Implementing an eMule 7.0 energy storage system

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Declaration

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Munich, the 10. Juli 2025

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Abstract

This thesis dealt with the documentation of the electrical conversion of a vehicle that was converted from a conventional combustion engine to an electric drive, specifically the Kawasaki Mule 610. The following objectives were to be achieved as part of the implementation of an energy storage system in the converted vehicle model ‘Kawasaki eMule’: The creation of current circuit diagrams as well as assembly plans for the electrical/electronic vehicle circuits. Standardisation and integration of the plans for the system and its individual components and the creation of a 3D CAD model (computer-aided design) of the self-developed energy storage system. In addition, the neighbouring team was to be supported in the implementation of autonomous driving.

The creation of the circuit and assembly plans ran parallel to the creation of the CAD model. Support for autonomous driving was integrated towards the end of the project. In phases where there was no immediate workload, support was offered by other teams.

A total of six circuit diagrams were created in accordance with the DIN EN (German industrial standard, European standard) 60617 standard and two assembly diagrams. In the course of creating these plans, a separate library was developed on the basis of DIN EN 60617 and a structure was created for the efficient expansion and integration of the library. As part of the CAD model creation, numerous small individual models were created and assembled into a large overall model. A separate library was also implemented for this purpose. In addition to the specific tasks of our own team, we were also able to support other project teams with various tasks.

Kurzfassung

Diese Arbeit befasste sich mit der Dokumentation der elektrischen Umsetzung eines Fahrzeugs, das von einem konventionellen Verbrennungsmotor auf einen Elektroantrieb umgerüstet wurde, konkret dem Kawasaki Mule 610. Im Rahmen der Implementierung eines Energiespeichersystems in das umgebaute Fahrzeugmodell „Kawasaki eMule“ sollten die folgenden Ziele erreicht werden: Die Erstellung von aktuellen Stromlaufplänen sowie Bestückungsplänen für die elektrisch/elektronischen Fahrzeugschaltkreise. Eine Standardisierung und Integration der Pläne des Systems sowie seiner Einzelkomponenten und die Erstellung eines 3D-CAD-Modells (Computer-Aided Design)des selbst entwickelten Energiespeichersystems konstruiert werden. Zusätzlich sollte das Nachbarteam bei der Implementierung des autonomen Fahrens unterstüzt werden.
Die Erstellung der Stromlauf- und Bestückungspläne lief parallel zu der Erstellung des CAD-Modells. Die Unterstützung des autonomen Fahrens wurde gegen Ende des Projekt eingebunden. In Phasen, in denen keine unmittelbare Arbeitsbelastung vorlag, wurde die Unterstützung anderer Teams angeboten.
Insgesamt wurden sechs Stromlaufpläne gemäß der Norm DIN EN(Deutsche Industrienorm, Europäische Norm) 60617 und zwei Bestückungspläne erstellt. Im Zuge der Erstellung dieser Pläne wurde eine eigene Bibliothek auf Basis der DIN EN 60617 entwickelt und eine Struktur zur effizienten Erweiterung und Integration der Bibliothek geschaffen. Im Rahmen der CAD-Modell Erstellung wurden zahlreiche kleine Einzelmodelle erstellt und zu einem großen Gesamtmodell zusammengesetzt. Hierfür wurde ebenfalls eine eigene Bibiliothek implementiert. Neben den spezifischen Aufgaben des eigenen Teams konnte auch die Unterstützung anderer Projektteams bei verschiedenen Aufgabenstellungen erfolgen.

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1 Intro

The global shift towards more sustainable mobility solutions is well underway. In light of mounting environmental regulations and growing awareness of the detrimental impact of fossil fuels, we are witnessing a paradigm shift away from traditional combustion engines towards electric drives. This technological upheaval is affecting not only the private automotive sector, but also commercial and specialised vehicles, which are increasingly being converted to electric power.[Pis23] As part of a university project, we successfully converted a Kawasaki Mule 610 vehicle from a combustion engine to an electric drive. This conversion was a first milestone that enabled us to demonstrate the advantages of electric mobility in a practical application. The project is now to be developed further in order to optimise the efficiency and range of the vehicle through targeted improvements - such as the use of a more powerful battery - and to set new standards in electric drive technology.

Problem statement

Our predecessors converted the „Kawasaki Mule 610“ from an internal combustion engine to an electric motor drive. The vehicle was renamed the „Kawasaki eMule“. The conversion documentation was poorly executed, if at all, and was not standardised. The existing documentation for each circuit diagram is according to a different standard. There are no legends for the standards used. The accuracy of the existing documentation must be verified for each circuit diagram by comparing it with the vehicle's installation status and consulting the instructor, Mr Khamis Jakob.

The following considers only the aspects of the problem relating to the creation of circuit diagrams, assembly plans and CAD-models. The first issue is selecting a suitable software for creating the documentation. The difficulty here is finding a programme that meets all the requirements. These are:

- The software must be as cost-effective as possible, as only a limited budget is available.
- The software must be designed for both Windows and macOS operating systems to ensure that every team member is able to work optimally.
- The software must be able to create circuit diagrams, assembly plans as well as CAD-models, as several software licences cannot be financed due to the limited budget.
- The software must support the selected standard or offer the option of creating your own libraries with components.

If the software does not support the selected standard, creating a separate library would involve an enormous amount of additional time and effort. This additional work could jeopardise the project's time targets. Another issue is that none of the team members have ever worked with CAD software or on a project of this scale without proper documentation.

Objective

The following objectives are defined for the „TFE team“ for the second working period in the summer semester of 2025:

- Creation of current circuit diagrams and assembly plans for the electrical/electronic vehicle circuits
- Standardisation and communitisation of the system’s plans and its individual components
- Construction of a 3D CAD model for the energy storage system
- Supporting the implementation of autonomous driving

Planned procedure

To achieve the goals in the best possible way, the eMule team should be divided into smaller groups. This enables the various subtasks to be completed as efficiently as possible. Firstly, the entire eMule team must gain an overview of the vehicle and its condition. This includes the mechanical and electrical/electronic condition of the vehicle as a whole and its individual components. Both the current status and future potential are identified. Next, the tasks for each team are redefined or continued. In this work, only the tasks of the „TFE team“ are considered.

The initial step is to acquaint oneself with the novel functionalities of the software, undertaking this endeavour with full responsibility. This step is intended to ensure that as little time as possible is lost when working with the programme at a later stage. In the course of the familiarisation process, it is also recommended that the project environment be created for the purpose of subsequent sharing. The project's digital database is also served by this.

Circiut Diagramms

In the process of devising the plans, it is imperative to exercise due diligence to ensure that the numbering of the components is sequential and that the newly formulated plans are incorporated into the extant documentation. The predefined standard is utilised to ensure the consistency of the plans.
The creation of assembly plans involves the examination and comparison of existing documentation with the current assembly status. Documentation that does not correspond to this standard must be disregarded. It is imperative that a new, comprehensive description of the overall system is created. This description must be based on the existing documents and the vehicle's assembly status.

In order to standardise the individual plans, they are subjected to further review to ensure clarity. If necessary, the plans are adapted and transferred to a DIN A3 format, complete with title block and legend.

CAD Modeling of the Battery Housing

In the upcoming design phase, a modular lithium-ion battery housing will be developed using Autodesk Fusion 360. The process will begin by creating a fully parametric CAD model, allowing for efficient adjustments and future scalability. Initial steps will include defining the base geometry and arranging 21700-format cells in a compact layout. Functional features such as temperature sensor pockets and cable routing channels will be incorporated to support monitoring and assembly. These components will then be assembled virtually to verify spatial fit and clearances. Design-for-additive-manufacturing (DfAM) principles will guide the modeling to ensure that all parts are optimized for 3D printing. The completed model will be exported in formats suitable for slicing software and maintained in a version-controlled environment for ongoing refinement.

2 Foundations

The subsequent chapter provides a synopsis of the theoretical foundations that are prerequisite for the present thesis. The second chapter provides a more detailed examination of the history of electric vehicles. In the subsequent chapter, Chapter 2.2, the focus is on lithium-ion batteries. Chapter 2.3 then deals with standards for drawing circuit diagrams, and Chapter 2.4 analyses the Autodesk Fusion 360 tool used to create the documentation.

2.1 The history of electric vehicles

The history of electric vehicles is an intriguing chapter in the development of mobility. Despite the contemporary perception of electric vehicles as a technology that is poised for imminent widespread adoption, their origins can be traced back to the early days of automotive engineering, thus underscoring their deep-rooted history.

The beginnings in the 19th century

The foundations for electric vehicles were established in the early 19th century. The Scotsman Robert Anderson is widely regarded as one of the first to construct an electrically powered vehicle, a feat which was achieved in the 1830s. The vehicle was uncomplicated in design and was equipped with a non-rechargeable battery. In the subsequent decades, the practicality of electric vehicles increased significantly due to the advancement of rechargeable batteries and electric motors.[Vat25] An important contribution was made by the Frenchman Gaston Planté, who developed the first functional lead-acid accumulator in 1859. This rechargeable battery was pivotal in enabling the continuous operation of electric motors and laid the foundation for the subsequent development of electric vehicles.[Ind25]

The heyday of electric vehicles around 1900

Electric vehicles experienced a period of significant popularity around the turn of the century. In comparison with the prevalent steam or combustion engine vehicles of that era, the new vehicles were characterised by a quieter operation, a more pristine condition and a simplified operational process. In urban areas, electric cars were particularly favoured due to their limited range and ease of use.[Ene25b] Brands like Baker Electric and Detroit Electric shaped this era [Ein25].

Electric vehicles had significant market advantages at the time. In contrast to the often laborious and sonically disagreeable process of manually engaging combustion engines, electric vehicles were initiated with a mere flick of a switch, thus facilitating a more expeditious and less strenuous operation.[Blo25] The ranges of around 50 to 100 kilometres per battery charge were perfectly adequate for urban use [ADA25].

The decline due to the combustion engine

However, the dominance of electric vehicles began to wane in the first third of the 20th century. The main factors behind this were:

- The invention of the electric starter motor by Charles Kettering in 1912, which made the hand crank on combustion engines superfluous [Gre25]
- The increasing availability of cheap crude oil, which made fuels for internal combustion engines affordable [gün25]
- The mass production of vehicles with internal combustion engines by Henry Ford, which drastically reduced the cost of cars [alp25]

By the 1930s, electric vehicles had largely disappeared from the market [alp25].

Revival in the 20th century

The energy crises of the 1970s and growing environmental awareness led to a renewed interest in electric vehicles [Wis25]. Car manufacturers experimented with prototypes to develop alternatives to fossil fuels [Ene25a]. During this phase, vehicles such as the General Motors EV1, which was launched in 1996, were created [Ins25a]. Despite its technical advances, however, production was discontinued after a few years [Ene25a].

