POLITECNICO DI TORINO

Master's Degree's in Automotive Engineering

Master's Degree's Thesis

Hardware integration of sensors and processors for automotive application

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Abstract

The recent tightening of regulations on vehicle emissions is causing automakers to look for solutions that improve efficiency and produce fewer pollutants. This, together with the need to remain competitive, has led to various solutions: one of them is hybrid electric vehicles. In this context, the present work has been developed to contribute to the progress of a project called Auto-Eco, which aims to hybridize an Iveco Daily light vehicle with an electric engine and a 48V battery. It is born from the collaboration of different companies and is financed by the Piedmont Region through "Pi.Te.F", Piattaforma Tecnologica di Filiera, public notice. The project strives to take advantage of the opportunity offered by the integration of hybrid propulsion and autonomous driving systems, such as sensors, to propose an improved solution.

The contribution of this work to the project is related to the hardware integration of all sensors and processing units that were not present in the vehicle. The starting point is the definition of the signal required by the Simulink model embedded in the main processing unit. Based on this information, the best communication methods are then determined and selected, analyzing the characteristics and requirements of each component. Finally, for each component, the pinout is defined to determine the electrical configuration and draw the schematic required to develop the wiring to be mounted in the vehicle. For this purpose, different configurations for powering up the component are analyzed. A part is related to the simulation of the battery consumption and the influence of the battery capacity on the results.

As a result, it is expected that the developed system can be integrated into a first prototype vehicle to test the system's functionalities.

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Acronyms

ADAS
Advanced Driving Assistance Systems

BEV
Battery Electric Vehicle

HEV
Hybrid Electric Vehicle

EM
Electric Machine

ICE
Internal Combustion Engine

SOC
State-of-Charge

ECMS
Equivalent Consumption Minimization Strategy

WLTC
Worldwide harmonized Light vehicles Test Cycles

Chapter 1

Introduction

Exhaust emission standards are becoming increasingly stringent, posing a challenge to the automotive market, which aims to reduce fuel consumption and emissions while maintaining sustainable costs. One of the solutions under development that desires to achieve these results is the hybrid powertrain. Based on the combined use of thermal and electric propulsion, there are several variants with different levels of complexity and different outcomes in terms of cost/benefit for both the vehicle manufacturer and the system suppliers.

Currently, advanced driver assistance systems and autonomous driving are also gaining interest and making rapid progress in the automotive sector. They use information from sensors that analyze the environment to assist the driver in his or her task, and in some cases even go so far as to replace him or her. The state-of-the-art analysis of the industry solution shows that these two systems are currently used as stand-alone solutions, with no integration that could deliver better results.

This thesis contributes to the development of a project called Auto-Eco, which has the above argument as its main motivation. It is born from the collaboration of different companies and is financed by the Piedmont Region through the public tender "Pi.Te.F", Piattaforma Tecnologica di Filiera [1]. The project aspires to seize the opportunity to propose a more competitive system compared to the existing ones, through the integration of hybrid powertrains and autonomous driving systems.

1.1 Project description

The Pi.Te.F public notice aims to fund industrial research projects or experimental development projects that promote innovative solutions. It is within this framework that the Auto-Eco project was born, the result of the collaboration between the companies Dayco Europe S.r.l [2], Tecno System [3], Podium Advanced Technologies [4], Italtecnica [5]and Politecnico di Torino [6]. The aim of the project is to propose and validate on a demonstration vehicle an integrated system, consisting of a 48V hybrid drive module and a control unit, which will make it possible to improve the vehicle's energy efficiency by using the information available from the driver assistance systems and the connectivity system. The driver assistance systems are based on sensors (cameras, radar, lidar), trajectory and longitudinal dynamics control systems. The information coming from these devices can also be used to optimize the use of the traction hybrid system and reduce fuel consumption. The subject of this study is a light-duty vehicle, particularly an Iveco Daily, and the project consist of four main steps:

1. Hybridization of the vehicle installing an Electric machine in P1 configuration;
2. Development of a torque split logic to minimize consumption;
3. Development of a control logic that exploiting sensors perception of ambient and traffic condition for fuel consumption reduction;
4. Evaluate the reduction on the WLTC homologation cycle.

The first part consist of mounting on the existing vehicle an electric motor in P1 position (different hybrid configuration will be explained better in Chapter 2) and a battery sized in order to fulfill the requirement of the WLTP cycle. The next step is to develop a control logic that guarantees that the torque split between the two means of propulsion is always optimal in terms of fuel consumption. For the project, previous work has developed an ECMS, Equivalent Consumption Minimization Strategy, which is an instantaneous optimization algorithm whose cost function includes fuel consumption and also a penalty for battery use [7].

The cost function is then modified to take advantage of the sensor's perception of the environment and traffic conditions. To do this, conditions are added that take into account what state the vehicle will be in the next moment to find the best combination of the two machines that minimizes fuel consumption.

In the final step, once the vehicle is equipped with the hybrid unit and the control unit of the entire system, it must be tested with the WLTP [8]homologation cycle to analyze the results obtained in terms of fuel consumption and determine whether the solution developed can be a viable option for manufacturers.

1.2 Thesis contribution for the project

This thesis was written during an internship at Podium Advanced Technologies and focuses mainly on the hardware integration part. Based on the work previously done, especially the model of the vehicle shown in Section 2.5, the signals that the control algorithm needs from the vehicle's ECUs and the signals that the new ECU sends to the vehicle's actuators are listed with their characteristics in order to investigate which communication means can be used for their transmission (Chapter 4). Then in Chapter 5, the power supply of each component was also considered to determine what voltages would be required for the power supply and whether the existing batteries in the vehicle could already meet the requirements or whether a converter would need to be integrated. At the end of this process, a possible architectural diagram was drawn with all the components, their means of communication and their supply lines. The next step was to design the electrical schematic of the components that must be installed in the vehicle, highlighting for each device the pinout for both the communication port and the power supply port. This part also determined the power and amperage required by each element to include cable sizing and fuse selection in the schematic as well (Chapter 6). This scheme is provided to allow the positioning of the physical elements in the vehicle.

1.3 Thesis Outline

This thesis consists of seven chapters: the first, which concludes with this section, presents the context in which the project is set, its motivation, and expected results, together with the contribution that this work makes.

The second chapter aims to give an overview of the configurations of hybrid vehicles currently on the market, in order to explain what advantages and disadvantages these solutions include. In this part, a comparison between high voltage and low voltage is also included, focusing also on the differences in terms of cost. Finally, the model used to simulate the system will be presented.

In the third chapter, the battery technologies used in hybrid vehicles today are presented to explain the different stored energy and power requirements for each application. To emphasize this, an example of preliminary sizing of a hybrid unit is presented in this section.

The fourth chapter begins the hardware integration part. A brief overview of the communication means currently used in vehicles is followed by an analysis of the signals required for the proper operation of the system.

The fifth chapter examines the integration of sensors and ECUs. This involves determining which connections are required and how power can be supplied to all devices. An architectural configuration is presented that also takes into account the converter required to ensure proper operation.

The sixth chapter deals with the electrical schematic of the vehicle. Each component is shown with the pinout of its connector to draw the interconnecting cables sized for power and current consumption. In the end, the selection of fuses is also presented to ensure the safety of the system.

In the seventh and final chapter, a summary of what has been done during the project development and what to expect next is given.

Chapter 2

Hybrid vehicles

2.1 Context

In recent years, awareness of environmental issues has increased dramatically, and attention is focused on emissions that cause climate change, such as greenhouse gases such as CO, NO_x, and CO_2. Given that transport is a major contributor to CO_2 emissions, there is a growing focus on limiting the pollutants that vehicles can produce to achieve the goal of decarbonizing transport. Clearly, the presence of internal combustion engines is the main contributor to vehicle greenhouse gas emissions, so electric vehicles have been chosen as a fallback solution to reduce pollution. EVs also grant zero emissions considering the possibility to use renewable energy to recharge their batteries. This solution has drawbacks such as limited range, high initial cost, and long charging time compared to conventional internal combustion engines. This and the gradual increase in regulatory requirements have led manufacturers to investigate interim solutions to comply with regulations while maintaining economic convenience.

This solution is now being individuated in hybrid electric vehicles that can overcome the shortcomings of the early-stage deployment of electric vehicle technology. HEV technology combines the benefits of both internal combustion engines and electric vehicles to reduce emissions and improve fuel efficiency to ensure a reasonable driving range.

2.2 Hybrid vehicles architecture

As pointed out, hybrid vehicles combine the powertrain of a traditional thermal engine with at least one electric machine. Other elements required are a battery, an inverter to control the EM, and a DC/DC converter to connect the conventional 12V system to the higher voltage system. Some details for each component are presented in the paragraphs below.

Electric machine The electric machines used in hybrid vehicle applications are 3-phase motors that can propel the vehicle by providing torque but also functions as a generator to produce energy and recharge the battery. The type of machine used depends on the maximum power and torque requested, size, and cost, which must be optimized for the specific application.

Battery The batteries commonly used in hybrid vehicles are 48V lithium-ion devices, although some applications use lower or higher voltages. The specific type used depends on the power capacity and energy density required by the vehicle, details of which are provided in the following section 3.

Inverter and DC/DC converter An inverter is required to convert the direct current supplied by the battery into the alternating current needed to power and control the electric machine in traction mode, while it converts the AC generated in the recovery process into direct current to supply the battery. Modifying the amplitude and frequency of the 3-phase current, torque and speed control of the machine can be achieved. Instead, DC/DC converters are necessary to integrate the traditional 12V system, still present, to the higher voltage wiring, allowing the ability to increase and decrease the voltage, some of which are detailed in this section 5.3.

2.2.1 Hybrid vehicles typologies

Hybrid electric powertrains can be divided into three different categories based on how the two propulsion systems are connected: series, parallel and complex hybrids.

Series hybrids In a series hybrid vehicle, the main traction is provided by the electric machine, the engine is used only to power the generator that produces electrical energy. The traction machine can be powered by the battery or directly by the ICE-generator system. Moreover, both power sources can be used simultaneously. EM can also be used to recover energy during deceleration, recharging the battery. This architecture has the advantage of decoupling the engine from the power required by the driver, allowing it to operate at optimum efficiency with reduced emissions. However, some disadvantages still exist, such as the need for two electric machines, one to generate traction and one to generate electrical energy to charge the battery. It also offers some inefficiencies due to the need for more conversions to power the traction machine and the higher weight due to having a second electric machine.

Parallel hybrids In a parallel hybrid configuration, both propulsion systems are mechanically linked to the drive shaft and can therefore provide traction individually or simultaneously to the vehicle. This configuration does not require a second machine to act as a generator because the EM can recover energy during deceleration. The electric machine can be also used to exploit the energy from the ICE when the traction power requested is low, to generate energy. This configuration allows for a smaller power rating of the ICE and of the electric machine, with cost and weight benefits.
The parallel hybrid systems are then segmented according to the position of the machine in the drive line, as shown in the following figure (Figure 2.1), some details for each category are provided below:

P0: In this configuration, the electric machine is connected to the ICE front end through a belt connection and cannot be decoupled from it. The EM is used to restart the engine after shut-off, but the 12V starter and battery are maintained for cold starts. The belt connection between the EM and the ICE causes some friction losses, reducing torque transmission and energy recovery capabilities. However, this layout is the easiest way to implement a hybrid system, requiring little costs and effort.

P1: The EM is connected directly to the internal combustion engine on the transmission side before the clutch. The inability to separate the two machines results in a reduction in the braking energy that the EM can provide due to the engine's traction friction that occurs during recovery. This configuration, compared with P0, reduces losses due to friction in the belt connection, allowing higher torque transmission, but costs increase due to difficulty in packing.

P2: This layout is similar to P1 except that the electric machine can be decoupled from the engine via a clutch inserted between them, enabling pure electric driving and increasing recuperation capabilities. The EM can be mounted directly on the axis, with packaging problems but reduced friction losses, or off-axis with a belt or chain connection, a solution more compact but with losses due to the connection.

P3: The EM is connected to the output shaft of the transmission and therefore is always linked to the wheels. This configuration can exploit higher energy recuperation as there is no friction loss due to the engine and the transmission. Adversely this layout does not allow optimizing the EM working point since it is directly connected to the wheels, which also means that restarting the engine cannot be performed.

P4: In this configuration the electric machine is connected to the axis that is not powered by the ICE drive-train, allowing the all-wheel drive mode. The benefit of reducing friction loss of the P3 remains, at the expense of the clutch required to separate the EM from the axle at high vehicle speeds. To overcome this problem, a two-speed gearbox could be used for electric machines, but the complexity and weight of the system increased.

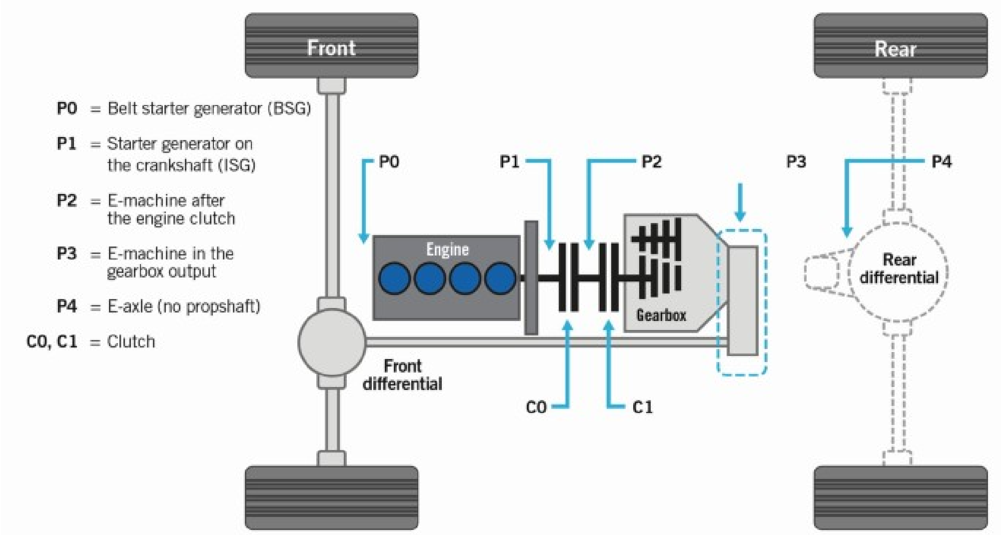

Figure 2.1: Parallel Hybrid Configurations

Complex hybrids Complex hybrid configuration includes the benefits of both series and hybrid layouts, allowing both functioning principles. This consent a smaller EM sizing with respect to series hybrids and a smaller ICE sizing compared to parallel hybrids, but increases the complexity of the system. To achieve this result, these configurations use at least two electric machines, both of which can operate in either motor or generator mode, thus increasing the capacity of the system. [9]

2.2.2 Functionalities

The presence of a hybrid system allows the exploitation of certain functions that have the potential to increase the vehicle's performance both in terms of torque output and pollutant emissions. In the following, some of them will be discussed.

