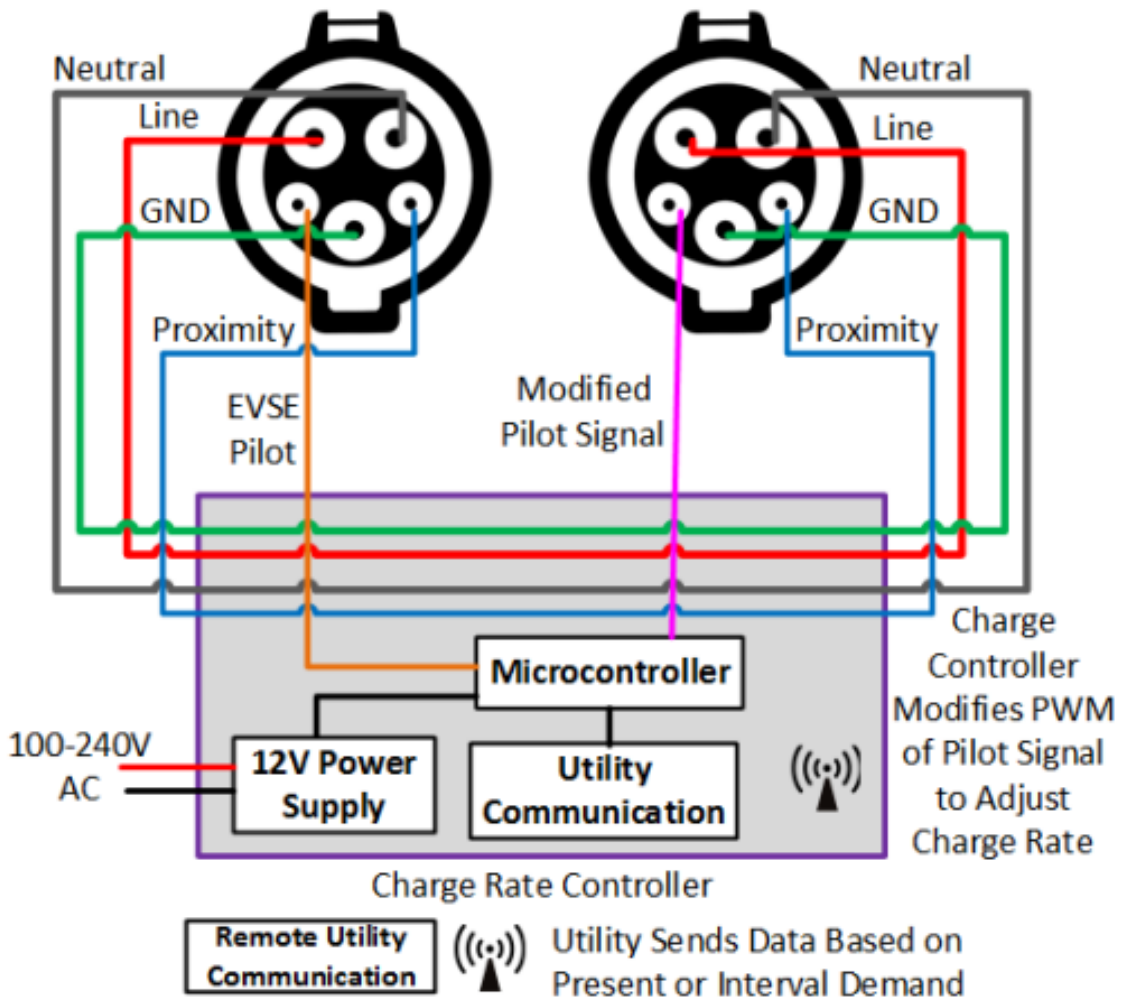


Figure 3.4: System concept2.

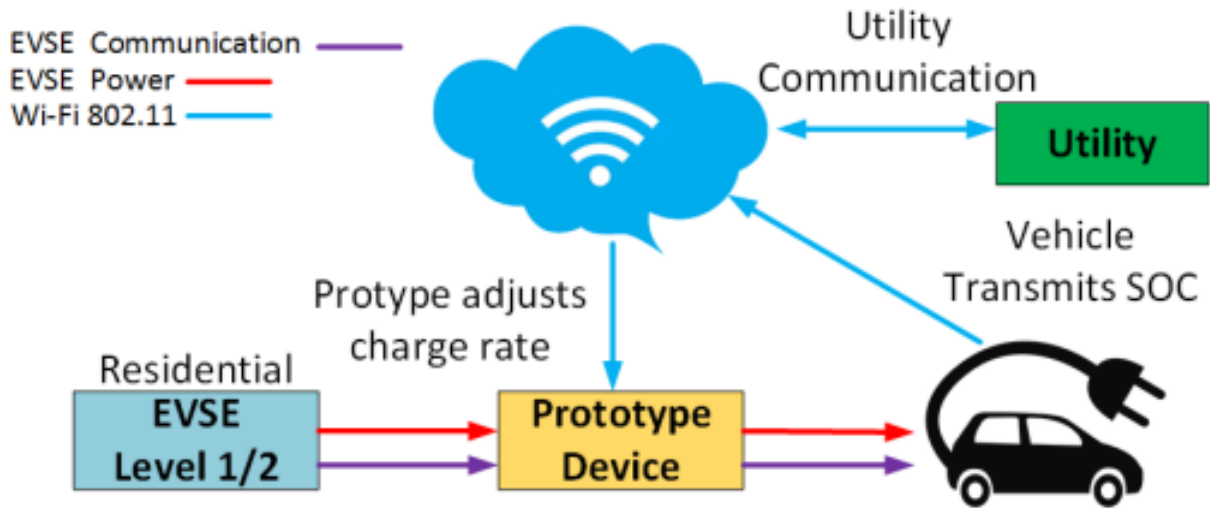


Figure 3.5: System concept.

3.4 Power split

Power conversion is the process of changing the form of electric energy in all branches of electrical engineering. An electrical or electromechanical device for converting electrical energy is called a power converter. A power converter can change the voltage or frequency of the current, convert AC into DC, or do any combination of these things. A power converter could be as straightforward as a transformer or incredibly complex, like a resonant converter. The phrase can also be used to describe a group of electrical devices that change the frequency of an alternating current. Voltage regulation and redundant components are frequently used in power conversion systems.

3.4.1 TDK-LAMBDA

TDK-Lambda offers a broad range of standard power supplies for many applications.



Figure 3.6: kmd15-1212.

The KM series was designed especially for applications in medicine and industry. Due to their robust, yet light and compact design, these enclosed power supplies resist dust and moisture. The KMD series is available with 15W and 40W power and has dual output. It covers the most common voltages. The protection class II construction with double insulation can be operated without earthing connection (protective conductor).

3.5 Microcontroller selection

The ESP32 is a low-cost, low-power system-on-microcontroller, with integrated Wi-Fi and dualmode Bluetooth and low power support, all in a single chip. This board is selected because it reduces the cost of the monitoring system and specially for its high processing performances. ESP32 board is based on Tensilica 32-bit dual-core CPU Xtensa, LX6 Microcontroller [21]. One of its most significant features is that it can be programmed using a variety of open-source platforms and languages. In this project, the Arduino IDE was used to develop the code that was uploaded then directly to the board. Fig 3.7 shows

the ESP32 DEVKITC board used in this project [21].