The renaissance of electric vehicles in the 21st century

The beginning of the 21st century marked a new era for electric vehicles. Advancements in battery technology, notably the development of lithium-ion batteries,

have rendered electric cars more potent and more appropriate for daily utilisation.[Lab25] Simultaneously, an increase in demand was precipitated by environmental regulations and government subsidy programmes.
A significant turning point was marked by the establishment of Tesla Motors in 2003. The Tesla Roadster, which was launched on the market in 2008, demonstrated that electric vehicles could be both environmentally sustainable and aesthetically pleasing. This development subsequently influenced the introduction of other models, including the Nissan Leaf, the BMW i3, and the electric version of the Volkswagen Golf.[Ins25b]

Challenges and perspectives

Despite the successes, electric vehicles still face challenges. The infrastructure for charging stations must be expanded to ensure nationwide coverage.[Sta25] Furthermore, the manufacturing expenses of batteries remain substantial, though they are gradually declining due to economies of scale and technological advancements.[Pro25]
Nonetheless, the outlook for electric vehicles appears to be favourable. The ongoing development of solid-state batteries and the integration of renewable energies into power generation could drive electric mobility forward in the long term. The global transition towards zero-emission vehicles has been highlighted by political initiatives, such as the prohibition on combustion engines in certain countries, effective from 2035.[ISI25]

2.2 Lithium-ion batteries

Lithium-ion batteries have been utilised within the domain of computer technology for an extended period, attributable to their compact configuration. The applications for these devices range widely, encompassing smartphones and laptops. In

consideration of the imminent prohibition on the use of lead in vehicles, their utilisation is becoming progressively significant within the automotive sector. It is anticipated that their use will be indispensable in the future.
A lithium-ion battery with a nominal voltage of X volts consists of cells connected in series. In this configuration, the cell voltages are added together, but the total capacity is limited by the capacity of the weakest cell. In scenarios where increased capacity is required, the cells are connected in parallel, resulting in the summation of their individual capacities without altering the voltage. The evaluation of such a battery is classically based on its nominal capacity, the stored electrical energy and its performance.

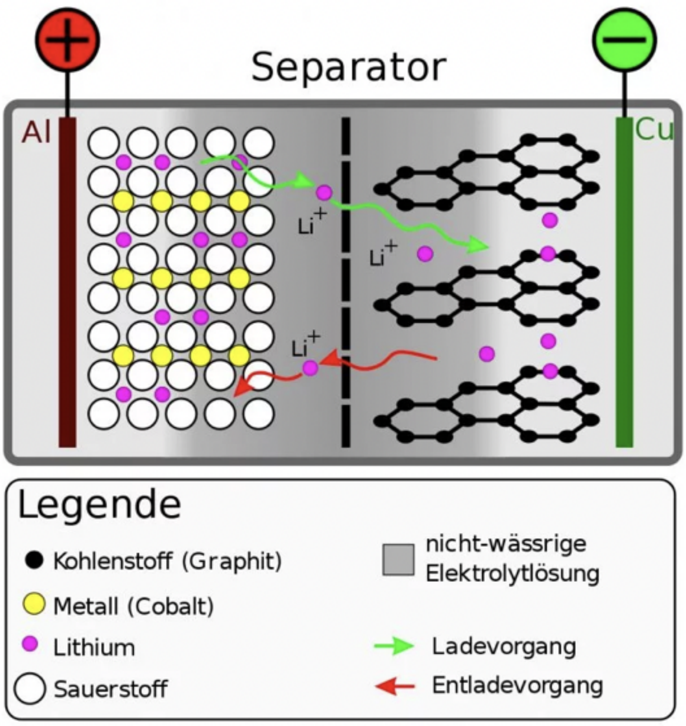


Figure 2.1: Structure of a lithium-ion cell [– D25]

As illustrated in 2.1, a lithium-ion cell comprises an anode, a cathode, a separator, arresters and an electrolyte. The positive area of the cell is located on the side of the anode, which is composed of a trap coated with a layer of graphite, i.e. carbon. The material most frequently utilised for the arrester is copper; nickel is employed on less frequent occasions. Conversely, the cathode constitutes the negative element of the cell and consists of an aluminium arrester coated with materials such as lithium cobalt oxide, lithium manganese oxide or lithium iron phosphate. The space between the two electrodes is filled with a liquid electrolyte that facilitates the movement of ions between the electrodes. This ensures the highest possible conductivity, thereby guaranteeing operation of the cell within a temperature range of -40 °C to +80 °C.[Sie15] An electrolyte is defined as a liquid that has been enriched with conductive salts to facilitate the movement of ions. Furthermore, the electrolyte must demonstrate exceptional stability in order to withstand numerous charge and discharge cycles, often numbering in the thousands.[Kor13, S.61f.] The separator constitutes a separating layer within the electrolyte between the electrodes of a lithium-ion cell. The material under discussion is typically composed of a membrane or a non-woven fabric, which is manufactured using materials such as glass fibre or plastics. The material possesses a porosity of approximately 40%. The subject's distinctive attribute is its selective permeability for ions, which are indispensable for the conversion of chemical energy into electrical energy. Conversely, electrons are obstructed by the separator, thereby ensuring their transportation to consumers, such as a control unit, via external lines. Following utilisation, the electrons return to the cell via the external circuit, where they reach the ions on the opposite side.

The separator plays a crucial role in preventing internal short circuits that would occur without it. Furthermore, it has been demonstrated that the subject in question facilitates gas exchange by means of the absorption of the electrolyte. The physical characteristics of the separator, including its thickness and porosity, exert a substantial influence on the internal resistance of the cell. Consequently, these characteristics are pivotal in determining the overall performance of the system.[Kor13, S. 80] In the context of lithium-ion battery operation, the positive electrode functions as the anode during the charging cycle and as the cathode during the discharging cycle. The charging process is typically executed through the utilisation of the Constant Current - Constant Voltage (CC-CV) method. In the initial step of the process, a constant current (CC) is applied until the battery has been stabilised at a fixed voltage. The voltage is then maintained at a constant level (constant voltage, CV), resulting in a progressive decrease in current flow. The charging process is typically terminated by the expiry of a stipulated time limit or when a predetermined current threshold is attained.[Kor13, S. 15] Lithium-ion batteries exhibit a substantial temperature dependency. It has been demonstrated that, at low temperatures, there is a substantial increase in internal resistance. This phenomenon can be attributed to the reduced rate of chemical reactions within the cell. Furthermore, it is imperative to refrain from overcharging the battery, as this can precipitate so-called decay reactions. The intensity of these reactions is contingent on the materials utilised for the cell components, with the potential to exert a substantial influence on the service life and safety of the battery.[Kor13, S. 15f.]

2.3 Technical Context of a Battery Enclosure

Battery enclosures are critical components in the design of energy storage systems, particularly in mobile and compact applications. They serve as structural containers for lithium-ion cells and provide necessary protection against environmental and mechanical influences. Their design must reconcile several competing requirements: mechanical robustness, thermal management, electrical insulation, compactness, and manufacturability. With the increasing adoption of 3D printing technologies, engineers now have more flexibility to prototype and produce such enclosures, particularly for small-series or custom applications [Geb16].

Modern lithium-ion cells come in standardized formats, such as cylindrical (e.g., 18650), prismatic, or pouch cells. Each of these formats imposes specific geometric and thermal constraints on the enclosure. Cylindrical cells, for example, are highly space-efficient in tightly packed arrays but require firm fixation and vibration dampening, as well as thermal spacing to avoid overheating. Enclosures for such cells often include integrated cell holders, structural ribs, and defined cooling pathways [PL18].

An essential consideration in battery pack design is thermal management. Since lithium-ion batteries are sensitive to excessive heat, the enclosure must ensure proper heat dissipation. Passive solutions, such as airflow channels or thermally conductive plastics, can be incorporated into the design. In high-performance applications, the enclosure may include embedded cooling elements. The thermal behavior of the entire assembly must be taken into account early in the design phase to avoid heat accumulation and ensure battery safety and longevity.

Mechanical constraints also play a decisive role. Battery packs are often subjected to vibration, shocks, and compression forces. Therefore, the housing material must be both strong and lightweight. Common materials used in 3D printing for such applications include ABS, PETG, and polyamide (PA12), each of which offers a specific balance of mechanical resilience, thermal resistance, and printability [Geb16].

The enclosure design must also accommodate connectors, cable guides, ventilation openings, and possibly fasteners for mounting within a device or vehicle. All of these features must be precisely aligned and dimensioned to ensure a secure and reliable assembly. Such complexity makes parametric and constraint-based design software particularly valuable.

2.4 Standards for drawing circuit symbols

The origins of standards can be traced back to the industrial revolution, a period which witnessed a significant increase in the demand for standardised processes and products. It is evident that discrepancies in dimensions, drawings and designations have resulted in a number of issues, including misunderstandings, inefficiencies and errors in production and communication. In order to combat this apparent chaos, a set of standards were established that now serve as legally binding regulations. Standards serve to facilitate a uniform language across the engineering, manufacturing and user communities. The primary functions of the components in question are threefold: firstly, to ensure compatibility; secondly, to improve quality; and thirdly, to promote international trade. In the context of technical drawings, particularly circuit symbols, standards play a pivotal role in ensuring the comprehension of technical plans on a global scale. This is achieved by transcending linguistic and regional barriers, thereby facilitating understanding irrespective of individual differences.

The most widely recognised standard symbols for circuit design

Three of the most widely recognised standart symbols for circut design are:

- **DIN standards (Germany):** These standards, promulgated by the German Institute for Standardisation, are particularly widespread in German-speaking countries. The course material covers a broad spectrum of standards, encompassing those pertaining to electrical, hydraulic and pneumatic circuit symbols.

- **IEC standards (International):** The International Electrotechnical Commission (IEC) is responsible for the development of standards that are applicable on a global scale. The IEC 60617 series, for instance, provides a standardized framework for the representation of symbols employed in the domain of electrotechnical systems and components.

- **ANSI standards (USA):** The American National Standards Institute (ANSI) is the preeminent standardisation organisation in the USA. ANSI drawings are frequently encountered in North American projects.

The choice of standard depends on the region and the application. While European projects are often based on DIN or IEC standards, ANSI standards dominate in the USA.

The DIN standard for circuit symbols in detail

In Germany, DIN standards play a pivotal role in the realm of technical drawing and circuit diagram creation. The DIN EN 60617 standard, which provides a comprehensive description of electrical circuit symbols, is of particular relevance in this context. The standard in question was developed in cooperation with the International Electrotechnical Commission (IEC), an international standards organisation that facilitates international connectivity.

DIN EN 60617 regulates in detail:

- **The representation of components:** Electronic components such as resistors, capacitors or switches have clearly defined symbols.
- **The layout of circuit diagrams:** Specifications for line routing, connection points and distances between symbols ensure clarity.
- **Connecting cables:** The visualisation of lines and crossings avoids misunderstandings, for example by clearly marking connections.

The DIN standard is predicated on the principle of reducing complexity and promoting intuitive readability. Moreover, the standard incorporates contemporary technologies and developments, necessitating regular updates to maintain currency.

Adherence to the DIN standard is of paramount importance for engineers seeking to ensure the accurate interpretation of their circuit diagrams within both their own organisation and on an international level. Standards can therefore be regarded not only as a tool for standardisation, but also as a means of improving quality and simplifying technical processes.

2.5 Autodesk Fusion 360

Autodesk Fusion 360 is an integrated platform for computer-aided design (CAD), computer-aided engineering (CAM) and computer-aided manufacturing (CAE) that was developed as a cloud-based solution (Jones, 2019). The integration of mechanical and electronic design processes is facilitated, thereby providing engineers, designers and developers with a centralised platform for product development. The following discussion will firstly provide a brief overview of the company history of Autodesk, the developer of this software. Following this, the core and special functions for creating electronic circuit diagrams will be outlined in detail.

History and development

Autodesk Incorporated (Inc.) was founded in 1982 by John Walker and a group of programmers and quickly specialised in software solutions for architecture, engineering and digital media [Wik24b]. The release of AutoCAD in 1982 set an important milestone for computer-aided design and became the leading CAD software for architects and engineers worldwide[Wik24a].

The advent of novel requirements within the manufacturing industry, coupled with the integration of electronics into mechanical systems, prompted Autodesk to embark on the development of a novel software type. The objective of this initiative was to consolidate mechanical and electronic development on a unified platform, thereby facilitating collaborative, cloud-based operations. This development subsequently led to the introduction of Fusion 360 in 2013.[con24] The integration of conventional CAD/CAM/CAE functions with cloud-based collaboration has resulted in the popularity of Fusion 360 as a tool in product development, thereby enabling Autodesk to achieve a novel market position in the domain of digital manufacturing.