The most basic function is to restart the engine after shut-off with the vehicle stopped, which eliminates fuel consumption when idling. Another development of this feature is the ability to stop the engine when the vehicle is decelerating at low speeds, which requires an appropriate control system capable of starting the engine quickly at the driver's command.

One of the main possibilities that the presence of electric machines opens up is the ability to recover energy during deceleration and braking. The EM generator mode exploits the force of inertia to generate electrical energy and provide the torque needed to slow or stop the vehicle. The need to use the combined mechanical brake is related to the maximum braking torque the machine can provide, the battery charge status, and the front/rear brake distribution.

One feature used to reduce the inefficiency of internal combustion engines is to use an electric machine as a generator to increase the load on the engine when the vehicle's propulsion demand is low, corresponding to points where efficiency is low. The electric machine used as the motor can provide more torque to the vehicle, allowing the engine to be reduced in size while maintaining the same performance but allowing the engine to operate at more efficient load points. In particular, the ability of EM to have high torque at low RPM helps to bridge the gap caused by engine response lag during fast transitions. Under normal conditions, the available torque from the electric machine can be added to the motor's torque to maintain the same overall performance even when the motor is downsized.

Of course one of the possibilities is to exploit the electric part of the power-train to power accessories when the engine is shut off during coasting, also giving torque to extend the coasting period avoiding using the ICE at low load inefficient points. This functionality requires that the EM is decoupled from the ICE, otherwise, the efficiency of the system will be lowered by the engine and transmission frictions.

The final feature is the ability to drive in all-electric mode within a certain range, depending on EM power and battery capacity.

All of these features can optimize vehicle performance, reduce inefficiencies and allow engine size to be reduced. This is an important step in reducing emissions as the ICE can operate at higher efficiency points by taking advantage of the electric machine to fill in the reduced engine power [10].

2.2.3 Voltage levels

The ISO 6469-3 norm classifies the voltage levels in the automotive environment, as presented in table 2.1, specifying also which safety requirement each class level must fulfill.

In hybrid applications, different voltage levels are used, starting from 12 V for micro-hybrid applications, going through 48 V commonly used in mild hybrid vehicles, and ending with voltages up to 400 V for full hybrid or plug-in hybrid.

Voltage Class	**Maximum working voltage**	
	DC in V	AC in V (rms value)
A	$0 < U \leq 60$	$0 < U \leq 30$
B	$60 < U \leq 1500$	$30 < U \leq 1000$
B1	$60 < U \leq 75$	$30 < U \leq 50$
B2	$75 < U \leq 60$	$50 < U \leq 1000$

Table 2.1: Voltage Classes.

Higher voltages are used to achieve higher output power without increasing current, which can cause system problems.

For class A, there is no risk of electric shock, so no insulation is needed, the negative electrical path can be managed through the chassis and mechanical protections to avoid contact with the living voltage parts. For class B, there is a risk of electric shock if there is electrical contact with the positive and negative voltage terminals. As a result, mechanical protections are introduced to avoid direct contact with the living voltage parts and complete isolation of the HV circuits is required to increase safety.

While the ISO standard places higher requirements on voltages above 60V, car manufacturers are focusing their efforts on developing hybrid systems that use voltages below this threshold, such as 48V. This can help reduce technical effort and system implementation costs. [11] [12]

2.3 HV vs LV

In this section, an analysis of the main difference between high voltage and low voltage hybrid vehicles is presented, highlighting the differences in component and architecture, with the intent to underline the reason that lead to deciding for a 48V hybrid for the project developed.

2.3.1 Architectures and components differences

All elements that must operate at high voltage require special attention in the design to meet safety requirements, adding safety and monitoring devices to control and protect the system as well as the passengers during operation. The higher voltage allows a lower current to maintain the same level of power, this means that the cross-section of the active part of the cable can be lower, however, the complete diameter, including the insulation, is similar to a low voltage cable. This is due to the increased insulation required to ensure the isolation of the system from the environment. The regulation establishes safety measures that must be taken into account for operation at high voltage, starting from the color of the cable that is part of the high voltage wiring, which must be orange and clearly distinguishable from low voltage cable. A key element required by high voltage systems is the high voltage interlock loop, HVIL. That is a safety device of hybrid and electric vehicles that has the effect of protecting people during vehicle assembly, repair, maintenance, and operation. It acts as a circuit breaker that sends a warning or trouble code to the driver if the high-voltage connection is loose, disconnected, or damaged during vehicle operation. HVIL also helps protect the driver and passengers in the event of an accident. This system uses a continuous low-voltage loop to monitor all high-voltage connectors and components. If the low-voltage HVIL signal is interrupted for any reason, this indicates a problem with the high-voltage system that needs to be addressed. When the HVIL circuit fails, a diagnostic trouble code is activated and a warning appears on the vehicle's dashboard informing the driver that they need to service the vehicle. Trouble codes also provide information to service technicians about the nature of the problem so they can avoid any safety-related problems.

Another element that a high-voltage system requires is the addition of a pre-charge circuits, usually composed by a switch and a resistor, that are used to avoid high in-rush current to the system.

Safety problems

In electric systems if protections are not implemented or faults take place, two typologies of risks could take place:

1. Arcs from short circuit or separation under load;
2. Electric shock with current passing through the human body.

The first can take place even at 12Vdc but can be managed at the design and procedure level trying to avoid the arc risk or at least to limit its energy, also the usage of Personal Protection Equipment such as protective eye shields, hearing protection, and protective gloves, can help to avoid risk. Instead, regarding electric shock it can happen only at voltages higher than 60Vdc, for that reason in this system complete electrical isolation of the HV circuits is required. This is obtained by insulating also the negative pathway from the vehicle chassis and mechanical protections are introduced to avoid direct contact with the living voltage parts. Some other protective devices are implemented to enable safety in high- voltage circuits, such as:

- easily recognizable high-voltage wiring and connector convention, individuated with orange color;
- access cover protection;

- HVIL system, already explained in the preceding paragraph, to shut down the HV system if its integrity is compromised;
- continuous monitoring of the system insulation with Loss of Insulation Circuit.

The correct application of these measures and procedures should allow a safe operation of high voltage systems reducing as much as possible the risks. Of course, the application of these requirements for HV circuits increases the system's complexity and possibly its costs compared to low-voltage ones.[13]

2.3.2 Cost differences

DC/DC converters HV-LV cost comparison In this section, it is included a comparison between high and low voltage, in particular referring to the costs of the system. To do so a component of the ones that will be used, the DC/DC converter which will be further investigate in Section 5.3, is used as a reference. To make a comparison between high-voltage and low-voltage configurations it is assumed that, instead of the real 48V unit a 400V battery will be used to power the vehicle. Therefore, in this case, the conversion required is from 400V to 24V and to 12V.

DC/DC converter efficiency The efficiencies of this devices is quite high for conversion from 48V to 24V, around 80-90%, but is even better for conversion from higher voltages. To exploit this characteristic the configuration selected for the two DC/DC devices required, is a "parallel" configuration, with a converter from 400V to 24V and another converter from 400V to 12V.

DC/DC devices selected for cost comparison To perform the comparison a quotation for two devices from DEUTRONIC is provided. [14] The elements selected are a low-voltage converter and a high-voltage one:

- DVC75-48-12: 8A, 75W device with an efficiency around 84-90%, of which the price is 95,20€; [15]
- DVCH1503-400-12: 112A, 1500W device with an efficiency around 93%, of which the price is 2016,00€.

The price for the other two devices required, from 48V to 24V and from 400V to 24V, is similar to the other two apart from the low voltage one that requires a higher power level, so will cost around 150€. Therefore the total cost for the two different configurations will be around 145,20€ for the low voltage and 4032€ for the high voltage.

Conclusion In this comparison, the focus was on the voltage conversion part of the system, where the cost difference is quite in favor of the low voltage one, but other considerations must be done to have a better picture of the differences between the two configurations. Since the application considered is a P1 hybrid vehicle, the power, and energy required for the hybrid unit are not high enough to need a high voltage system, considering also that working at this voltage level requires more protection for safety issues, that even the cost for cable, connectors, and other devices will be higher. This consideration leads to the conclusion that for the type of application, which is aiming to become a commercial solution for light-duty vehicles, a high-voltage hybridization unit is not a proper choice because will increase the costs without adding evident benefits to the system.

2.4 Specification of the vehicle under study

The vehicle under study is an IVECO Daily equipped with a 2.3L Diesel engine and will be integrated with a 48V hybrid system composed of an electric machine and a battery. The electric machine is a 3-phase Interior Permanent Magnet that will be mounted in a parallel P1 configuration, directly on the shaft. The EM power and torque characteristics are listed in the table below.

Peak Power	30kW @1300-2500 rpm
Continuous Power	20kW @1450-2500 rpm
Peak Torque	220Nm @0-1300rpm
Continuous Torque	130Nm @0-1450rpm

Table 2.2: EM power and torque characteristics

To the existing vehicle, some components will be added. First of all a set of sensors currently used for advanced driving assistance systems, such as a stereo camera and a radar. The second sensor may be substituted by a Lidar in the future. To allow the collection of the information coming from these sensors, a nVidia processing unit is included and will perform the fusion of the information coming from the two devices to obtain the best information possible. Then to control the electric machine by exploiting also the information coming from the sensors a Scalexio Autobox processing unit is embedded. On this component, the Simulink model previously developed will be implemented and will control the torque split. [16]

2.5 Model of hybrid electric vehicles

After presenting the physical layout hybrid vehicles, in this section, a brief explanation of the virtual model developed in Simulink/Matlab to simulate the vehicle under study, preview the possible results and optimize the control algorithm, is provided. The model here presented is composed of two main elements: the controller and the plant. The first contains the control algorithm that, receiving the input from the external environment and the feedback from the vehicle, determines in each instant which is the correct power-split between the electric machine and the internal combustion engine. The second is composed by the model of the vehicle dynamic, with the ICE and the EM, receiving the commands from the controller and giving back the feedback as the vehicle will do.

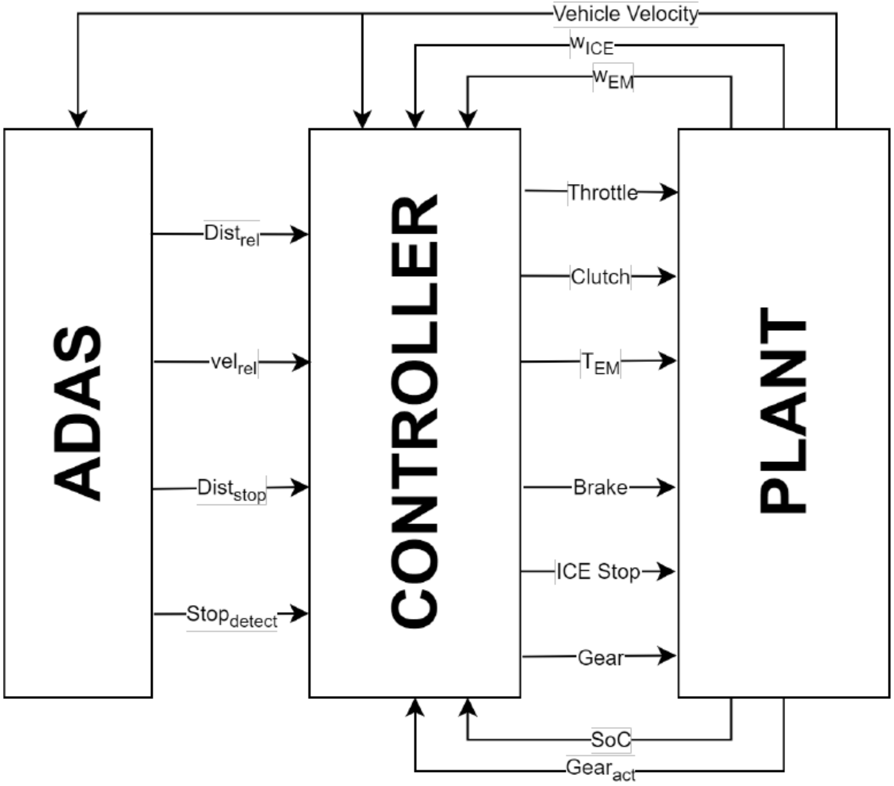

Figure 2.2: Vehicle model overview

2.5.1 Controller

The controller component is made up of a main element which is the block that implements the control algorithm. It includes different configurations of the control algorithm and can be set up to utilize the one of interest for the simulations. In this study, the control algorithm that is selected to drive the hybrid unit is an Equivalent Consumption Minimization Strategy, ECMS, which principles will be briefly explained in paragraph Equivalent Consumption Minimization Strategy.
The model can also simulate different control algorithms, particularly it is possible to simulate a simpler power-split algorithm, that takes into consideration only the power available from the electric unit and the state-of-charge to determine the power split. Obviously, this control is easier to implement and tune, but will definitely not be an optimal solution in terms of fuel consumption and hybrid utilization. It is also possible to simulate an all-ICE vehicle, this option is only used in order to check which are the emissions if the vehicle is not equipped with an electric machine.

The inputs can be provided starting from a defined homologation driving cycle, in the case under study the reference one is the WLTC, or by the information available from the ADAS sensors equipped on the vehicle, such as the relative distance and velocity from the preceding vehicle if the system is working as an Adaptive Cruise Control.

In the first case, the input is the reference velocity, which is derived from the reference driving cycle, and it is sent to a model of the driver to obtain a throttle command that is a further converter in a torque request that is the parameter that the control algorithm uses to determine the functioning point. In the current model, the driver is represented as a PI controller, which is a simple but effective model.
In the case of an ACC functioning the input from the ADAS sensors will be interpreted by a sensor fusion algorithm to obtain as control input the following parameters:

- Acceleration required, that is converted to a throttle command;
- Relative distance;
- Relative velocity.

Also in this situation, the major parameter needed by the controller algorithm is the throttle command converted in a torque request.

