FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Interface Development for a Conversion of an Electric Vehicle

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Resumo

Num mundo em que as restrições contra veículos poluentes continuam a aumentar, o veículo eléctrico sobe como a melhor alternativa. Embora o mercado de veículos eléctricos novos esteja a aumentar, ainda há uma pegada de carbono deixada pela sua produção, e o mesmo acontece com a eliminação de veículos antigos. Para ultrapassar isto, a conversão de um veículo a combustível fóssil pode ser uma solução: embora já reduza as emissões, também diminui a quantidade de resíduos criados quando os veículos de motor de combustão interna chegam ao fim das suas vidas.

Ao converter os automóveis convencionais com motores de combustão interna em veículos totalmente eléctricos, a falta de padronização dos principais componentes é um problema. Dado que cada automóvel terá características diferentes, e portanto componentes diferentes a serem instalados, a tarefa de ter compatibilidade total entre todos os dispositivos torna-se muito difícil.

A interface presente no painel de bordo é um componente crítico em qualquer veículo. Fornece informações importantes sobre o estado do veículo, tais como o estado da bateria, medições de temperatura e potência instantânea. Ao mesmo tempo, precisa de exibir informação de forma simples, para que o condutor esteja plenamente consciente do estado do veículo.

Esta dissertação irá descrever um processo de conversão de um Jaguar XK8 Supercharged 2001 em totalmente eléctrico, abordando cada componente principal que desempenha um papel na referida conversão. Os componentes estudados foram a bateria, o motor e o controlador, os carregadores e o dashboard. Após análise da documentação de cada um deles, foi então possível descobrir quais eram as mensagens CAN necessárias que transportavam a informação para o desenvolvimento de uma interface do dashboard do veículo. Isto foi concebido através do software OPUS Projektor, desenvolvido pela empresa Topcon, que também produz os ecrãs utilizados neste projecto.

A referida interface é capaz de mostrar ao condutor a tensão, corrente, potência, estado da carga (SOC), RPM, temperaturas e indicadores de falhas do Jaguar convertido, de uma forma clara e simples. Esta interface também é capaz de ser adaptada a outras conversões ou mesmo a novos projectos eléctricos personalizados, com apenas algumas modificações necessárias, mudando apenas o CAN ID dos dispositivos utilizados e elementos visuais.

Abstract

In a world where restrictions against polluting vehicle keep increasing, the electric vehicle rises as the best alternative. Even though the market for new electric vehicles is rising, there still is a carbon footprint left by their production, and the same happens with the disposal of old vehicles. To overcome this, converting a fossil fuel vehicle can be a solution: while already reducing the emissions, it also decreases the amount of waste created when ICE vehicles reach the end of their lives.

When converting conventional internal combustion engines cars to fully electric, the lack of standardization of the main components is an issue. Given that every car will have different characteristics, and therefore different components to be installed, the task of having full compatibility between all devices gets very difficult.

The interface present in the dashboard panel is a critical component in any vehicle. It provides important status information of the car, such as battery state of charge, temperature measurements and instant power. At the same time, it needs to display information in a simple way, for the driver to be fully aware of the status of the vehicle.

This dissertation will describe a process of converting a 2001 Jaguar XK8 Supercharged into fully electric, by approaching every main component that plays a role in said conversion. The studied components were the battery, motor and controller, chargers and the dashboard. After reviewing the documentation of each of them, it was then possible to find out what were the required CAN messages that carry the information for the development of an interface of the vehicle dashboard. This was designed through the OPUS Projektor software, developed by Topcon, that also makes the displays used in this project.

The said interface is capable of showing the driver the voltage, current, power, state-of-charge (SOC), RPM, temperatures and fault indicators of the converted Jaguar, in a clear and simple way. This interface is also able to be adapted to other conversions or even custom new electric projects, with only a few modifications necessary, mostly the CAN ID from the devices used.

Samenvatting

In een wereld waar de beperkingen tegen vervuilende voertuigen blijven toenemen, komt de elektrische auto als beste alternatief naar voren. Hoewel de markt voor nieuwe elektrische voertuigen toeneemt, laat hun productie nog steeds een ecologische voetafdruk achter. Hetzelfde gebeurt met de verwijdering van oude voertuigen. Om dit te ondervangen kan het ombouwen van een voertuig op fossiele brandstof een oplossing zijn: terwijl het de uitstoot al vermindert, vermindert het ook de hoeveelheid afval die ontstaat wanneer ICE-voertuigen het einde van hun levensduur bereiken.

Bij het ombouwen van conventionele auto's met verbrandingsmotor tot volledig elektrische auto's, is het gebrek aan standaardisatie van de belangrijkste onderdelen een probleem. Aangezien elke auto andere kenmerken heeft, en dus ook andere onderdelen die moeten worden geïnstalleerd, wordt het erg moeilijk om volledige compatibiliteit tussen alle apparaten te bereiken.

De interface in het dashboardpaneel is een kritisch onderdeel in elk voertuig. Het verschaft belangrijke statusinformatie over de auto, zoals de ladingstoestand van de accu, temperatuurmetingen en momentaan vermogen. Tegelijkertijd moet het de informatie op een eenvoudige manier weergeven, zodat de bestuurder volledig op de hoogte is van de status van het voertuig.

Deze dissertatie zal een proces beschrijven van het ombouwen van een 2001 Jaguar XK8 Supercharged naar een volledig elektrische auto, door alle hoofdcomponenten te benaderen die een rol spelen bij deze ombouw. De bestudeerde componenten zijn de batterij, de motor en de controller, de laders en het dashboard. Na het bekijken van de documentatie van elk van hen, was het vervolgens mogelijk om uit te vinden wat de vereiste CAN-berichten waren die de informatie dragen voor de ontwikkeling van een interface van het dashboard van het voertuig. Deze werd ontworpen met behulp van de OPUS Projektor software, ontwikkeld door Topcon, dat ook de in dit project gebruikte displays maakt.

De genoemde interface is in staat om de bestuurder op een duidelijke en eenvoudige manier de spanning, stroom, vermogen, laadtoestand (SOC), toerental, temperaturen en storingsindicatoren van de omgebouwde Jaguar te tonen. Deze interface kan ook worden aangepast aan andere conversies of zelfs aangepaste nieuwe elektrische projecten, met slechts een paar noodzakelijke wijzigingen, meestal de CAN ID van de gebruikte apparaten.

Acknowledgements

First and foremost, I would like to express my gratitude to my supervisor Professor Fernando Fontes, for his support throughout this dissertation, for the constructive criticism and handy suggestions. I would like to also thank my co-supervisor Celso Menaia, for all the patience and mentoring skills that contributed immensely to this thesis.

I extend my appreciation to all the New Electric staff for welcoming me with open arms and helping me in every step.

The final word goes to my family and friends, that showed unconditional support in this adventure, motivating and supporting me in all kind of ways.

Jorge Vieira

“Failure is the opportunity to begin again more intelligently.“

Henry Ford

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Abbreviations and Symbols

ICE	Internal Combustion Engine
EV	Electric Vehicle
NiMH	Nickel Metal Hydride
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
PLC	Programmable Logic Controller
BMS	Battery Management System
BMCU	Battery Management Central Unit
LMU	Local Monitoring Unit
EVCC	Electric Vehicle Charger Controller
SOC	State Of Charge
UI	User Interface

Chapter 1

Introduction

1.1 Motivation

Regarding the motivation for this dissertation, many factors had a role on it. The biggest one was undoubtedly the opportunity of developing it abroad, in the Netherlands, with such an uprising company like New Electric, in an environment where academic and business are combined.

After spending one year in Slovakia through the Erasmus+ program, my experience made me realize how important it is to leave the comfort zone and push yourself to new experiences. That leads to continuous research about an internship, preferably abroad, where I could get to know other cultures.

In a world where restrictions against polluting cars keep increasing, the electric vehicle (EV) rises as the best alternative. Even though the market for new electric vehicles is rising, there still is a carbon footprint left by their production, and the same happens with the disposal of old cars. To overcome this, converting a fossil fuel vehicle can be a solution: while already reducing the emissions, it also decreases the amount of waste created when cars reach the end of their lives.

Based in Amsterdam, New Electric has been converting all kinds of vessels and cars since 2008 and supplying complete drive trains for independent conversions. At the moment, they have already expanded to other cities in the Netherlands and also in Ireland.

1.2 Context and Objectives

When converting conventional ICE cars to fully electric, the lack of standardization of implemented components is an issue. Given that every vehicle will have different characteristics and therefore different components to be installed, having full compatibility between all devices gets very difficult. This applies specifically to the interface of the said vehicle since it combines information from several components.

This dissertation will describe a process of how to develop an interface from scratch that can be fully customized to each project, allowing more liberty when choosing parts to integrate in a converted EV.

This work presented here is the dissertation developed as part of the final project of the master's degree at the Faculdade de Engenharia da Universidade do Porto, regarding the specialization field of Renewable Energies.

The present dissertation has the following goals:

- Provide an overview on every main component responsible for the conversion of an electric vehicle;
- Determine which parameters are relevant for the interface of said EV;
- Develop the interface with a responsive UI and easily readable, giving room for future improvements.

This dissertation aims to provide an overview on how to convert an internal combustion engine (ICE) car to fully electric and specifically how to develop a completely customized interface for the said vehicle, after an overview of the state-of-the-art. It is also the objective for the said interface to be flexible, being able to adapt it to other projects with different components.

1.3 Dissertation Outline

The dissertation is organized as follows:

The present Chapter 1 contains a general outline of the dissertation scope. It introduces the dissertation, exposing the context and motivation for the project and the objectives.

Chapter 2 contains the state-of-the-art about EVs, their batteries and what kind of communication takes control of said vehicles. Also, it will specifically disclose the current situation about EV conversion and the state of the development of interfaces that reveal important information for the driver.

Chapter 3 presents the process of conversion of a Jaguar XK8, and with a focus on the three main components: motor, battery, and charger. It will present the configuration necessary for a seamless operation of the vehicle and overcome possible obstacles that can appear with the conversion.

Chapter 4 dives into the main focus of the dissertation by presenting the development of an interface for a dashboard of the Jaguar. It will first approach the research of the already existing material and then explain the choices implemented and the process for reaching a final version.

Chapter 5 summarizes the main outputs and also the conclusions that were obtained. It will consider other methods and different «concepts that can be utilized as a way of improving the obtained results, as well as possible adversities. For Future Improvements, it will cover some research subjects that can be further introduced.

Chapter 2

Electric Vehicle State of the Art

This chapter exposes the state-of-the-art of EV history and the evolution of the main components such as the battery, vehicle communication and dashboard. It also describes the background of converted electrical vehicles and their interface.

2.1 Electric Vehicle History

There is a common misconception of how EVs emerged since they first appeared in the mid-19th century. They came long before the ICE sort and there were many attempts to make them the leading choice of transportation during the years.

After some motorized carriages that contained non-rechargeable batteries (making them not viable), English inventor Thomas Parker built the first production EV in Wolverhampton in 1884, as visible in the Figure 2.1.

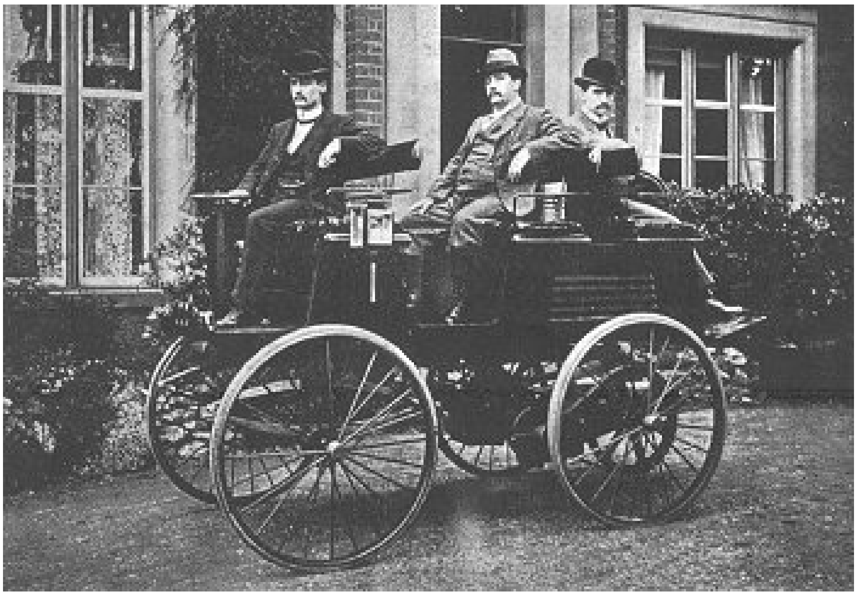


Figure 2.1: One of Thomas Parker's early vehicles. Figure taken from [1]

In the United States, William Morrison, a Scottish chemist living in Des Moines, Iowa, United States, came up with an electric carriage with front-wheel drive, 4 HP and a top speed of 23 km/h. It had a 24 cell battery that needed charging every 80 miles.

After the success at the beginning of the 20th century, the EV began to lose relevance in the automobile market and consequently the rise of the ICE vehicle, due to several reasons:

- The improved road infrastructure reduced travel times, which lead to the need and development of vehicles with a greater range;
- The invention of the electric starter by Charles Kettering in 1921 also eliminated the need for the hand starting crank in an ICE vehicle, which was sometimes dangerous;
- Worldwide discoveries of large petroleum reserves that led to the wide availability of inexpensive gasoline;
- The beginning of mass production of gas-powered vehicles by Henry Ford lead to a significant price reduction.

With the emergence of the metal-oxide-semiconductor field-effect transistor (MOSFET), it was then possible to develop a power MOSFET, designed to handle significant power levels, by Hitachi in 1969. This technology, combined with a generic microcontroller, a single-chip microprocessor, led to significant advances in several industries, including the vehicle one. The MOSFET enabled operations at much higher switching frequencies, reduced power losses at a cheaper cost when compared to previous EVs, while the microcontroller made it possible, for example, to manage the battery and monitor drive control.

In 2010 the Nissan Leaf, as shown in the Figure 2.2, was introduced in Japan and the United States, becoming the first modern all-electric five-door hatchback with zero emissions to be mass-produced by a major manufacturer. It was listed as the all-time best-selling electric passenger vehicle until December 2019.

Figure 2.2: 2017 Nissan LEAF. Figure taken from [2]

Currently, Tesla is ranked as the best-selling manufacturer of plug-in and battery electric passenger vehicles globally [21]. After developing the Roadster, Model S and Model X, the American company created the Model 3, exposed in the Figure 2.3, cheaper when compared to previous Tesla vehicles, and with a direction towards the mass market. Now, it is the world's best-selling plug-in EV ever, surpassing the Nissan Leaf [22].

Figure 2.3: Tesla Model 3. Figure taken from [3]

2.2 Batteries

An electric-vehicle battery, or traction battery, is designed to have a high power-to-weight ratio, specific energy and energy density, in order to provide power over sustained periods of time.

2.2.1 Lead-Acid

The first type of energy storage for EVs was the lead-acid battery, invented in 1859 by Gaston Planté, a French physicist. Due to its low price and simplicity to use, it was the most common battery in the beginning of EV history. They are still used in ICE vehicles, providing the high current necessary required by the starter motor.

For electric vehicles, instead of a regular engine starter battery that is appropriate for combustion engines, usually they require a deep cycle (or flooded) battery, suitable for longer periods of discharging. Although sometimes it's possible to find some vehicles with regular lead-acid batteries.

The characteristics of a typical flooded lead-acid battery are presented in the Table 2.1.