ESP32 Wroom DevKit Full Pinout

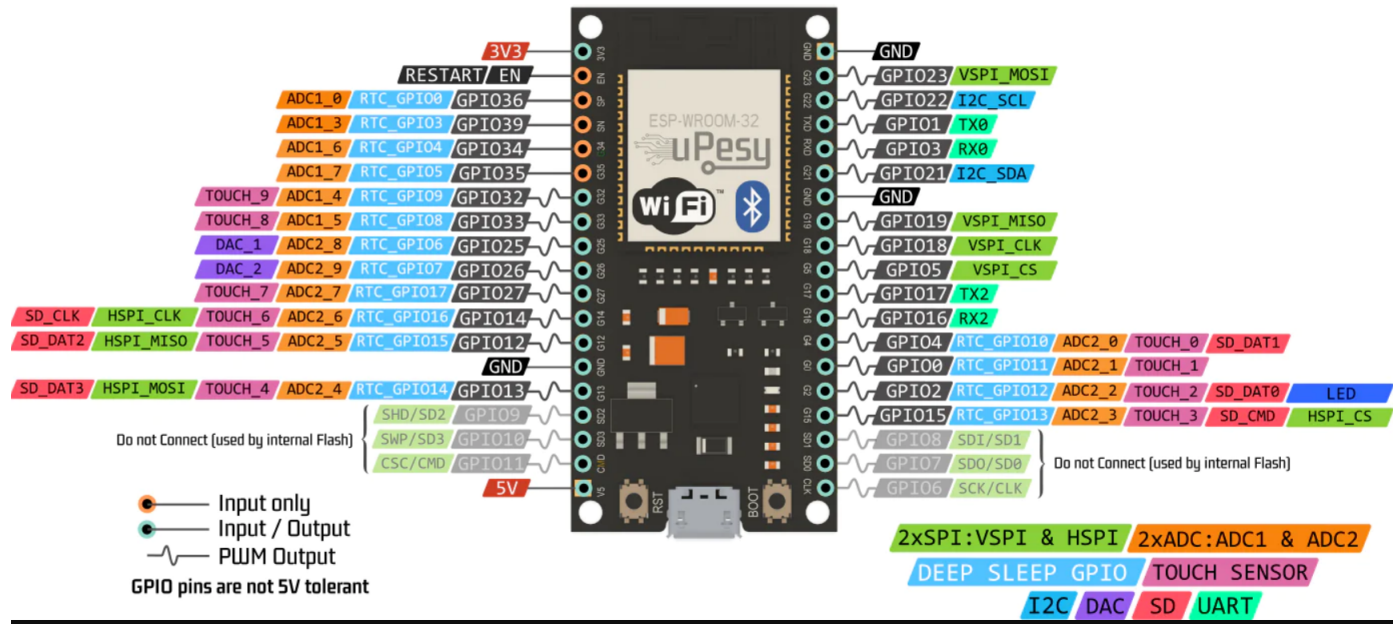


Figure 3.7: Microcontroller esp32.

Contrary to the ESP32, many Linux based boards like Raspberry Pi, Beaglebone, etc. supports Operating Systems (OS),but require an external ADC devices to read analog measurements and also have a higher cost and more energy consumption. Moreover, the ESP32 provides the benefits of low-cost boards such as Arduino that require extra shields to connect to Wi-Fi. Furthermore ,ESP32 supports Real-Time Operating Systems (RTOS) like freeRTOS, making it operate optimally the tasks required, it integrates 16 ADC channels of 12 bits and in-built Wi-Fi and other features as shown in table 3.1 [21].

Table 3.1: ESP32 specifications.

Feature	Value
Operating voltage	3.3V
Input voltage	5-12V
Digital I/O pins (GPIO)	39
Analog input pins (ADC)	16
Analog outputs pins (DAC)	2
UART	3
SPI	2
I2C	2
Flash memory	4MB
SRAM	520 KB
Clock speed	240MHz
Wi-Fi	802.11 b/g/n

3.6 Battery model

It is feasible to quantify the stresses on the vehicle and, as a result, on the drivetrain using the vehicle model. The battery is attached to the drivetrain and provides the vehicle with electrical power. As a result, it's vital to show the battery's electrical properties. A battery's performance is influenced by a variety of factors, including capacity, State of Charge (SoC), temperature, health, and age. As a result, a wide range of models exist, each with differing degrees of complexity and each aimed at a certain goal. Electrochemical models, electrical models, and mathematical models are among the models available. Electrochemical models are used to link the underlying mechanics of porous electrodes and concentrated solutions to the battery's electrical behavior. Electrochemical models are exceedingly complicated and computationally costly due to the nature of this association. Mathematical models may be used to show how a system works, but they are not practical. Instead, electrical models depict batteries in combination with other systems using analogous electrical circuits based on resistors and capacitors. Electrical models have a number of advantages, including their minimal complexity and ease of use in circuit simulators. They are often utilized in the estimate of SoCs. An electrical model is utilized to analyze the efficacy of the wireless power transfer (WPT) system using the

SoC. Extensions for input parameters are very simple to build. The open circuit voltage, internal resistances and capacitance of the battery are dependent on the SoC of the battery, which is an essential element of the battery model. The electric equivalent battery model utilized is shown in Figure 3. It's a hybrid of a Thevenin-based and a runtime-based approach. In compared to the simplest equivalent battery model, which uses just a single resistor and capacitor, the model uses two resistor-capacitor pairs, which increases accuracy while keeping the model simple. It is also feasible to investigate the transitory reaction in this manner [22].

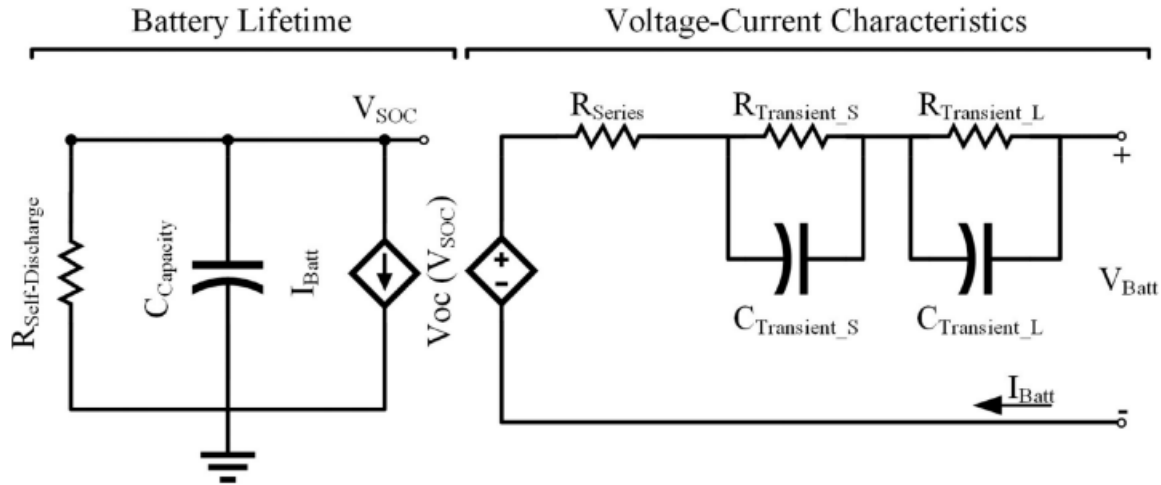


Figure 3.8: Batteries equivalent electric model[22].

3.7 System design

3.7.1 Pilot signal interface

The pilot signal is the primary method that a J1772 compliant EVSE uses to communicate with a vehicle. The pilot signal is based on a 1 kHz, $\pm 12 V$ PWM signal that is transmitted to a vehicle through the charge cord. The vehicle can then respond by placing various loads on the line, affecting the voltage.

3.7.2 Pilot signal states

The EVSE connection and negotiation occurs through several states of the PWM signal and load resistances of the vehicle. Table 3.2 shows the states of the PWM.

PWM

Pulse-width modulation, or pulse-duration modulation (PDM) is a technique for decreasing the average power produced by an electrical signal by breaking it down into discrete components. By rapidly flipping the switch between supply and load on and off, the average value of voltage (and current) provided to the load can be regulated. The higher the overall power supplied to the load, the longer the switch is on relative to the off times. It is one of the principal methods of decreasing the output of solar panels to that which can be used by a battery, along with maximum power point tracking (MPPT). PWM is especially well suited for running inertial loads like motors, which are less affected by discrete switching due to their inertia. The PWM switching frequency must be high enough to avoid affecting the load, which means the waveform seen by the load must be as smooth as possible. Depending on the load and application, the rate (or frequency) at which the power supply must switch can vary substantially. An electric stove, for example, must switch several times per minute; a lamp dimmer must switch at 100 or 120 Hz (double the utility frequency); a motor drive must switch between a few kilohertz (kHz) and tens of kHz; and audio amplifiers and computer power supplies must switch at tens or hundreds of kHz. The key benefit of PWM is that it has a very low power loss in the switching devices. There is nearly no current when a switch is turned off, and there is almost no voltage drop across the switch when it is turned on and power is transmitted to the load. Because power loss is the product of voltage and current, it is near to zero in both circumstances. PWM also works well with digital controls, which can quickly establish the required duty cycle due to their on/off nature. PWM has also been utilized in communication systems, where the duty cycle is employed to transmit data over a communications channel [23].