The controller receives the inputs from the vehicle control units, which are summarized below:

- Actual velocity
- Maximum and minimum P1 available power
- State-of-charge
- Engine rotation speed
- Electric machine rotation speed

All these parameters are used by the control algorithm to find in each instant all the possible working points based on the requested torque and find the optimal to minimize fuel consumption and emissions.

Equivalent Consumption Minimization Strategy ECMS is an optimization algorithm that, based on the state of the system identifies the best power split between ICE and EM [17]. This is done by trying to minimize the function representing the equivalent consumption:

$$\dot{m}_{eqv} = \dot{m}_{fc} + s\frac{P_{bat}}{LHV} \tag{2.1}$$

As visible from the equation it has two terms: one is considering the cost of utilizing the internal consumption engine, and the parameter used is the fuel mass flow rate; instead the second one is considering the electric part, it takes into account the fuel required to restore the energy in the battery. The second parameter is multiplied by a coefficient s, equivalence factor, which can be tuned to guarantee that the control algorithm respects the operation specifics. If it is set too low the electrical energy will be used mostly and this cannot ensure charge sustainability, which is a major requirement in mild hybrid vehicles; besides, setting it too high will lead the algorithm to prefer the usage of the internal combustion engine not exploit the full potentiality of the hybridization of the vehicle. To ensure that the battery depletion is kept as the application requires, an additional factor multiplying the second term of the cost function is added, it is p, which is a function of the state-of-charge. It is higher than one if the SOC is lower than the target (favoring the usage of the thermal part) and it becomes lower than one when the SOC is higher than the target one (reducing the cost related to the usage of the electrical part).

The controller sub-block contains also a block that manages braking: checking if the electric machine is capable of guaranteeing the torque required to stop the vehicle, it defines if a braking command must be sent to the mechanical brakes and which is the necessary brake pressure.

2.5.2 Plant

The plant element in this application is representing the vehicle, that receives the torque request from the controller and provides it the feedback from the internal combustion engine and the electric machine. It is composed of two main parts: the vehicle longitudinal dynamics block and the P1 power-train block.

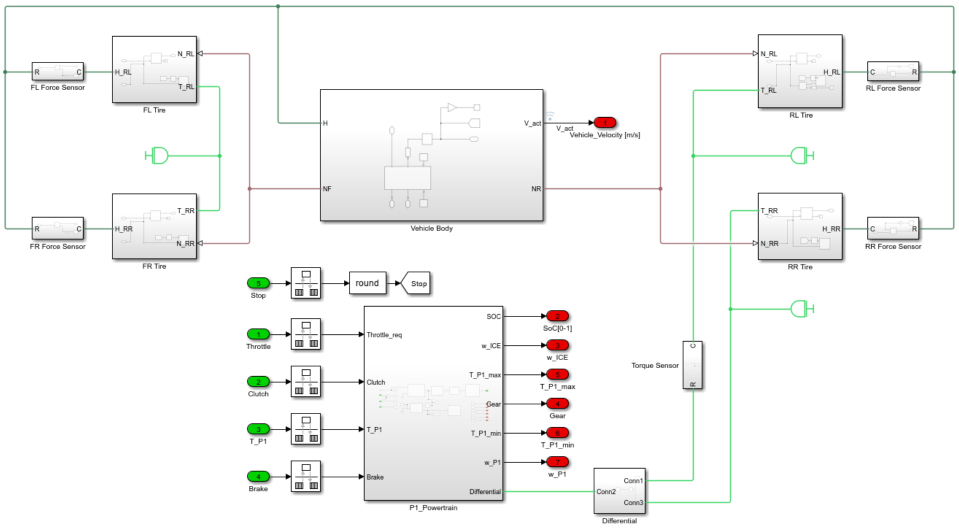

Figure 2.3: Plant model overview

The vehicle longitudinal dynamic is modeled using predefined Simulink's blocks of the Simscape library, a brief explanation of these blocks and the other elements of the plant model is provided in the following. As visible in the picture 2.3, the central block is the *Vehicle Body* that contains all the vehicle physical parameters and represents the vehicle body longitudinal motion, it is connected to the four wheels sub-systems, these are modeled using block which implements the tire behavior via the Magic Formula [18] and with blocks that represents the disc brakes with all their parameters. Since the vehicle is rear-wheel driven, the two rear wheels blocks are connected through the differential to the P1 power-train block. In the power-train block there are the sub-systems of each component, as visible in Figure 2.4:

- ICE, it receives the torque request and simulates the engine behavior in terms of actual torque provided and fuel consumption, it also includes blocks to represent resisting torque and idle working. The working point is found using the engine map that is provided by the manufacturer, from the map is also possible to derive the fuel consumption and, therefore the emissions;

- Torque converter and gearbox, these two elements are modeled using existing blocks of the Simscape's library;
- Electric machine, it receives the torque request and exploiting the map of the machine it determines the working point to derive the power request, both in motoring both in generator condition;
- Battery, is modeled using built-in blocks of Simscape toolbox, receiving the electric power coming from the electric machine computes the current flowing to and from the battery and determines the state-of-charge.

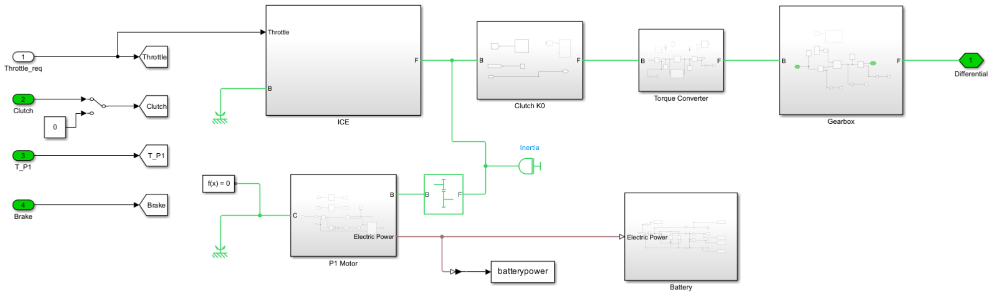

Figure 2.4: Power-train model

The expected output of the plant is the vehicle status, starting from the longitudinal dynamics to the working point of the two machines in terms of torque delivered and rotational speed. This provides the feedback required by the controller and allows for determining fuel consumption, therefore emission, and battery status.

Chapter 3

Battery for Hybrid vehicles

3.1 Battery technology state-of-the-art

This chapter presents the current state of the art in batteries for electric and hybrid vehicles, with particular attention to the cell technologies used and under development. The last part of the chapter gives an example of how a preliminary sizing of a battery for the hybrid application of the project could be done and gives the main parameters and information needed to perform this sizing.

3.1.1 Battery general definition

The component usually referred to as the "battery" is a complex system that includes several elements: the battery pack, the Battery Management System (BMS) Master, the thermal management system, and the power supply interface. The battery pack consists of series-connected battery modules composed of cells, i.e. individual electrochemical batteries, the type of which is deepened in Section 3.1.2, connected in series or in parallel. This arrangement makes it possible to obtain the required power and capacity of the whole system.

Electrochemical batteries are devices consisting of two electrodes immersed in an electrolyte that convert electrical energy into potential chemical energy during charging and vice versa during discharging.

Various characteristics can be used to classify battery technologies. The most important parameters are described below:

- Specific power is the maximum power per unit battery weight (W/Kg) that the battery can produce. It is related to the internal resistance of the battery which should be as low as possible, resulting in low energy loss and high electrical capacity;

- Specific energy is the energy capacity per unit battery weight (Wh/kg). Its theoretical value can be computed as the maximum energy that can be generated per unit mass of the cell reactant. The value obtainable in reality is usually 25–50% of the theoretical value;

- Energy efficiency is the ratio of the discharged energy to the charged energy. Its value during a charging-discharging cycle shows a maximum in the middle range of the state-of-charge, to exploit this characteristic the HEV's controller must maintain the SOC value in this range to limit temperature rise due to inefficient use of energy;

- The calendar lifetime describes the time for which a battery can be stored inactive, such that its capacity remains above 80% of its initial capacity. This parameter depends on the SOC level at which the battery is stored. The temperature at which batteries are stored also affects the calendar life since an increase in temperature increases the rate of unwanted chemical reactions which increment the degradation of the battery.

- Cycle life is the number of complete charge-discharge cycles a battery can go through before its capacity drops to 80% of its original capacity. The cycle life of a battery is affected by the temperature at which it is operated. The rate at which the battery is charged and discharged also affects the life of the battery. This parameter is also affected by the maximum and minimum values of SOC. In the case of lithium-ion batteries, too high charge or discharge values will degrade their capacity more rapidly. [19]

Since a vehicle battery is made of several cells connected in series the battery control system must consider each of them independently. The manufacturing differences among cells cause unbalancing, if one cell in a stack has slightly less capacity than the others, it can limit the total capacity of the battery pack. To avoid damages or stack failure that cell must be balanced with the others, doing so requires individual monitoring of the voltage of each cell separately. This is normally performed by the BMS, which is the system responsible for controlling the relevant parameter of the battery pack to ensure its correct operation, principally the current, voltage, and temperature of each cell.[20] By using these parameters, the BMS determines the voltage limit that each cell can maintain at that time, limiting the battery's performance to prevent damage. Thermal management is fundamental also to guarantee that the battery is not subjected to extreme conditions that may result in damage to the system and also to ensure the highest performance possible remaining in the best temperature range that is between 15 and 35°C.

3.1.2 Battery cells technologies

In this section, a summary of the battery technologies currently used is provided in Table 3.1, listing the advantages and disadvantages of each of them. [21] [22]

Technology	Advantages	Disadvantages
Lead Acid	• Low cost • Relatively high power capability • Good cycle life	• Low energy density • Poor temperature characteristics • Danger due to sulfuric acid
Nickel-Metal Hydride	• Low cost • Wide range of operating temperatures • Long cycling life	• High self-discharge at high temperature • High heat generation at high temperature • Memory effect
Lithium-Ion Polymer	• Higher life cycle than Lithium-Ion	• Functional instability in case of overload or over-discharge
Lithium-Ion	• Large power storage capacity • Good energy density • Low self-discharge	• High cost • Limited life cycle

Table 3.1: Summary of battery technologies advantages and disadvantages

Since the most common battery type in modern electric vehicles is Lithium-Ion because of its high energy density compared to its weight, the following is a list of the different cathode materials used with their major characteristics:

Lithium Cobalt Oxide (LCO) High specific energy but limited safety, therefore not used in automotive;

Lithium Nickel Cobalt Manganese Oxide(NMC) Excellent specific energy, lowest self-heating of all;

Lithium Iron Phosphate (LFP) Excellent safety and long life span but lower energy density;

Lithium Manganese Oxide (LMO) High-temperature stability and safety, high capabilities due to low internal cell resistance;

Lithium Nickel Cobalt Aluminum Oxide (NCA) High specific energy, long life span but less safety and highest cost;

Lithium Titanate Oxide (LTO) Excellent low-temperature discharge characteristics, long lifetime, fast charge capability, is among the safest, but has high cost and lower energy density.

3.1.3 Battery using profiles and application

By analyzing the different typologies of vehicles that are mounting battery packs, it is possible to identify the different requirements that each specific user profile and application has. Particularly, starting from pure-electric cars, their major requisite is to ensure a proper range. This can be full-filled with a battery with high specific energy, to obtain a great capacity without increasing too much the battery weight, a thing that is detrimental to vehicle performance. Continuing with plug-in hybrid vehicles, the battery capacity requirement is less stringent since the vehicle is equipped also with an ICE and the pure-electric range necessary is limited, but the charge-discharge cycles number is increased compared to pure-electric vehicles. Last, for not rechargeable hybrid vehicles the main problem is the power capabilities of the battery pack since it is designed to support the thermal engine in its operation, mostly during hard acceleration and deceleration.
Considering the different capacities of the battery packs mounted on these vehicles it is possible to notice also that the amount of power flow relative to the energy capacity of the battery is vastly different for the batteries in the different electrified vehicles. [23] Moreover, each application it's characterized by a different discharge profile to meet the application requirements, three different using profiles can be found:

- Charge Depletion (CD) mode: the battery is fully charged with a battery charger and progressively depleted during driving. Normally used in BEVs application with batteries mainly sized to maximize specific energy;

- Charge Sustaining (CS) mode: the battery is charged and discharged on board around intermediate SoC values, to exploit the maximum efficiency range. Classical profile for HEV mounting batteries mainly sized to maximize specific power;

- Dual mode: used in PHEV, initially operates in charge-depleting till a pre-defined SOC, then switch to charge sustaining to maintain the pure-electric range. In this case, the battery is dimensioned with acceptable energy content for the pure EV range.

3.2 Battery sizing

Starting from what has just been explained, it is clear that the size of a vehicle's battery pack is a major concern in the design process. This chapter is intended to provide an overview of what can be a preliminary analysis to get the first size of the battery pack that can meet the project requirements. As mentioned earlier, there are two main parameters that are very important in every application: specific capacity of the battery and specific power. Assuming that the vehicle under study will be equipped with a hybrid powertrain, it is pointed out that between the two, the most important parameter for this type of vehicle is the specific power. Indeed, for this application, the electric propulsion is only intended to assist the ICE, so it must provide power during the transition. Energy reserve is also a minor issue as the range guaranteed by the thermal propulsion system and the ability to recover energy during braking can provide enough energy to recharge the battery.
The dimensioning procedure is started from the defined parameters: the battery voltage, which is 48V, and the velocity profile on which the vehicle will be tested, the WLTP homologation cycle. From the Simulink model developed, with this information it is possible to derive which is the power requested to the battery in each instant of the driving cycle. Since the vehicle will be a P1 parallel hybrid, the battery should be operated in charge-sustaining mode, so the SoC should not exceed the threshold defined which is, starting from 50% of battery charge, to stay in the range between 45%-55%. To determine a possible battery dimension, the model used at Podium to simulate the battery cells and packs has been exploited. The first step was choosing a suitable cell between the ones available, considering also that the application is intended to be implemented in commercial vehicles where the price is also a concern. The choice went on the Molicel INR-21700-P42B [24] whose main characteristics are listed in the table below (Table 3.2).