Table 2.1: Technical Specifications of the Flooded Lead-Acid Battery. Table taken from [16]

Nominal Cell Voltage (V)	2.1
Specific Energy (Wh/kg)	35-40
Energy Density (Wh/L)	80-90

The Table 2.2 contains some advantages and disadvantages of the lead-acid battery:

Table 2.2: Advantages and disadvantages of the Lead-Acid Battery

Advantages	**Disadvantages**
Inexpensive and simple to manufacture; Low self-discharge; Good behaviour in low and high temperature.	Low specific energy; Charges slowly; Limited lifespan; Toxic to the environment.

The Figure 2.4 shows an example of a lead-acid battery.

Figure 2.4: Lead-Acid Battery from Varta

2.2.2 Nickel Metal Hydride

Research on nickel-metal-hydride started in 1967. However, instabilities with the metal-hydride led to the development of the nickel-hydrogen (NiH) instead. New hydride alloys discovered in the 1980s eventually improved the stability issues and today NiMH provides 40 percent higher specific energy than the standard NiCd [23]. These batteries replaced their predecessor, nickel-cadmium, due to a much superior capacity, energy density and memmory effect.

The characteristics of the nickel-metal hydride battery are present in the Table 2.3.

Table 2.3: Technical Specifications of the NiMH Battery. Table taken from [17]

Nominal Cell Voltage (V)	1.2
Specific Energy (Wh/kg)	70-100
Energy Density (Wh/L)	170-420

The Table 2.4 contains some advantages and disadvantages of the NiMH battery:

Table 2.4: Advantages and disadvantages of the NiMH Battery

Advantages	Disadvantages
Friendly to the environment; Safe storage and transport; Good behaviour in low and high temperature.	Limited lifespan; High self-discharge; Sensitive to overcharging; Generates heat while fast charging.

This technology has proved to be a good option for EV. Considering only its life expectancy, it proves itself to be a much better option compared with lead-acid technology. It was widely used in first-generation hybrid vehicles like the Toyota Prius, which is shown in the Figure 2.5, and curiously still used in the present days, in vehicles such as the hybrid 2020 Toyota Highlander.

Figure 2.5: The high-power NiMH battery of a Toyota Prius. Figure taken from [4]

2.2.3 Lithium-ion

The first commercial non-rechargeable lithium battery appeared in the early 1970s. There were attempts to develop rechargeable ones in the 1980s, but they were revealed to be highly unstable due to the lithium metal used as an electrode.

Then, based on earlier research by Rachid Yazami, M. Stanley Whittingham, John Goodenough and Koichi Mizushima in the 1970s, a prototype Li-ion battery was developed by Akira Yoshino. A commercial version was later developed by Sony and Asahi Kasei, in 1991.

The main advantage of the li-ion batteries lies in the high cell voltage and higher specific energy when compared to other technologies.

The Table 2.5 contains some advantages and disadvantages of the NiMH battery:

Table 2.5: Advantages and disadvantages of the Li-ion Battery

Advantages	**Disadvantages**
High specific energy; Long lifespan; Low self discharge; High capacity; No memory; No need for exercising (full discharge).	Needs protection against overheating; Not safe to ship overseas; Can't quick charge in freezing temperatures.

The specifications of the li-ion battery are present in the Table 2.6.

Table 2.6: Technical Specifications of the Li-ion Battery. Table taken from [18]

Nominal Cell Voltage (V)	3.6
Specific Energy (Wh/kg)	200-260
Energy Density (Wh/L)	170-693

While lithium-ion batteries were initially developed for consumer electronics at first, their long life cycle and superior energy density made them the de facto choice for EVs. Recent EVs are now using variants of the li-ion technology that achieve higher durability, are less risk-prone to fire and even environmentally safer. However, these variants sacrifice specific power and energy. In the Figure 2.6 it is possible to see the cross-section of a Nissan Leaf's battery pack.

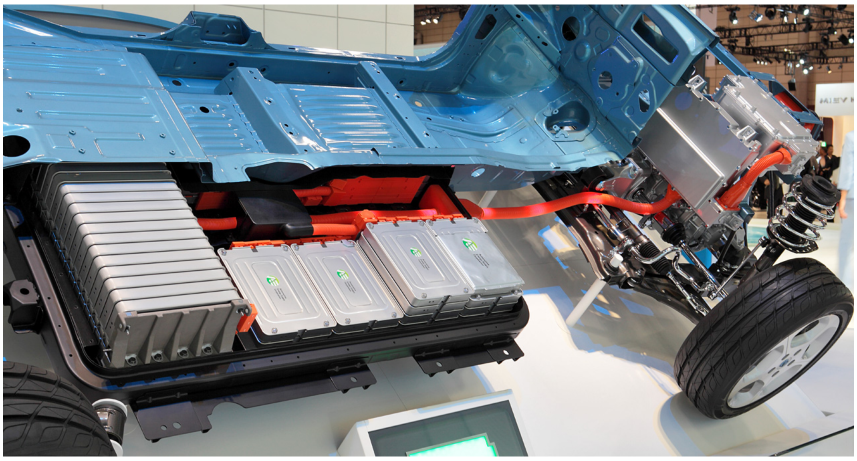


Figure 2.6: Nissan Leaf's Li-ion battery pack. Figure taken from. Table [5]

2.2.4 Solid-State Batteries

Even though Li-ion and NiMH are the most common type of batteries, both energy storage systems have several limitations that create the need for developing a superior solution.

The current li-ion technology uses a graphite anode and a liquid electrolyte, reducing its specific energy. With solid-state technology, pure lithium replaces the graphite and a solid polymer or ceramics replace the liquid electrolyte. It should be mentioned that this technology is somewhat similar to the early development of the lithium-polymer in the 1970s, that was discontinued due to performance and safety reasons.

Solid-state battery advantages include an expected to deliver 2.5 times higher energy density and less volatile and toxic components are involved. It is also predicted that solid-state will allow for faster charging.

A study from Maria Helena Braga, Chandrasekar M. Subramaniyam, Andrew J. Murchison, and John B. Goodenough [19] allowed to demonstrate in an early state the potential of this new type of technology. The Table 2.7 contains a comparison between li-ion and solid-state batteries.

Table 2.7: Electrochemical Characteristics of Different Classes. Table taken from [19]

Cathode	**Theoretical Capacity (mAh g^{-1})**	**Experimental capacity (mAh g^{-1})**	**Experimental Average Voltage (V)**	**Experimental Specific Energy (Wh kh^{-1})**
$LiNi_{1/2}Mn_{3/2}O_4$ (liquid electrolyte)	147	135 (cutoff: 3.5 V), first cycle	4.7 (cutoff: 3.5 V), first cycle	635 (cutoff: 3.5 V), first cycle
$LiNi_{1/2}Mn_{3/2}O_{3.8}F_{0.2}$ (glass electrolyte)	114	224 (cutoff: 3.5 V), cycle 308	3.8 (cutoff: 3.5 V), cycle 308	908 (cutoff: 3.5 V), cycle 308

An all-solid-state rechargeable battery cell with a lithium anode and a conventional oxide host as the active material of the cathode can provide a low cost, high voltage, room-temperature cell of high gravimetric energy density, fast charge and discharge, and long cycle life [19].

BMW [24] has already declared interest in this type of technology, stating in 2021 that their development aims for making solid-state suitable for use in road vehicles by the end of the decade.

2.3 European Charging Standards

The charging equipment plays a critical role for EV development: only with a good structure and easy access is it possible to use an EV daily. Their configuration depends on the frequency, voltage and standards of the country where they are located.

2.3.1 European Standards

To avoid a vast amount of different adapters and cables for EV charging, the European Commission demanded a standard to be set. At the same time, this decision would promote the internal EV market and prevent manufacturers from creating market barriers.

Today's standards related to charging, plugs, and sockets are contained in the IEC 61851 [13]-[14]. This standard classifies a type of charger based on its rated power and recharges time:

- Slow charging, with a rated power of 3.7kW or less, mostly from a regular domestic outlet;
- Quick charging, from 3.7 kW to 22 kW, provided by a charging station;
- Fast charging, superior to 22kW, available in public charging stations.

The Table 2.8 summarizes the electrical ratings defined in IEC 61851:

Table 2.8: Electrical Ratings of Different EVs Charge Methods in Europe. Table taken from [20]

Charge Method	**Connection**	**Power (kW)**	**Max Current (A)**	**Location**
Normal Power	Single-Phase AC	3.7	10-16	Domestic
Medium Power	Single or Three-Phase AC	3.7-22	16-32	Semi-Public
High power	Three-Phase AC	>22	>32	Public
	DC	>22	>3225	Public

2.3.1.1 Charging modes

The IEC 61851 [13]-[14] also defined four modes of charging related to the type of power received: DC, single or three-phase, the charging voltage and the presence of grounding and communication between the vehicle and the charging station:

- Mode 1: slow charging in AC, with a regular household outlet;
- Mode 2: slow charging in AC, also with a regular household outlet but provided with an in-cable protection and control device;
- Mode 3: slow or fast charging in AC, with a specific socket for EV and included protection, control and communication abilities;
- Mode 4: fast charging in DC, with an external charger.

These modes are represented in the Figure 2.7.

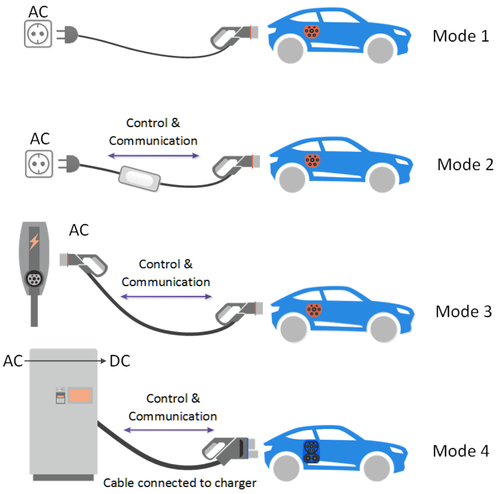


Figure 2.7: The four charging modes. Figure taken from [6]

2.3.1.2 Connectors

The EV charging connector or standard type of plug varies across region and models (as shown in the Figure 2.8):

- Type 1 (SAE J1772) - AC single-phase vehicle coupler, a North American standard;
- Type 2 (Mennekes) - AC single-phase vehicle coupler, an Europe standard;
- CCS (Combined Charging System) - combines either Type 1 or Type 2 AC connectors with DC fast charging;
- CHAdeMO - DC fast charging standard created in Japan.

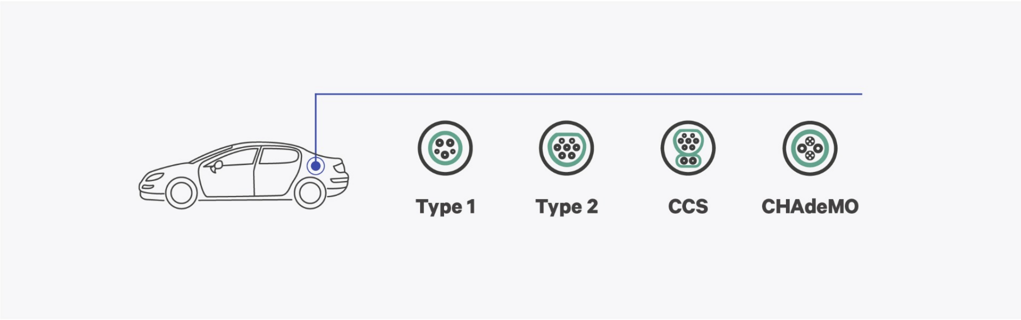


Figure 2.8: The four plugs. Figure taken from [7]

2.4 Controller Area Network

Automotive manufacturers used to connect electronic devices through individual point-to-point wiring. The increase of electronic devices in vehicles lead to bulky wire harnesses that became expensive and heavy. Therefore, a need for a structured network arose, and Robert Bosch GmbH invented the Controller Area Network bus protocol. The automotive industry quickly adopted the high-integrity serial bus system and became the international standard as ISO 11898. The essence of the vehicle communication before and after CAN is displayed in the Figure 2.9.

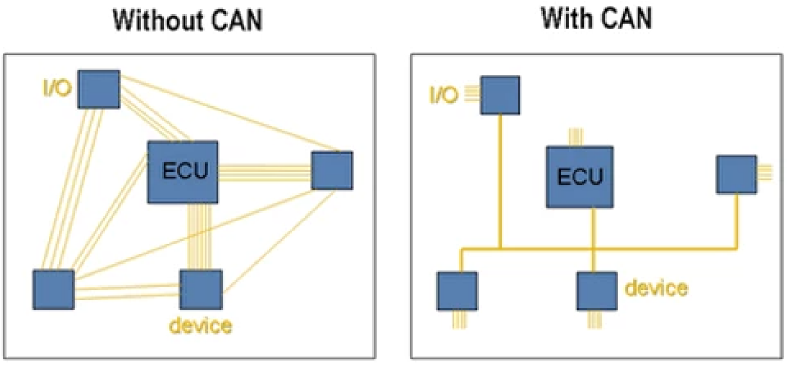


Figure 2.9: Advantages of the CAN protocol. Figure taken from [8]

CAN bus is now used in almost every kind of vehicle due to its benefits, such as:

- **Low-cost and simple** - the Electronic Control Unit (ECU) communicates with each node through a single system, reducing errors and costs;
- **Centralized** - all the data is easily accessible for diagnostics, logging and configuration;
- **Efficient** - every message has its own priority, and therefore there is no interruption in communication;
- **Error detection** - CAN messages carry a Cyclic Redundancy Code (CRC) that performs error checking, allowing nodes to stop transmitting errors or simply disconnecting from the network.

As an example, the Figure 2.10 shows how a CAN Frame looks like, with the 11 bits identifier, the type that is used in most vehicles.

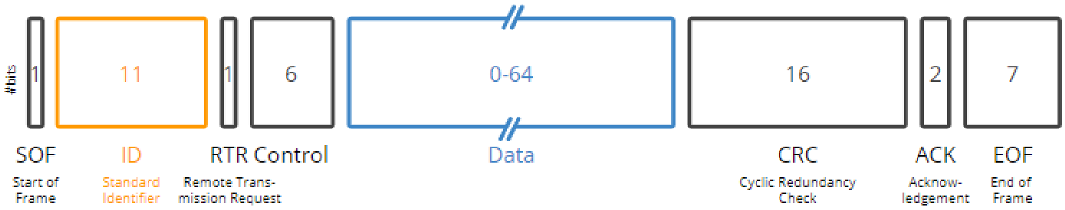


Figure 2.10: Standard CAN Frame. Figure taken from [9]

Each message field can be further developed as followed in the Table 2.9:

Table 2.9: Description of a CAN Frame

Message	Description
SOF (Start of Frame)	Tells other nodes that a node intends to talk
ID	Frame identifier, defining the priority
RTR (Remote Transmission Request)	Indicates if the node is sending or requesting data
Control	Contains the IDE (Identifier Extension Bit) and the DLC (Data Length Code)
Data	Payloads that can be extracted and decoded for information
CRC (Cyclic Redundancy Check)	Provides data integrity verification
ACK (Acknowledgement)	Verifies if the node has received the data correctly
EOF (End Of Frame)	Signals the end of the message

The CAN bus has a maximum speed of 1 Mbit/second, even though the most common baud rates are 250 and 500 kbit/s.

2.5 Electric Vehicle Conversion

Even though the EV is getting increasingly popular, the conversion development is somewhat scarce and not trusted by the average person. Most of the online documentation is purely academic, only with the purpose of proof of concept, and therefore vehicles with minimal range and power.