When an EVSE is turned on, it runs a series of self-tests before entering State A.

Table 3.2: States of the PWM.

STATE	HIGH V	low V	FREQUENCY	RESISTANCE	DESCRIPTION
State A	12V	N/A	DC	N/A	not connected
State B	9V	-12V	1KHZ	2.74	EV connected ready to charge
State C	6V	-12V	1KHZ	0.882	EV charging
State D	3V	-12 V	1KHZ	0.246	EV charging ventilation required

When the EVSE is ready, the connection process is completed in a few stages.

1. The EVSE connects the pilot wire to a 12 V supply. When the plug is plugged in, this transmission alerts the vehicle.
2. When the plug is attached, the car places a 2.74-k load on the pilot line (this drops the voltage to 9 V).
3. The EVSE switches to State B, allowing the PWM to tell the vehicle how much current it may consume. The EVSE closes the relays, allowing the car to receive power.
4. the vehicle draws power and switches to the 822 Ω load, dropping the voltage to 6 V and signaling the EVSE that charging has begun.
5. The charging process ends when the cable is unplugged, returning the voltage to 12 V (most vehicles continue to pull low amounts of power in State C even when fully charged). The EVSE measures this process and closes the relays and returns to State A .

3.7.3 Pilot signal circuit

The pilot signal must traverse several meters of cable and overcome a load resistance. The pilot signal is a bipolar $\pm 12V$ signal that necessitates extra attention. Choose an amplifier with a wide input range and a decent power output to accommodate these specifications. The OPA171 is suited for this application because it has a voltage rating of 18 V and a current rating of 475 mA. Most EVSEs do not require automotive certification, however if this feature is necessary, a Q1-rated form of the OPA171 is available. The amplification circuit is a simple OPA171 device rail-to-rail output setup, with the MCU I/O driving the positive input. The pilot amplifier's output is also routed into a simple voltage divider, allowing the MCU to measure the voltage during operation and detect the vehicle's load

resistance. This subsystem's schematic is shown in Figure 3.9.

Pilot in 12 V

$$R_{36} = 910 \quad \Omega$$

$$R_{50} = 1000 \quad k\Omega$$

$$R_{41} = 300 \quad k\Omega$$

$$R_{57} = 82 \quad k\Omega$$

$$R_{50-57} = \frac{R_{57}}{R_{50}} = \frac{82 \times 100}{82 + 100} = \frac{8200}{182} = 45,055K\Omega$$

$$pilot-in(+12V) = \frac{R_{50-57}}{R_{50-57} + (R_{36} + R_{41})} \times 12 = \frac{45.055K}{45.055 + 300 + 0.910} \times 12 = \frac{45.055}{345,965} \times 12 = 1.563V$$

$$pilot - in(-12V) = -1,563V$$

Pilot in 3V3

$$pilot - in(3V3) = 3,3 \times \frac{R_{(36+41)} \times R_{50}}{R_{(36+41)} + R_{50}} \times \frac{1}{\frac{R_{(36+41)} \times R_{50}}{R_{(36+41)} + R_{50}} + R_{57}}$$

$$pilot - in(3V3) = 3,3 \times \frac{300,91 \times 100000}{300,910 + 100000} \times \frac{1}{\frac{300,910 \times 100000}{300,91 + 100000} + 82000}$$

$$pilot - in(3V3) = 3,3 \times \frac{75056,7}{75056,7 + 82000} = \frac{247687,26}{157056,7} = 1.577V$$

$$pilot \text{ in on} = 1,563 + 1,577 = 3,14 \text{ V}$$

$$pilot \text{ in off} = 1,577 - 1,563 = 0,014 \text{ V}$$

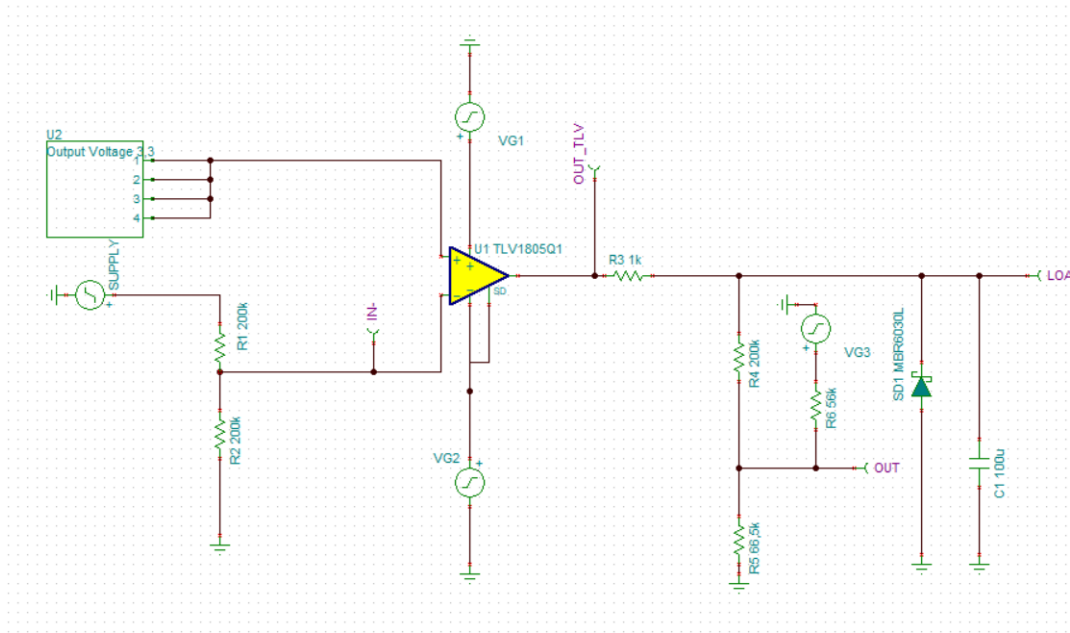


Figure 3.9: Signal generation.

3.8 GFCI fault detection and test

Ground-fault circuit interrupters (GFCI) are designed to detect and clear ground-fault leakage current, providing employees with shock safety. When an accidental electric current travels through a person and into the ground, an electric shock occurs. An electric shock can cause death (electrocution) depending on the quantity of current, duration, and passage through the body. GFCIs must be sensitive enough to detect a little quantity of leakage current because the human body can only withstand a few milliamperes of electric current [24]. A GFCI's trip threshold is governed by its class. GFCI Classes A, B, and C (also known as special-purpose GFCIs, or SPGFCIs) are meant to detect leakage currents of 6 mA and higher, whereas GFCI Classes C, D, and E (also known as SPGFCIs) are designed to interrupt power when the leakage current detected is 20 mA [25] Class C GFCIs may have trip thresholds more than 6 mA but less than 15 mA to provide limited let-go protection [26].

A critical element of any electrical system that is to be used in potentially adverse

environments is a ground-fault circuit interrupter (GFCI) subsystem. Because the typical areas to use an EVSE are garages or outdoor environments, the potential for electric shock as a result of water ingress is present. A GFCI detects unbalanced current through the primary conductors. If the current through these primary conductors is not balanced, then it must be flowing somewhere else, which indicates a fault somewhere else. The whole system must respond immediately by cutting power to the load.