INR-21700-P42B	
Minimum Capacity	4000 mAh
Nominal Voltage	3.6 V
Maximum Discharge Current	45 A

Table 3.2: Molicel INR-21700-P42B main characteristics

With the value of the nominal cell voltage, it is possible to determine the number of cells in series necessary to reach the target voltage level of 48V, using the formula:

$$N_c = \frac{V_{batt}}{V_c} \tag{3.1}$$

Where: N_c is the number of cell in series;
V_{batt} is the battery voltage (48V);
V_c is the cell voltage.
Obtaining that the minimum number is 14 cells in series, reaching a nominal voltage of 50,4 V.
After that it is necessary to define the number of parallel cells, this parameter is strictly connected to the battery capacity, through the equation:

$$C_{batt} = N_p * C_c \tag{3.2}$$

Where: C_{batt} is the capacity of the battery in Ah;
N_p is the number of parallel cells;
C_c is the capacity of the cell in Ah.
Considering a target capacity of at least 30Ah, it is possible to obtain an estimation of the number of cells that will be mounted in parallel, which should be around 8. Then the battery pack, which is identified as 14s8p for the number of cells and their connection, is modeled and simulated considering as input the power required to perform the WLTP cycle. The results obtainable from the model are the battery pack current and voltage, the cell current, and the battery state-of-charge. To make an analysis the results are presented in the following pictures:

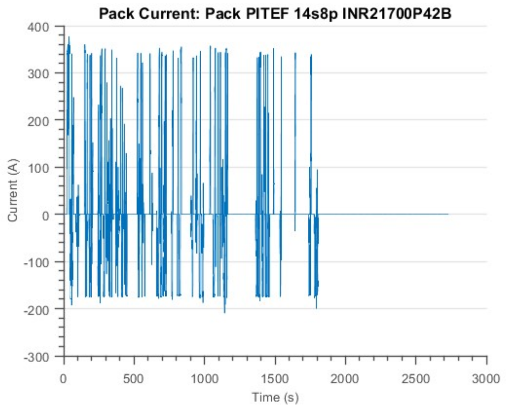

Figure 3.1: Battery Pack current-14s8p

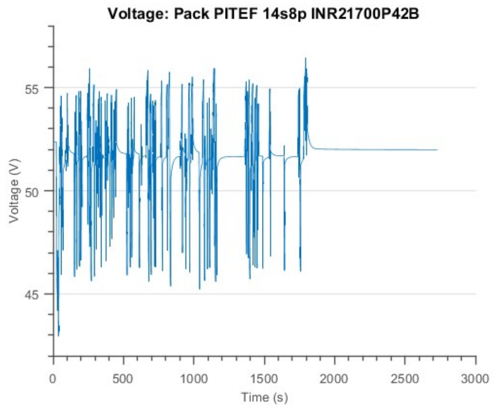

Figure 3.2: Battery Pack Voltage-14s8p

From 3.3 it is possible to verify that the SoC is kept between the limits and that the value at the end of the cycle is close to the starting point. The battery

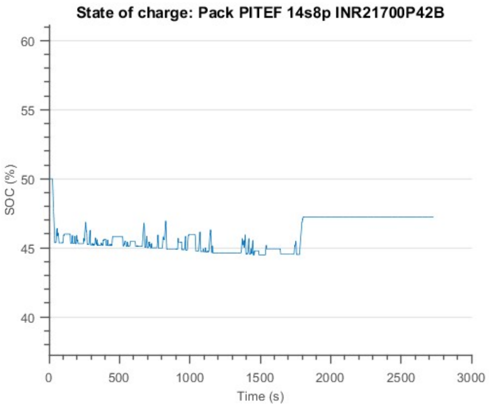

Figure 3.3: SoC Level-14s8p

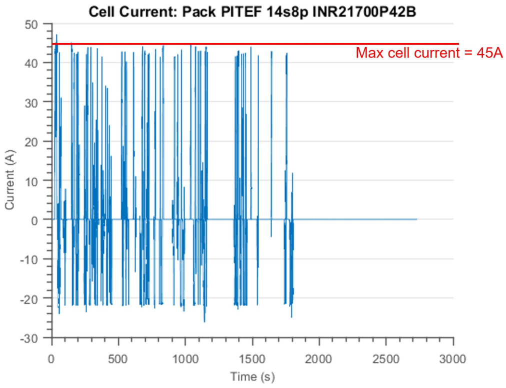

Figure 3.4: Cell Current-14s8p

voltage shows some peaks of overvoltage and undervoltage, but for short time, that will not damage the pack. The graph of the battery current allows to define the C-rate at which the battery is discharged, compute as the maximum current divided by the capacity of the battery, which is around 12,5 as a peak value. Due to the short period during which the current request is at high levels, it should be sustainable. This is also confirmed by graph 3.4, where the current of the single cell is represented, where it is clear that the current level is below the maximum achievable by the cell. The only peak over the threshold will not be problematic for the same reason explained before.
To make a comparison two other configurations, one with less capacity and one with higher capacity, are modeled and simulated.
The first is a 14s7p with 28Ah of capacity, the graphs below (Figures 3.5; 3.6; 3.8; 3.7) show the same results that were presented before. It is visible that the SoC goes for a large period below the level of 45% and the value at the end of the cycle is lower than the target one. Besides that, the major problem is the cell current which is higher than the maximum in several moments of the cycle. This could give problems for the cell in the long term.

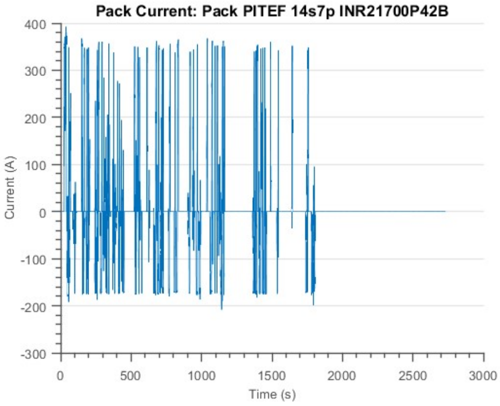

Figure 3.5: Battery Pack current-14s7p

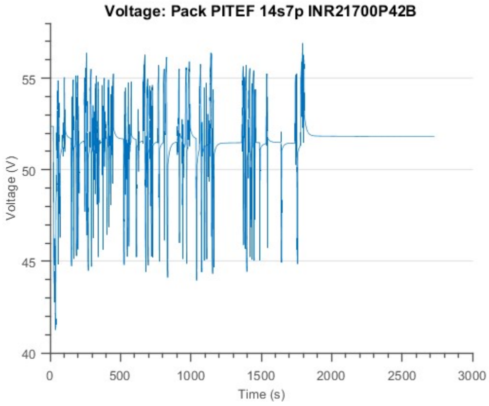

Figure 3.6: Battery Pack Voltage-14s7p

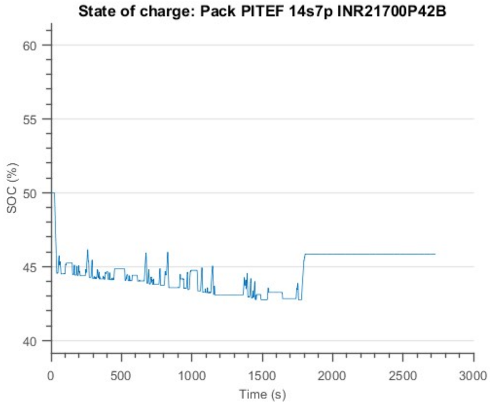

Figure 3.7: SoC Level-14s7p

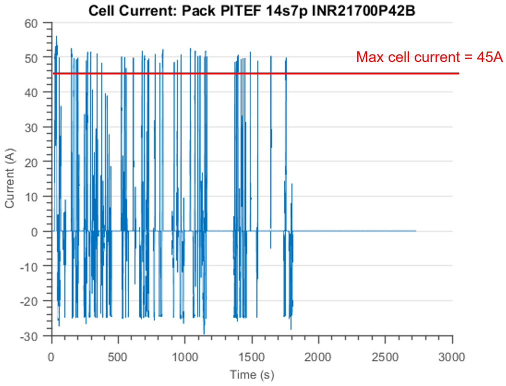

Figure 3.8: Cell Current-14s7p

The last battery simulated is a 14s9p, which capacity is 36Ah, as before the results are presented in Figures 3.9; 3.10; 3.12; 3.11. This battery pack respects the state-of-charge requirement for all the cycle and the currents are lower than the maximum value of the cell. In this case, also the C-rate is lower since the pack's current levels are reduced.

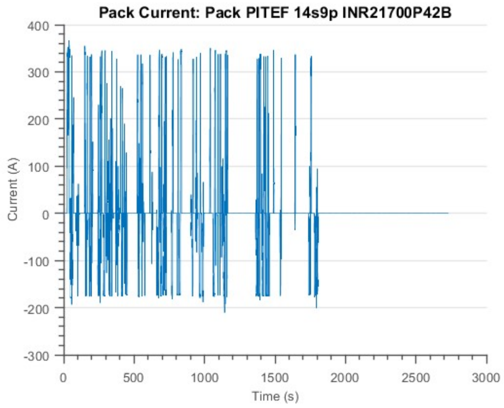

Figure 3.9: Battery Pack current-14s9p

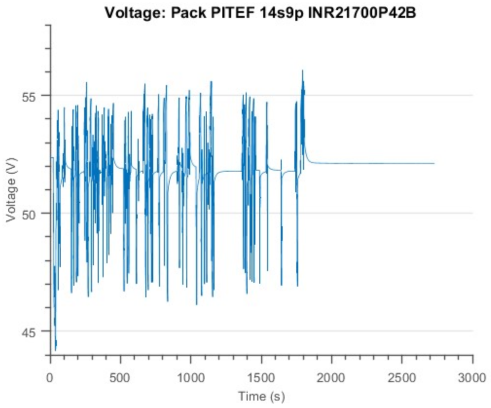

Figure 3.10: Battery Pack Voltage-14s9p

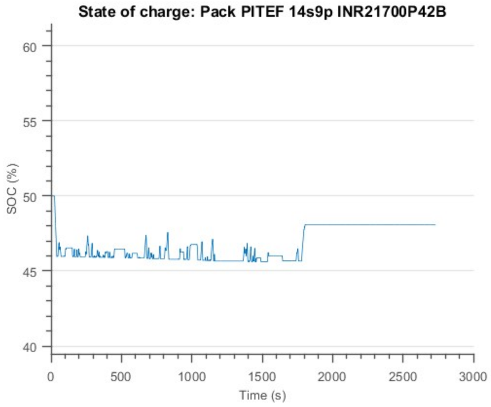

Figure 3.11: SoC Level-14s9p

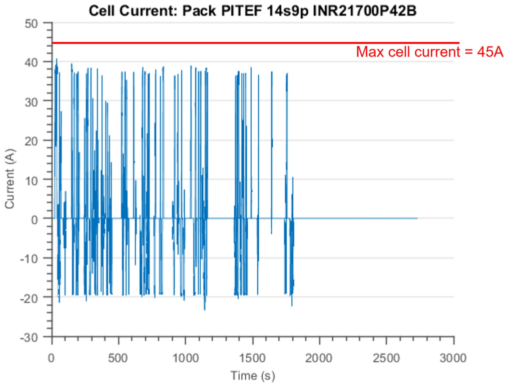

Figure 3.12: Cell Current-14s9p

In conclusion, a graph resuming the delta of SoC that the battery packs present is depicted in Figure 3.13, from which it is clear that the 14s7p battery shows a higher variation.
The analysis performed allowed to define that the two viable solutions are 14s8p or 14s9p since they can guarantee the requirement without exceeding the limit value of the cell and pack. To determine which will be the best choice further analysis must be performed, also regarding the temperature that the cells and battery will reach.

These considerations were intended to give a reference for the dimension of the

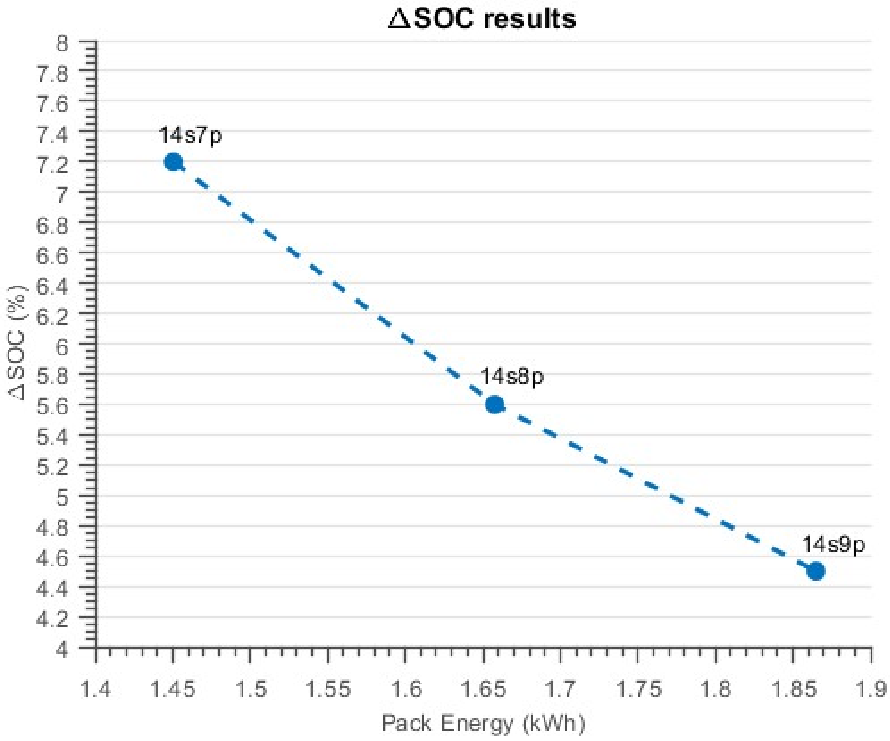

Figure 3.13: Delta in the SoC during WLTC

battery, keeping in mind that the battery that will be used for the project will not be designed ad hoc but will be an existing model.

Chapter 4

Communications Protocols and Signals transmitted

Today's vehicles require reliable communication between the ECUs that control all subsystem functions. These tools require a lot of information exchange between them: sensors must send their measurements to processors, which will provide actuators in different locations with the results of commands from the controller. Therefore, to properly operate such a complex system, it is necessary to design a reliable communication network on the vehicle.

Concerning this argument, the following sections provide a basic introduction to the communication methods currently used in the automotive environment with their basic characteristics, advantages, and disadvantages.

In the second part of the chapter, the signals defined for the Auto-Eco project are presented and the means of communication used to transmit them to and from the devices are listed, providing some details about how they are selected.