In 2012, a vehicle was converted to electric in the Universiti Teknikal Malasya Melaka [25]. The developed EV had 13 unit modules of Lithium Polymer (LiPo) battery with a nominal voltage of 7.5 V with a total up of 97.5 V when connected in series, an induction motor with 50 hp rated horsepower and able to deliver 110 Nm torque during its operation.

The Figure 2.11 contains the converted EV developed:

Figure 2.11: Developed Electric Vehicle. Figure taken from

Later in 2008, another conversion project occurred in Portugal, called CEPIUM [10]. The project had three main initial objectives. The first one was to have a vehicle that would be following the Portuguese legislation, the second objective was to circulate between the two campuses of Guimarães and Braga, and the last objective was only to integrate new technologies whose design and implementation were developed inside the research group.

The AFIR-S permanent magnet synchronous motor (as shown in the Figure 2.12) was used in this conversion, bringing high efficiency and power density, reduced size, high power factor and low maintenance costs.

Figure 2.12: AFIR-S Motor used in the CEPIUM. Figure taken from [10]

Since one of the aforementioned objectives was integrating technologies inside the research group, the controller for the motor was developed, which includes a three phase inverter, a digital control system, one monitoring panel, and some data acquisitions and protection systems. The Figure 2.13 illustrates said controller.

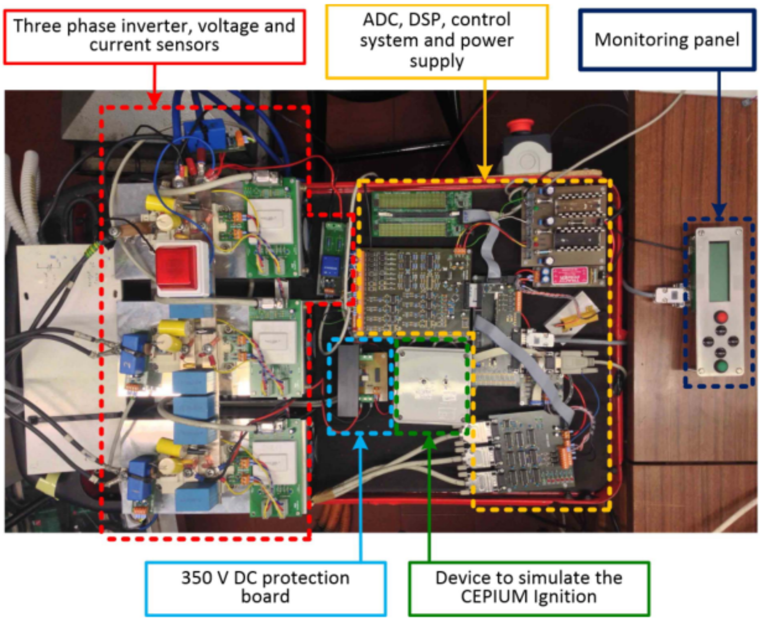


Figure 2.13: Developed AFIR-S motor controller. Figure taken from [10]

In an early state of the project, the of the CEPIUM conversion were made of Absorbed Glass Matt (AGM), due to its reduced weight, increased energy density, improved reliability, and lower cost. The battery pack had the capacity of 6.7 kWh.

The Figure 2.14 illustrates the finished product of the project.

Figure 2.14: Final look of the converted vehicle. Figure taken from [10]

From these two projects, we can conclude that, while very important from a development point of view, these vehicles were not ready for being transformed into an end product, available to a consumer who wishes to convert the vehicle into fully electric.

2.6 Interface Development

2.6.1 Conventional Electric Vehicle

The interface development for a commercial EV has been growing alongside the improvements of the car itself. These cars generally don't have an analog instrument cluster like a standard ICE vehicle, making it easier to behave more dynamically when showing information to the driver. As an example, the Figure 2.15 contains the dashboard of the 2010 Nissan Leaf, one of the first conventional EVs of the modern era.

Figure 2.15: Dashboard of the 2010 Nissan Leaf. Figure taken from [11]

Most recently, Tesla has been combining their interfaces in two displays: one as a digital instrument cluster, where it shows the crucial information about the vehicle, and a centered dashboard with a big display, containing a varied set of controls regarding heating, seat positioning, multimedia and map navigation. With a very functional and intuitive UI, combined with a high-resolution display, it is one of the most advanced interfaces in the market. The Figure 2.16 illustrates both displays in the 2021 Tesla Model X.

Figure 2.16: Dashboard of the 2021 Tesla Model X. Figure taken from [12]

2.6.2 Converted Electric Vehicle

The interface development for the dashboard of a converted EV has not evolved as gracefully as it did for conventional EVs. Only recently, the displays available in the market started having proper specifications for more complex graphical elements and calculations. This could be also explained by the high number of components available to use in the conversion, making it impossible to create a standard. Another reason lies in the fact that, as stated in the Chapter 2.5, the conversion paradigm has been primarily academic, where the interface only needs to be functional, making the UI not that relevant for the project.

The development of a dashboard for an electric Ligier microcar, in 2011, will be used as an example [13]. After a first implementation using a small hand-held device (Palm Pilot), the development suffered several limitations: small screen, low processing power and limited memory. For this reason, it was then decided to utilize a full-fledged computer. The Figure 2.17 illustrates the final state of the developed dashboard.

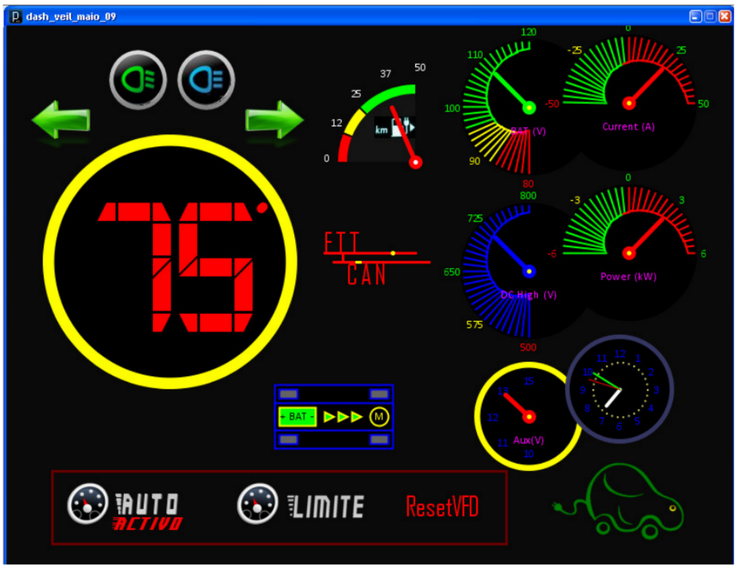


Figure 2.17: Dashboard of the Ligier Microcar. Figure taken from [13]

Although it is functional, it is not convenient to carry a desktop-sized computer inside a vehicle to obtain information from it. The interface itself has a straightforward UI, which would require several modifications for a final product for consumer use.

Another dashboard was developed in 2014 [14], for a Corsa-EV that showed some improvements from a UI perspective. It was developed in LabVIEW. The Figure 2.18 represents the main dashboard view.

Figure 2.18: Dashboard of the Corsa-EV. Figure taken from [14]

Chapter 3

Conversion of an Electric Vehicle

This chapter aims to expose the conversion of a client's vehicle used for the development of the interface, in order to grasp an understanding of the components involved. The client requested New Electric for this vehicle to be fully converted to electric.

3.1 Vehicle

The vehicle used for the conversion was a 2001 Jaguar XKR Supercharged (as shown in the Figure 3.1), a two-door coupé. This model was launched in 1996, being the first generation of the XK series. Originally, the Jaguar had a 216 kW (or 290 hp) peak power engine [26], and a sophisticated CATS (Computer Active Technology Suspension), that can be summarized as an active dampening of the suspension according to the speed of the car.

Figure 3.1: 2001 Jaguar XKR Supercharged

3.2 Motor and Controller

The motor installed in the Jaguar was a squirrel cage induction Siemens 1PV5135-4WS14 AC, with a continuous power rating of 50 kW and a voltage rating of 215 V. Given the company's past experience with this motor, it was also decided to change the transmission to a model with better integration with it. However, it was, in fact, convenient that the original model also had an automatic gearbox, which made it possible to keep the original gear lever. Both the motor and the transmission module are visible in the Figure 3.2.

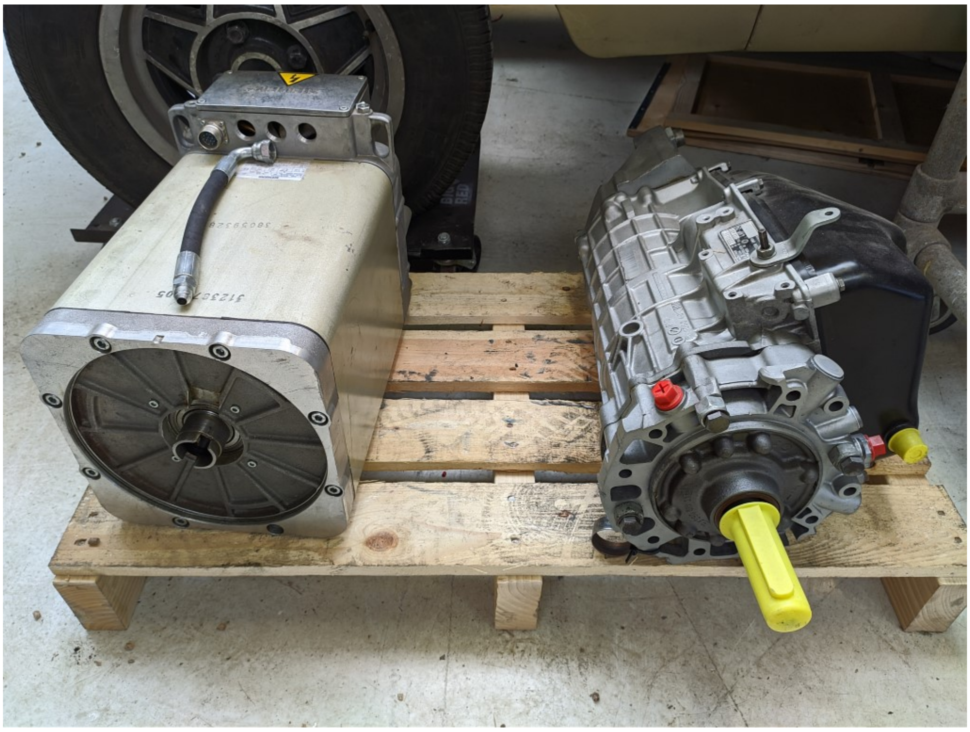


Figure 3.2: Motor and transmission before installed in the vehicle

The test data of the motor is available in the Appendix A.

With the motor installed, it was later necessary to install a controller that can regulate the speed, enable start and stop functions, limit torque, and protect against electrical faults. The device chosen was a SEVCON Gen4 (datasheet available in the Appendix B. According to the manufacturer [27], these are the main features:

- Advanced motor control algorithms;
- AC induction motor support;
- Up to 400V DC supply voltage;
- Up to 100kW peak power output;
- Up to 60kW of continuous power output;

- Includes an additional dedicated safety supervisory processor;
- Dual processing and conform to automotive safety standards;
- IP66 Protection;
- Advanced flux vector control for minimal power consumption;
- Regenerative braking allowing reduced battery power consumption;

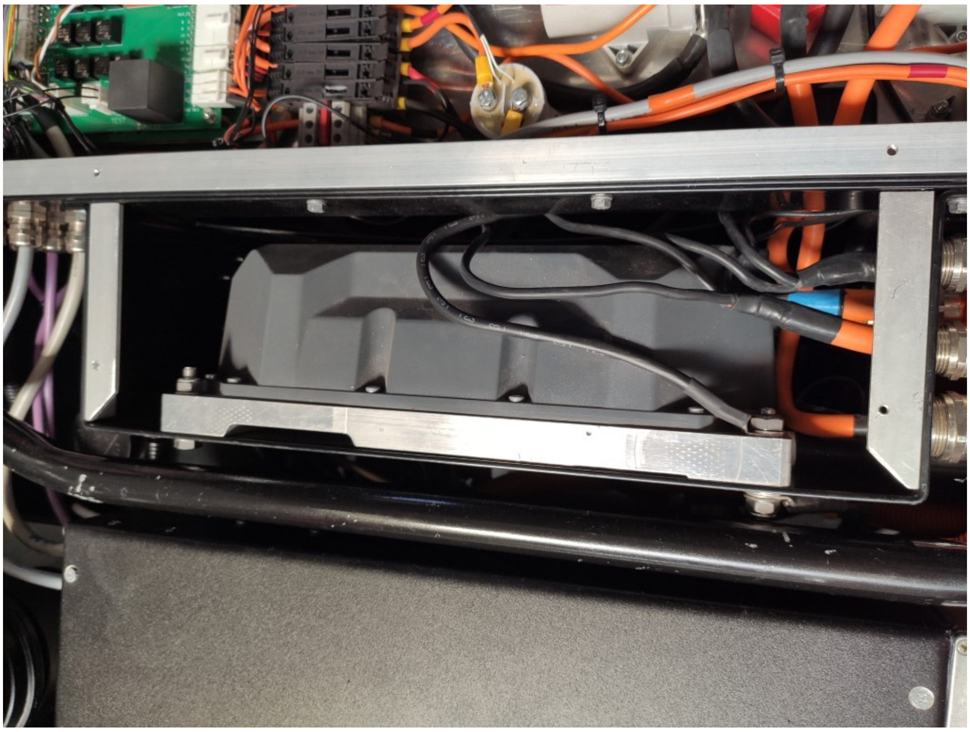


Figure 3.3: SEVCON installed in the front of the vehicle, inside a metal frame

3.3 Battery and BMS

The BMS consists of a BMCU (Battery Management Control Unit) master board that communicates with the Local Monitoring Units (LMU). They monitor individual voltages of 3 to 8 cells. These units were provided by Lithium Balance, a Danish company specialized in management systems for lithium batteries. The included datasheet is available in the Appendix C.

With each module having 16 LG li-ion cells, it was installed six strings of five modules each, making a total of 50 kWh of batteries spread out in the front and back of the EV. They were be distributed evenly through the vehicle, so it does not compromise it is dynamic behavior. The configuration is visible in the Figure 3.4.

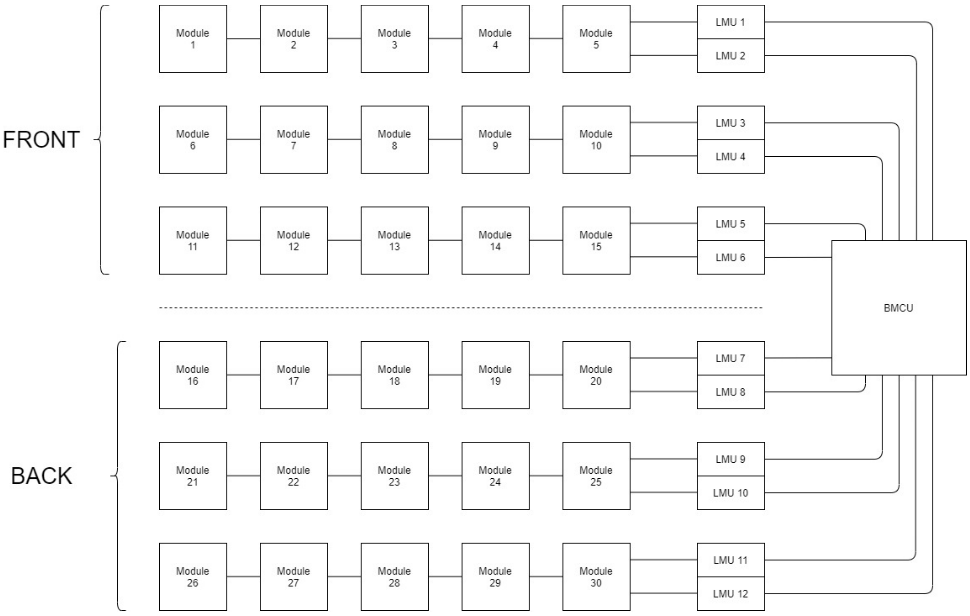


Figure 3.4: Scheme of the configuration of the batteries in the vehicle

After installing the batteries, it could be seen through the Lithium Balance software that the cells were not completely balanced, which should be fixed automatically by the BMS. This results in a significant difference between the average cell and the highest or lowest cell voltage. The cells in question were charged manually to circumvent this issue, approximating them to the average value. This was done by connecting them to an external charger to the front of the vehicle, while reading the measured voltage from the multimeter.