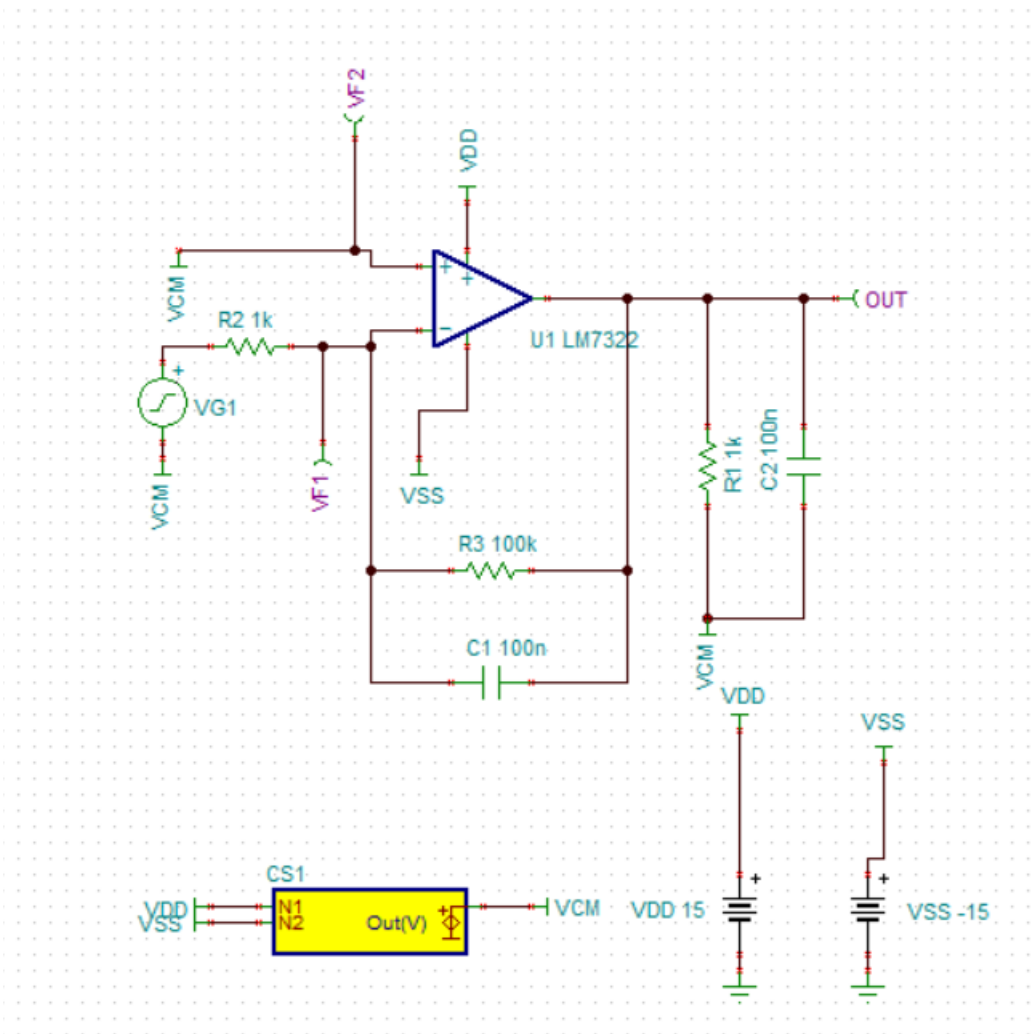


Figure 3.10: GFCI Detection.

3.8.1 High ratio wire lead transformers

CR Magnetics CR8400 Series of Wire Lead Current Transformers are available in a wide range of sizes and materials to meet any AC current sensing needs. Our General Purpose designs are made from the highest quality silicon steel cores available, and meet most of the common AC current measurement needs. Our Revenue Grade (-N) are made from a nickel alloy core which provides the most linear response over temperature and current level. A line of Ground Fault (-G) are for measuring low AC currents including electrical shields. Nanocrystalline (-A) is the most versatile providing accuracy, high saturation point and a linear response in high frequency applications. The High Frequency (-F) products are designed for high frequency applications such as high frequency power supplies and motor drives.

CR8400 SERIES



Figure 3.11: CR8400.

Applications:

Motor Load Measurement

Power Meters

High Frequency Current Sensing

Ground Fault Sensing

Features

High Ratio

Standard Footprints

Specifications

Maximum Continuous Primary Current $4 \times I_r$

Insulation Voltage 3500 Vac/1min

Storage Temp. $-45^{\circ}C$ thru $+85^{\circ}C$

Operating Temp. General Purpose & Nickel $-40^{\circ}C$ thru $+85^{\circ}C$.

Operating Temp. High Frequency $-45^{\circ}C$ thru $+85^{\circ}C$. [27]

3.9 Simulator

Figure 3.12 represents the real circuit of our system's simulation.

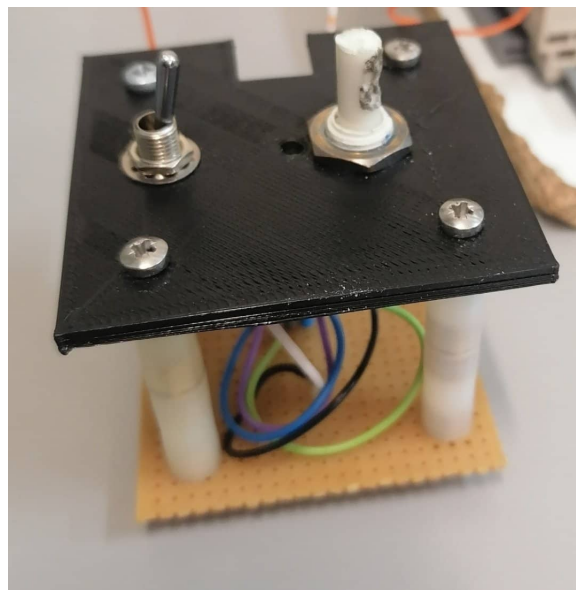


Figure 3.12: Simulator.

Simulator circuit

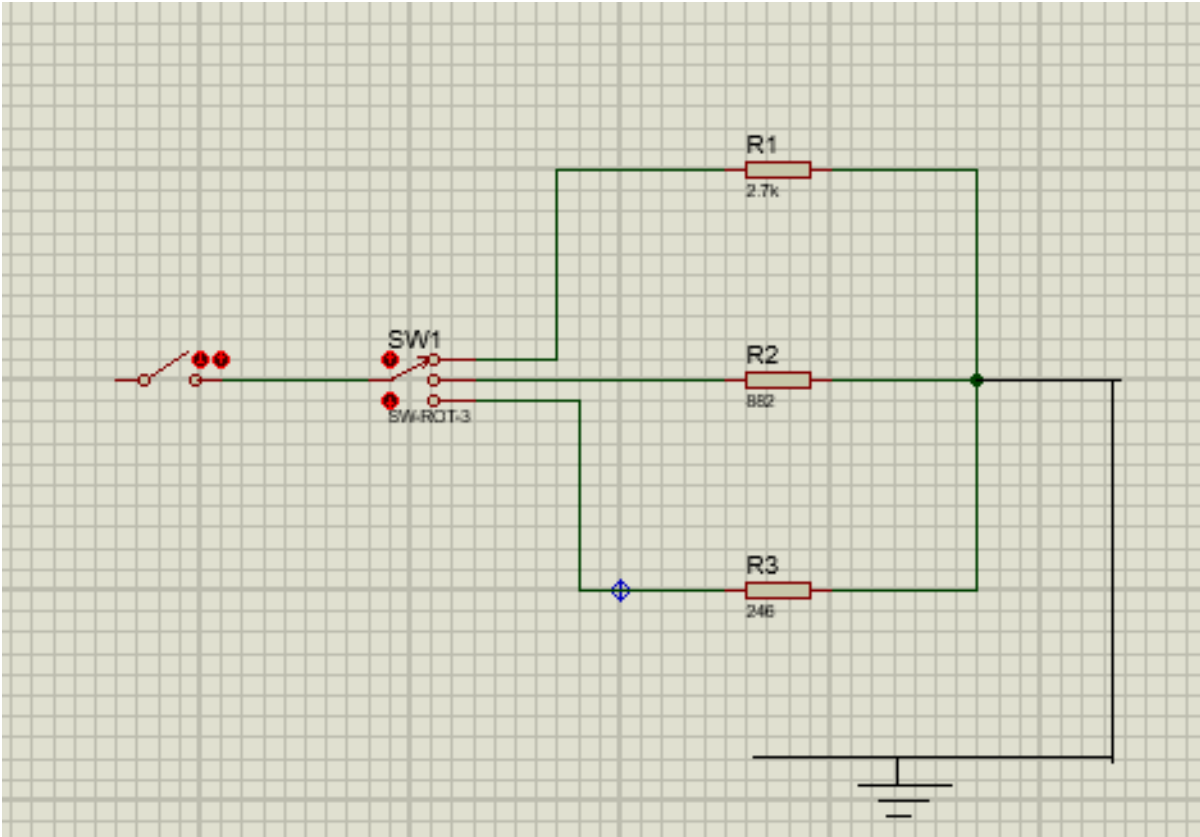


Figure 3.13: Cuircuit simulator.

Table 3.3: Position of simulator

	SW	SW-R1	SW-R2	SW-R3
State A	Active			
State B		Active		
State C			Active	
State D				Active

TO Explain the simulator works we start by the first state, we must close the first switch, and to switch from one state to another, we must move from position 1 to position 2 to position 3.