4.1 Communication Means

The high number of devices needing to communicate in a vehicle and the high number of signals and information to be transmitted, made necessary the development of a communication network not only connecting two devices together but enabling the whole system to provide information on a shared medium. This allows for reducing the wiring harnesses and guarantees more reliable information exchange, but necessitates protocols to manage communications and grant bus access. Currently used communication means are based on these requirements.

The first classification of the different protocols was made by SAE (Society for Automotive Engineers), based on the maximum speed of data transmissions.

Class A networks, with data rates lower than 10 kbps are normally used in the body domain to transmit simple control data. An example of a Class A network is LIN (Local Interconnected Network) and the information exchange is not safety critical such as seat control, door lock, or lighting. Class B networks are used to exchange information between ECUs, to share them, and to reduce the number of sensors. Normally the data rates for these networks are from 10kbps up to 125kbps and one of the most used of this type is Low-speed CAN (Controlled Area Network).

Class C networks are used for powertrain and chassis communication, needing high-speed (from 125kbps to 1Mbps) real-time communication. One example for this class is High-speed CAN.

Class D, not defined by the standard, is considered for networks with data rates higher than 1Mbps, such as Ethernet, which are used for applications that are safety critical or as a gateway between networks.

In current vehicles, it is common that all these typologies of networks coexist and are interconnected by gateways. [25]

Event-triggered vs Time-triggered One of the key requirements of communication network design is that messages transmitted on the bus must respect their real-time constraints, ensuring limited response times. This is especially important when transmitting information that could affect vehicle safety. To meet this requirement, there are two different communication methods in automotive systems: event trigger and time trigger.

Event-triggered means that the signals are transmitted for the occurrence of a significant event, this requires the protocol to define a method to access the bus avoiding collision assigning a priority to each frame. This method is efficient in terms of bandwidth usage since only the necessary messages are transmitted and keep the network flexible if a node is to be added. A problem in this type of communication is that verifying the temporal constraint and check if a node fails can be difficult.

In time-triggered communication, the signals are transmitted at a predetermined point in time, which is defined previously during the design of the network. This is optimal for transmitting periodic messages because each frame is scheduled for transmission in a specific interval of time, enabling also an easy way to check if the timing constraints are met. Moreover, if a message is missing it is simple to identify it and maybe detect that a node is not working properly. Besides these benefits, a problem in time-triggered communication is that the efficiency in terms of network utilization is lower and the transmission of non-periodic messages can be difficult. Differently from event-triggered ones, in this case, the addition of a node will require all the other nodes to be modified to fit the new scheduling of messages.

In today's communication networks, there are methods such as CAN and FlexRay that support both typologies of communication, an ability that well suits the automotive environment where both control loops and warnings must be transmitted.[26]

4.1.1 LIN

The Local Interconnect Network (LIN) [27] communication protocol is a serial communication protocol that is widely used in automotive applications for in-vehicle networking. It is designed to provide a simple and cost-effective way to connect sensors, actuators, and other devices within a vehicle. The LIN protocol is based on the Master-Slave architecture, which consists of a master node and several slave nodes. The information flow is divided into clusters consisting of one master task and several slave tasks. The master node contains both the master task and both tasks of all the slaves, to manage all the communication. A slave node can be part of different clusters enabling it to respond to different tasks.
The main characteristics of the LIN protocol are:

- Low-cost: The LIN protocol is designed to be low-cost, making it an ideal choice for automotive applications where cost is a major concern. It uses a single wire for communication, which reduces the cost of the hardware required to implement the protocol.

- Simple: The LIN protocol is simple to implement and use, making it a popular choice for automotive applications. It uses a single wire for communication and does not require complex hardware or software to implement.

- Master-Slave architecture: The LIN protocol uses a Master-Slave architecture, where one node, known as the LIN Master, controls all communication on the network. The LIN Master is responsible for initiating and controlling all communication on the network.

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- Error detection: The LIN protocol includes error detection mechanisms, such as checksums, to ensure that data is transmitted accurately and without errors.

- Flexible: The LIN protocol is flexible, allowing a node to be added without requiring hardware or software changes in other slave nodes, but only in the master.

- Limited data rate: The LIN protocol has a limited data rate of 20 kbps, which may not be sufficient for some applications that require higher data rates.

The LIN communication protocol uses a data frame structure to transmit data between nodes on the network. The data frame consists of several elements, including a header and a response. The header that is provided by the master task, contains a frame identifier, which uniquely defines the purpose of the frame. The slave task appointed for providing the response associated with the frame identifier transmits it. The frame structure visible in the picture 4.1, is divided into several fields:

1. Break field: used to signal the beginning of a new frame, is always generated by the master task;
2. Sync field: has a fixed value (a sequence of 0 and 1) and allows the slave nodes to detect the beginning of a new frame and to be synchronized at the start of the identifier field;
3. Protected Identifier field: it is divided into two subframes, the first is the frame identifier and the second is the parity;
4. Data field: can contain up to eight bytes of data;
5. Checksum: the last field of a frame is calculated over the data bytes and the protected identifier, enabling detection of incorrectness in the transmission.

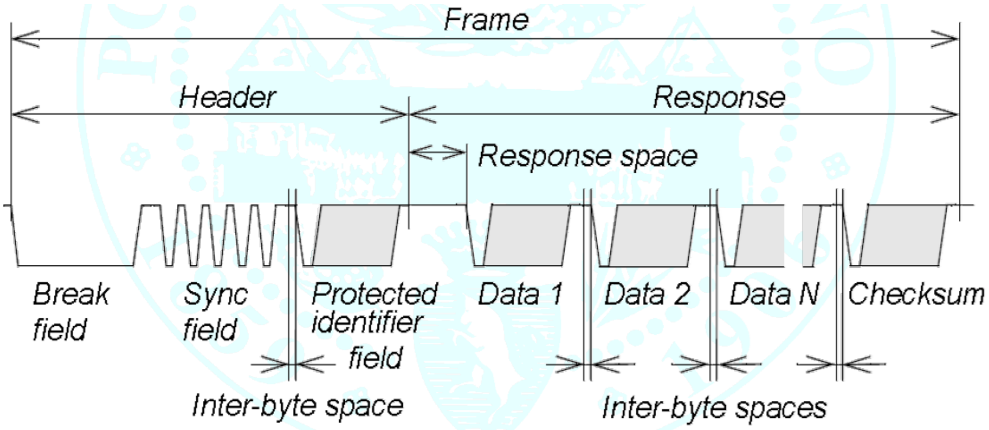

Figure 4.1: Lin Frame

The scheduling of the transmissions is controlled by the master task that provides the schedule table, in which are specified the frames and the interval between the start of a frame and the start of the following frame.

In conclusion, the LIN communication protocol is a simple, low-cost, and flexible serial communication protocol that is widely used in automotive applications for in-vehicle networking. It is based on a Master-Slave architecture and includes error detection mechanisms to ensure accurate and error-free data transmission. However, it does have some limitations, such as a limited data rate, distance, and the number of nodes. Despite these limitations, the LIN protocol is a popular choice for automotive applications due to its low cost and ease of implementation.

4.1.2 CAN

The Controlled Area Network (CAN) protocol is a serial communication protocol widely diffused in the automotive environment with data rates up to 1Mbps. The basic layout is made by a shared medium with all the devices connected to it. The CAN architecture stack is composed of three layers: the Logical Link Control (LLC) that provides a common interface to the upper layers, the Medium Access Control (MAC) that implements the access protocol to the transmission medium and the physical that manages the transfer of bits on the shared medium.

CAN uses non-return-to-zero (NRZ) bit representation with a bit stuffing of length five. This is required since the stations need to be synchronized and to do that a transition is required. So the transmitter inserts a stuff bit when it detects a sequence of five consecutive identical bits. The receiver will apply the inverse procedure and de-stuff the frame.

Since the medium is the same for all the transmitters in order to avoid collisions a priority-based communication method is used: the lowest message identifier, which is contained in the header field of the frame, has the highest priority.

The MAC layer in the CAN protocol present four possible frame types:

- DATA: carry information from source to destination;
- REMOTE: request for the transmission of a DATA frame from the destination;
- ERROR: informs all nodes that is identified an error on the bus;
- OVERLOAD: reserve the bus for some time.

The CAN protocol uses a data frame that consists of several fields, as depicted in 4.2. The first field is the arbitration field, which contains the identifier of the message, that can be composed by 11 bit in the standard version or by 29 bit in the extended one. The second field is the control field, which contains the length of the data field and the remote transmission request (RTR) bit. The third field is the data field, which can contain up to 8 bytes of data. The fourth field is the cyclic redundancy check (CRC) field, which is used to detect errors in the data frame. The final field is the acknowledgment field, which is used to confirm that the message was received correctly.

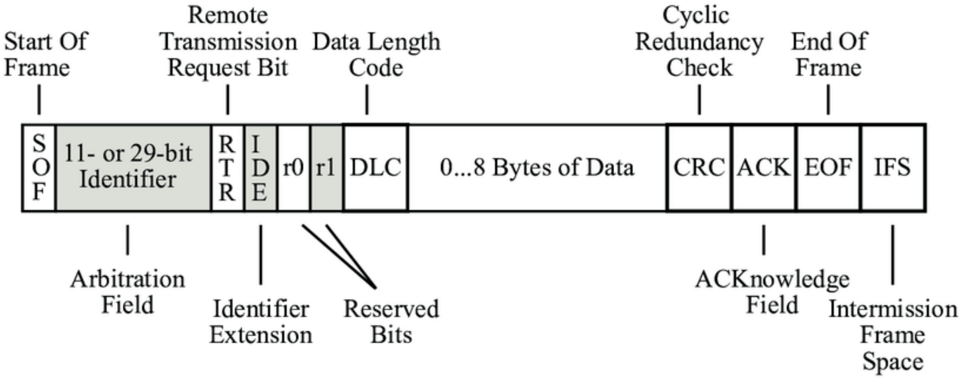

Figure 4.2: CAN Frame

The main benefit of CAN communication is that in the protocols there are more than one methods to check if the communication has been successful and therefore different errors can be detected:

1. bit error: if a recessive bit is received when sending a dominant bit;
2. stuff error: after five identical bits the sixth one is not changed;
3. form error: a fixed value bit in the frame has a wrong value;
4. Acknowledgment error: no ACK delimiter in the ACK field;
5. CRC error: the receiver CRC is different from the CRC in the frame.

When one of these errors is detected an error frame is sent an each station that detects an error sends an “error flag” which is a particular type of frame composed of six consecutive dominant bits that allows all the stations on the bus to be aware of the transmission error.

Concluding, the CAN protocol is one of the most used in automotive fields since the ECUs can communicate via a single system instead of complex signal lines reducing errors, wiring, and costs. The shared medium enables to have a central diagnostic point with data logging and configuration. The identifier methods used to avoid collision made the communication reliable and guarantee that the messages with higher importance are received first. [28]

A recent improvement of this protocol is CAN-FD, the last version of CAN network, with Flexible Data Rate. In this case the payload increases from 8 bytes of CAN to 64bytes. This reduces overload and increases efficiency.

4.1.3 Ethernet

Ethernet is a communication protocol that reaches data rates higher than 1Mbps and can connect 1024 nodes. In the bus topology configuration, it uses 1-persistent CSMA/CD: if a collision is detected the transmitting nodes send the jamming sequence and then become silent. All colliding nodes retry to transmit when the channel is sensed free again. Collisions can still occur due to the distance among simultaneously transmitting nodes, or due to the persistence parameter of the protocol.

To establish a connection between multiple nodes, a switch can be introduced in the system. Switches are layer 2 devices that receive Ethernet packets from their inputs, store and forward them to the correct output port according to a First Come First Serve (FCFS) policy. Therefore if devices are connected through switches collisions do not occur and the available bandwidth is shared between the switch and terminal.

The Ethernet frame structure is presented in the figure below (4.3) and briefly described below:

- Preamble: used to synchronize the signal between origin and destination;
- Start of Frame Delimiter: it is a 10101011 sequence which indicates the start of the frame;
- Destination and Source Address: indicate the address of the recipient and sender station respectively;
- Length: length of the next field;
- LLC-PDU: payload of the transmitted data;
- Pad: it guarantees a minimum length;
- Frame Check Sequence: it contains the Cyclic Redundancy Check (CRC) to check errors.

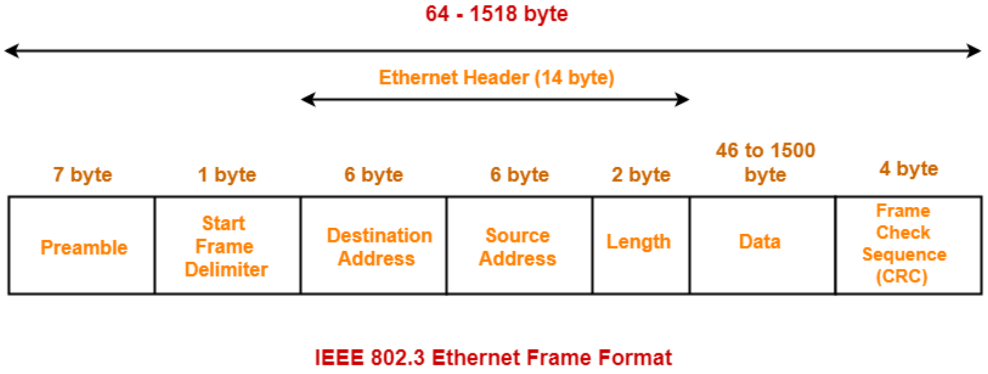

Figure 4.3: Ethernet Frame

Ethernet in cars The main problem of Ethernet communication protocol is the EMC (ElectroMagnetic Compatibility) of an Ethernet LAN with unshielded Twisted Pair wiring in a car. To guarantee compliance with automotive specifications Shielded Twisted Pairs (STP) cables must be used, this causes an increase in the costs of cables and connectors. Not all car networks can be built with these cables so a UTP-based solution should be found: a possible solution is Unshielded Twisted Single Pair (UTSP) from BMW.
The network topologies possibilities in automotive are different but the most used is the star topology, where all ECUs are connected to a central switch. Safety-critical application uses also ring topology, where Data travels from node to node, with each node along the way handling every packet.
Automotive ethernet has a base rate higher than 100mbps, which is comparatively much more cost-effective than other networking protocols. The wiring used in automotive ethernet for vehicles is much lighter and more efficient compared to traditional cabling used for in-vehicle connectivity. Light weighted wiring allows manufacturers to reduce connectivity costs up to 80% and weight up to 30%. [29]

4.1.4 RS232

This type of communication is not commonly used in the automotive environment but is inserted for completeness since the communication between the radar and the control unit will be performed using this technology, due to the fact that the decoding algorithm used is based on serial communication.
RS232 is a serial communication protocol, meaning that data is transmitted one bit at a time over a single communication line, therefore in order to establish two-way communication, we need at least three wires (RX, TX, and GND) apart from the control signals. The protocol supports a wide range of baud rates which allows for flexible communication speeds. RS232 uses asynchronous communication, so there

is no clock signal transmitted with the data, hence it uses start and stop bits to inform the receiver when to check for data. First, the transmitter sends a Start bit to the receiver to inform it that data transmission starts from the next bit. The Start bit is always '0'. The next 5 to 9 characters are data bits. If a parity bit is used, a maximum of 8 bits can be transmitted. If parity is not used, then 9 data bits can be transmitted. After the data is transmitted, the transmitter sends the stop bits. A byte of data can be transmitted at any time provided the previous byte has already been transmitted. The following image (4.4) shows the frame format of the RS232 protocol.
The protocol supports a number of control signals, including a request to send (RTS), clear to send (CTS), data terminal ready (DTR), and data set ready (DSR), which can be used for flow control and other purposes.