In the Figure 3.5 and 3.6 it is possible to see both battery packs, as well as the LMUs and BMCU installed in the front.

Figure 3.5: Pack of batteries installed in the back of the vehicle

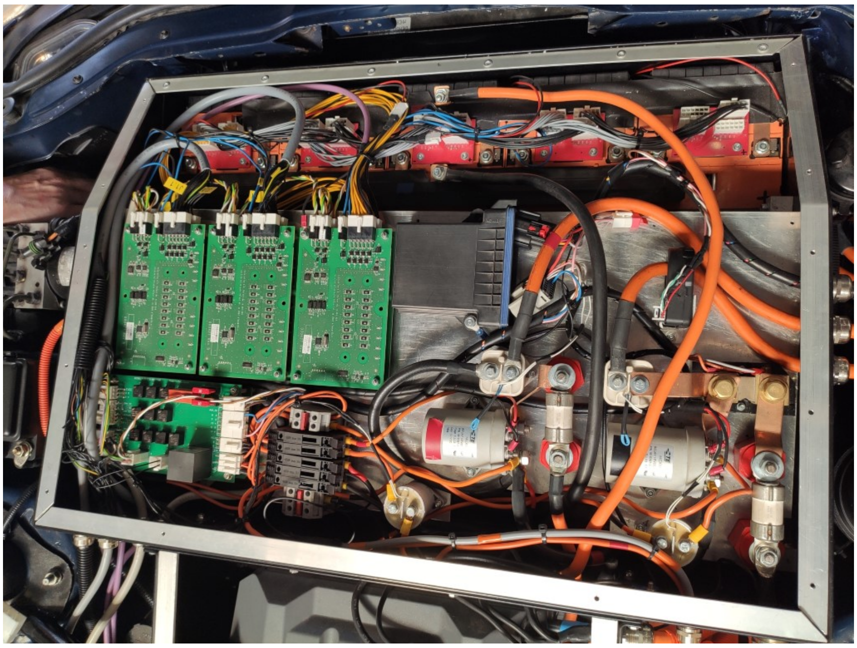


Figure 3.6: Pack of batteries and BMS installed in the front the vehicle

Finally, after a few tests, it was determined that the range of this electric vehicle would be around 150 km. This value takes into account the weight of the vehicle, weather conditions, efficiency of the motor and controller, and most importantly, the installed capacity of the batteries.

The 12 V lead-acid battery was not replaced since it is necessary for critical devices. To maintain the battery, a DC/DC converter replaced the alternator powered from the battery, which made charging from the traction battery possible. It was also necessary to add a PLC to measure the voltage of the battery.

3.4 Chargers

Three onboard battery chargers from TCCH were installed in the back of the vehicle (one per phase), providing single or three-phase charging, with each having 3.3 kW of power. The Appendix D contains the datasheet of the said chargers.

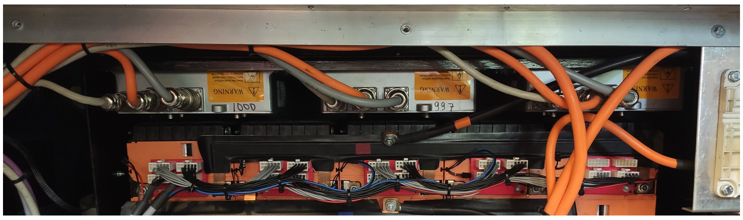


Figure 3.7: AC Chargers installed in the back of the vehicle

These chargers are controlled by the Electric Car Charge Controller (EVCC) from Thunderstruck, visible in the Figure 3.8.

The EVCC [28] integrates charger CANBUS control and J1772 functionality in a simple to use, cost-effective enclosure. Charge parameters such as maximum voltage, maximum current, and total charge time are configured, saved in nonvolatile memory, and used when charging to control a charger. Since the EVCC uses CAN communication, it uses approximately 45 mA from a 12 VDC source while in charge mode. Charger output for lithium is adjustable for current, maximum voltage, maximum charging time and termination current.

Figure 3.8: EVCC mounted in the back of the Jaguar

3.5 Sockets

It was equipped with a Type 2 charging port for AC charging (as shown in the Figure 3.9), installed in the previous location of the gasoline filler cap, and a CHAdeMO port (Figure 3.10) for fast charging, in the front of the vehicle.

Figure 3.9: Type 2 socket, for AC charging

Figure 3.10: CHAdeMO socket for fast charging

3.6 Mounting dashboard

Since there was some available space above the console of the Jaguar, a cutout was made to install the dashboard screen, visible in the Figure 3.11:

Figure 3.11: Dashboard already mounted in the vehicle

There was some testing done beforehand to see if the display was bright and visible sideways, most notably from the driver's perspective. For convenience, a USB extender was added to the dashboard, leading to the glove compartment. This was done to make it easier to flash new firmware of the interface since otherwise, it would be impossible to reach the side USB port of the display.

Chapter 4

Interface Development

This chapter formally presents the step-by-step development of the interface, as well as detailed explanations for each decision made.

4.1 Interface Preparation and Research

Firstly, it is essential to clarify the difference between dashboard and interface. The dashboard is considered to be a display loaded with software that makes it functional, while the interface represents the software and visual UI presented in said display.

The dashboard is one of the critical components of the electric vehicle. The driver must know how much SoC and some measurements such as temperature readings, fault indicators, and instant power drawn.

An important question needs to be asked beforehand: why the need to develop an interface? The answer lies in the fact that there is no present standard besides the use of CAN for in-vehicle communication. The multitude of choices available for components to be used in the conversion makes it impossible to do so, causing the need for an interface to be developed instead of buying some off the shelf product.

In this particular conversion, since the vehicle was previously using fossil fuels, it already possessed an instrument cluster able to show speed at a more convenient location when compared to the dashboard in the center console.

The next step of development was deciding the parameters to be added to the dashboard. After the research was done for electric vehicle dashboards, documented in Section 2.6, the elements chosen to be displayed in the interface were as follows:

- Voltage of the battery (V);
- Current drawn to the battery (A);
- Power (kW);
- Battery percentage (SOC);

- Motor RPM;
- Controller temperature (ºC);
- Motor temperature (ºC);
- Fault indicator;
- Ready for driving status;
- 12V battery voltage (V).

To be able to present every information in the dashboard, it is necessary to find out the address of each CAN message and give instructions for the interface to listen to them.

After converting the vehicle, there are three devices responsible for sending the appropriate messages: the BMS, the PLC and the SEVCON. All of these elements were configured and documented beforehand, so it was as simple as identifying the necessary messages, as showed in the Table 4.1.

Table 4.1: CAN Messages for the BMS

Variable	**Group**	**Owner**	**CAN ID**	**Data Type**	**Min**	**Max**	**Scaling**
Battery voltage (V)	BMS CAN	PC_Client	0x401	Unsigned16	0	1000	0.1
Battery current (A)	BMS CAN		0x401	Integer16	-10000	10000	0.1
SOC (%)	BMS CAN		0x401	Unsigned8	0	100	1
Error Flag (IO6)	BMS CAN		0x402	Boolean	0	1	1
12V (V)	PLC		0x406	Unsigned16	0	65355	1
Motor Temperature (ºC)	SEVCON		0x104	Integer16	-50	250	1
Controller Temperature (ºC)	SEVCON		0x104	Integer8	-128	127	1
RPM	SEVCON		0x104	Integer32	-128	127	0.1

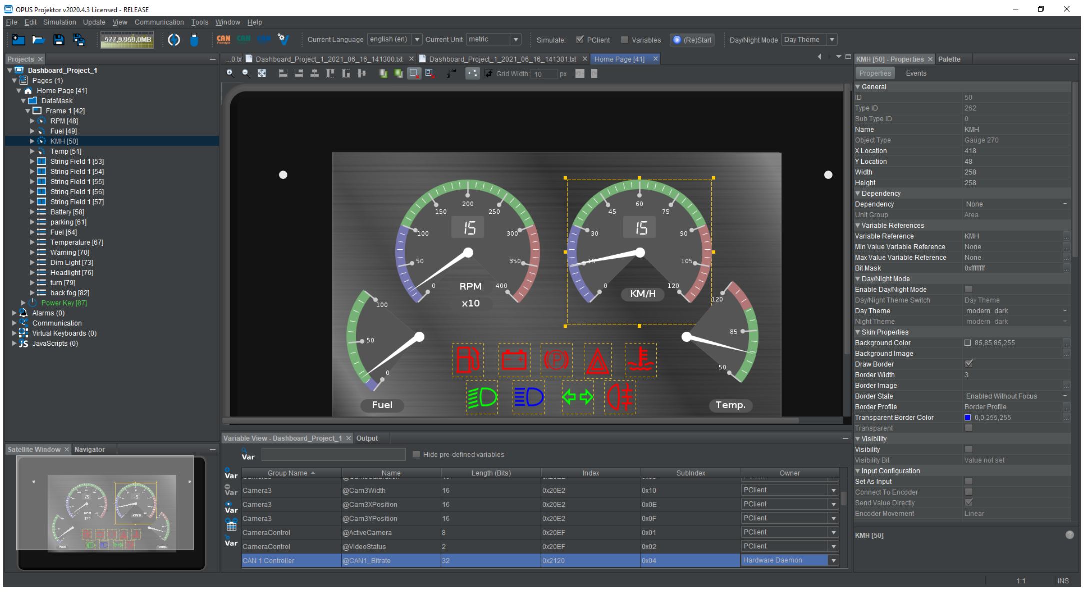
The display used for this project was the OPUS B3 (as shown in the Figure 4.1) from Topcon. It has a capacitive touch TFT Color Graphic LCD with LED back-lighting, a resolution of 800x480 pixels and supports all the CAN bus speed used in the vehicle. The 12 V battery is what provides power to the display. The datasheet is available in the Appendix E.

Figure 4.1: OPUS B3 Display. Figure taken from [15]

4.2 Development

4.2.1 Software

The software used for the interface development is called OPUS Projektor, developed by Topcon. It has a user-friendly graphical interface, completely customizable, and a possibility for JavaScript for more complex manipulation of objects or calculations. This played a major role in the choice of the display.



Variable View - Dashboard_Project_1

Group Name	Name	Length (Bits)	Index	SubIndex	Owner
Camera3	@Cam3Width	16	0x20E2	0x10	PClient
Camera3	@Cam3XPosition	16	0x20E2	0x0E	PClient
Camera3	@Cam3YPosition	16	0x20E2	0x0F	PClient
CameraControl	@ActiveCamera	8	0x20EF	0x01	PClient
CameraControl	@VideoStatus	2	0x20EF	0x02	PClient
CAN 1 Controller	@CAN1_Bitrate	32	0x2120	0x04	Hardware Daemon

KMH [50] - Properties

General	
ID	50
Type ID	262
Sub Type ID	0
Name	KMH
Object Type	Gauge 270
X Location	418
Y Location	48
Width	258
Height	258
Dependency	
Dependency	None
Unit Group	Area
Variable References	
Variable Reference	KMH
Min Value Variable Reference	None
Max Value Variable Reference	None
Bit Mask	0xffffffff
Day/Night Mode	
Enable Day/Night Mode	☐
Day/Night Theme Switch	Day Theme
Day Theme	modern dark
Night Theme	modern dark
Skin Properties	
Background Color	85,85,85,255
Background Image	
Draw Border	☑
Border Width	3
Border Image	
Border State	Enabled Without Focus
Border Profile	Border Profile
Transparent Border Color	0,0,255,255
Transparent	☐
Visibility	
Visibility	☐
Visibility Bit	Value not set
Input Configuration	
Set As Input	☐
Connect To Encoder	☐
Send Value Directly	☑
Encoder Movement	Linear

Figure 4.2: OPUS Projektor example project

4.2.2 Parameters and Configuration

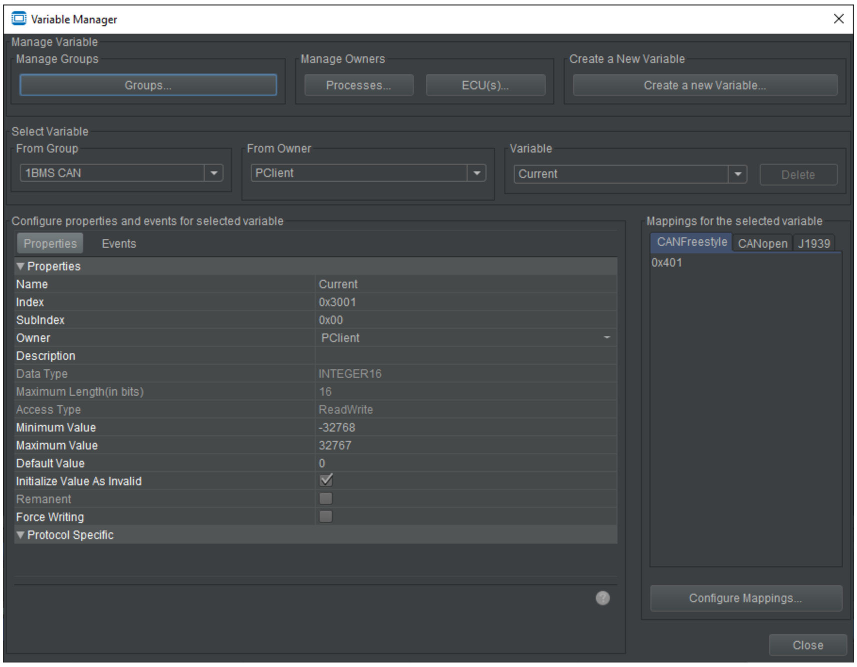
The first step was to add the variables to the project within the Variable Manager, saving them in the display's memory.