2.6 3D Design Approach Using Fusion 360

Autodesk Fusion 360 provides an integrated environment for computer aided design (CAD), simulation, and Computer-Aided Manufacturing (CAM), which makes it particularly well-suited for iterative design and prototyping of technical components like battery enclosures. Its parametric modeling capabilities allow engineers to define the relationships between different parts of the geometry, ensuring that dimensional adjustments propagate automatically throughout the model [Hog].

Using Fusion 360, a designer can first define a master sketch that includes key dimensions such as cell spacing, wall thickness, and screw positions. Through extrusion and patterning, these base geometries are transformed into 3D solids. Additional features such as ventilation slots or mounting flanges can be added using derived sketches and Boolean operations[Hog]..

Assemblies in Fusion 360 enable designers to position and constrain battery cells within the enclosure, simulating real-world configurations. This allows for spatial validation and interference checking early in the process, reducing the risk of design flaws during manufacturing[Hog]..

Moreover, Fusion 360 supports exporting the final design directly into formats suitable for additive manufacturing, such as STL or 3MF. This integration streamlines the workflow from design to production, making it ideal for rapid prototyping and validation[Hog]..

From a manufacturability perspective, the designer must also follow principles of Design for Additive Manufacturing (DfAM). This includes minimizing unsupported overhangs, ensuring even wall thicknesses, and aligning features for optimal layer orientation. Fusion 360 offers visualization tools and slicer integration to help evaluate the printability of the part [And20].

In summary, Fusion 360 offers the necessary flexibility and functionality to develop complex battery enclosures that meet structural, thermal, and electrical requirements. Its parametric design environment, combined with visualization and export tools, makes it an effective platform for realizing functional prototypes that are ready for testing and refinement.

3 Documentation

In order to ensure the best possible documentation of the system structure, it is imperative that the preparations for the task are given the requisite consideration. These can be divided into two major parts. Of the two aforementioned steps, the selection of a suitable tool for creating the documentation is of greater importance. In this context, factors such as ease of use, functionality, compatibility with operating systems, and financial considerations are of paramount importance. In order to make this selection with sufficient care, the following procedure is employed:

A comprehensive review of available CAD software programmes is conducted to ascertain their suitability. The functions are of paramount importance in this context. It is imperative that the programme has the capacity to generate circuit diagrams and assembly plans. The subsequent priority is the cost of the programme. Given the budgetary constraints inherent to the project, it is imperative that these expenses remain minimal. However, it is important to note that the costs must be proportionate to the performance offered by the programme. It is evident that both the *Autodesk Fusion 360* and *EPlan* software programmes hold considerable potential. It is evident that both programmes demonstrate equivalent levels of user-friendliness. Following a thorough evaluation of the available options, it was determined that Autodesk Fusion 360 would be the most suitable solution, given the incompatibility of EPlan with macOS.

In the subsequent stage of the preparatory process, it is imperative to undertake a thorough and comprehensive familiarisation with the programme. In this particular instance, emphasis is placed on the following aspects: the creation of circuit diagrams; the creation of assembly plans; the creation of libraries; the creation of new components; and the programme project structure.

3.1 Installation instructions Fusion 360

The following instructions outline the procedure for creating a student account and downloading Fusion 360 Electronics.

Creation of an Autodesk student account

To use Fusion 360 Electronics, it is necessary to create an Autodesk student account. This allows free access to the software.

Registration

- Access to the registration page: Autodesk Registrierungsseite.
- Fill in the form with the necessary information:
  - First name and surname
  - Valid e-mail address
  - Password in accordance with the security guidelines

E-Mail verification

- After submitting the form, you will receive a confirmation e-mail.
- Open the e-mail and click on the confirmation link to verify the address.

Completion of the profile information

- Login to Autodesk account.
- Provide additional information such as institution, field of study and year of study to confirm student status.

Verification of student status

- Upload a document that proves enrolment (e.g. a certificate of enrolment).
- Autodesk checks the documents within a few days and sends a confirmation by e-mail.

Download und installation of Fusion 360 Electronics

Access to the Download-area

- Once the account has been successfully verified, you can log in and navigate to the Autodesk Education Community.
- Select Fusion 360 from the list of available software.

Download and installation process differ for different operating systems. the differences between Windows and macOS are explained below.

Windows

- When selecting the download file, please note the differences between the software versions for the various Windows operating systems. These differ in the version number (e.g. „Windows 11“) and in the bit versions (32- and 64-bit).

- Steps to identify the Windows version:

  1. Press the key combination Windows key + I to open the settings.

  2 Go to System → About.

  3. In the context of Windows specifications you will find the exact version and edition of Windows (for example „Windows 11 Pro“, „Version 22H2“).

- Steps to identify the bit-version:

  1. Press the key combination Windows key + I to open the settings.

  2 Go to System → About.

  3. Under Device specifications → System type you will see, for example, „64-bit operating system“.

- Click on ‘Download now’ and follow the instructions on the screen.

- Once the download is complete, open the installation file and follow the installation instructions.

macOS

- When selecting the download file, please note the differences between the software version for operating systems with Apple Silicon processor and Intel processor.
- Steps for identifying the installed processor:
  1. Click on the Apple icon in the top left.
  2. Select Äbout this Mac".
  3. Look in the window that opens:
     If it says „Chip“ followed by, for example, „Apple M1“ or „Apple M2“, an Apple Silicon processor is installed.
     If it says „Processor“ followed by an Intel processor (for example, „Intel Core i5“), an Intel processor is installed in the Mac.
- Click on ‘Download now’ and follow the instructions on the screen.
- Once the download is complete, open the installation file and follow the installation instructions.

Activation of the education licence

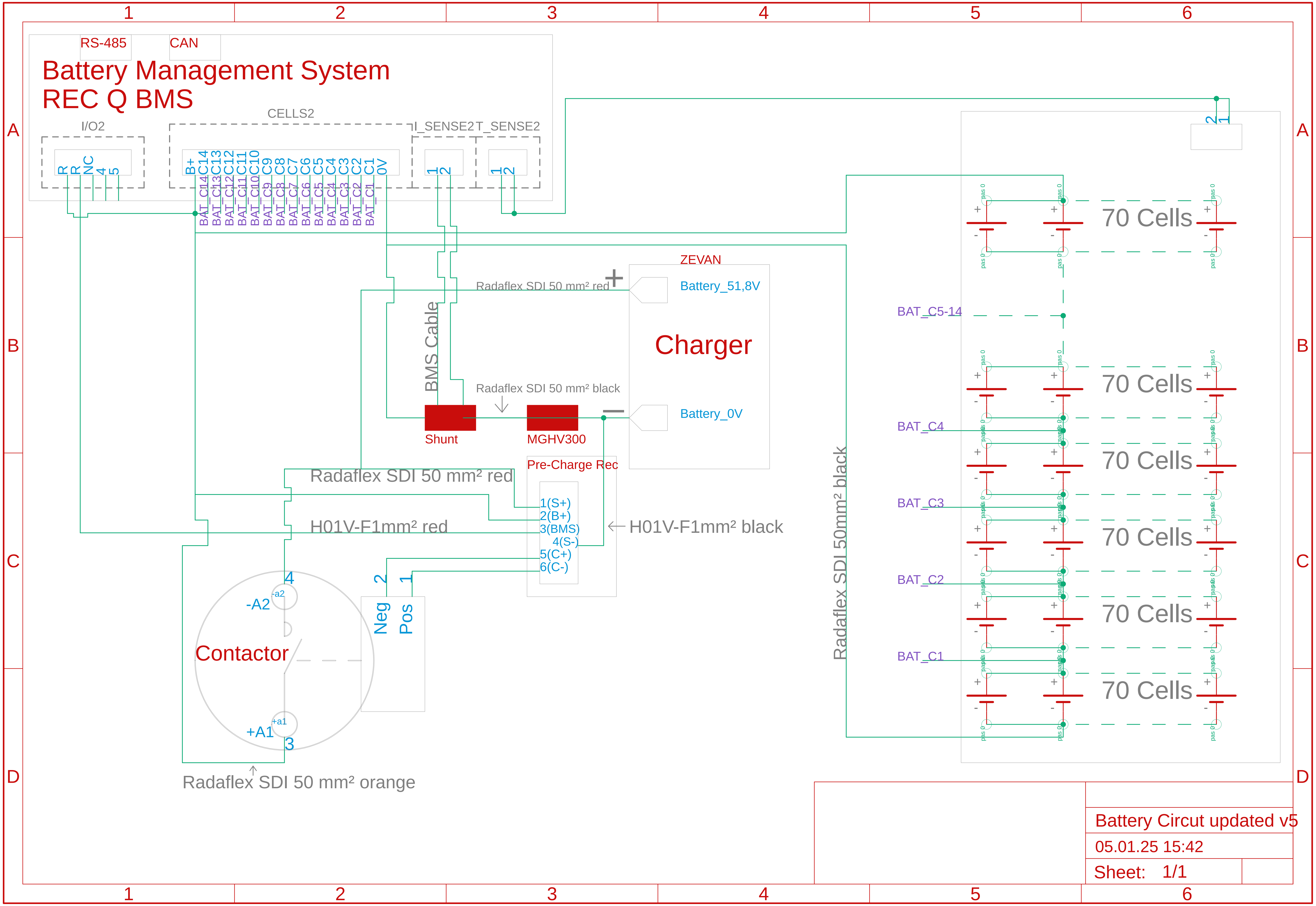
- When Fusion 360 is started for the first time, the login information is entered.
- The software automatically recognises the student status and activates the corresponding licence.

3.2 Circuit diagrams

3.2.1 Circuit diagram of the battery circuit

In order to create the *battery circuit* (see figure 3.1), the existing diagram is first printed out, and the circuit is then created in accordance with the defined standard and current installation status. In the initial phase, the circuit diagram is meticulously examined for any inconsistencies, including the absence of connections or the ambiguity of symbols. Any errors detected during this process are subsequently annotated in the subsequent stage, and then rectified, thus ensuring conformity with the relevant electrotechnical standards. The layout has been adapted to improve clarity. In the final step, it is necessary to determine the standard according to which the circuit diagram was created. It is imperative that this standard is thoroughly researched and „translated“ into our chosen DIN EN 60617 standard. The revised circuit diagram is then transferred to a DIN A3 format using Autodesk Fusion 360. The integration of the title block and legend is paramount in ensuring the maintenance of a professional and legible appearance.