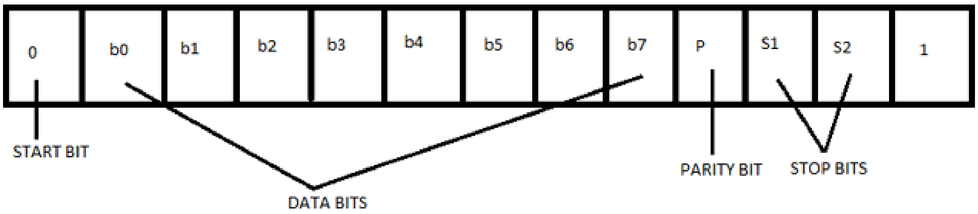

Figure 4.4: RS 232 Frame

The main drawbacks of RS232 are the limited maximum cable length of 15m (to avoid too much capacitance), making it unsuitable for communication over longer distances without the use of signal boosters or repeaters, and that the protocol does not provide error detection or correction, which can lead to data loss or corruption during transmission. Moreover, RS232 uses a non-standard voltage level for signaling, which can cause compatibility issues when connecting to devices with different voltage levels. [30]

4.2 Signals transmitted

Following the development of the simulation model of the system to be implemented, to ensure integration with the existing vehicle, it is necessary to identify which signals have to be communicated to the vehicle control units and which signals are instead needed as feedback from the latter.

Signals The first step to ensure compatibility between the existing system and the one to be integrated is to determine what signals are sent and received by the

different devices during their operation, to define the communication systems and, if CAN is used, the database of messages to be received and sent.
For this purpose, the Simulink model previously developed was analyzed to determine which signals must be sent from the existing vehicle to the dSpace processor to ensure the functioning of the control algorithm, and which signals are sent from the dSpace processor to the engine control units and the electric machine to implement the commands. The list also includes the signals received from the available sensors, which are sent to the processors that perform the processing of the information.
The list obtained is represented in the following table 4.1, which also indicates: the source of the signal, the range of the physical value communicated, and the resolution required to guarantee the functioning of the algorithm.

As visible from the table (Tab. 4.1) the signals used can be divided into three major families: the ones that are coming from the control units of the vehicle, the ones that are obtained through the sensors mounted on the vehicle, and the signals produced by the central processing unit on which the Simulink model will work.
The first category includes all the information coming from the engine control units, such as the engine rotation speed, but also other relevant information such as the vehicle speed and the gear engaged. Here are also present the signals from the control unit that is managing the electric machine and the battery: from the first, the main information is the rotation speed, instead from the second it is possible to retrieve the state-of-charge computed by the processing unit included in the battery management unit.
The signals coming from the sensors include information about the relative speed and relative velocity of the preceding vehicle, which are necessary to enable the cruise control functioning of the system. In the table are not inserted the signals coming from the stereo camera that will be mounted on the vehicle since all the information coming from this device will be processed by the Nvidia processing unit and sent to the central processing unit where the sensor fusion will be performed.
In the last category are included the signals produced by the model running on the processing unit. Two boolean signals enable the torque request to the electric machine and the ICE, which, if active receives the torque request computed on the basis of the information available from the system. Other relevant signals are the one enabling to turn off the engine during the start and stop function and the brake request to be sent to the brake pumps.
In the table is also listed the digital signal that will be provided by several buttons, which will activate the cruise control functioning.
The ranges visible in the table are derived from the characteristics of the components, for example the maximum and minimum rotation speed or the limits of the torque developable from the two propulsion means. The ones indicated for the

Signal	**Origin**	**Range**	**Resolution**
System activation	Digital input	boolean	/
Engine torque request enable	dSpace	boolean	/
Engine torque request	dSpace	0-350 Nm	1 Nm
Engine rotation speed	ICE	0-5000 rpm	1 rpm
Vehicle speed	TCU	0-200 km/h	1 km/h
Electric motor rotation speed	EM	0-4000 rpm	1 rpm
Electric motor torque request enable	dSpace	boolean	/
Electric motor torque request	dSpace	-220 – 220 Nm	1 Nm
Engaged gear	Transmission	0-8	1
Clutch command	Transmission	boolean	/
Battery State of Charge	Battery	0-100%	1%
Relative distance	Radar	0-150 m (MRR) 0-30 m (USRR)	0,68 m (MRR) 0,043 m (USRR)
Relative velocity	Radar	-40 – 40 m/s (MRR) -10 – 10m/s (USRR)	0,1 m/s (MRR) 0,32m/s (USRR)
Engine Stop command	dSpace	boolean	/
Brake pressure request	dSpace	/	/

Table 4.1: Signals transmitted

radar are obtained from their datasheets. The resolution instead is determined to be the minimum variance that is allowed to keep the system working properly.
The fundamental signals for the functioning of the algorithm are inherent to the engine and the electric machine, such as the rotation speed and torque requests. The dSpace processor, on the other hand, will send the torque requests to the vehicle control units also based on the information that will be available from the radar.

Communication methods used In this section, the methods of communication used to connect all the devices are briefly presented. The choice of them is performed based on the component's characteristics and the amount of information that must be transmitted by each of them. In the scheme below (Fig. 4.5) a graphical representation is given for clarity.

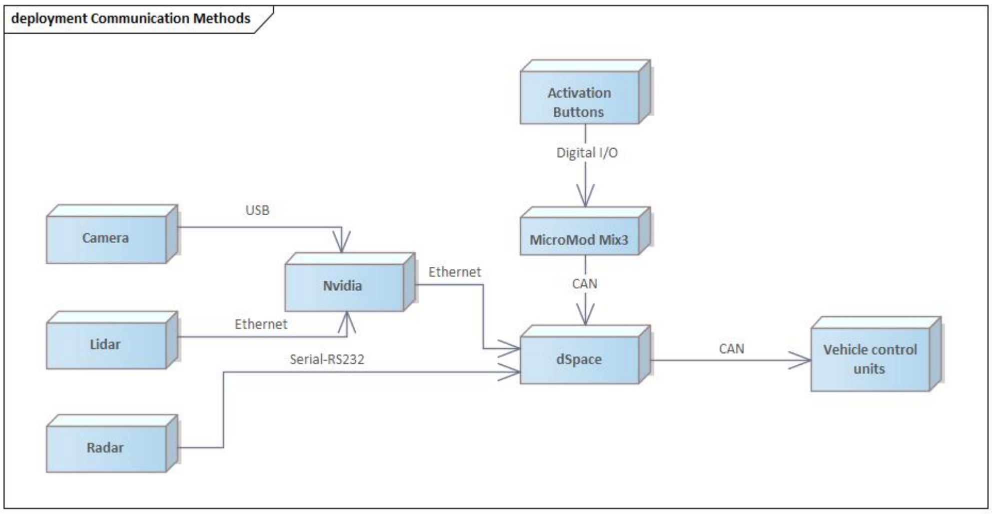

Figure 4.5: Communication methods

The starting point for the definition of the communication methods was related to the available ones on the vehicle: the control units already mounted are all connected through a CAN network, so the outputs of the control unit that compute the torque requests must be on this communication line.
Regarding the other components the choice is constrained by their characteristics, so the more convenient communication methods available on the device has been chosen. For the camera, a USB connection with the Nvidia processing unit is used, then the Nvidia exploits an ethernet connection to the dSpace to have a high data rate necessary for the amount of information to be transmitted.
The radar has different possibilities to connect with the processing units: both CAN and serial communication are available. The choice was made considering that the model developed for decoding the information coming from it has been based on serial communication, therefore, to avoid modifying it, a serial connection (using the standard RS-232) is selected.
The lidar, which application is still under development, is connected through a connection box, given with the product, with an ethernet and a power connectors.
Lastly, the buttons that will allow to activate and regulate the cruise control functioning, are connected using a digital input/output connection to the digital to CAN converter, to then reach the dSpace.

Chapter 5

Components Integration - Power supply

A step further in the integration between the existing systems and the ones to be implemented is the power-up of each new device. In particular, since this application is intended to be a research prototypal vehicle, the components used are not standard automotive elements, therefore it is necessary to provide each of them with the correct voltage levels to ensure their proper functioning.

5.1 Power Supply Relevance

Certification of the correct voltage level and consequently the delivered power is of great importance to get the best performance of all devices, especially sensors.

Radar and lidar systems play a critical role in the development of autonomous vehicles, and accurate detection of objects and obstacles in the environment is essential for their safe operation. For these systems to function properly, a stable and adequate power supply is required.

These systems rely on the generation and transmission of high-frequency radio waves or laser pulses to detect objects in the environment. Therefore their voltage power-up is critical as it determines the energy available to transmit the signals: if the voltage power is insufficient, the signals transmitted by the system will be weaker and less able to penetrate obstacles such as fog, rain, or snow, this will result in a reduction in the accuracy of the system and a higher rate of false detections, which can compromise the safety of the vehicle and its passengers. On the other hand, if the voltage power-up is too high, it may cause damage to the sensor and reduce its lifespan. Therefore, a stable voltage power-up is necessary to ensure that the sensor produces accurate readings.

To ensure the stability of the voltage power, it is necessary to use voltage regulators, which can maintain the voltage within a proper range, even in the presence of fluctuations in the input voltage. To sum up, voltage power-up is essential for the operation of radar and lidar systems since it controls the amount of energy available to send signals and the voltage stability. The precise identification of objects, the effective working of the system's components, and the general dependability and safety of the system all depend on having sufficient and stable voltage power.

5.2 Components characteristics

The first step in the determination of the power-up configuration of all the system's components is the definition of their characteristics. To do so, an analysis of the datasheets available for each device has been carried out to retrieve detailed electrical information. The result of this analysis is presented in the following table (Tab 5.1), where the individual devices are listed with the relative supply voltages. Finally, the current and power absorbed by each of them is included for subsequent consideration.

Component	**Type**	**Voltage level**	**Power absorption**
Camera	ZED Stereocamera 2	5V	2W (380 mA)
Lidar	Hesal Pandar XT-32	12V	30W (2.5A)
Radar	AWR1843	5V	10W (2A)
Nvidia	nVidia PX Pegasus	24V	40W (3.3A)
Processing unit	dSpace Scalexio Autobox	24V	170W (7A)
Digital to CAN converter	MicroMod Mix3	12V	720 mW (60mA)
IMU	SBG systems Ellipse-N	5V	600 mW (120mA)

Table 5.1: Component's characteristics

It is clearly visible that the voltage levels required are three: 5V for the camera and the radar, 12V for the Lidar and the MicroMod Mix3, and 24V for the two processing units, dSpace, and nVidia. Therefore, taking into account that once the vehicle has been hybridized it will have two batteries available: a 12V one already present in the vehicle and a 48V one included in the hybrid system, it is necessary to define which of the two would be more suitable as an energy source for devices installed in the vehicle. Analyzing the hybrid vehicle currently on the market, it was possible to notice that the main trend in the 48V application is to remove the 12V alternator and provide power to all the vehicle components using the electric machine as a generator.
The use of a 48V battery to power up the vehicle's devices provides several

advantages over a 12V battery. Starting from the 48V battery higher voltage, which means it can deliver more power to the vehicle's components, providing a more efficient and effective power-up. Secondly, the 48V battery is capable of handling higher current loads, which means it can support the power needs of the vehicle's components, such as the electric motor, more effectively.

In addition to the benefits of hybridization, the additional 48-volt system also makes it possible to operate a selection of electrical components in the vehicle at higher voltages. High-power components, such as compressors, pumps, or heaters, run more efficiently at higher voltages, and transferring them to the 48-volt onboard power system also reduces the load on the 12-volt system.

However, for electronics systems, a 12V battery is still used since most of these systems are standardized in the automotive environment. Moreover, for energy efficiency purposes it is recommended to split into two different harnesses the devices requiring high power and the ones working with lower power requests. The presence of a low-voltage battery allows also to disconnect the high-voltage battery from the rest of the system if the vehicle is not ready, for example in the case of an accident, the 12V provides a safety functions avoiding that circuits are under high-voltages.

From these analyses, it is determined that the 48V battery is selected to power up the added devices, while the 12V will provide power to the control units already on the vehicle. The possible configurations to obtain so, are presented in Section 5.3.2 [31] [32].

5.3 DC/DC converters configurations

After determining which are the voltage levels required by each component, in this section the different configurations of DC/DC converters that could satisfy the request from the batteries available on the vehicle are presented and the considerations leading to the choice of the definitive one are explained. In the first part, a brief basic introduction to DC/DC converters is included.

5.3.1 DC/DC Converter Basics

DC/DC converters are devices that are used to convert a direct current (DC) voltage into another DC voltage. They are widely used in various applications, including the automotive industry, where they play a crucial role in ensuring that electrical systems in vehicles operate efficiently and safely.

Buck and boost converters, the two basic types of DC/DC converters, are described along with their features, operating concepts, and applications in automotive systems.

Buck converters are designed to convert a higher voltage DC into a lower voltage

DC. These converters work by using a switch that is rapidly turned on and off, and an inductor that stores energy in the magnetic field when the switch is on and releases energy when the switch is off. The switch and inductor work together to create a series of voltage pulses that are filtered by a capacitor and transformed into a stable lower voltage DC output.