Each variable gets the following properties assigned:

- **Name**;
- **Index**: an address for memory management from the interface side;
- **Subindex**: usually 0x00, changes if the bit size of the variable is so small that it is possible to assign two variables to the same index but different subindex;
- **Owner**: every custom variable requires to be owned by "PC Client" to the interface to be able to access it;
- **Data type**: depends on the type of variable, could be a boolean (true or false), integer (supports negative values) or unsigned (doesn't support negative values);

- **Maximum length**: goes from 1 to 32 bits;
- **Minimum value**;
- **Maximum value**;
- **Default value**;
- **Initialize value as invalid**: useful for detecting errors if there is no CAN bus communication;
- **CAN ID**: the address for the received message;

As an example, the Figure 4.3 was included for further clarification:



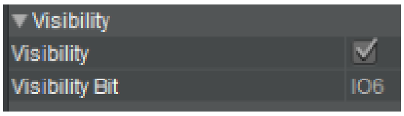
From Group: 1BMS CAN
From Owner: PClient
Variable: Current

▼ Properties	
Name	Current
Index	0x3001
SubIndex	0x00
Owner	PClient
Description	
Data Type	INTEGER16
Maximum Length(in bits)	16
Access Type	ReadWrite
Minimum Value	-32768
Maximum Value	32767
Default Value	0
Initialize Value As Invalid	☑
Remanent	☐
Force Writing	☐
▼ Protocol Specific	

CANFreestyle: 0x401

Figure 4.3: Editing prompt of the Current variable

The Fault Error function was implemented through the "Visibility" property, which is possible to attribute to a visual element, and that said element will only appear if the associated variable contains a value different than 0. This proved to be very useful because the "Error Flag (IO6)" works the same way: if there is some fault present in the vehicle, the variable will have a value different from 0, making it visible in the display. If it is 0, it will be invisible, telling the driver that all systems are working correctly. This option is visible in the Figure 4.4.



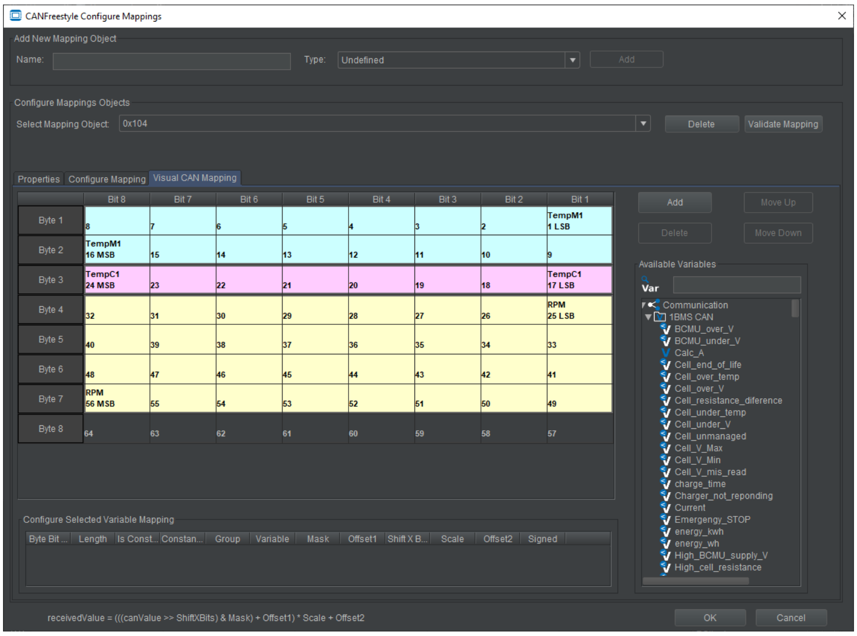
▼ Visibility

Visibility	☑
Visibility Bit	IO6

Figure 4.4: Properties of the Fault Error visibility bit

When all the variables were added to the project, the next step consisted of mapping some of those variables to each CAN ID, which were already document in 4.1. This is the way of telling the display where to get the messages, so it can present the values accurately. In this step, it was necessary to consider that each CAN ID is only capable of transporting 8 bytes of information.

The procedure was as simple as dragging the variables to an empty slot on the right side of the mapping. The final result for the four used CAN addresses, is shown in the Figures 4.5, 4.6, 4.7 and 4.8.



Name:

Type: Undefined

Select Mapping Object: 0x104

	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1
Byte 1	8	7	6	5	4	3	2	TempM1 1 LSB
Byte 2	TempM1 16 MSB	15	14	13	12	11	10	9
Byte 3	TempC1 24 MSB	23	22	21	20	19	18	TempC1 17 LSB
Byte 4	32	31	30	29	28	27	26	RPM 25 LSB
Byte 5	40	39	38	37	36	35	34	33
Byte 6	48	47	46	45	44	43	42	41
Byte 7	RPM 56 MSB	55	54	53	52	51	50	49
Byte 8	64	63	62	61	60	59	58	57

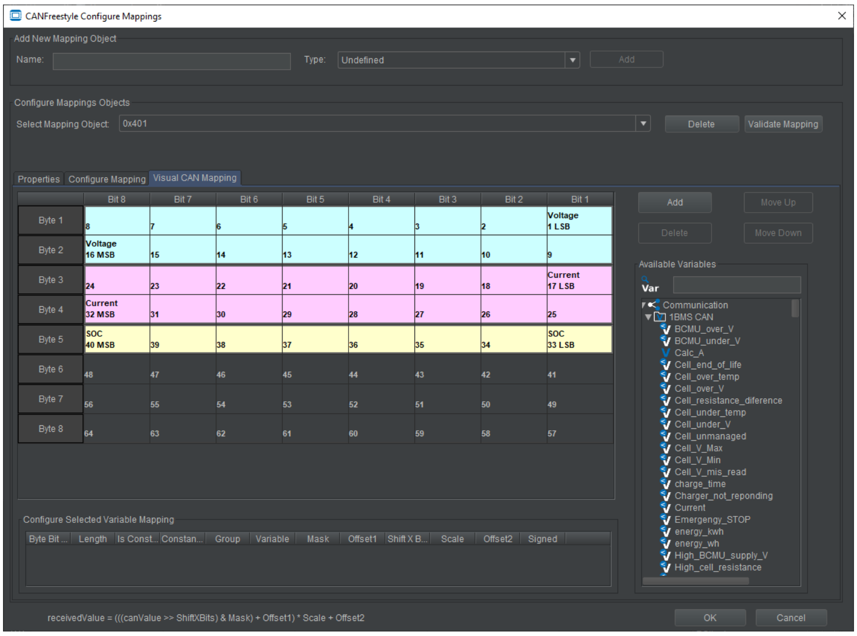
Var

- Communication
  - 1BMS CAN
    - BCMU_over_V
    - BCMU_under_V
    - Calc_A
    - Cell_end_of_life
    - Cell_over_temp
    - Cell_over_V
    - Cell_resistance_diference
    - Cell_under_temp
    - Cell_under_V
    - Cell_unmanaged
    - Cell_V_Max
    - Cell_V_Min
    - Cell_V_mis_read
    - charge_time
    - Charger_not_reponding
    - Current
    - Emergengy_STOP
    - energy_kwh
    - energy_wh
    - High_BCMU_supply_V
    - High_cell_resistance

Byte Bit ...	Length	Is Const...	Constan...	Group	Variable	Mask	Offset1	Shift X B...	Scale	Offset2	Signed

receivedValue = (((canValue >> ShiftXBits) & Mask) + Offset1) * Scale + Offset2

Figure 4.5: CAN mapping of the SEVCON variables



Name:

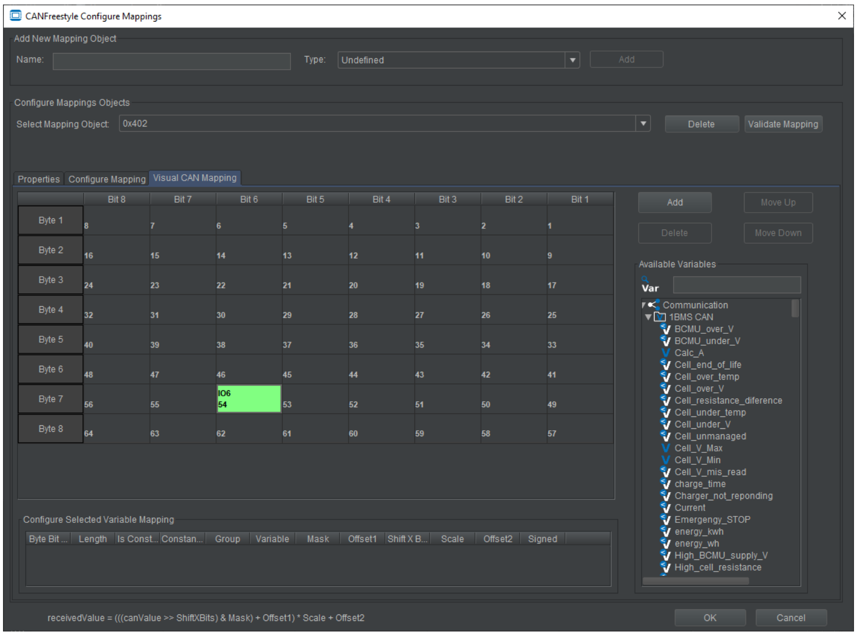
Type: Undefined

Select Mapping Object: 0x401

	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1
Byte 1	8	7	6	5	4	3	2	Voltage 1 LSB
Byte 2	Voltage 16 MSB	15	14	13	12	11	10	9
Byte 3	24	23	22	21	20	19	18	Current 17 LSB
Byte 4	Current 32 MSB	31	30	29	28	27	26	25
Byte 5	SOC 40 MSB	39	38	37	36	35	34	SOC 33 LSB
Byte 6	48	47	46	45	44	43	42	41
Byte 7	56	55	54	53	52	51	50	49
Byte 8	64	63	62	61	60	59	58	57

receivedValue = (((canValue >> ShiftXBits) & Mask) + Offset1) * Scale + Offset2

Figure 4.6: CAN mapping of the BMS variables



Name:

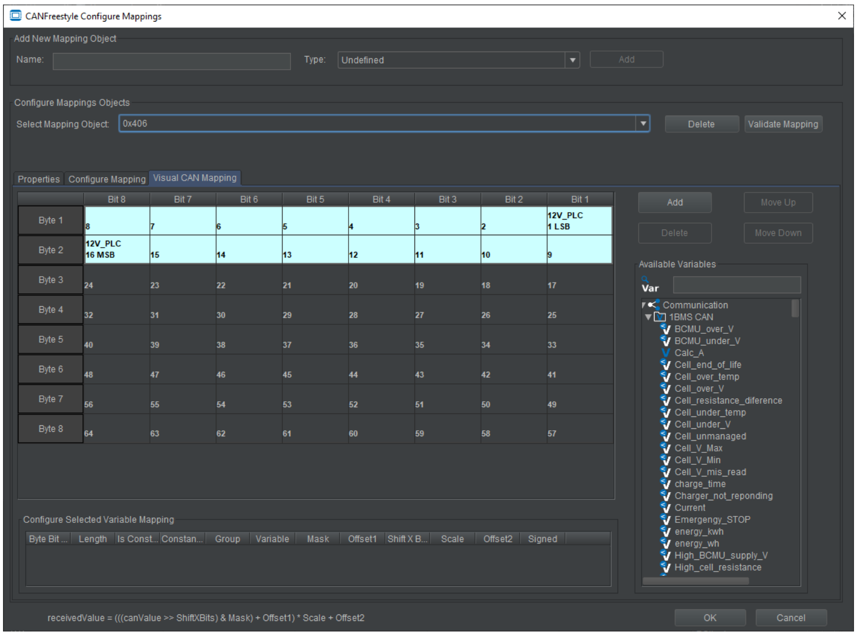
Type: Undefined

Select Mapping Object: 0x402

	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1
Byte 1	8	7	6	5	4	3	2	1
Byte 2	16	15	14	13	12	11	10	9
Byte 3	24	23	22	21	20	19	18	17
Byte 4	32	31	30	29	28	27	26	25
Byte 5	40	39	38	37	36	35	34	33
Byte 6	48	47	46	45	44	43	42	41
Byte 7	56	55	IO6 54	53	52	51	50	49
Byte 8	64	63	62	61	60	59	58	57

receivedValue = (((canValue >> ShiftXBits) & Mask) + Offset1) * Scale + Offset2

Figure 4.7: CAN mapping of the IO6 variable



Name:

Type: Undefined

Select Mapping Object: 0x406

	Bit 8	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1
Byte 1	8	7	6	5	4	3	2	12V_PLC 1 LSB
Byte 2	12V_PLC 16 MSB	15	14	13	12	11	10	9
Byte 3	24	23	22	21	20	19	18	17
Byte 4	32	31	30	29	28	27	26	25
Byte 5	40	39	38	37	36	35	34	33
Byte 6	48	47	46	45	44	43	42	41
Byte 7	56	55	54	53	52	51	50	49
Byte 8	64	63	62	61	60	59	58	57

Var

- Communication
  - 1BMS CAN
    - BCMU_over_V
    - BCMU_under_V
    - Calc_A
    - Cell_end_of_life
    - Cell_over_temp
    - Cell_over_V
    - Cell_resistance_diference
    - Cell_under_temp
    - Cell_under_V
    - Cell_unmanaged
    - Cell_V_Max
    - Cell_V_Min
    - Cell_V_mis_read
    - charge_time
    - Charger_not_reponding
    - Current
    - Emergengy_STOP
    - energy_kwh
    - energy_wh
    - High_BCMU_supply_V
    - High_cell_resistance

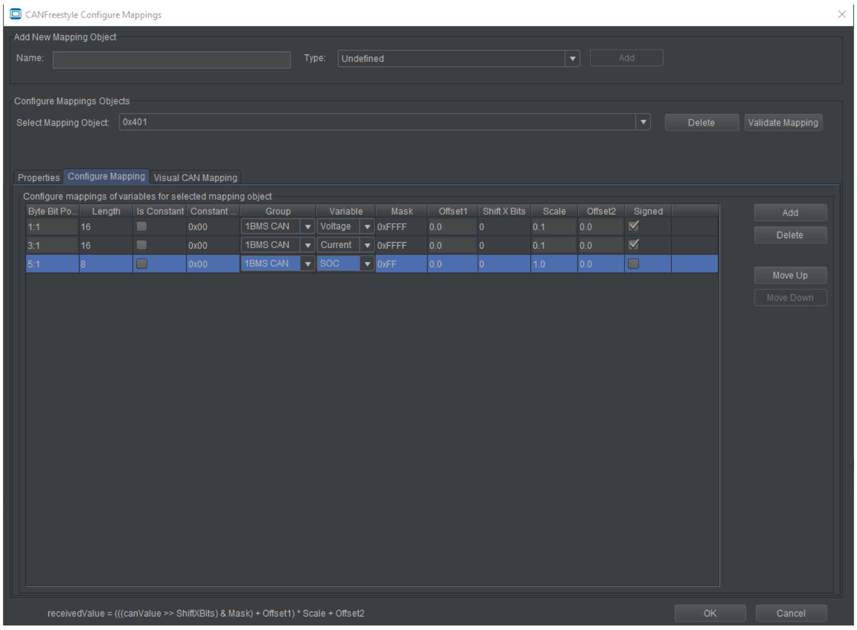
Configure Selected Variable Mapping

Byte Bit ...	Length	Is Const...	Constan...	Group	Variable	Mask	Offset1	Shift X B...	Scale	Offset2	Signed

receivedValue = (((canValue >> ShiftXBits) & Mask) + Offset1) * Scale + Offset2

Figure 4.8: CAN mapping of the PLC variable

After all the CAN addresses were inserted, the scaling properties were added, using the Table 4.1 as a reference. The process is exemplified in the Figure 4.9.