Figure 3.1: Circut diagram of the Battery Circuits

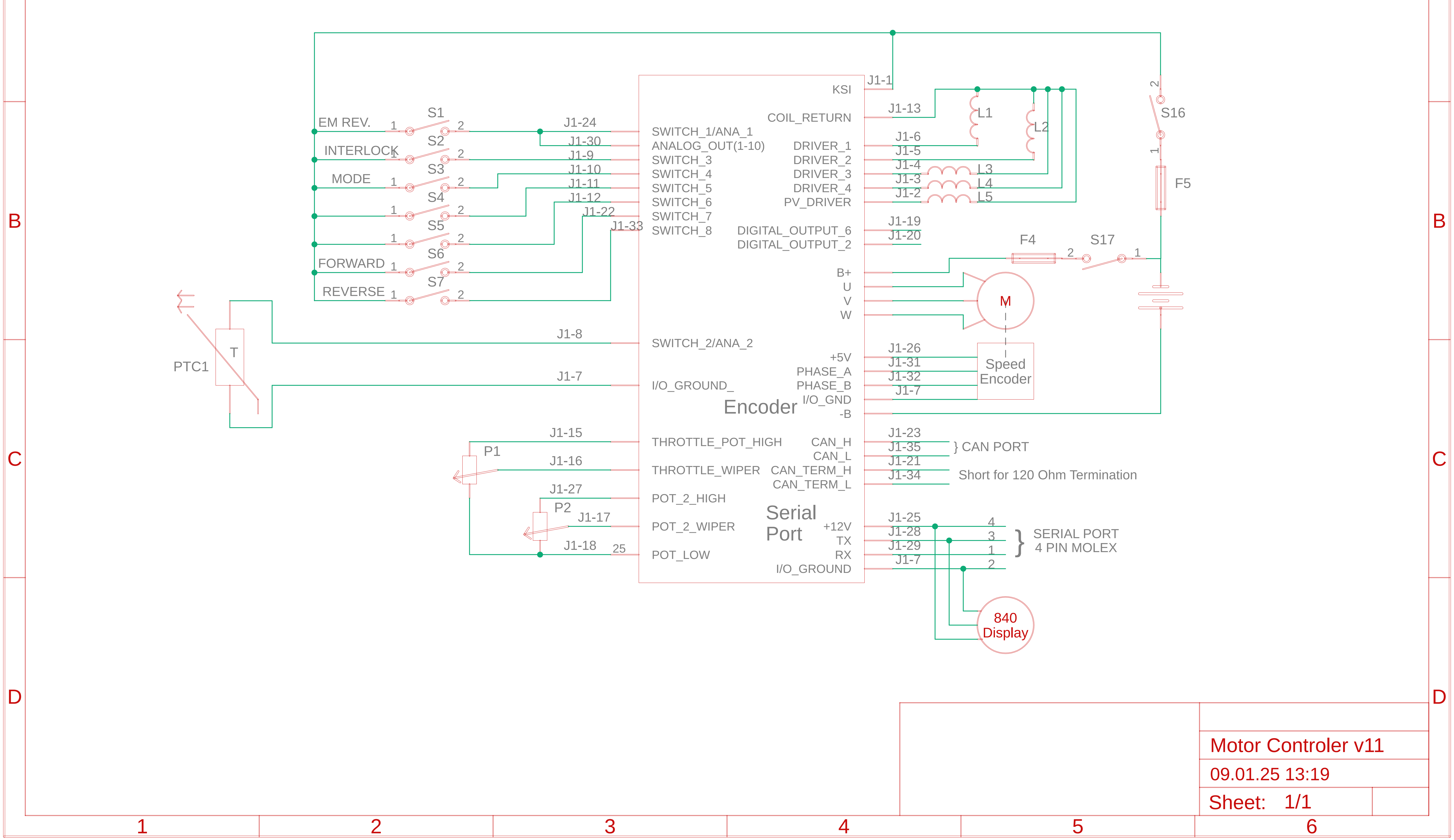


05.01.25 15:44 f=1.50 /Users/philippbellmann/Desktop/DH/eMule/circuts/Battery Circut updated v5.pdf (Sheet: 1/1)

3.2.2 Circut diagram of the motor controller

In order to create the *motor controller* (see figure 3.2) the existing diagram is first printed out, and the circuit is then created in accordance with the defined standard and current installation status. In the initial phase, the circuit diagram is meticulously examined for any inconsistencies, including the absence of connections or the ambiguity of symbols. Any errors detected during this process are subsequently annotated in the subsequent stage, and then rectified, thus ensuring conformity with the relevant electrotechnical standards. The layout has been adapted to improve clarity. In the final step, the standard according to which the circuit diagram was created must be determined. It is imperative that this standard is thoroughly researched and translated into the DIN EN 60617 standard selected by us. The revised circuit diagram is then transferred to a DIN A3 format using Autodesk Fusion 360. The integration of the title block and legend is a deliberate design choice that serves to enhance the document's professionalism and legibility.

Figure 3.2: Schaltplan des Motor Controllers

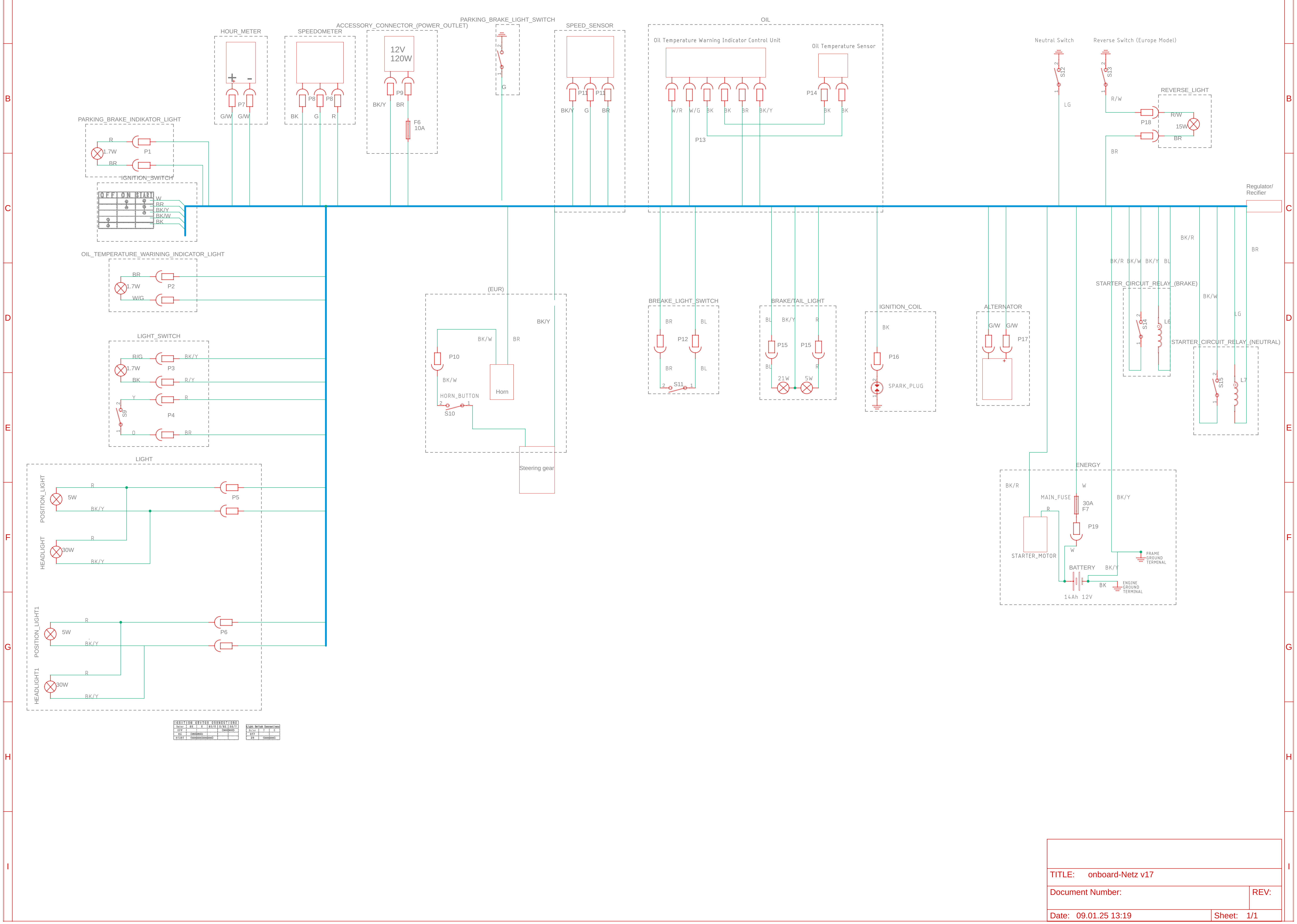


09.01.25 13:33 f=1.50 /Users/macbookvonrafael/eMule/circuts/Motor Controler.pdf (Sheet: 1/1)

3.2.3 Circut diagram of the LV onboard power supply

In order to establish the LV onboard power supply (see figure 3.3), the circuit diagram must be created in accordance with the defined standard and current installation status. To this end, the existing diagram is to be printed out. In the initial phase, the circuit diagram is meticulously examined for any inconsistencies, including the absence of connections or the ambiguity of symbols. Any errors detected during this process are subsequently annotated in the subsequent stage, and then rectified, thus ensuring conformity with the relevant electrotechnical standards. The layout has been adapted to improve clarity. In the final step, the standard according to which the circuit diagram was created must be determined. It is imperative that this standard is thoroughly researched and translated into the DIN EN 60617 standard, which has been selected by us. The revised circuit diagram is then transferred to a DIN A3 format using Autodesk Fusion 360. The integration of the title block and legend is a deliberate design choice that serves to enhance the document's professionalism and legibility.

Figure 3.3: Circut diagram of the LV onboard power supply



3.2.4 Circut diagram of the charger temperature control

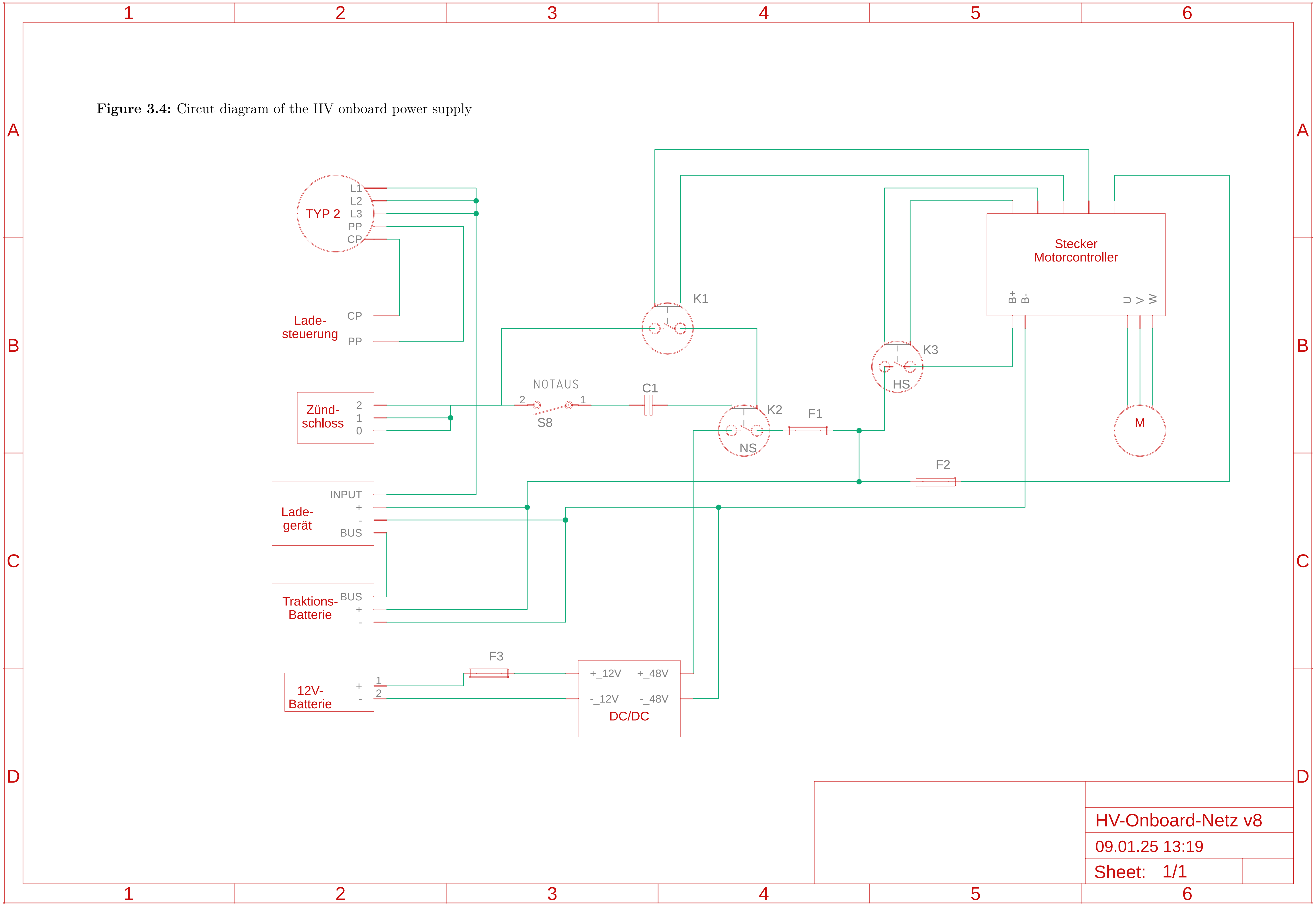
In order to create the circuit diagram for the charger temperature control (see Figure **??**), it is first necessary to create a manual sketch of the system. This is to be done according to the defined standard and current installation status. The creation of the manual sketch is the responsibility of the colleagues who are responsible for installation. It is then necessary to pass the sketch to the documentation team. In the initial phase, the circuit diagram is meticulously examined for any potential discrepancies, including the absence of connections or the ambiguity of symbols. Any errors detected during this process are subsequently annotated in the subsequent stage, and then rectified, thus ensuring conformity with the relevant electrotechnical standards. The layout has been adapted to improve clarity. In the final step of the process, the conformity of the circuit diagram with the relevant standards must be checked. The revised circuit diagram is then transferred to a DIN A3 format using Autodesk Fusion 360. The integration of the title block and legend is a deliberate design choice that serves to enhance the document's professionalism and legibility. ***!!!!!!!Einfügen @Buck***