Boost converters, on the other hand, are designed to convert a lower voltage DC into a higher voltage DC. This is accomplished by storing energy in the magnetic field of an inductor, which is created when the switch is turned on, and then releasing that energy to the output when the switch is turned off. Also in this case, the inductor and switch work together to create a series of voltage pulses, which are filtered by a capacitor to produce a stable higher voltage DC output.

One of the key characteristics of DC/DC converters is their efficiency. The efficiency of a DC/DC converter is defined as the ratio of output power to input power. The higher the efficiency, the less energy is lost as heat, and the more energy is available to the load. This is important in automotive applications because it helps to reduce the power consumption of the electrical system and improves the fuel efficiency of the vehicle.

Another important characteristic of DC/DC converters is their stability. The stability of a DC/DC converter refers to its ability to maintain a constant output voltage level despite changes in the load or input voltage. This is essential in automotive applications because it helps to ensure that sensitive electronic components receive a consistent voltage level, even during periods of high electrical demand.

In conclusion, DC/DC converters play a critical role in ensuring that electrical systems in vehicles operate efficiently and safely. Buck converters are typically used for applications that require a lower voltage, such as in hybrid vehicles to connect the higher voltage wiring harnesses to the low voltage components commonly embedded in the vehicles. [33]

5.3.2 DC/DC Converters Layout

As noted above the added devices require different supply voltages which are not available in the original vehicle. This made it necessary to analyze possible configurations using DC/DC converters to obtain the required voltage levels.

The analyzed possibilities are represented in the pictures below:

It is evident that all three configurations require three different DC/DC converter devices since the voltages required are three. Comparing the datasheet of different converters it is possible to notice that the conversion efficiency from 48V to 24V and to 12V is higher than the conversion efficiency from 24V to 12V, therefore the first decision is to exclude the configuration 5.1, which is also unfavorable due to the low efficiency of the conversion from 24V to 5V. The decision between the

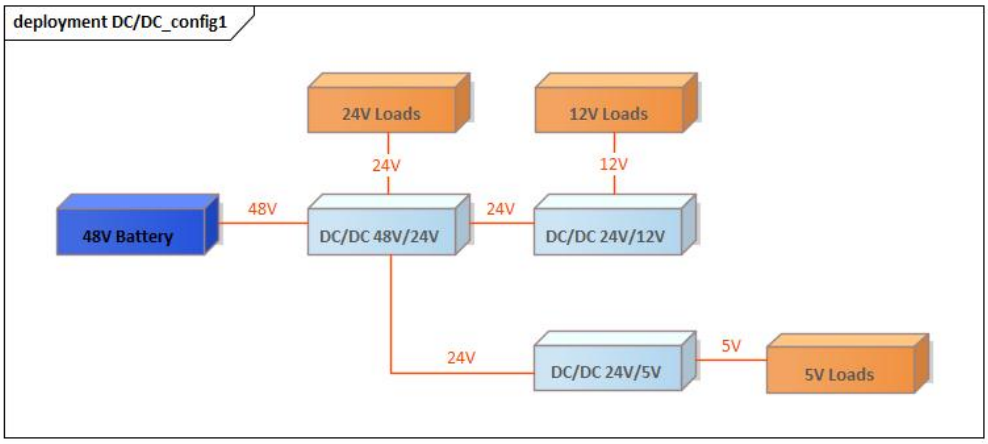

Figure 5.1: DC/DC Converters Layout 1

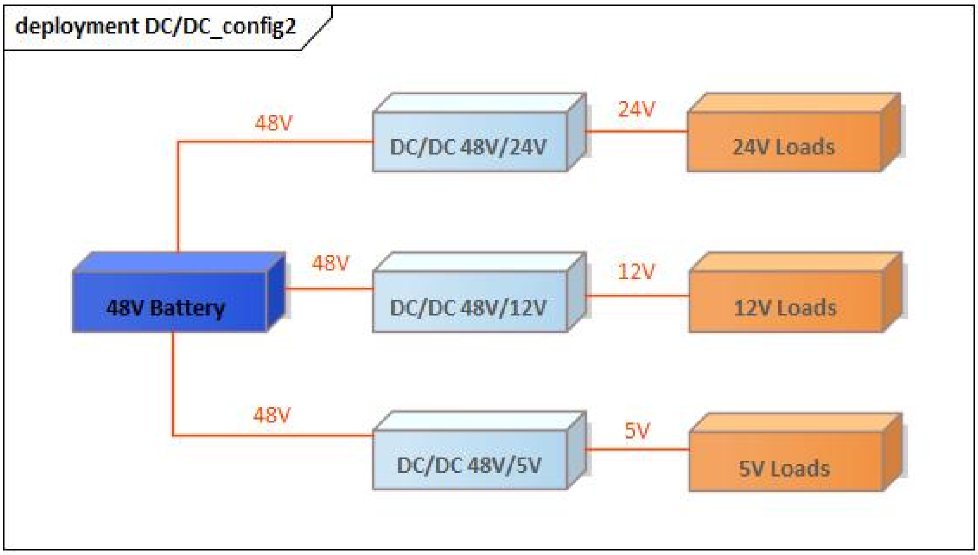

Figure 5.2: DC/DC Converters Layout 2

remaining two configurations was made based on two different considerations: one is a study developed in [34], where it is showed that to power up a Lidar the best configuration of converters is a hybrid one, with two steps of conversion; the second is the availability of converter from the supplier, which do not provide a converter from 48V directly to 5V.

The selected configuration is therefore 5.3, which includes three converters: one from 48V to 24V to power up the two processing units, one from 48V to 12V for the Lidar and the digital to CAN converter, and one from 12V to 5V for the remaining

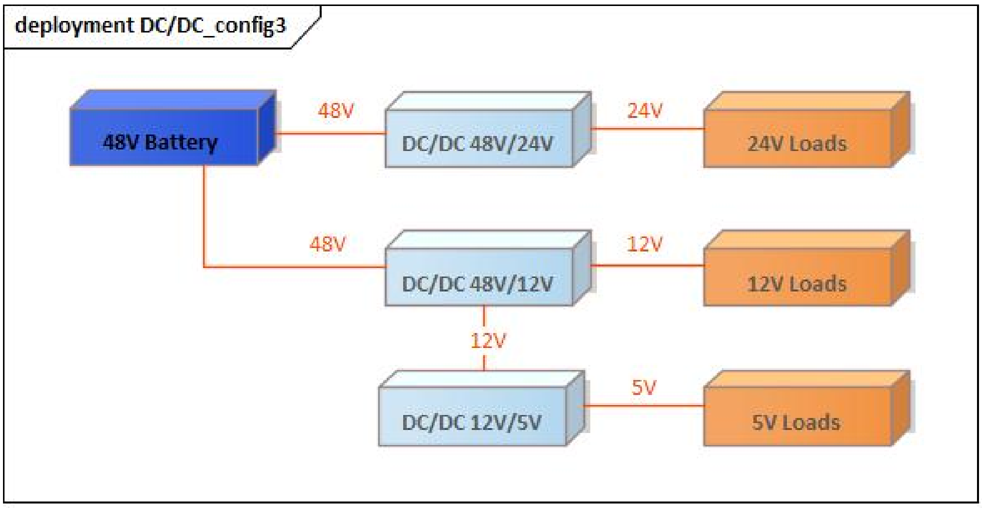

Figure 5.3: DC/DC Converters Layout 3

components. A further step performed was to consider that the camera and the IMU are directly powered by the USB connection with the nVidia, therefore they do not require a power supply from batteries.
This led to the decision to not include the DC/DC converter to 5V, at least in the current phase of the project, to keep the system as simple as possible and reduce the costs while the system is still under validation. The same reasoning was performed regarding the 12V devices, since the vehicle has already onboard a battery with this voltage, it will be used to validate the component.
In conclusion, the selected configuration for the definitive layout is the one in Figure 5.3, but in this phase, only the 24V converter is implemented, while other voltage levels are obtained from sources already on the vehicle [35].

Chapter 6

Vehicle electric schemes

The next step in the integration design of the new system is to draw the wiring harness electrical schematics for physical implementation. A few operations are required to achieve this. First, we need to determine the pinout of the component's connector. Next, get the power consumed by each component to define the cable size and fuse required to protect the system.

The result is a complete system wiring necessary for the technicians to set it up and implement it in the vehicle.

6.1 Component Pinout

To allow interchangeability and the correct working of connectors contacts, their function, whether signal or power, must be specified.

In electronics, connectors pinout is used to refer to each contacts its function. Connecting contacts with different functions can cause failure or damage, therefore when mating to connectors it is necessary to ensure that each pin on one mate with a pin on the other with the same function. Therefore, pinouts are an important criterion to build cables and connectors mating. In fact, given a particular wire in the cable, how it connects to the contact of the electrical connector defines the wiring scheme.

Moreover, in multi-pin connectors there are multiple ways to map wires to pins, so different configurations may be created that superficially look identical but function differently. This configuration needs to be defined in the pinouts in order to guarantee the functioning of the connection.

For these reasons each component included in the system is analyzed, recovering information about the pinout of their connector in order to list and insert them in a specific software (OrCAD Capture). With this software, it is possible to create the connectors starting from their pinout and insert them in an electric schematic.

6.2 Power absorption

In drawing an electric schematic, a crucial phase is defining the maximum power each component can handle. This is necessary because the current absorbed by the system is a fundamental parameter when defining cable and fuse dimensions.
Thus, for each element, the required information are retrieved from their datasheets. Results are summarized in the following section, along with some information about how ratings are determined.

6.2.1 Cable dimensioning

Cable dimensioning refers to the process of selecting the appropriate size of cable for an electrical system. The size of the cable is determined by the maximum current that will flow through the cable, the distance between the power source and the load, and the voltage drop that is acceptable for the system. The most commonly used parameter for cable dimensioning is the cross-sectional area of the conductor. Cable size has a significant impact on the performance and safety of an electrical system, so selecting the right size of cable is crucial to ensuring that the system works efficiently and safely.
The cross-sectional area of the conductor determines the amount of current that can flow through the cable without causing damage. The current carrying capacity of a cable is dependent on its temperature, which is influenced by the current flowing through the cable, the ambient temperature, and the insulation material used. As the temperature of the cable increases, the current carrying capacity decreases, so it is essential to choose a cable with a cross-sectional area that is large enough to accommodate the maximum expected current without overheating.
The voltage drop across the cable is also influenced by the impedance of the cable and the load. The impedance of the cable is a complex quantity that includes both resistance and reactance. The impedance of the cable and the load can have a significant impact on the voltage drop and the amount of current that can flow through the cable, so it is essential to choose a cable with a low impedance and a large cross-sectional area to minimize the voltage drop.
In addition to the cross-sectional area and impedance, the choice of cable material is also important for cable dimensioning. In order to achieve the best results in terms of resistance, reactance, and temperature characteristics, it is important to choose the right cable material according to the needs of the system. Among the most common materials used for electrical distribution cables are copper and aluminum, both of which have different characteristics of resistance, reactance, and temperature.
Another factor that must be considered when dimensioning cables is the ambient temperature of the environment in which the cable will be used. The ambient

temperature affects the temperature of the cable and the current carrying capacity, so it is important to choose a cable that is appropriate for the ambient temperature of the environment.

Finally, it is important to consider the standards and regulations that apply to the electrical system when dimensioning cables. The standards and regulations specify the minimum requirements for the cable size, insulation material, and current carrying capacity, so it is important to ensure that the cables used in the system comply with the applicable standards and regulations.

By taking these factors into account, it is possible to choose the appropriate size of cable for an electrical system, ensuring efficient and safe operation.

For this reason in the development of this project the AWG - American Wire Gauge standard for cable dimensioning, is used. This method allows, once the number of cores of the cable to be used has been established, to determine the diameter of the conductor inside the cable, based on the current that the components absorb from the line. In our application, 7-24 core cables were chosen and, using the standard's specific reference table, the sizing of the cables was identified as is listed in the table (Tab. 6.1) [36].

Component	**Maximum current required**	**AWG Rating**
dSpace	7A	16AWG
nVidia	1.6A	22AWG
Radar	2.5A	20AWG
Lidar	2.5A	20AWG
DVC251-48-24	8.6A	14AWG

Table 6.1: Cable AWG ratings

Regarding CAN, ethernet, and USB communication cables, they have been selected, considering that they are standard currently on the market, such as 24AWG.

6.2.2 Fuses

Other instruments to ensure the safe and efficient operation of the electrical system are fuses.

A fuse is a device that protects the system from overloading and short circuits by interrupting the flow of current when the current exceeds a predetermined level. The selection of the appropriate fuse is influenced by several factors, including the current rating, voltage rating, and environmental conditions.

Fuses work by interrupting the flow of current in the electrical system, using a piece of metal that melts when the current exceeds the predetermined level. The

fuse element is placed in a container that contains the metal and a fuse holder, which holds the fuse element in place.
The current rating of a fuse is the maximum current that the fuse can carry without melting. The current rating of a fuse must be chosen based on the maximum expected current in the electrical system. If the current rating of the fuse is too low, the fuse will frequently melt, interrupting the flow of current and causing inconvenience and inefficiency. On the other hand, if the current rating of the fuse is too high, the fuse will not protect the system from overloading and short circuits, which can result in damage to the system and pose a safety risk.
The voltage rating of a fuse is the maximum voltage that the fuse can withstand without breaking down. The voltage rating of a fuse must be chosen based on the voltage in the electrical system. If the voltage rating of the fuse is too low, the fuse will break down when exposed to the voltage, interrupting the flow of current and causing inconvenience and inefficiency. On the other hand, if the voltage rating of the fuse is too high, the fuse will not be effective in protecting the system.
A fuse's important characteristic is the time-current one, which determines how fast it responds to different overcurrents. All fuses have inverse time-current characteristics, so opening time decreases as overcurrents increase.
The environmental conditions of the electrical system also influence the selection of a fuse. Environmental conditions, such as temperature, can affect the performance of the fuse, so it is important to choose a fuse that is appropriate for the specific environmental conditions of the system. In fact, at higher ambient temperatures, a fuse will respond faster to a given overload. Conversely, at lower ambient temperatures, a fuse will respond slower to a given overload [37].
To protect the developed system a fuse box, containing fuses for the system, is included in the schematic. The fuse rating is established starting from the maximum current required by each component, considering also a safety factor of 25% (visible in table 6.2), and the fuses are selected from UniVAL Blade fuses commonly used in the automotive application.