3.10 Conclusion

The methods presented in this chapter are the most commonly used in our system; as a result, we have ensured a well-defined type of charger, system conception, and GFCI fault detection methods, as well as paying attention to the charger's security level to protect the vehicle from danger risks.

Chapter 4

Results

This chapter presents the tests performed with the selected hardware and software components, the results obtained during the charging of the project , Figure 4.1 shows a test setup photo of the final system.

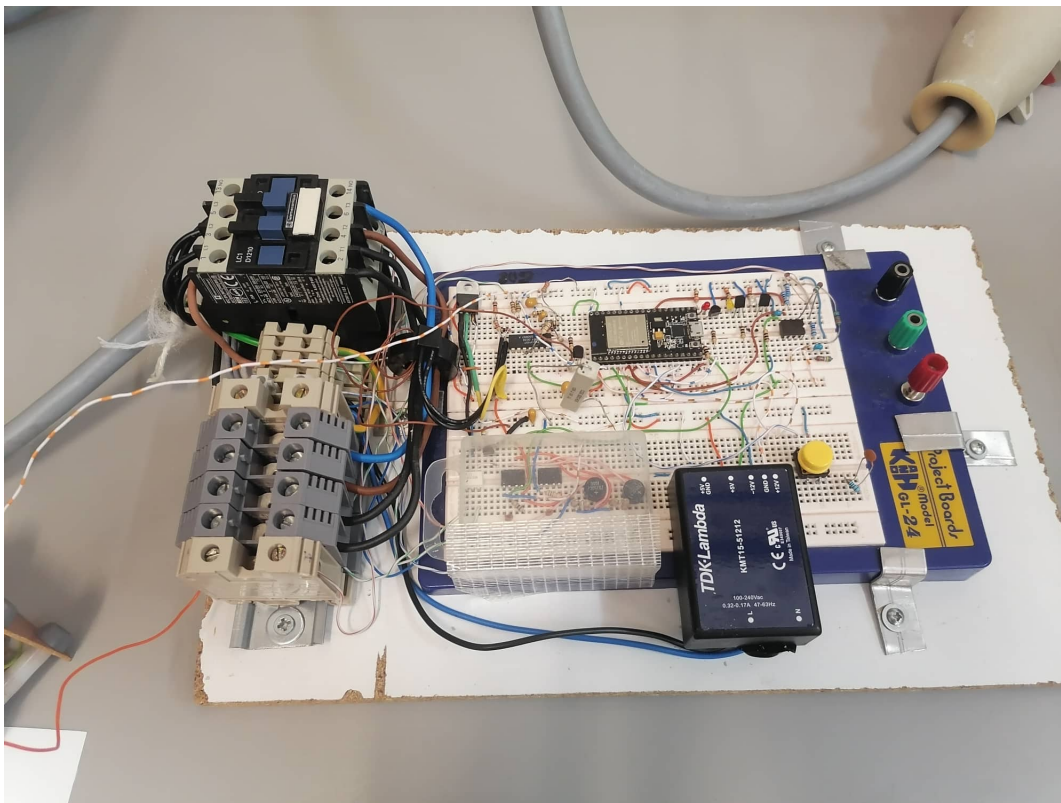


Figure 4.1: System as tested.

4.1 Application state machine

The different states of the J1772 pilot signal protocol are mainly transitioned between them as part of the basic functionality of the EVSE. The simplest way to allow this movement is to use the simple state machine that has been built into the foreground of the energy library. The base of the state machine is a function of the application layer of the energy library. Figure 4.2 shows the basic design of the state machine used.

The following list describes the state machine process implemented

- **Step 1** : Start - The entry point of the state machine. Any additional initialization can be placed here.
- **Step 2** : GFCI check.
- **Step 3** : GFCI Expected - Verify here that the GFCI test has been correctly detected. Trigger a GFCI check fault and go to the fault state if necessary. If the test is successful, change to the GFCI Passed state
- **Step 4** : GFCI Passed - The Passed state is a near-empty state to facilitate any additional functionality that may be required prior to initiating J1772 signalling.
- **Step 5** : State A - To start signalling, the pilot line is brought to the high state at the start of State A. The only possible output from here is state B. The only possible output is state B, when the voltage drop on the pilot line has been signalled. If a different voltage has been detected, this state can change to the fault state with a condition J1772. with a condition J1772.
- **Step 6** : State B - State B activates the PWM output on the pilot line. From here, the only possible output is State C, indicating that the vehicle has switched to resistance to signal that it is ready to accept the charging voltage, state A indicating that the vehicle is ready to accept the charging voltage.

- **Step 7** : State C - State C activates the charging voltage by closing the relay. Possible outputs include State B indicating that the vehicle has changed resistance to signal that it has finished charging, State A indicating that the connector has been disconnected from the vehicle, State D indicating that venting is required, or a J1772 fault condition detected in the background.
- **Step 8** : State D - Indicates that venting is required. This state is implemented in software, but can only be returned to state C or the fault condition. state C or the fault condition.
- **Step 9** : Fault - The main faults that can be triggered by the system are: GFCI check failure, GFCI trip, blocked relay, or a J1772 pilot signal fault. These faults are all critical and require a system restart to clear.

The primary mechanism for switching between these states is the pilot wire measurement. When a voltage change is measured, the foreground state machine detects this change and moves accordingly. Figure 4.2 presents the diagram of our system

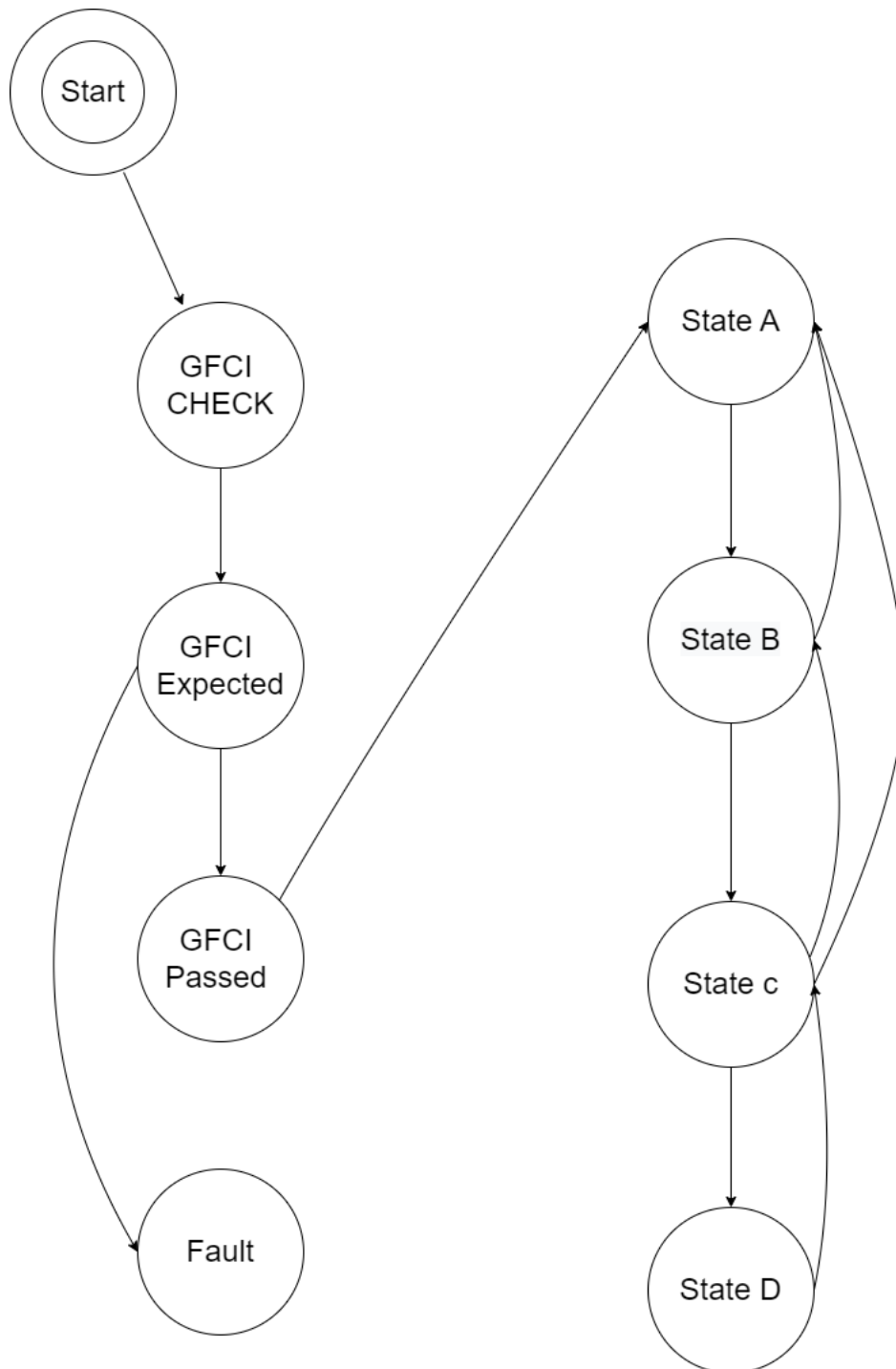
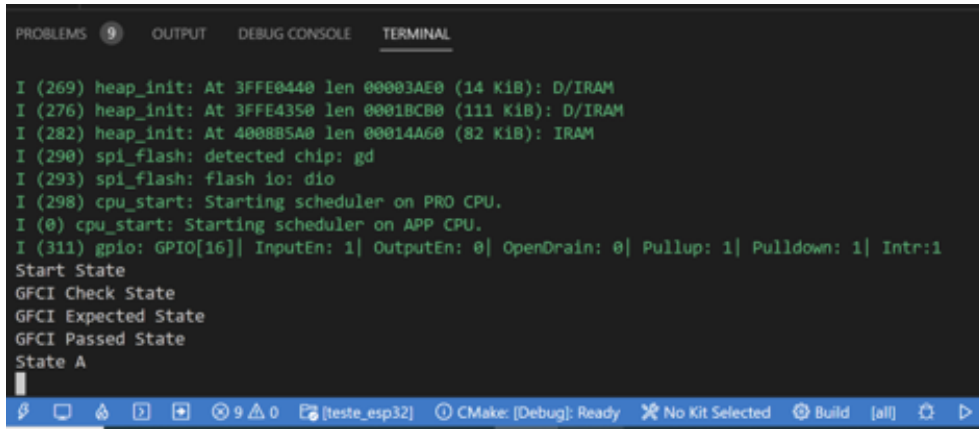