3.2.5 Circut diagram of the HV onboard power supply

The creation of the HV onboard power supply (see Figure 3.4) is to be undertaken in accordance with the defined standard and current installation status. To this end, a manual sketch of the system is to be made by the installation team and subsequently passed to the documentation team. In the initial phase, the circuit diagram is meticulously examined for any potential discrepancies, including the absence of connections or the ambiguity of symbols. Any errors detected during this process are subsequently annotated in the subsequent stage, and then rectified, thus ensuring conformity with the relevant electrotechnical standards. The layout has been adapted to improve clarity. In the final step of the process, the conformity of the circuit diagram with the relevant standards must be checked. The revised circuit diagram is then transferred to a DIN A3 format using Autodesk Fusion

360. The integration of the title block and legend is a deliberate design choice that serves to enhance the document's professionalism and legibility.

Figure 3.4: Circut diagram of the HV onboard power supply

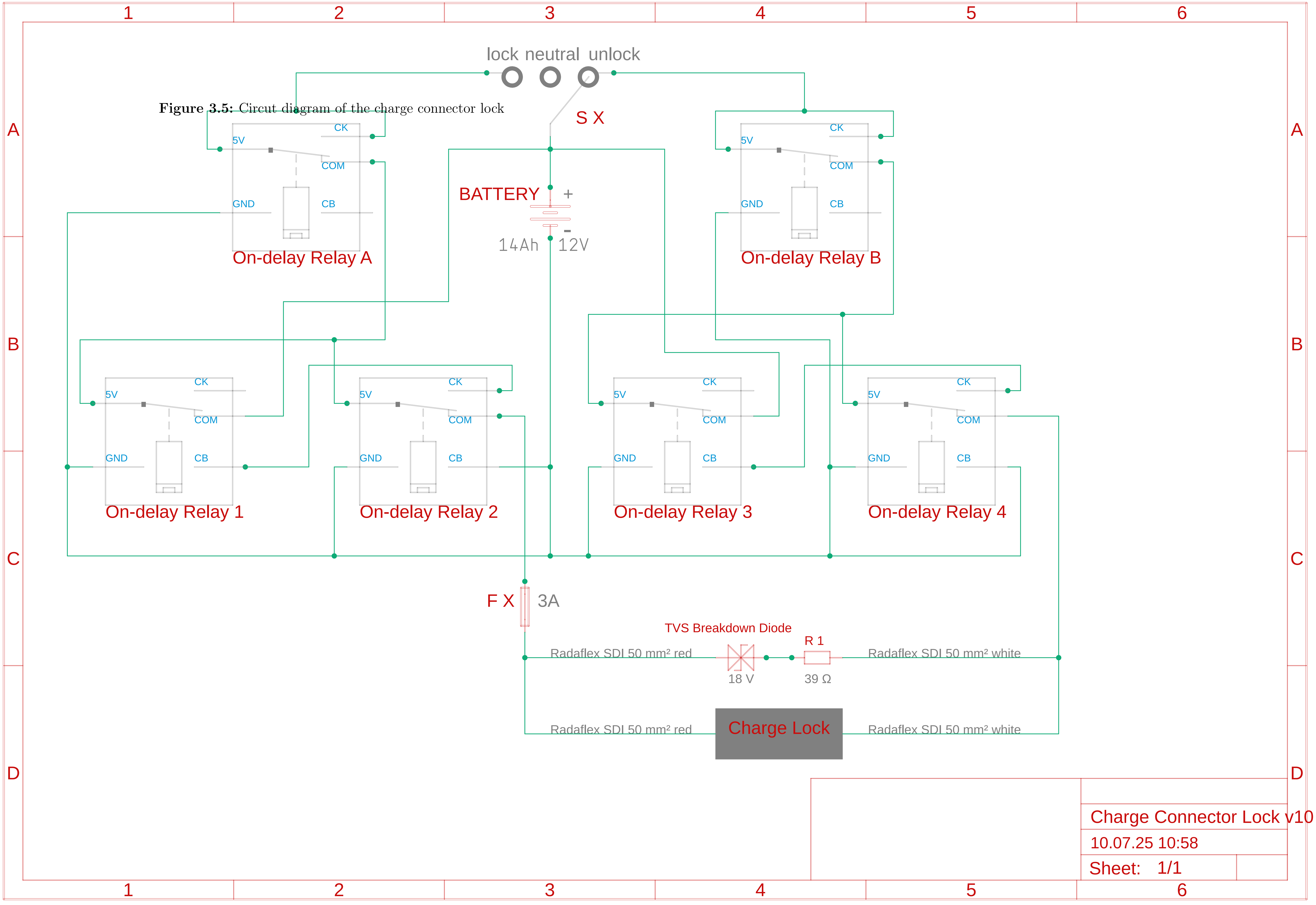


09.01.25 13:31 f=1.50 /Users/macbookvonrafael/eMule/circuts/HV-Onboard-Netz.pdf (Sheet: 1/1)

3.2.6 Circut diagram of the charge connector lock

In order to create the charge connector lock (see figure 3.5), it is first necessary to create a manual sketch of the system. This is to be done according to the defined standard and current installation status. The creation of the manual sketch is the responsibility of the colleagues who are responsible for installation. It is then to be passed on to the documentation team. In the initial phase, the circuit diagram is meticulously examined for any potential discrepancies, including the absence of connections or the ambiguity of symbols. Any errors detected during this process are subsequently annotated in the subsequent stage, and then rectified, thus ensuring conformity with the relevant electrotechnical standards. The layout has been adapted to improve clarity. In the final step of the process, the conformity of the circuit diagram with the relevant standards must be checked. The revised circuit diagram is then transferred to a DIN A3 format using Autodesk Fusion 360. The integration of the title block and legend is a deliberate design choice that serves to enhance the document's professionalism and legibility.

Figure 3.5: Circuit diagram of the charge connector lock



3.3 Legende der Schaltzeichen

The subsequent table (see figure 3.1) provides a comprehensive explanation of the circuit symbols employed in the circuit diagrams, in accordance with the DIN EN 60617 standard. These symbols are employed to denote the electrical components and their interconnections in the circuit diagram in a manner that is both clear and standardised. The legend offers a comprehensive overview of the symbols utilised in the preceding circuit diagrams, thereby facilitating comprehension of the system architecture and functionality of the individual diagrams and the overall system. The directory under discussion currently includes:

- Contactor
- Capacitor
- Spark gap
- Ground
- Battery
- Fuse
- Switch
- PTC (Positive Temperature Coefficient) resistor
- Potentiometer
- Plug
- LED (Light Emitting Diode)
- Coil/Inductor
- Three-phase motor

Im weiteren Verlauf des Projekts kann dieses Verzeichnis beliebig um weitere Schaltzeichen ergänzt und angepasst werden.

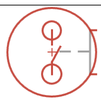
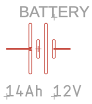
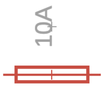
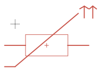
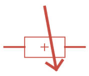
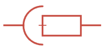
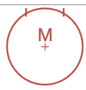
Symbol	Beschreibung
	Contactor
	Capacitor
	Spark gap
	Ground
	Battery
	Fuse
	switch
	PTC resistor
	Potentiometer
	Plug
	LED
	Coil/Inductor
	Three-phase motor

Tabelle 3.1: Legende der Symbole

3.4 Assembly plans

3.4.1 Network assembly plan

The *network assembly plan* (**see figure 3.6**) has been formulated in accordance with the current installation status. For the purpose previously outlined, the existing plan is to be printed out. The initial step in this process is to methodically review the existing circuit diagram to identify any inconsistencies, such as erroneous or missing connections, and ambiguous symbols. In the subsequent stage, the errors that have been identified are marked and corrected. Furthermore, the layout has been meticulously revised to enhance clarity. It is imperative that the components are positioned in the same location in the plan as in the vehicle. The relevant component connections are visualised in the planning stage. In the concluding step of the process, the revised circuit diagram is transferred to DIN A3 format using Autodesk Fusion 360. In this particular context, the integration of the title block and legend is paramount to ensure both professionalism and legibility.