Component	**Maximum current x1.25 SF**	**AWG Rating**
dSpace	9.3A	10A
nVidia	2.13A	3A
Radar	3.33A	4A
Lidar	3.33A	4A
DVC251-48-24	14A	15A
48V Battery	20A	20A

Table 6.2: Fuses Rating

6.3 Schematics

In this section, the resulting schematics ,drawn by means of OrCAD Cadence, are presented in the following figures (Fig. 6.1 and Fig. 6.2) and briefly discussed.

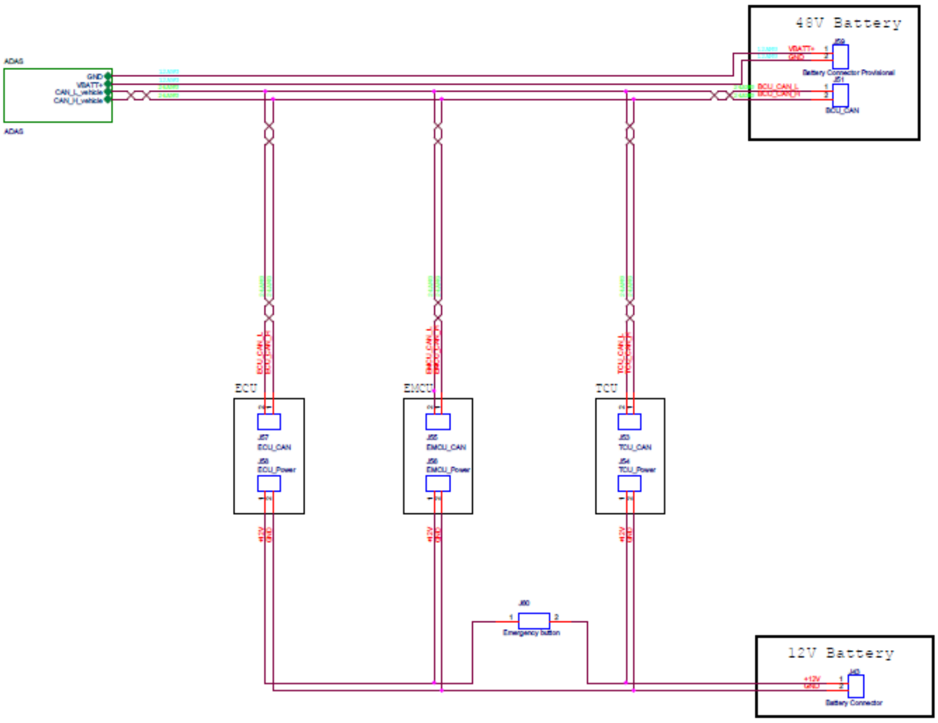

Figure 6.1: Vehicle Level Schematic

The diagram shows how from the 48V battery (indicated in the diagram at vehicle level) the power supply network connects to the DC/DC converters to obtain 24V voltages, since the 5V voltage required for some components will be implemented using another source and the 12V will be obtained exploiting the battery already available on the vehicle. The lines are then directed towards the sensors and are connected to the power connectors of the latter, of which the communication connectors are also inserted.
In this application the communication systems used are: Ethernet, CAN, and USB, as can be seen from the connectors used. The LIDAR is supplied with a "connection box", shown in the diagram, which houses an ethernet socket for communication, a DC power socket, and a GPS port (not used for this application); the sensor is connected to it via a cable and a specific connector.
The diagram also includes three digital buttons for controlling the functions, in

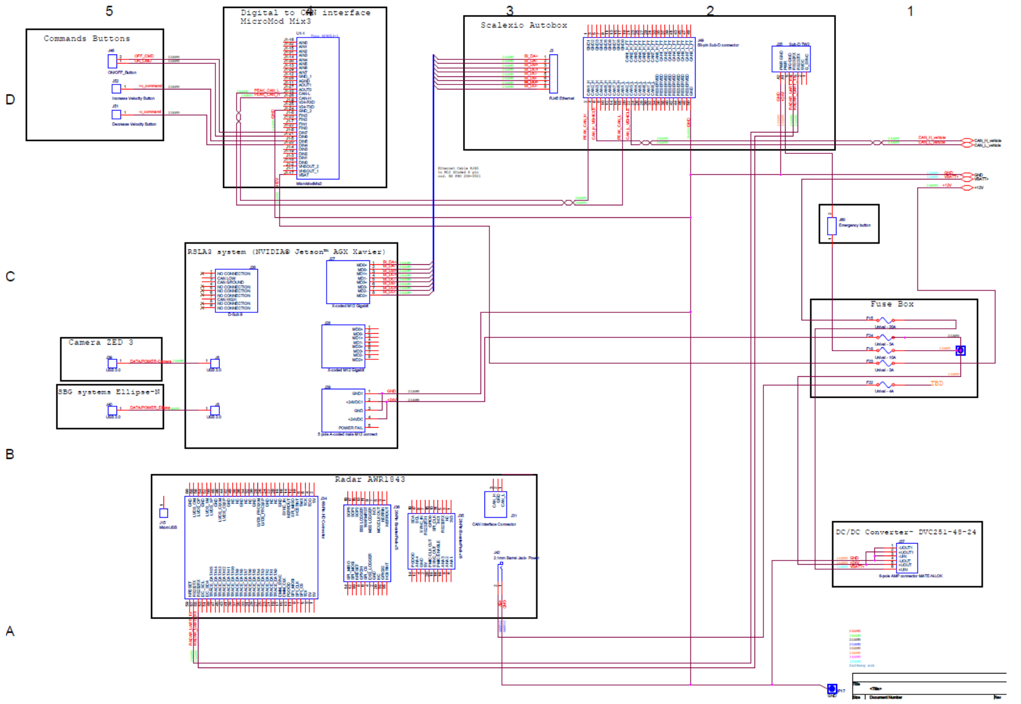

Figure 6.2: Sensors and ECUs Level Schematic

particular:

1. System activation/deactivation
2. Increase the set speed in case of operation in "Cruise Control"
3. Reduction of the set speed in case of operation in "Cruise Control"

For the functioning of these buttons, a digital signal to CAN signal converter has been inserted, it is a Peak MicroMod Mix 3, which allows to receive the digital signal from the buttons and convert it into a CAN signal to be sent to the dSpace processor. This component may not be necessary if there are digital ports available in the dSpace or if it is possible to convey the digital commands of the buttons on the vehicle, which originally command the native Cruise Control system.
Considering then that the system will be installed on board a prototype vehicle, two emergency button has been inserted one will intervene on the ECU and EMCU preventing any torque request from the thermal engine or the electric machine in the event of a malfunction of the control systems implemented, and the second one will cut the power supply to the dSpace to shut-down the system. This can be implemented by inserting a switch on the line that powers the control units and making sure that, in the event of no communication, the torque request is reset.

The fuses selected are placed to protect the system are placed before the DC/DC converter and before each sensor and processing unit, to avoid that in the event of overcurrent one of them is damaged.

The developed schematics are necessary to define the physical wiring that will be built and implemented on the vehicle by the technicians.

Chapter 7

Conclusions

This final chapter presents the current status of the project and the last section briefly discusses the next steps required to complete the project.

7.1 Current Status

Following the development of the schematic, an inspection of the vehicle was conducted to determine the length required for the wiring. With the help of a technician, the best solutions for the cable passages were determined and, as a result, the two schemes in the following images (Figures 7.1, 7.2) show how the cable will run from the sensors to the processing units in the cargo compartment.

For the radar, since it will be mounted on the front bumper where there is the predisposition for the optional radar for the vehicle, the cable will pass in the engine bay, then exploiting the existing trimming it will pass to the cabin, arriving in the area below the steering wheel. From here passing under the floor cover it will go to a passage that will be created in the panel separating the cabin from the cargo compartment.
Instead, for the camera, which will be mounted in the zone of the central rearview mirror, the cable will pass under the plastics of the ceiling and of the A-pillar to reach the zone of the steering will, starting from where the cable will join the radar one to run till the cargo compartment.
For both the element it is required to develop support for the prototypal vehicle to ensure that the sensors are detecting correctly the external environment. The radar will be equipped with support designed starting from the front bumper geometry that includes a region to fit the radar that the vehicle can equip as optional. The support will be produced using a professional 3D printer.

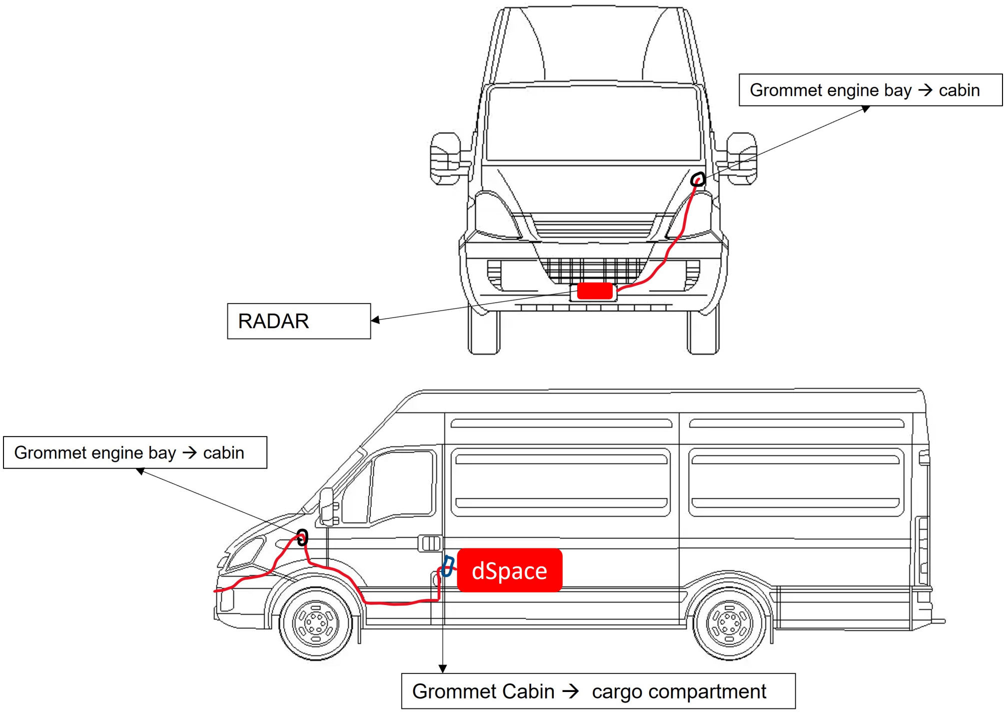

Figure 7.1: Wiring scheme for radar connection

Regarding the camera, since it will be mounted inside the vehicle, it is important to place it with the correct inclination with respect to the windshield to reduce possible reflections that will impair the data collected. To obtain the optimal result a support sized to fit the camera and with one of the sides inclined as the windshield, has been produced and is now under test to validate the solution.

7.2 Further development

The next to be performed to proceed with the project are: producing the wiring required for the connection of all the devices and with the existing cabling of the vehicle, mounting all the components on the vehicle, and testing the system to validate the results obtained in virtual simulations.
The first step is currently under development, starting from the collection of all the components required such as connectors and cable, it will continue to ensure that the complete cabling is ready for mounting when the vehicle will be at disposal of Podium after the implementation of the hybrid unit.
The testing will be performed after that the vehicle is completed and has the goal

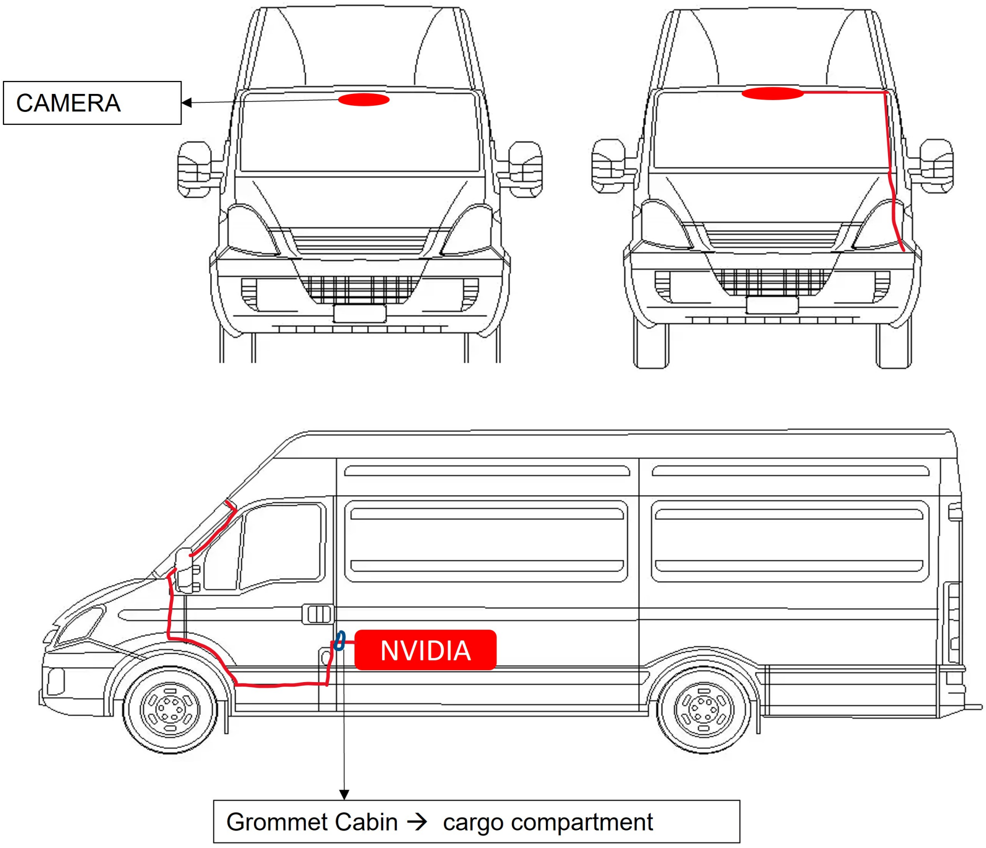

Figure 7.2: Wiring scheme for camera connection

to ensure that the integration between the components and the existing system has been perfectly obtained and that the whole system is stable. In the second part, the test will pass to the validation in the real world of the result obtained in simulation, to very that the system can guarantee the reduction in emissions expected.

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