Figure 4.2: State Machine Overview.

4.2 Results and discussions

In this part we will present all statuses of this work we starts with the first state

- **State A:** The programming present the state A in figure 4.3



```
PROBLEMS 9 OUTPUT DEBUG CONSOLE TERMINAL
I (269) heap_init: At 3FFE0440 len 00003AE0 (14 KIB): D/IRAM
I (276) heap_init: At 3FFE4350 len 0001BCB0 (111 KIB): D/IRAM
I (282) heap_init: At 4008B5A0 len 00014A60 (82 KIB): IRAM
I (290) spi_flash: detected chip: gd
I (293) spi_flash: flash io: dio
I (298) cpu_start: Starting scheduler on PRO CPU.
I (0) cpu_start: Starting scheduler on APP CPU.
I (311) gpio: GPIO[16] InputEn: 1| OutputEn: 0| OpenDrain: 0| Pullup: 1| Pulldown: 1| Intr:1
Start State
GFCI Check State
GFCI Expected State
GFCI Passed State
State A
```

Figure 4.3: State A.

After passing the GFCI test, the microcontroller enters state A. In this state, the EVSE pilot line is at 11.6V (ideally 12V) DC awaiting connection to the electric vehicle (figure 4.4). Figure 4.4 shows the EVSE pilot line in the State A, the pilot has an expected value of 12-V DC.

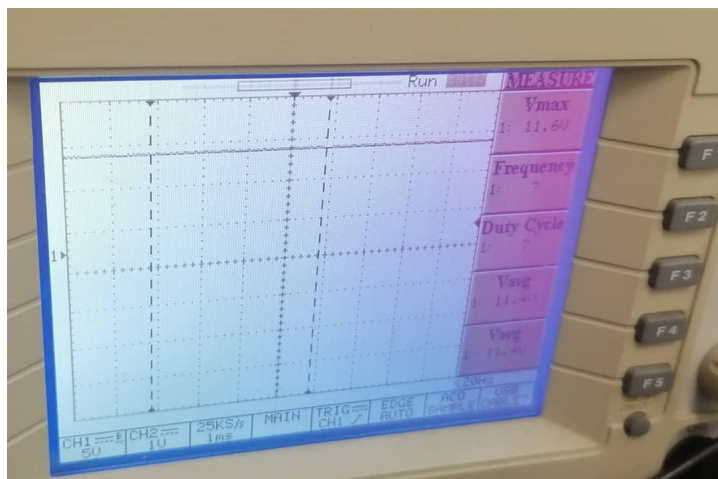


Figure 4.4: Result state A.

- **State B:** The second step of the programming is the state B showed in figure 4.5 bellow

```

PROBLEMS 9 OUTPUT DEBUG CONSOLE TERMINAL
I (290) spi_flash: detected chip: gd
I (293) spi_flash: flash io: dio
I (298) cpu_start: Starting scheduler on PRO CPU.
I (0) cpu_start: Starting scheduler on APP CPU.
I (311) gpio: GPIO[16]| InputEn: 1| OutputEn: 0| OpenDrain: 0| Pullup: 1| Pulldown: 1| Intr:1
Start State
GFCI Check State
GFCI Expected State
GFCI Passed State
State A
evse.pilot_adc =3213 pilot_voltage = 7.649846
State B
pwm = 81

```

Figure 4.5: State B.

The EVSE pilot in State B is depicted in Figure 4.6. Once the EVSE is plugged into the vehicle, this condition develops. When State A, 12 V is detected, the car connects a $2.74k\Omega$ resistor between the pilot and ground. The voltage drop to 9V, the microcontroller initiates 1kHz PWM signal to the car. In the picture, the signal frequency is a 35 % PWM. This value was only used for simulation purposes. In real operation, the duty cycle value contains information on the current available for the load. The relationship between duty cycle and current is defined by two different equations depending on the current range specified; for a 6- to 51-A service, is:

$$DutyCycle = \frac{I}{0.6}$$

For a higher service in the 51- to 80-A range, is:

$$DutyCycle = \frac{I}{2.5} + 64$$

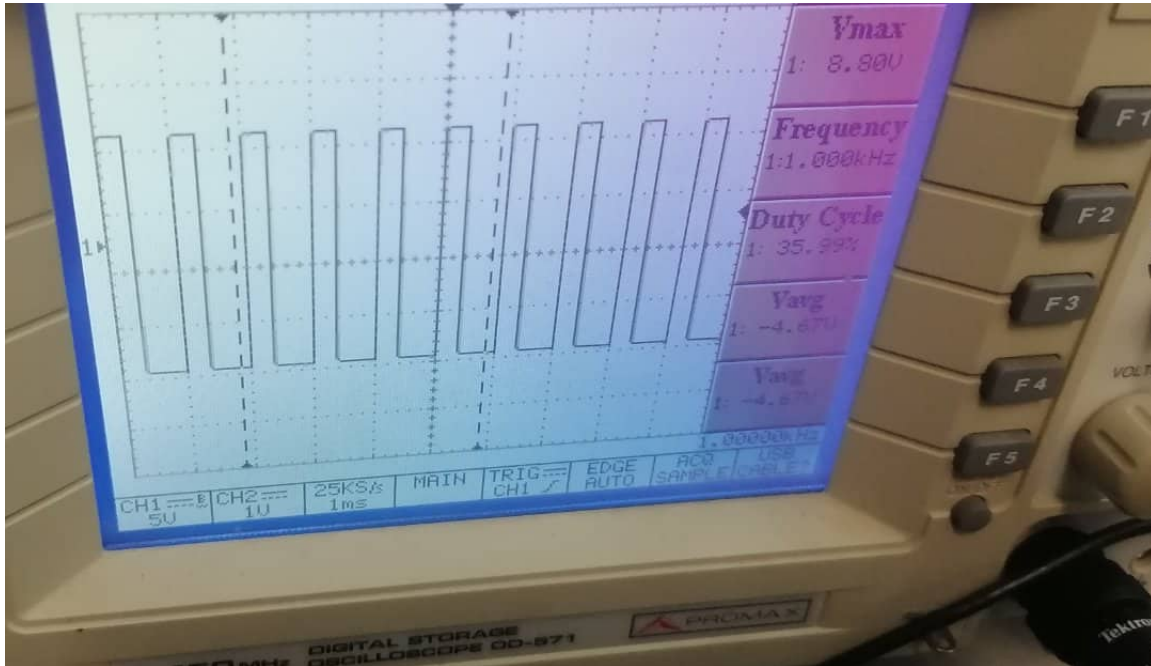


Figure 4.6: Result state B.