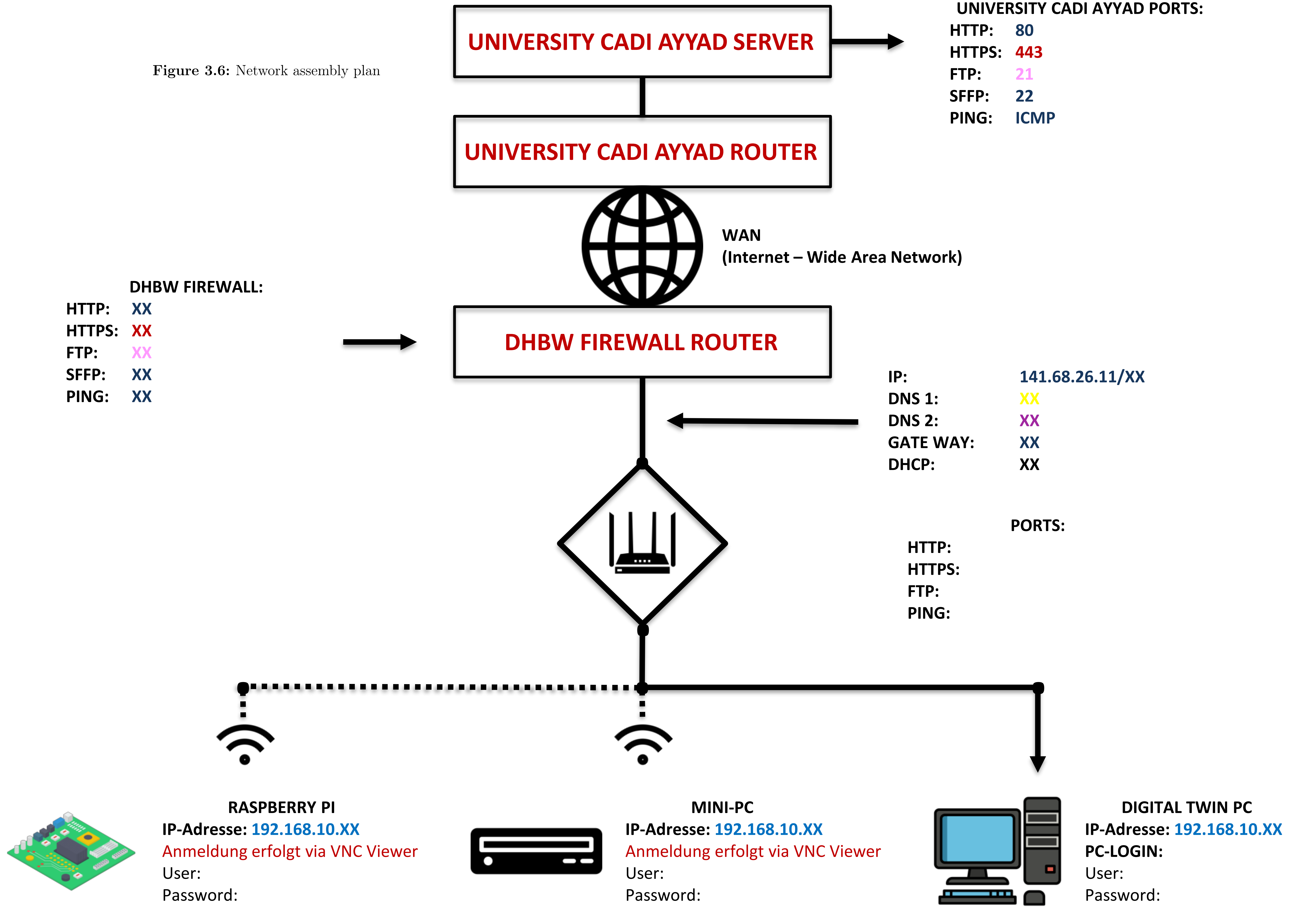
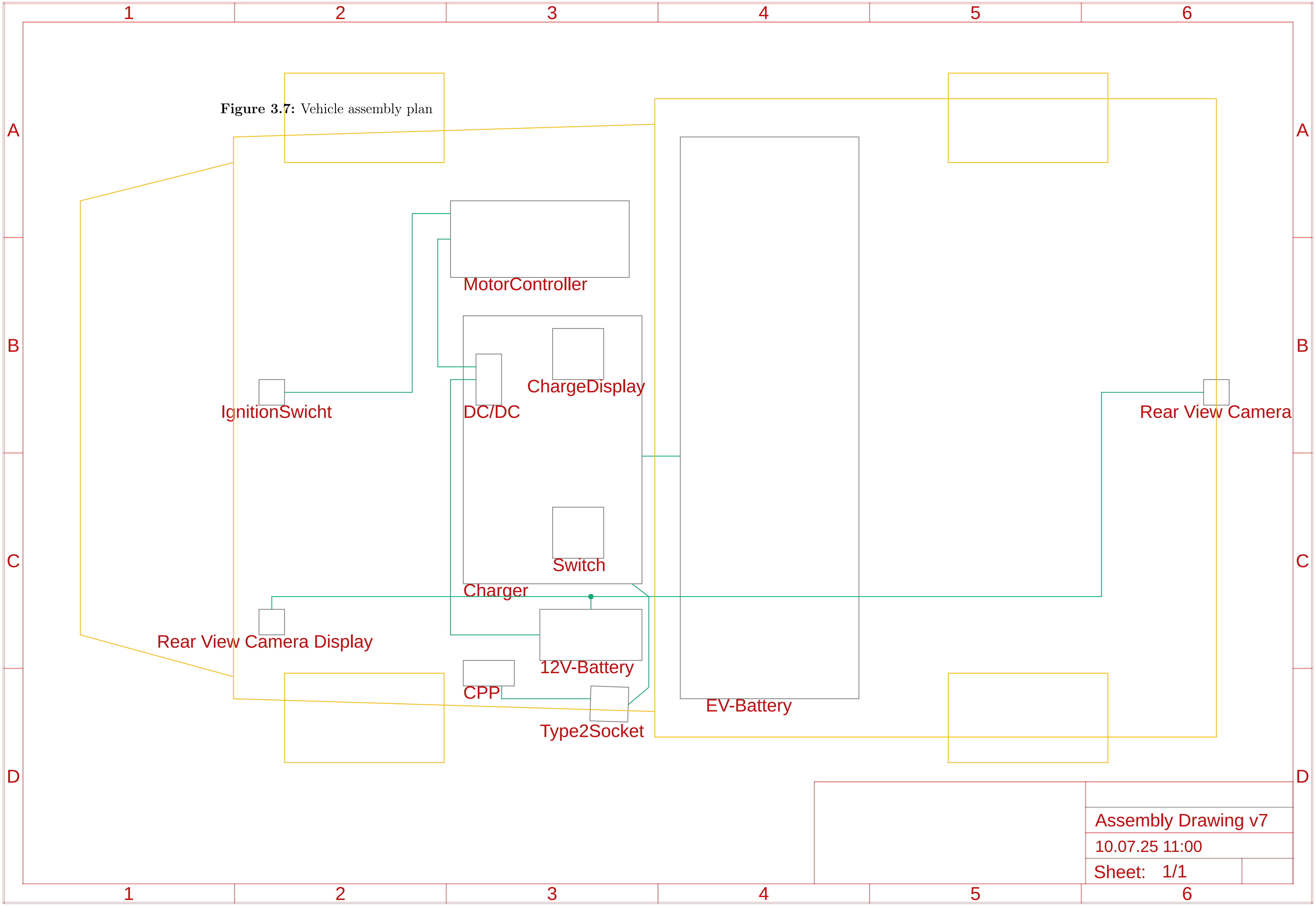


Figure 3.6: Network assembly plan

3.4.2 Vehicle assembly plan

The *vehicle assembly plan* (see figure 3.7) has been created according to the current installation status. For the purpose of illustration, a manual sketch of the system is initially created and subsequently printed. The initial step in this process is to methodically review the sketch of the assembly plan to identify any inconsistencies, such as erroneous or missing connections, and ambiguous symbols. In the subsequent stage, the errors that have been identified are marked and corrected. Furthermore, the layout has been meticulously revised to enhance clarity. The components must be placed in the plan with the utmost precision, ensuring that they are positioned identically to their counterparts in the vehicle to ensure optimal functionality. The relevant component connections are visualised during the planning phase. In the concluding step of the process, the revised circuit diagram is transferred to DIN A3 format using Autodesk Fusion 360. In this context, the title block and legend are integrated to ensure both professionalism and legibility.

Figure 3.7: Vehicle assembly plan



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4 3D Modelling

The design of battery housings is an essential step in developing reliable energy storage systems. Autodesk Fusion 360 offers an integrated CAD environment ideal for creating precise and adaptable models, especially when targeting additive manufacturing methods. This section focuses on the detailed process of creating, structuring, and refining battery enclosure CAD files within Fusion 360, emphasizing parametric design and manufacturability [Hog].

4.1 Design and Development of a Modular Lithium-Ion Battery System

The design illustrates a modular lithium-ion battery storage system, developed for high-density energy applications such as stationary energy storage, backup infrastructure, or mobile electrification platforms. The system is based on 21700-format lithium-ion cells, arranged in a densely packed structural configuration to optimize both volumetric energy density and thermal dissipation properties. The design process was carried out using CAD modeling tools, including parametric 3D assemblies, with iterative thermal and structural simulations executed to ensure mechanical and thermal stability under nominal and elevated load conditions.

4.2 Parametric Modeling Principles

Parametric modeling underpins efficient design workflows in Fusion 360. By defining key dimensions and constraints as parameters, changes can be propagated throughout the model automatically. This approach enables rapid iteration and consistent accuracy across complex geometries [And20].

Initial modeling begins with sketches representing cross-sectional profiles of the battery cells and enclosure features. These sketches are converted into 3D geometry via extrusion, revolution, or other solid modeling operations. Parameters controlling dimensions such as cell diameter, wall thickness, and sensor pocket size are set at the outset, allowing easy adjustments during development [Geb16].

4.3 Base Geometry and Cell Arrangement

The first step is designing the footprint to hold the battery cells securely. For cylindrical 18650 cells, a circular sketch with a diameter of 18.6 mm is created. To accommodate tolerances and thermal expansion, an additional clearance of approximately 1.5 to 2 mm is added around each cell [PL18]. Using Fusion 360's pattern features, this base slot is duplicated to form the desired cell matrix arrangement.

Next, the outline of the overall enclosure is sketched, defining the external boundaries. The sketch is extruded to form the base structure, with wall thickness set according to mechanical strength requirements and printability constraints, typically ranging from 2 mm to 4 mm [Geb16].

4.4 Feature Addition: Sensor Integration and Cable Management

A critical aspect of the enclosure design is the integration of temperature sensors. Dedicated pockets are created by cutting recesses adjacent to the battery cells using parametric cut operations. These pockets are dimensioned to fit common thermistors or digital sensors securely, ensuring reliable thermal contact [And20].

Additionally, routing channels for sensor wiring are incorporated into the design. These channels prevent wire interference and facilitate clean assembly. All such features are parameter-driven, allowing dimension adjustments as sensor specifications or wiring requirements evolve.

4.5 Assembly Modeling and Component Placement

Fusion 360's assembly workspace enables importing battery cell and sensor component models. These are positioned within the enclosure to verify fit, clearances, and spatial relationships. The assembly environment supports the use of constraints and joints, allowing realistic simulation of component interactions [Hog].

Parameters controlling cell spacing, sensor pocket depth, and cable routing pathways are globally defined. Altering any parameter updates the entire assembly model, significantly improving design iteration speed and accuracy.

4.6 Design for Additive Manufacturing (DfAM) Considerations

Throughout the modeling process, adherence to DfAM principles is crucial to ensure manufacturability via 3D printing. This includes minimizing overhangs exceeding recommended angles (usually 45°), maintaining uniform wall thickness to prevent warping, and designing features to reduce the need for support material [And20].

Fillets and chamfers are strategically applied to edges to improve mechanical strength and printing quality. The model is split into modular subassemblies where necessary, facilitating multi-part printing and post-processing.

4.7 Manufacturing Preparation and Export

The final step in the design workflow involves exporting the CAD files into formats compatible with slicing software, primarily STL or 3MF [Geb16]. Fusion 360's built-in manufacturing tools allow users to simulate print jobs, preview layer-by-layer builds, and optimize part orientation for strength and surface finish.

Subsequent iterations incorporate feedback from prototype prints, with dimension adjustments made via the parametric model to fine-tune fit and function.