Name:

Type: Undefined

Select Mapping Object: 0x401

Configure mappings of variables for selected mapping object

Byte Bit Po...	Length	Is Constant	Constant ...	Group	Variable	Mask	Offset1	Shift X Bits	Scale	Offset2	Signed
1:1	16	☐	0x00	1BMS CAN	Voltage	0xFFFF	0.0	0	0.1	0.0	☑
3:1	16	☐	0x00	1BMS CAN	Current	0xFFFF	0.0	0	0.1	0.0	☑
5:1	8	☐	0x00	1BMS CAN	SOC	0xFF	0.0	0	1.0	0.0	☐

receivedValue = (((canValue >> ShiftXBits) & Mask) + Offset1) * Scale + Offset2

Figure 4.9: CAN mapping of the PLC variable

4.2.3 Graphical Interface

The graphical development consisted of picking the visual elements (as shown in the Figure 4.10) that were to be displayed in the interface and then associating them with the variables already stored in the project. These visual elements need to be arranged in an orderly manner so that they are easily readable. That includes a clear font, bright colors and being careful not to overcrowd the available space in the display.

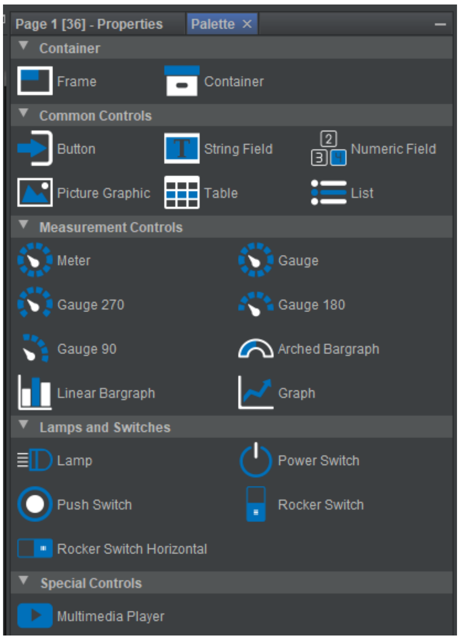


Figure 4.10: Elements available to use in the display

Three vertical bar graphs were added, one for the SOC and the two others combined for the voltage and current of the battery, which will have negative values if the battery is being drawn, or positive if charging. Two horizontal bar graphs were also included for better visualization of the RPMs of the motor and the power draw.

For the motor and controller temperature, two simple gauges were chosen for simulating the effect of a traditional instrument cluster.

Finally, three single elements were placed at the bottom of the interface: one single voltage readout for the status of the 12 V battery and the two status items for faults and ready to drive.

It was also decided, for aesthetic purposes, to include a New Electric logo alongside the Jaguar one (as shown in the Figure 4.11), making the interface look more polished and professional.

Figure 4.11: Jaguar and New Electric logos

4.2.4 JavaScript Programming

The programming side of this project managed to solve two problems with the desired implementation: the power calculation and the Driver Ready item.

Regarding the power calculation, it was as simple as multiplying the voltage and current received from the BMS, and then storing that value in a predefined variable set in the project, called Power. The script is shown in the Listing 4.1.

Listing 4.1: Script for the power calculation

```
var voltage = getVariableValue("Voltage");
var current = getVariableValue("Current");
var power = voltage * current;
setVariableValue("Power", power);
```

The goal was to show an item called Driver Ready when the vehicle was ready to be driven. Then, it was decided that it should appear when the vehicle RPM was bigger than zero. This happens because as soon as the vehicle starts, there is a small amount of RPM on the motor, even when the vehicle is still. This procedure is demonstrated in the Listing 4.2.

Listing 4.2: Script for the Drive Ready element

```
var rpm = getVariableValue("RPM");
if (rpm > 0) then
    BitReady = 1;
    setVariableValue("BitReady", BitReady);
else
    BitReady = 0;
    setVariableValue("BitReady", BitReady);
```

After that, the same logic applies from the Fault Error variable: the BitReady was set as a visibility bit to the Driver Ready item in the dashboard, being only visible when the value differs from 0.

4.2.5 Final Product

The OPUS software has the capability of simulating the interface in a separate window. Since it was not possible to connect the computer to the vehicle, since the project was being developed on a desktop, the simulation was made with custom values to get a general idea of how the final product would look. That final product can be seen in the Figure 4.12:

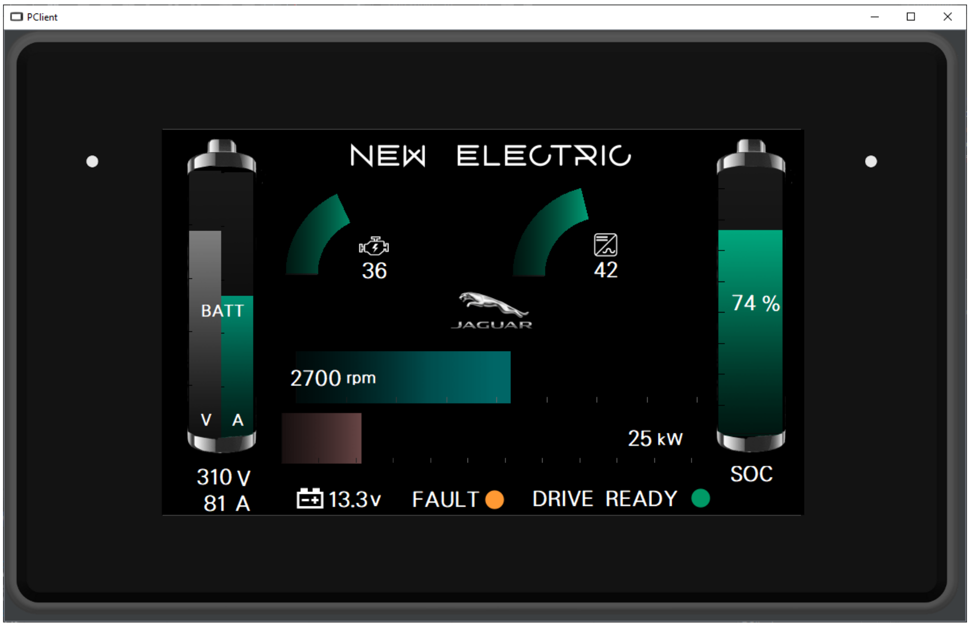


Figure 4.12: Simulation of the final project

Chapter 5

Conclusions

5.1 Achieved Goals

The conversion of the Jaguar transformed an ICE vehicle into fully electric, able to charge at any charging station and with no more restrictions related to pollution.

The developed interface was able to perform accurately its primary task: present in a clear way the status and measurements of the components that were added after the conversion. The type of display, combined with its software, allowed more creativity from a visual element perspective, making the result more in sync with recent times and professional. That was one of the main goals since this conversion is not purely academic but a finished product for a customer.

It is capable of showing the driver the voltage, current, power, state-of-charge (SOC), RPM, temperatures and fault indicators of the converted Jaguar.

After making all the decisions related to the elements to display, the process was very straightforward, and in a few steps it was possible to create a functional interface for the driver. This also proves flexibility and could be adapted to other vehicles. This could be achieved even with different components, as long as they possess CAN communication, and at the same time it allows creativity from the developer to make the visual changes it seems appropriate.

5.2 Future Improvements

While the project of the interface was still in development, there were some constraints due to the size of the display, to avoid the interface getting cluttered. When compared to a Tesla screen, that is around 12.3 inches, the OPUS B3 ECO cannot have the same elegance and optimization. From a user's perspective, it would be useful to combine the technical information already implemented, together with other type of controls.

For a newer version, it would be useful to add a more technical chart on a second page of the display, controlled by a software button, mainly to help the technician when servicing it. This includes, for example, status elements from each component, such as the BMS, the SEVCON or the PLC, and more information about regenerative braking.

Finally, the software used made it implicit that a Topcon display had to be used for this project. Perhaps it will be possible in the future to implement a functional interface through an open-source software, enabling all kind of options when it comes to displays.

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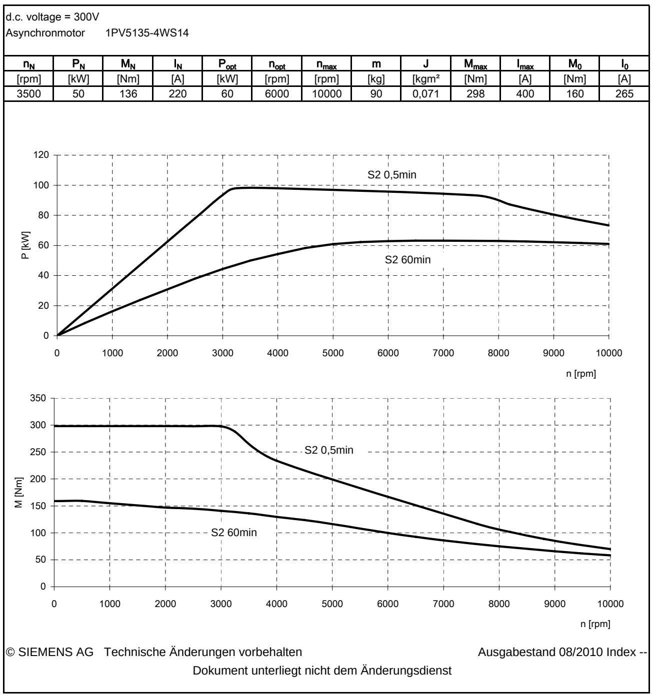
Appendix A

Testing Data of the Siemens 1PV5135-4WS14 AC



d.c. voltage = 300V
Asynchronmotor 1PV5135-4WS14

n_N	P_N	M_N	I_N	P_{opt}	n_{opt}	n_{max}	m	J	M_{max}	I_{max}	M_0	I_0
[rpm]	[kW]	[Nm]	[A]	[kW]	[rpm]	[rpm]	[kg]	[kgm²	[Nm]	[A]	[Nm]	[A]
3500	50	136	220	60	6000	10000	90	0,071	298	400	160	265

© SIEMENS AG Technische Änderungen vorbehalten Ausgabestand 08/2010 Index --
Dokument unterliegt nicht dem Änderungsdienst

Data taken from [29].

Appendix B

Datasheet of the Sevcon Controller

SEVCON®
Electrification Partner

Gen4
Size 2 Size 4
Size 6

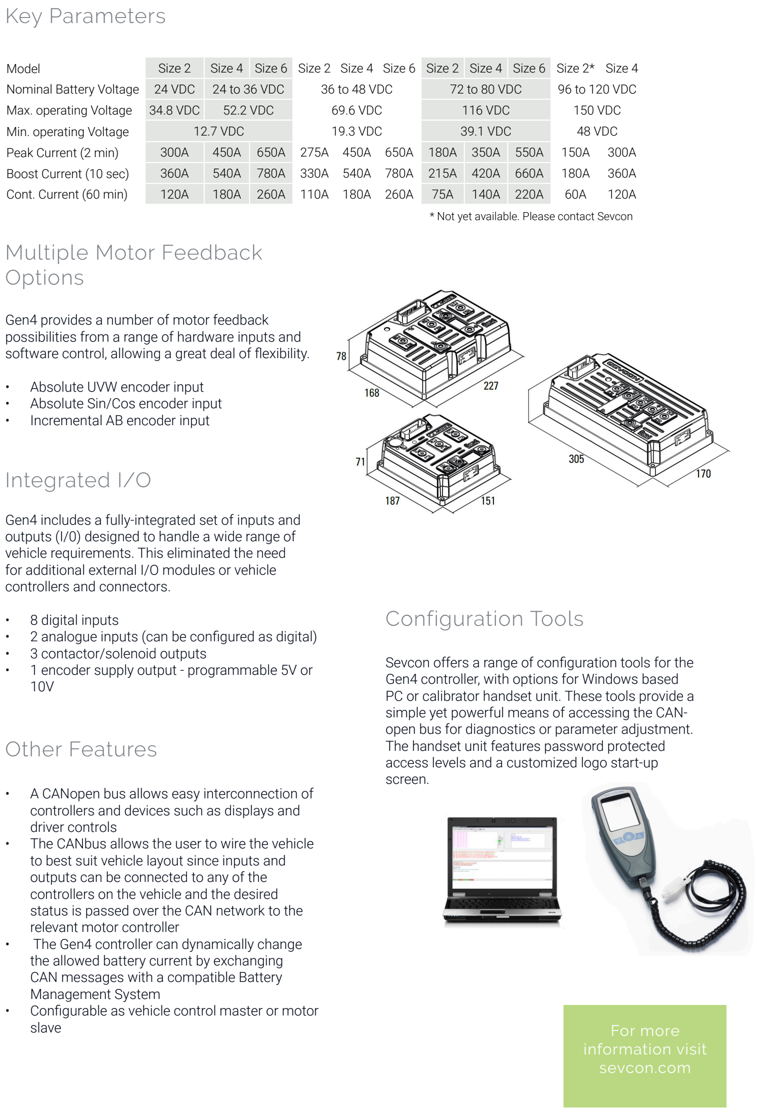
AC Motor Controller

The Gen4 range represents the latest design in compact AC Controllers. These reliable controllers are intended for on-road and off-road electric vehicles and feature the smallest size in the industry for their power capacity.

Thanks to the high efficiency it is possible to integrate these controllers into very tight spaces without sacrificing performance. The design has been optimised for the lowest possible installed cost while maintaining superior reliability in the most demanding applications.

Features

- Advance flux vector control
- Autocheck system diagnostic
- Integrated logic circuit
- Hardware & software failsafe watchdog operation
- Supports both PMAC and AC motor
- Induction motor control
- Integrated fuse holder
- IP66 protection



Key Parameters

Model	Size 2	Size 4	Size 6	Size 2	Size 4	Size 6	Size 2	Size 4	Size 6	Size 2*	Size 4
Nominal Battery Voltage	24 VDC	24 to 36 VDC		36 to 48 VDC			72 to 80 VDC			96 to 120 VDC	
Max. operating Voltage	34.8 VDC	52.2 VDC		69.6 VDC			116 VDC			150 VDC	
Min. operating Voltage	12.7 VDC			19.3 VDC			39.1 VDC			48 VDC	
Peak Current (2 min)	300A	450A	650A	275A	450A	650A	180A	350A	550A	150A	300A
Boost Current (10 sec)	360A	540A	780A	330A	540A	780A	215A	420A	660A	180A	360A
Cont. Current (60 min)	120A	180A	260A	110A	180A	260A	75A	140A	220A	60A	120A

* Not yet available. Please contact Sevcon

Multiple Motor Feedback Options

Gen4 provides a number of motor feedback possibilities from a range of hardware inputs and software control, allowing a great deal of flexibility.

- Absolute UVW encoder input
- Absolute Sin/Cos encoder input
- Incremental AB encoder input

Integrated I/O

Gen4 includes a fully-integrated set of inputs and outputs (I/0) designed to handle a wide range of vehicle requirements. This eliminated the need for additional external I/O modules or vehicle controllers and connectors.