- **State C** Third step program is presented in figure 4.7

```

PROBLEMS 9 OUTPUT DEBUG CONSOLE TERMINAL
evse.pilot_adc =3211 pilot_voltage = 7.645333
State B
pwm = 81
Pilot Voltage = 7.645333
State A
evse.pilot_adc =2725 pilot_voltage = 6.548718
evse.pilot_adc =2723 pilot_voltage = 6.544205
evse.pilot_adc =3216 pilot_voltage = 7.656615
State B
pwm = 81
Pilot Voltage = 7.656615
State C
Pilot Voltage = 6.573538

```

Figure 4.7: State C.

In state C, the electric vehicle connects an 882 Ω resistance, indicating that the

charging process has started. As a result, the voltage of the J1772 signal drops to 6.2V (ideally 6V) identifying state C (figure 4.8). Upon recognition of state C, the EVSE microcontroller closes the relay contacts to initiate power supply.

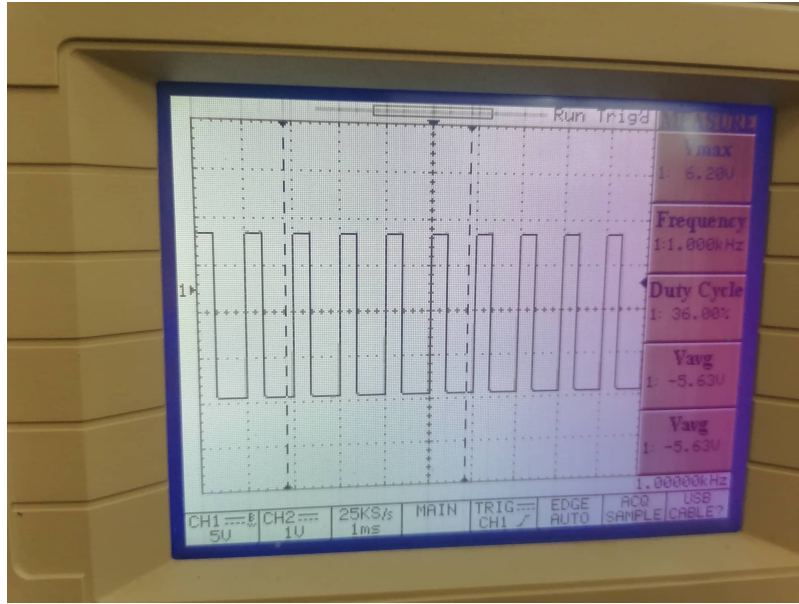


Figure 4.8: Result state C.

- **State D** Forth step presented in figure 4.9 is the state D

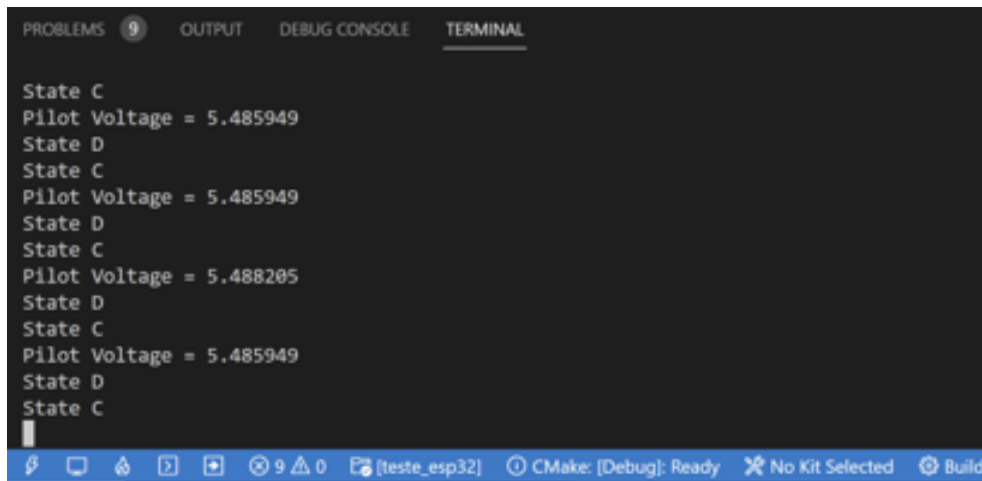


Figure 4.9: State D.

Figure 4.10 shows the EVSE pilot in State D. In this state the EV requires ventilation by applying a 246 Ω resistor. While the functionality for this state has not been

implemented, they exist in the reference design, and the state can still be detected. As result the pilot voltage level drop to 2.87 V (3 V ideally) and is detected by the software of microcontroller, but the EVSE implementation just returns to State C.

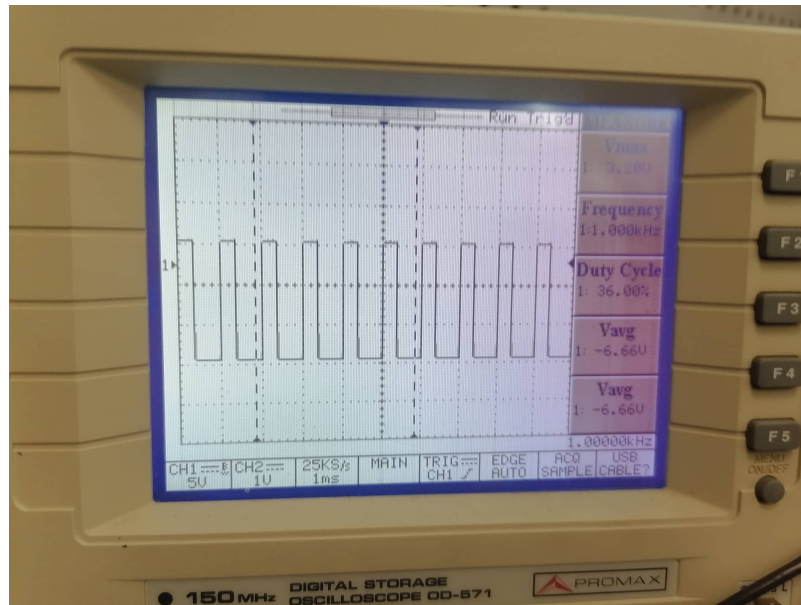


Figure 4.10: Result state D.

- **State C** Fifth step of the program presented in the figure 4.11

```
PROBLEMS 9 OUTPUT DEBUG CONSOLE TERMINAL
Pilot Voltage = 5.470154
State D
State C
Pilot Voltage = 5.490461
State D
State C
Pilot Voltage = 5.490461
State D
State C
Pilot Voltage = 5.485949
State D
State C
Pilot Voltage = 6.573538
```

Figure 4.11: State C.

Figure 4.12 shows the EVSE pilot in State C

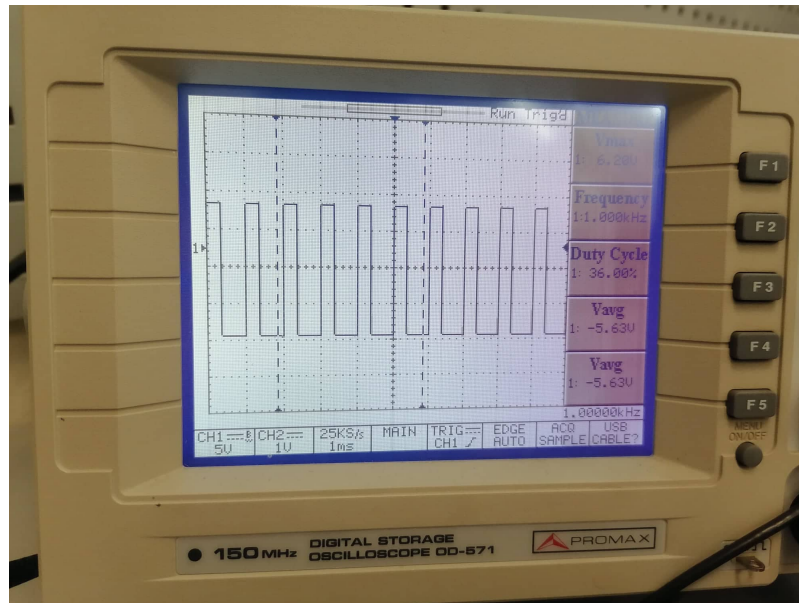


Figure 4.12: Result state C.