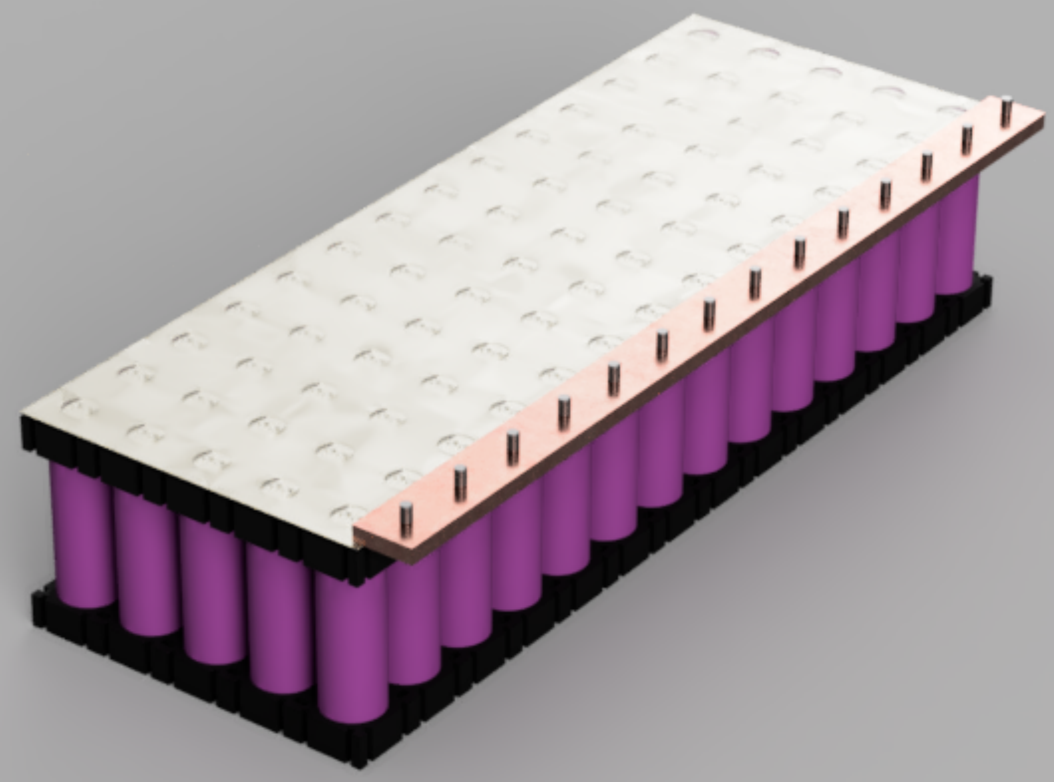
4.8 Iterative Refinement and Version Control

Due to the parametric nature of the model, any necessary refinements—such as modifying sensor pocket sizes or wall thickness—are efficiently implemented without reconstructing the design from scratch [Hog]. Fusion 360's version control system aids in tracking changes and managing design variants.

This iterative design methodology accelerates development timelines and reduces errors, particularly when integrating complex features like sensor integration and wiring management.

4.9 Application Context: Battery Housing for the E-Mule Energy Storage System

Figure 4.1: etailed 3D CAD rendering of a lithium-ion cell used in the energy storage system.



The battery pack presented in 4.1 was designed specifically for use in an electric utility vehicle—the E-Mule. In such mobile applications, energy storage must not only provide sufficient capacity and power density, but also fulfill mechanical and thermal requirements, ensure serviceability, and allow compact packaging. These constraints played a central role in the CAD modeling process and directly influenced key design decisions.

The final design was entirely created using Fusion 360, with a strong focus on modularity, manufacturability, and the physical integration of standard lithium-ion cells (type 21700). The enclosure and internal structures were tailored for additive manufacturing using PETG, a common thermoplastic with suitable strength and heat resistance [Geb16]. No electrical testing or thermal simulation was conducted as part of this stage; the focus remained on the mechanical layout and enclosure architecture.

4.10 Detailed CAD Design Process in Fusion 360

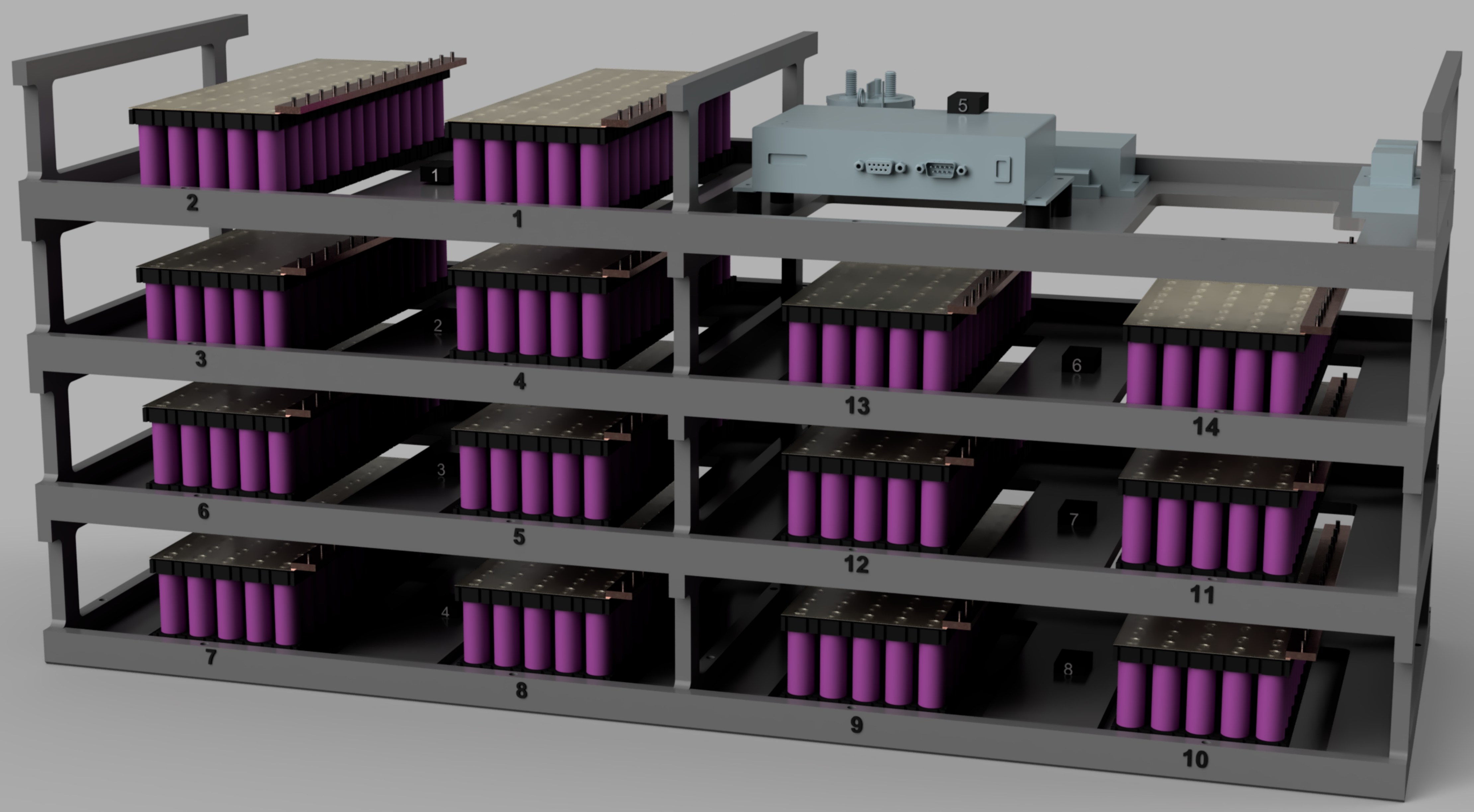
4.10.1 Cell Holder Design and Arrangement

The first modeling step was the design of an individual battery cell holder (4.1). Each cell is a cylindrical 21700 lithium-ion battery, typically 21 mm in diameter and 70 mm in length. In Fusion 360, a 2D sketch was created with circular cutouts for each cell, spaced evenly in a grid pattern. These cutouts were then extruded to form vertical cavities, which securely hold the cells while leaving sufficient clearance for thermal expansion and wiring.

To ensure consistent wall thickness and clearance, the design used parameterized dimensions tied to a master sketch. This allowed rapid iteration and adjustment of the number of cells in the matrix.

The resulting layout provides space for a total of 70 cells (14×5 array), which was deemed sufficient for the E-Mule's use case in terms of energy content. The precision and symmetry of the layout were maintained through pattern tools and the use of midplane construction lines.

Figure 4.2: Fully assembled energy storage module.



After creating the single cell holder as a component, it was duplicated and arranged in Fusion 360's assembly environment to simulate the full module layout, seen in 4.2. This stage focused on integrating all components—holders, cell blocks, connector slots, sensor openings—into a complete mechanical structure.

During assembly, care was taken to maintain access to each row for both cooling and cabling. Clearances were checked using section analysis and interference detection tools within Fusion 360. Dummy models of power connectors and temperature sensors were placed to simulate real-world installation.

4.10.2 Integration of the Protective Enclosure

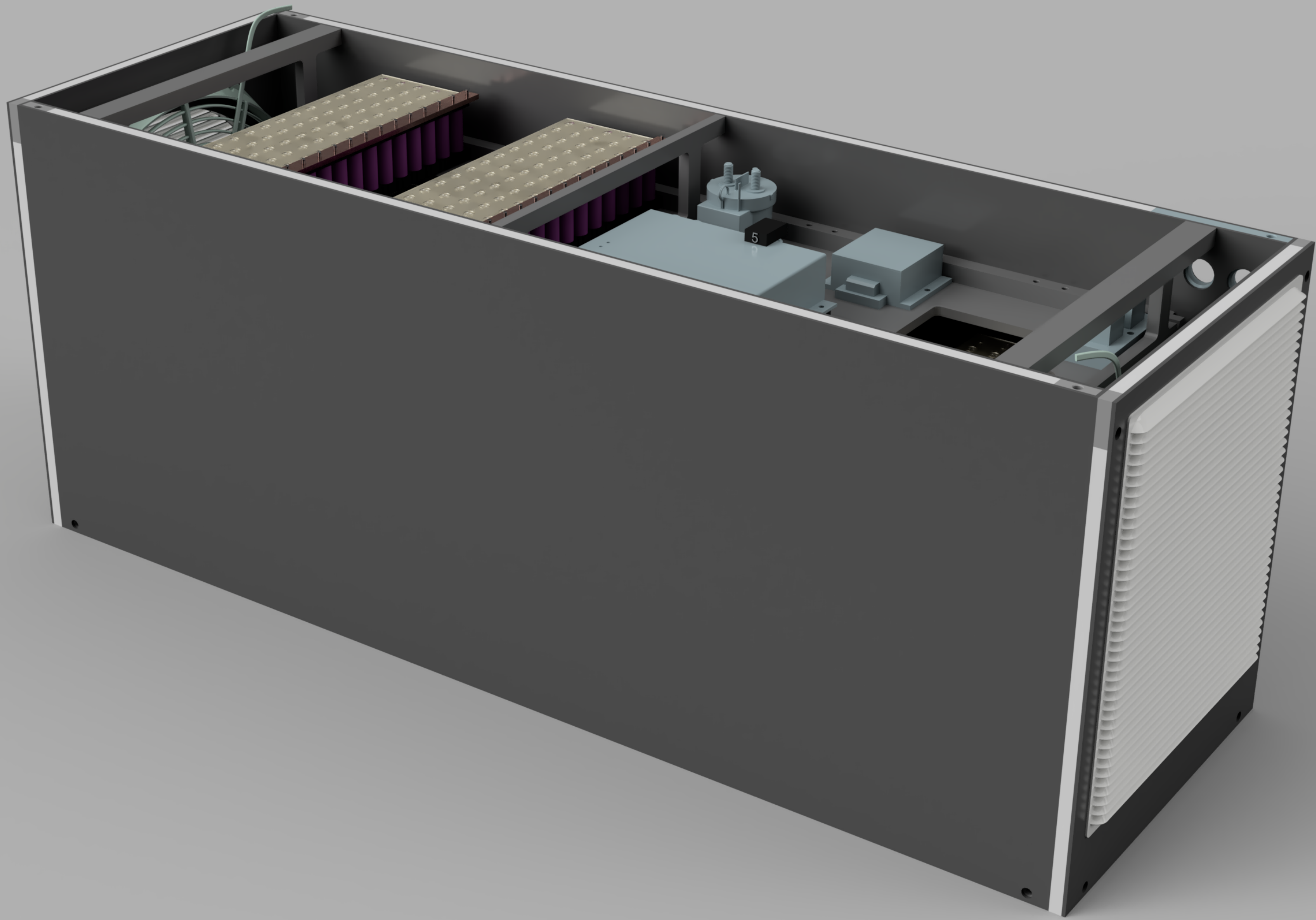


Figure 4.3: Fully assembled energy storage module with housing for use in the eMule vehicle.