- 8 digital inputs
- 2 analogue inputs (can be configured as digital)
- 3 contactor/solenoid outputs
- 1 encoder supply output - programmable 5V or 10V

Other Features

- A CANopen bus allows easy interconnection of controllers and devices such as displays and driver controls
- The CANbus allows the user to wire the vehicle to best suit vehicle layout since inputs and outputs can be connected to any of the controllers on the vehicle and the desired status is passed over the CAN network to the relevant motor controller
- The Gen4 controller can dynamically change the allowed battery current by exchanging CAN messages with a compatible Battery Management System
- Configurable as vehicle control master or motor slave

Configuration Tools

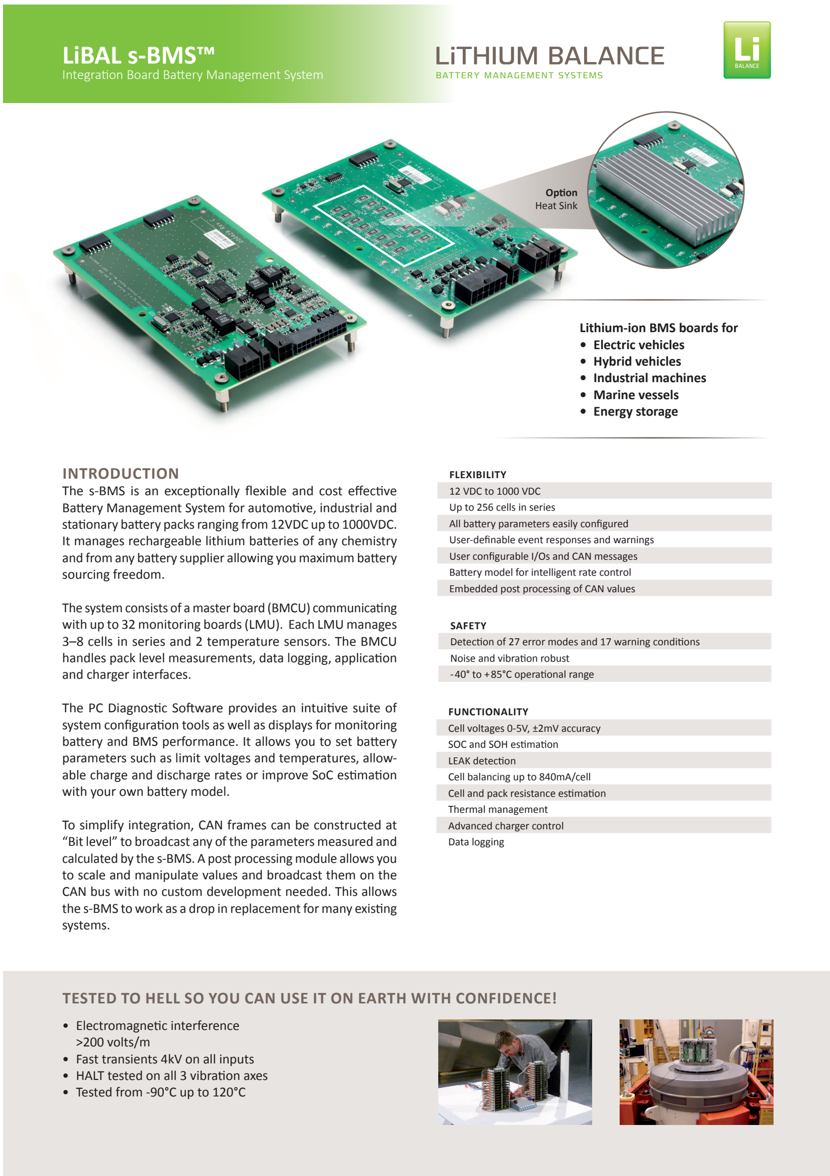
Sevcon offers a range of configuration tools for the Gen4 controller, with options for Windows based PC or calibrator handset unit. These tools provide a simple yet powerful means of accessing the CANopen bus for diagnostics or parameter adjustment. The handset unit features password protected access levels and a customized logo start-up screen.

For more information visit sevcon.com

Data taken from [30].

Appendix C

Datasheet of the Lithium Balance BMS



LiBAL s-BMS™
Integration Board Battery Management System

LiTHIUM BALANCE
BATTERY MANAGEMENT SYSTEMS

Lithium-ion BMS boards for

- **Electric vehicles**
- **Hybrid vehicles**
- **Industrial machines**
- **Marine vessels**
- **Energy storage**

INTRODUCTION

The s-BMS is an exceptionally flexible and cost effective Battery Management System for automotive, industrial and stationary battery packs ranging from 12VDC up to 1000VDC. It manages rechargeable lithium batteries of any chemistry and from any battery supplier allowing you maximum battery sourcing freedom.

The system consists of a master board (BMCU) communicating with up to 32 monitoring boards (LMU). Each LMU manages 3–8 cells in series and 2 temperature sensors. The BMCU handles pack level measurements, data logging, application and charger interfaces.

The PC Diagnostic Software provides an intuitive suite of system configuration tools as well as displays for monitoring battery and BMS performance. It allows you to set battery parameters such as limit voltages and temperatures, allowable charge and discharge rates or improve SoC estimation with your own battery model.

To simplify integration, CAN frames can be constructed at "Bit level" to broadcast any of the parameters measured and calculated by the s-BMS. A post processing module allows you to scale and manipulate values and broadcast them on the CAN bus with no custom development needed. This allows the s-BMS to work as a drop in replacement for many existing systems.

FLEXIBILITY

- 12 VDC to 1000 VDC
- Up to 256 cells in series
- All battery parameters easily configured
- User-definable event responses and warnings
- User configurable I/Os and CAN messages
- Battery model for intelligent rate control
- Embedded post processing of CAN values

SAFETY

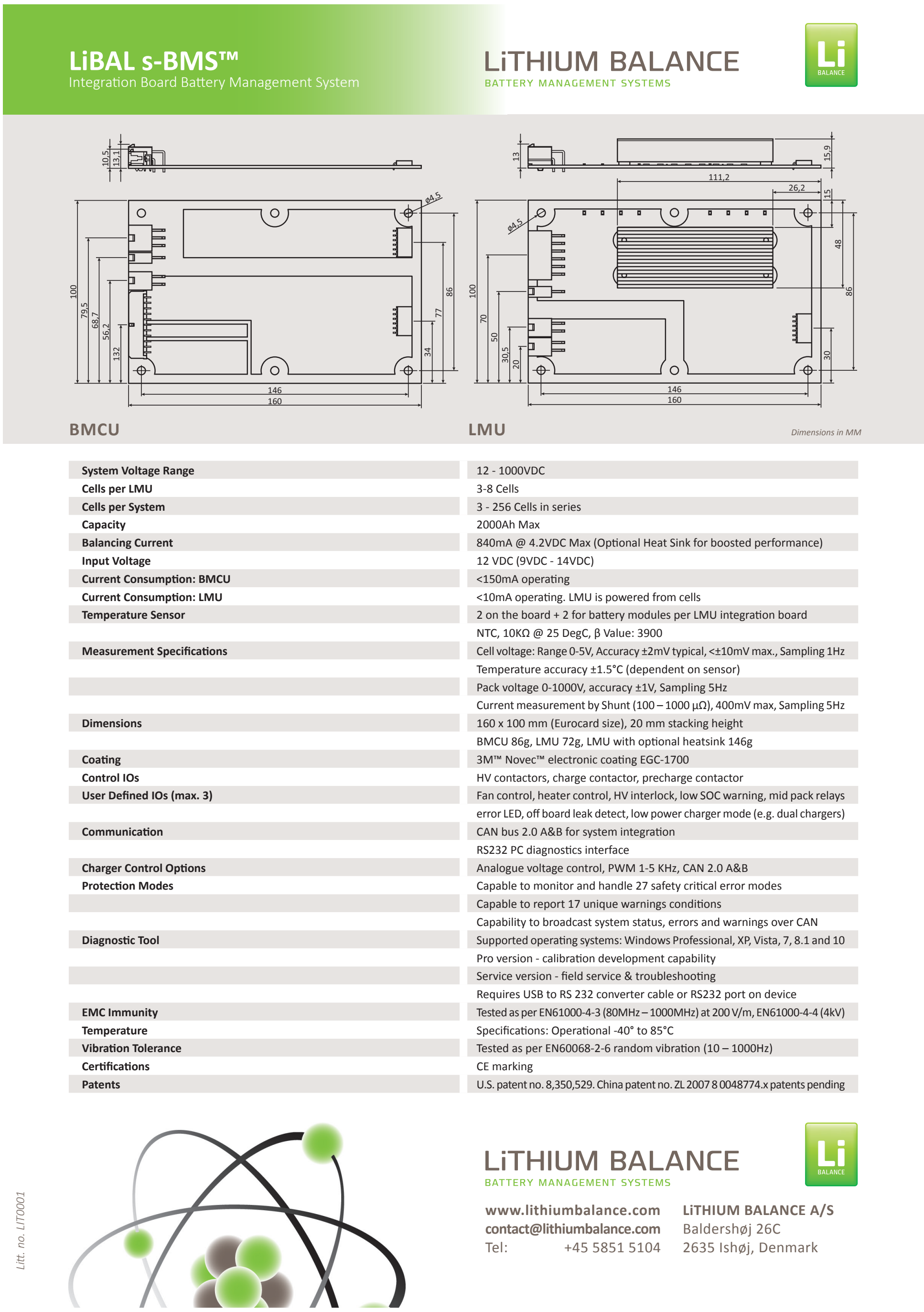
- Detection of 27 error modes and 17 warning conditions
- Noise and vibration robust
- -40° to +85°C operational range

FUNCTIONALITY

- Cell voltages 0-5V, ±2mV accuracy
- SOC and SOH estimation
- LEAK detection
- Cell balancing up to 840mA/cell
- Cell and pack resistance estimation
- Thermal management
- Advanced charger control
- Data logging

TESTED TO HELL SO YOU CAN USE IT ON EARTH WITH CONFIDENCE!

- Electromagnetic interference >200 volts/m
- Fast transients 4kV on all inputs
- HALT tested on all 3 vibration axes
- Tested from -90°C up to 120°C



LiBAL s-BMS™
Integration Board Battery Management System

LiTHIUM BALANCE
BATTERY MANAGEMENT SYSTEMS

System Voltage Range	12 - 1000VDC
Cells per LMU	3-8 Cells
Cells per System	3 - 256 Cells in series
Capacity	2000Ah Max
Balancing Current	840mA @ 4.2VDC Max (Optional Heat Sink for boosted performance)
Input Voltage	12 VDC (9VDC - 14VDC)
Current Consumption: BMCU	<150mA operating
Current Consumption: LMU	<10mA operating. LMU is powered from cells
Temperature Sensor	2 on the board + 2 for battery modules per LMU integration board
	NTC, 10KΩ @ 25 DegC, β Value: 3900
Measurement Specifications	Cell voltage: Range 0-5V, Accuracy ±2mV typical, <±10mV max., Sampling 1Hz
	Temperature accuracy ±1.5°C (dependent on sensor)
	Pack voltage 0-1000V, accuracy ±1V, Sampling 5Hz
	Current measurement by Shunt (100 – 1000 μΩ), 400mV max, Sampling 5Hz
Dimensions	160 x 100 mm (Eurocard size), 20 mm stacking height
	BMCU 86g, LMU 72g, LMU with optional heatsink 146g
Coating	3M™ Novec™ electronic coating EGC-1700
Control IOs	HV contactors, charge contactor, precharge contactor
User Defined IOs (max. 3)	Fan control, heater control, HV interlock, low SOC warning, mid pack relays
	error LED, off board leak detect, low power charger mode (e.g. dual chargers)
Communication	CAN bus 2.0 A&B for system integration
	RS232 PC diagnostics interface
Charger Control Options	Analogue voltage control, PWM 1-5 KHz, CAN 2.0 A&B
Protection Modes	Capable to monitor and handle 27 safety critical error modes
	Capable to report 17 unique warnings conditions
	Capability to broadcast system status, errors and warnings over CAN
Diagnostic Tool	Supported operating systems: Windows Professional, XP, Vista, 7, 8.1 and 10
	Pro version - calibration development capability
	Service version - field service & troubleshooting
	Requires USB to RS 232 converter cable or RS232 port on device
EMC Immunity	Tested as per EN61000-4-3 (80MHz – 1000MHz) at 200 V/m, EN61000-4-4 (4kV)
Temperature	Specifications: Operational -40° to 85°C
Vibration Tolerance	Tested as per EN60068-2-6 random vibration (10 – 1000Hz)
Certifications	CE marking
Patents	U.S. patent no. 8,350,529. China patent no. ZL 2007 8 0048774.x patents pending

Litt. no. LIT0001

LiTHIUM BALANCE
BATTERY MANAGEMENT SYSTEMS

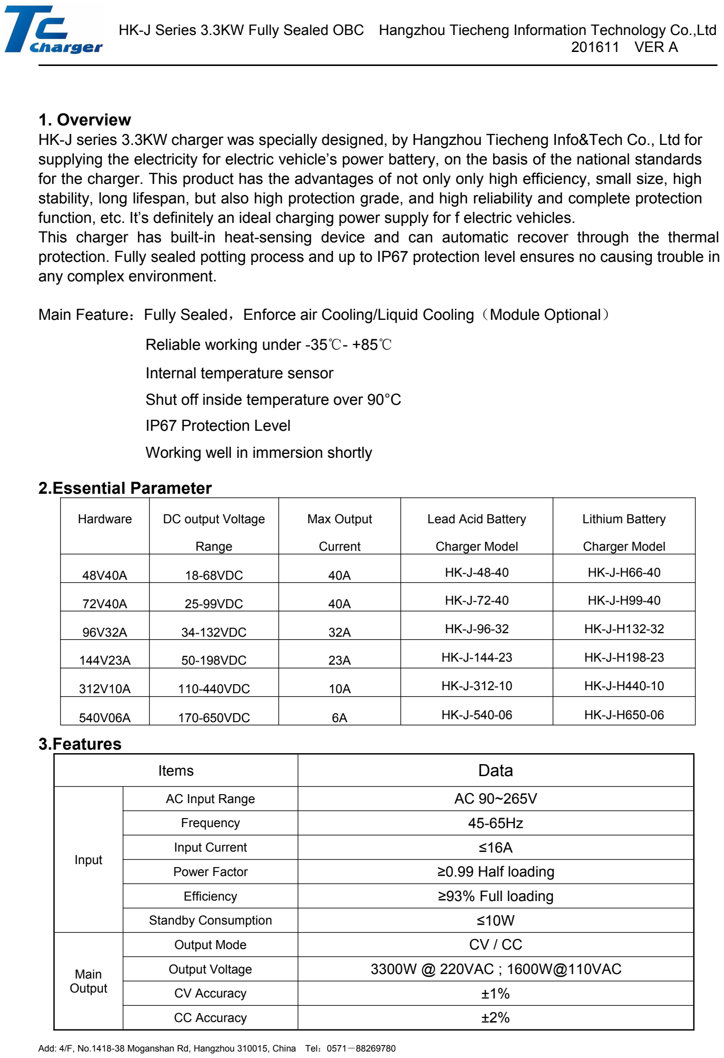
www.lithiumbalance.com
contact@lithiumbalance.com
Tel: +45 5851 5104

LiTHIUM BALANCE A/S
Baldershøj 26C
2635 Ishøj, Denmark

Data taken from [31].

Appendix D

Datasheet of the TCCH AC Charger



HK-J Series 3.3KW Fully Sealed OBC　Hangzhou Tiecheng Information Technology Co.,Ltd
201611　VER A

1. Overview

HK-J series 3.3KW charger was specially designed, by Hangzhou Tiecheng Info&Tech Co., Ltd for supplying the electricity for electric vehicle's power battery, on the basis of the national standards for the charger. This product has the advantages of not only only high efficiency, small size, high stability, long lifespan, but also high protection grade, and high reliability and complete protection function, etc. It's definitely an ideal charging power supply for f electric vehicles.

This charger has built-in heat-sensing device and can automatic recover through the thermal protection. Fully sealed potting process and up to IP67 protection level ensures no causing trouble in any complex environment.