- **State B** sixth step of the program presented in the figure 4.13

```
PROBLEMS 9 OUTPUT DEBUG CONSOLE TERMINAL
State D
State C
Pilot Voltage = 5.485949
State D
State C
Pilot Voltage = 6.573538
State A
E (212021) timer_group: timer_set_counter_value(86): HW TIMER NEVER INIT ERROR
E (212021) timer_group: timer_start(97): HW TIMER NEVER INIT ERROR
evse.pilot_adc =3215 pilot_voltage = 7.654359
State B
pwm = 81
Pilot Voltage = 7.654359
```

Figure 4.13: State B.

Figure 4.14 shows the EVSE pilot in State B

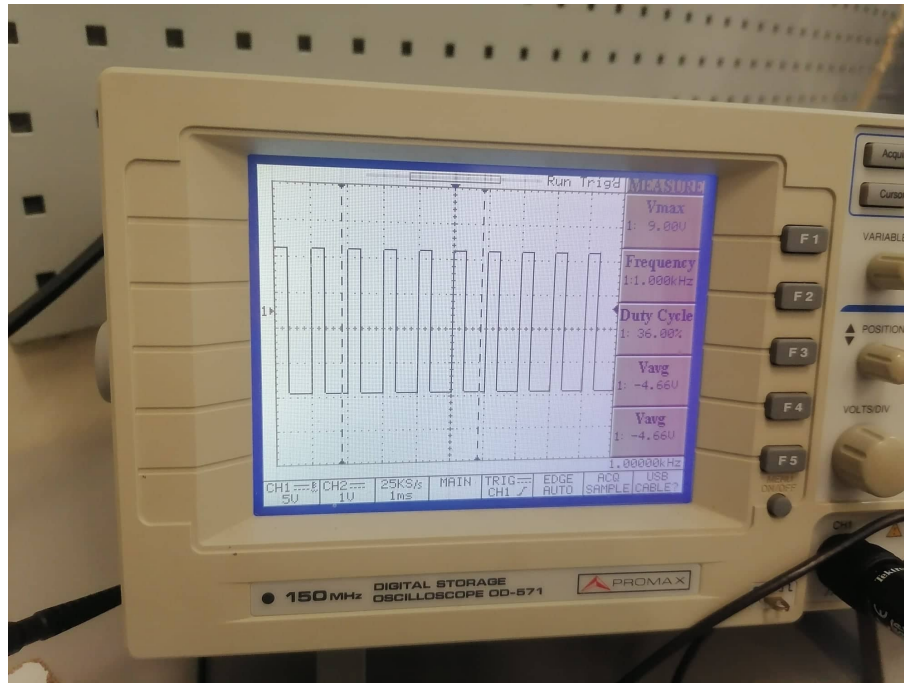


Figure 4.14: Result state B.

- **State A** seventh step of the program presented in the figure 4.15

```
PROBLEMS 9 OUTPUT DEBUG CONSOLE TERMINAL
State C
Pilot Voltage = 5.485949
State D
State C
Pilot Voltage = 6.573538
State A
E (212021) timer_group: timer_set_counter_value(86): HW TIMER NEVER INIT ERROR
E (212021) timer_group: timer_start(97): HW TIMER NEVER INIT ERROR
evse.pilot_adc =3215 pilot_voltage = 7.654359
State B
pwm = 81
Pilot Voltage = 7.654359
State A
```

Figure 4.15: State A.

Figure 4.16 shows the EVSE pilot in State A.

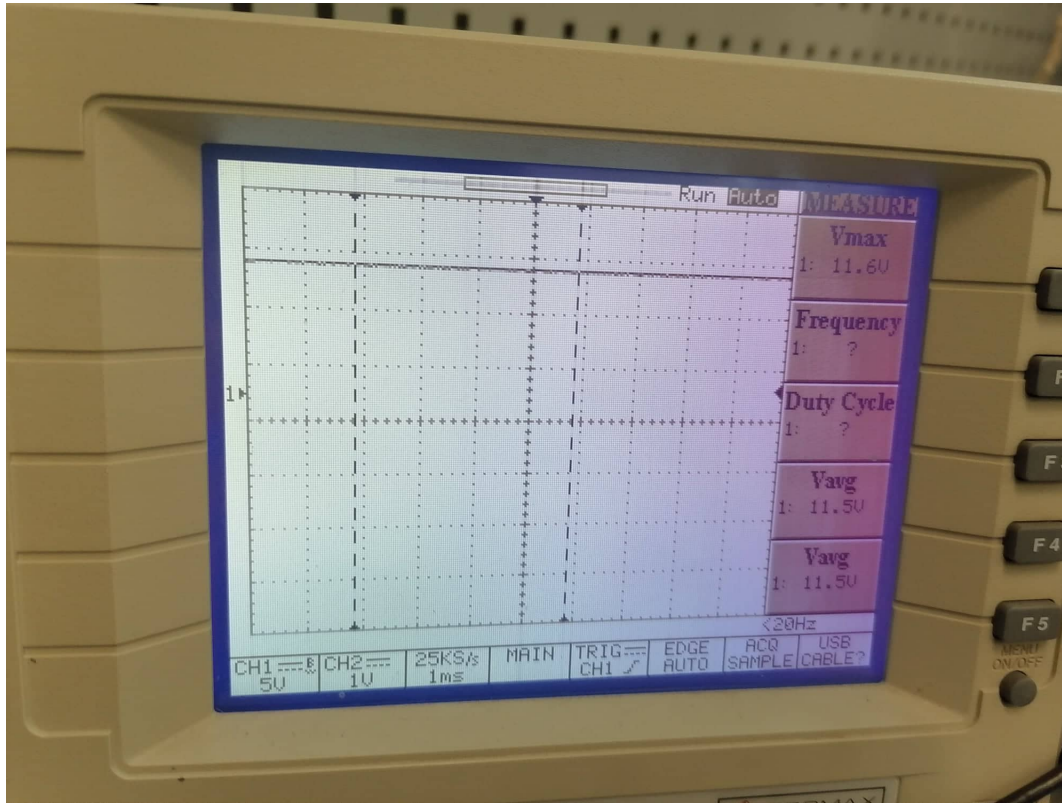


Figure 4.16: Result state A.

4.3 Conclusion

The code and test phase are an important part of the project design. This phase consists of concretizing the created conceptual model and allows for model confirmation on the one hand, as well as the identification of potential problems.

Chapter 5

Conclusion

To reduce the dependence on oil and environmental pollution, the development of electric vehicles has been accelerated in many countries. The implementation of EVs, especially battery electric vehicles, is considered a solution to the energy crisis and environmental issues. In the work presented on this master thesis, the development and implementation of Electric Vehicle Supply Equipment have been performed. Several software and experimental studies have been carried out on the laboratory of Institut Polytechnic of Braganca, according to the envisaged objectives. As first step, an overall literature review have been established regarding electrical vehicles. The bibliography research showed several types of electrical vehicles in which the deferrance remain on the engine emerged in the vehicle in term of different voltage satges as well as the type of supply signal which required a specific electric charger for each vehicule type, this results make this thesis a challenge for establishing a universal charger for all electrical vehicules controlled in term of voltage and electric signal. In the third chapter, the project study In software view have been performed. However, Tina proteus have been used to simulate the prototype, and C programing language have been used for the ESP 32 microcontroller. As last step, the designed circuits have been performed in hardware step to provide voltage values in several stages as already detailed on this report.

5.1 Future works

The practical work carried out allowed the development of a system that allows the recharging of the battery of an electric vehicle. It is recommended for future work to

Establish a wireless communication between the user.

Develop an application to make the monitoring of the system more accessible.

Communication and control by Wifi.

A cooling system for the electrical circuit.

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