Main Feature：Fully Sealed，Enforce air Cooling/Liquid Cooling（Module Optional）
Reliable working under -35℃- +85℃
Internal temperature sensor
Shut off inside temperature over 90°C
IP67 Protection Level
Working well in immersion shortly

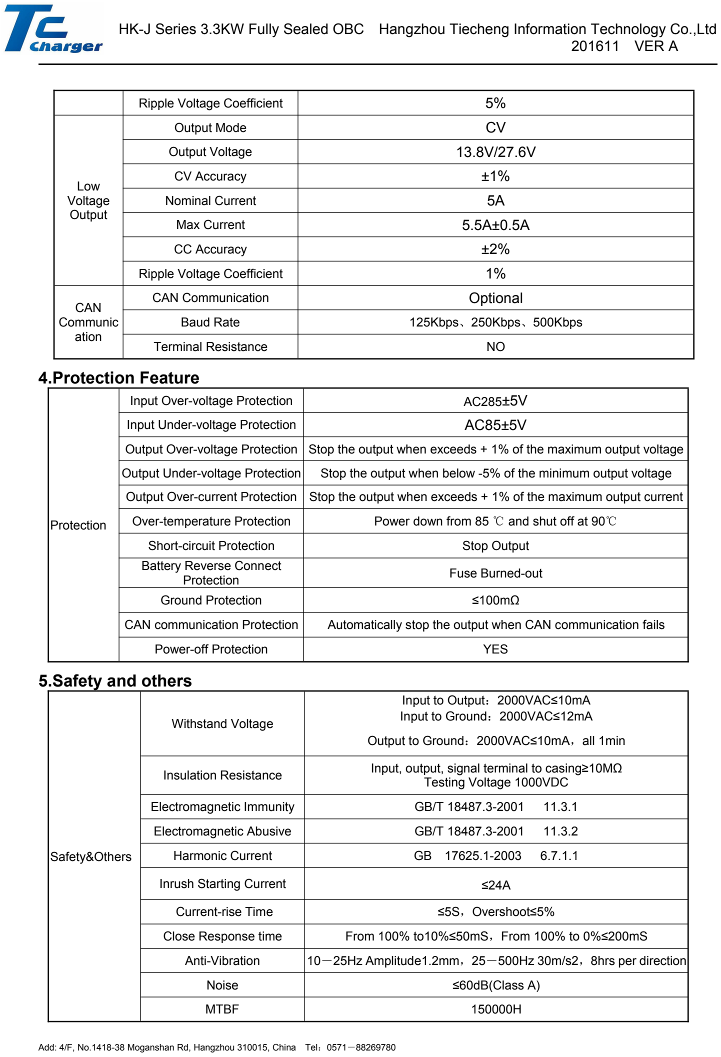
2.Essential Parameter

Hardware	DC output Voltage Range	Max Output Current	Lead Acid Battery Charger Model	Lithium Battery Charger Model
48V40A	18-68VDC	40A	HK-J-48-40	HK-J-H66-40
72V40A	25-99VDC	40A	HK-J-72-40	HK-J-H99-40
96V32A	34-132VDC	32A	HK-J-96-32	HK-J-H132-32
144V23A	50-198VDC	23A	HK-J-144-23	HK-J-H198-23
312V10A	110-440VDC	10A	HK-J-312-10	HK-J-H440-10
540V06A	170-650VDC	6A	HK-J-540-06	HK-J-H650-06

3.Features

Items		Data
Input	AC Input Range	AC 90~265V
	Frequency	45-65Hz
	Input Current	≤16A
	Power Factor	≥0.99 Half loading
	Efficiency	≥93% Full loading
	Standby Consumption	≤10W
Main Output	Output Mode	CV / CC
	Output Voltage	3300W @ 220VAC ; 1600W@110VAC
	CV Accuracy	±1%
	CC Accuracy	±2%

Add: 4/F, No.1418-38 Moganshan Rd, Hangzhou 310015, China　Tel：0571－88269780



HK-J Series 3.3KW Fully Sealed OBC Hangzhou Tiecheng Information Technology Co.,Ltd
201611 VER A

	Ripple Voltage Coefficient	5%
Low Voltage Output	Output Mode	CV
	Output Voltage	13.8V/27.6V
	CV Accuracy	±1%
	Nominal Current	5A
	Max Current	5.5A±0.5A
	CC Accuracy	±2%
	Ripple Voltage Coefficient	1%
CAN Communication	CAN Communication	Optional
	Baud Rate	125Kbps、250Kbps、500Kbps
	Terminal Resistance	NO

4.Protection Feature

Protection	Input Over-voltage Protection	AC285±5V
	Input Under-voltage Protection	AC85±5V
	Output Over-voltage Protection	Stop the output when exceeds + 1% of the maximum output voltage
	Output Under-voltage Protection	Stop the output when below -5% of the minimum output voltage
	Output Over-current Protection	Stop the output when exceeds + 1% of the maximum output current
	Over-temperature Protection	Power down from 85 ℃ and shut off at 90℃
	Short-circuit Protection	Stop Output
	Battery Reverse Connect Protection	Fuse Burned-out
	Ground Protection	≤100mΩ
	CAN communication Protection	Automatically stop the output when CAN communication fails
	Power-off Protection	YES

5.Safety and others

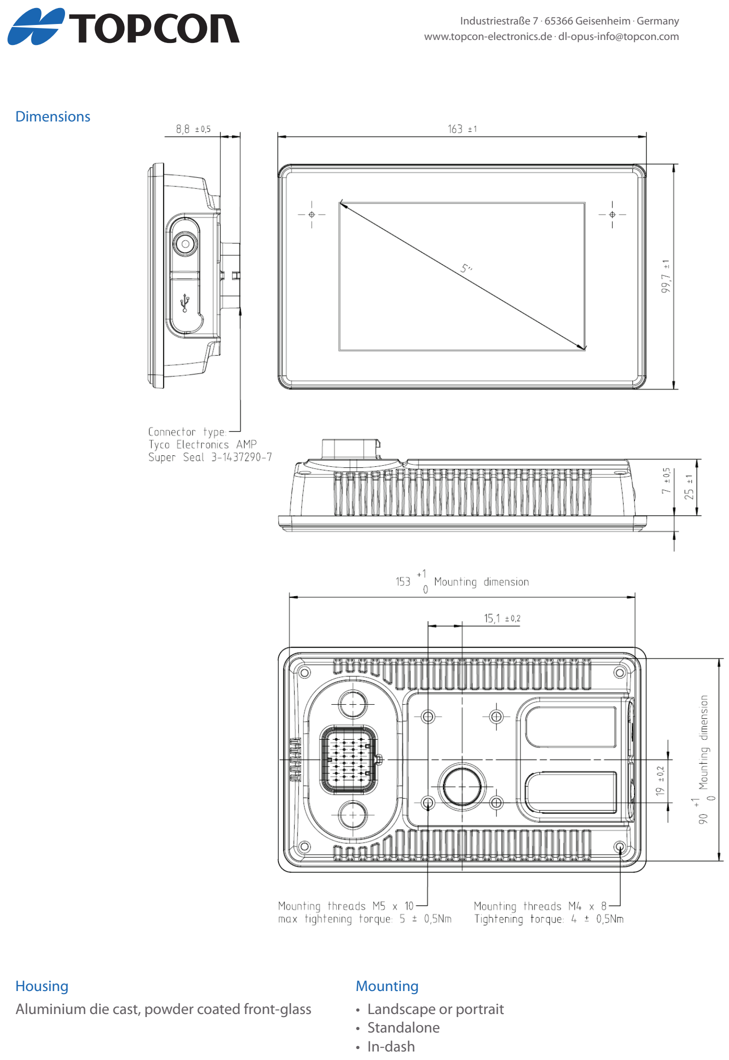
Safety&Others	Withstand Voltage	Input to Output：2000VAC≤10mA Input to Ground：2000VAC≤12mA Output to Ground：2000VAC≤10mA，all 1min
	Insulation Resistance	Input, output, signal terminal to casing≥10MΩ Testing Voltage 1000VDC
	Electromagnetic Immunity	GB/T 18487.3-2001 11.3.1
	Electromagnetic Abusive	GB/T 18487.3-2001 11.3.2
	Harmonic Current	GB 17625.1-2003 6.7.1.1
	Inrush Starting Current	≤24A
	Current-rise Time	≤5S，Overshoot≤5%
	Close Response time	From 100% to10%≤50mS，From 100% to 0%≤200mS
	Anti-Vibration	10－25Hz Amplitude1.2mm，25－500Hz 30m/s2，8hrs per direction
	Noise	≤60dB(Class A)
	MTBF	150000H

Add: 4/F, No.1418-38 Moganshan Rd, Hangzhou 310015, China Tel：0571－88269780

Data taken from [32].

Appendix E

Datasheet of the OPUS B3 ECO Display



Industriestraße 7 · 65366 Geisenheim · Germany
www.topcon-electronics.de · dl-opus-info@topcon.com

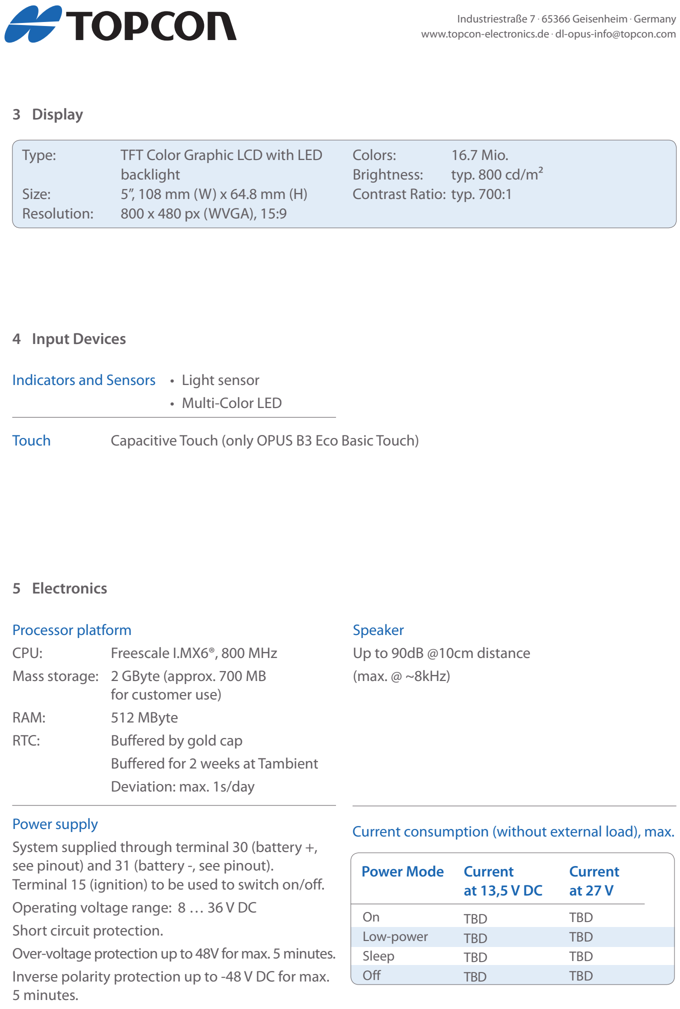
Dimensions

Housing

Aluminium die cast, powder coated front-glass

Mounting

- Landscape or portrait
- Standalone
- In-dash



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3 Display

Type:	TFT Color Graphic LCD with LED backlight	Colors:	16.7 Mio.
		Brightness:	typ. 800 cd/m^2
Size:	5", 108 mm (W) x 64.8 mm (H)	Contrast Ratio:	typ. 700:1
Resolution:	800 x 480 px (WVGA), 15:9		

4 Input Devices

Indicators and Sensors	• Light sensor • Multi-Color LED
Touch	Capacitive Touch (only OPUS B3 Eco Basic Touch)

5 Electronics

Processor platform

CPU:	Freescale I.MX6®, 800 MHz
Mass storage:	2 GByte (approx. 700 MB for customer use)
RAM:	512 MByte
RTC:	Buffered by gold cap Buffered for 2 weeks at Tambient Deviation: max. 1s/day

Speaker

Up to 90dB @10cm distance
(max. @ ~8kHz)

Power supply

System supplied through terminal 30 (battery +, see pinout) and 31 (battery -, see pinout). Terminal 15 (ignition) to be used to switch on/off.

Operating voltage range: 8 … 36 V DC

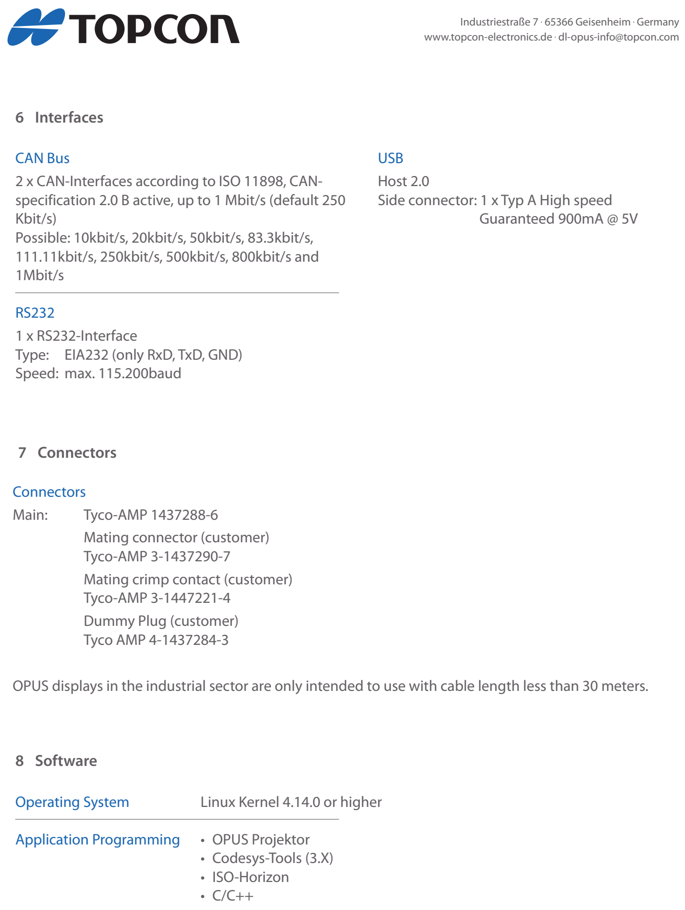
Short circuit protection.

Over-voltage protection up to 48V for max. 5 minutes.

Inverse polarity protection up to -48 V DC for max. 5 minutes.

Current consumption (without external load), max.

Power Mode	**Current at 13,5 V DC**	**Current at 27 V**
On	TBD	TBD
Low-power	TBD	TBD
Sleep	TBD	TBD
Off	TBD	TBD



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www.topcon-electronics.de · dl-opus-info@topcon.com

6 Interfaces

CAN Bus

2 x CAN-Interfaces according to ISO 11898, CAN-specification 2.0 B active, up to 1 Mbit/s (default 250 Kbit/s)
Possible: 10kbit/s, 20kbit/s, 50kbit/s, 83.3kbit/s, 111.11kbit/s, 250kbit/s, 500kbit/s, 800kbit/s and 1Mbit/s

RS232

1 x RS232-Interface
Type: EIA232 (only RxD, TxD, GND)
Speed: max. 115.200baud

USB

Host 2.0
Side connector: 1 x Typ A High speed
Guaranteed 900mA @ 5V

7 Connectors

Connectors

Main: Tyco-AMP 1437288-6

Mating connector (customer)
Tyco-AMP 3-1437290-7

Mating crimp contact (customer)
Tyco-AMP 3-1447221-4

Dummy Plug (customer)
Tyco AMP 4-1437284-3

OPUS displays in the industrial sector are only intended to use with cable length less than 30 meters.

8 Software

Operating System	Linux Kernel 4.14.0 or higher
Application Programming	• OPUS Projektor • Codesys-Tools (3.X) • ISO-Horizon • C/C++

Data taken from [33].