The final design step was the addition of a functional enclosure as seen in 4.3. The enclosure was modeled as a single shell body with integrated ventilation openings, flanged screw points, and access cutouts for connectors. Its purpose is to protect the cells from mechanical impact, environmental contamination, and unintentional contact.

The enclosure follows the contour of the internal components closely, minimizing unused space while allowing air to circulate between components. To accommodate additive manufacturing constraints, all overhangs were designed with a maximum angle of 45°, and fillets were added at all interior corners to prevent stress concentration. A removable lid was included to enable servicing of the battery.

The figure seen in 4.3 illustrates the fully enclosed battery system, ready for 3D printing.

5 critical reflection and perspective

As part of the eMule 7.0 project, a series of objectives were delineated for the summer semester of 2025, including:

1. Document circuit diagrams
2. Document assembly plans
3. 3D CAD model of the energy storage system
4. Support in the creation, testing and implementation of autonomous driving

The creation of circuit diagrams has been further refined through the use of sketches that are as realistic as possible, rather than merely schematically as was previously the case.

The circuit diagrams for all system components were created at the time of publication of this work. These plans comply with the standards of DIN EN 60617, have a standardised design and are integrated into a superordinate overall project. The creation of a total of six circuit diagrams was undertaken.

The following procedure was utilised in order to create the assembly plans in an efficient manner: Initially, a manual sketch of the system was created and subsequently printed. The initial step in the process entailed a systematic examination of the existing assembly plan to identify any potential inconsistencies, including but not limited to incorrect or missing connections and unclear symbols. In the subsequent stage, the identified errors were annotated and rectified. Furthermore, the layout was modified to enhance clarity. It was imperative that the components were placed in the same position in the plan as in the vehicle. The relevant component connections were visualised in the planning stage. In the final step of the process, the revised circuit diagram was transferred to DIN A3 format using Autodesk Fusion 360. In this particular instance, the integration of the title block and legend was a deliberate design choice to ensure the maintenance of a professional and legible aesthetic.

5.1 Conclusion on the CAD Design Process

Using Fusion 360 allowed for a highly structured, iterative, and parametric modeling workflow. All geometric relationships between components were carefully maintained, which significantly simplified later adjustments. The use of parametric sketches and pattern tools proved crucial in efficiently laying out large arrays of repetitive features, such as the cell holders.

The final result is a complete digital twin of the battery system, suited for additive manufacturing and integration in the E-Mule platform. While no physical tests or simulations were performed, the model meets the spatial, mechanical, and packaging criteria outlined at the beginning of the project.

The implementation of autonomous driving could not be supported. The team whose main task was the implementation was researching in the wrong direction, so it was not advanced enough to be able to utilise support at the level of our expertise.

5.2 Hiuer fehlt ne überschrift aber mir ist nix eingefallen

As part of this project, the team familiarised themselves more deeply with the Autodesk Fusion 360 software. In addition, the in-house library for the DIN EN 60617 standard was expanded, a separate library for CAD design was created, and a structure for easy expansion of the library was implemented. It was also ascertained that new team members can be readily incorporated into the project cloud.

In addition to the team-specific tasks, the team provided support to other project groups. This encompassed, for instance, the processes of loading, installing and removing the battery in the vehicle and **!!!Buck!!!**

Perspective

Following the conclusion of the 2025 summer semester, new teams will have the opportunity to assume responsibility for a number of tasks in future projects. The overarching objective remains the attainment of TÜV approval. The option of installing a music system remains.

The following objectives have been delineated for the ensuing processing periods:

- The replacement of the BMS is to be carried out
- The Affix of a cover for the charging lock
- The performance of a service is to be undertaken

- The establishment of an email account for the team
- The implementation of cloud technology
- The documentation has to be maintained in a consistently updated state
- Implementation af a complete eMule 3D Modell

Bibliography

[– D25] scinexx – Das Wissensmagazin. *Akku mit Schattenseiten: Ökologische und soziale Herausforderungen der Batterieproduktion*. Zugriff am 13. Januar 2025. 2025. URL: `https://www.scinexx.de/dossierartikel/akku-mit-schattenseiten/`.

[ADA25] ADAC. *Stromverbrauch von Elektroautos im ADAC-Test*. Zugriff am 13. Januar 2025. 2025. URL: `https://www.adac.de/rund-ums-fahrzeug/elektromobilitaet/elektroauto/stromverbrauch-elektroautos-adac-test/`.

[alp25] ARD alpha. *Henry Ford: Wie er das Auto und die Produktion revolutionierte*. Zugriff am 13. Januar 2025. 2025. URL: `https://www.ardalpha.de/wissen/geschichte/kulturgeschichte/henry-ford-automobil-auto-fliessband-erfinder-100.html`.

[And20] David M. Anderson. *Design for Manufacturability: How to Use Concurrent Engineering to Rapidly Develop Low-Cost, High-Quality Products for Lean Production*. Second edition. New York, NY: Routledge, Taylor & Francis, 2020. 1 S. ISBN: 978-0-429-28598-1 978-1-00-076478-9 978-1-00-076496-3 978-1-00-076487-1.

[Blo25] EnBW Blog. *Elektroautos: Vorteile und Nachteile im Überblick*. Zugriff am 13. Januar 2025. 2025. URL: `https://www.enbw.com/blog/elektromobilitaet/fahren/elektroautos-vorteile-und-nachteile-im-ueberblick/`.

[con24] Wikipedia contributors. *Autodesk – Wikipedia, Die freie Enzyklopädie*. [Online; abgerufen am 13. November 2024]. 2024. URL: `https://de.wikipedia.org/wiki/Autodesk`.

[Ein25] EinfacheAuto. *Die Geschichte des Elektroautos: Von den Anfängen bis heute*. Zugriff am 13. Januar 2025. 2025. URL: `https://einfacheauto.de/blog/die-geschichte-des-elektroautos-von-den-anfangen-bis-heute`.

[Ene25a] Energieleben. *Die Geschichte des EV1*. Zugriff am 13. Januar 2025. 2025. URL: `https://www.energieleben.at/die-geschichte-des-ev1/`.

[Ene25b] EnergyProfi. *Geschichte der Elektromobile und Hybridfahrzeuge ab 1900*. Zugriff am 13. Januar 2025. 2025. URL: `https://www.energyprofi.com/uncategorized/geschichte-der-elektromobile-und-hybridfahrzeuge-ab-1900/`.

[Geb16] Andreas Gebhardt. *Additive Fertigungsverfahren: additive Manufacturing und 3D-Drucken für Prototyping - Tooling - Produktion*. 5., neu bearbeitete und erweiterte Auflage. München: Hanser, 2016. 1 S. ISBN: 978-3-446-44539-0.

[Gre25] Greelane. *Charles Kettering und das elektrische Zündsystem*. Zugriff am 13. Januar 2025. 2025. URL: `https://www.greelane.com/de/geisteswissenschaften/geschichte--kultur/charles-kettering-electrical-ignition-system-4076281`.

[gün25] Tanke günstig. *Aktuelle Ölpreise: Überblick und Entwicklung*. Zugriff am 13. Januar 2025. 2025. URL: `https://www.tanke-guenstig.de/oelpreise`.

[Hog] Jo-Ann Hogan. „Getting Started with Fusion 360“. In: ().

[Ind25] Cosmos Indirekt. *Gaston Planté*. Zugriff am 13. Januar 2025. 2025. URL: `https://www.cosmos-indirekt.de/Physik-Schule/Gaston_Plant%C3%A9`.

[Ins25a] InsideEVs. *GM EV1: Das Elektroauto von 1996 und seine Historie.* Zugriff am 13. Januar 2025. 2025. URL: https://insideevs.de/news/586129/gm-ev1-1996-elektroauto-historie/.

[Ins25b] InsideTesla. *Tesla-Geschichte: Der Weg des E-Auto-Pioniers.* Zugriff am 13. Januar 2025. 2025. URL: https://insidetesla.de/tesla-geschichte-weg-des-e-auto-pioniers/.

[ISI25] Fraunhofer ISI. *Batterie-Rohstoffe und Preisschwankungen: Wie reagiert die Automobilindustrie? Auswirkungen auf die Zellkosten.* Zugriff am 13. Januar 2025. 2025. URL: https://www.isi.fraunhofer.de/de/blog/themen/batterie-update/batterie-rohstoffe-preis-schwankungen-wie-reagiert-automobil-industrie-auswirkungen-zellkosten.html.

[Kor13] Reiner Korthauer. *Handbuch Lithium-Ionen-Batterien.* SpringerLink Bücher. Berlin, Heidelberg: Springer Berlin Heidelberg, 2013. ISBN: 9783642306532. URL: https://doi.org/10.1007/978-3-642-30653-2.

[Lab25] Sonepar Innovation Lab. *Batterien 2023: Innovationen und Entwicklungen.* Zugriff am 13. Januar 2025. 2025. URL: https://sonepar-innovationlab.com/batterien-2023/.

[Pis23] Stefan Pischinger. „Die Revolution des Antriebsstrangs in der Automobilindustrie“. In: *MTZ - Motortechnische Zeitschrift* 84.9 (2023), S. 62–62. DOI: 10.1007/s35146-023-1510-1. URL: https://doi.org/10.1007/s35146-023-1510-1.

[PL18] Gianfranco Pistoia und Boryann Liaw, Hrsg. *Behaviour of Lithium-Ion Batteries in Electric Vehicles.* Green Energy and Technology. Cham: Springer International Publishing, 2018. ISBN: 978-3-319-69949-3 978-3-319-69950-9. DOI: 10.1007/978-3-319-69950-9. URL: http://link.springer.com/10.1007/978-3-319-69950-9 (besucht am 01. 07. 2025).

[Pro25] Automobil Produktion. *So hoch sind die Produktionskosten von Elektroautos*. Zugriff am 13. Januar 2025. 2025. URL: https://www.automobil-produktion.de/produktion/so-hoch-sind-die-produktionskosten-von-elektroautos-745.html.

[Sie15] Dipl.-Ing. Frank Siegert. *Lithium Polymer Akku-Technologie*. 2015. URL: https://www.elektromodellflug.de/files/Lit-Akku-Techn-Einfuehrung.pdf.

[Sta25] Statista. *Ladeinfrastruktur für Elektroautos: Statistiken und Fakten*. Zugriff am 13. Januar 2025. 2025. URL: https://de.statista.com/themen/8348/ladeinfrastruktur-fuer-elektroautos/.

[Vat25] Vattenfall InCharge. *Die Geschichte des Elektroautos: 1832 ging es los*. Zugriff am 13. Januar 2025. 2025. URL: https://incharge.vattenfall.de/wissens-hub/articles/die-geschichte-des-elektroautos-1832-ging-es-los.

[Wik24a] Wikipedia contributors. *AutoCAD version history — Wikipedia, The Free Encyclopedia*. [Online; accessed 11-November-2024]. 2024. URL: https://en.wikipedia.org/wiki/AutoCAD_version_history.

[Wik24b] Wikipedia contributors. *Autodesk — Wikipedia, The Free Encyclopedia*. [Online; accessed 11-November-2024]. 2024. URL: https://en.wikipedia.org/wiki/Autodesk.

[Wis25] Das Wissen. *Die Ölkrise der 1970er: Schock und Transformation*. Zugriff am 13. Januar 2025. 2025. URL: https://das-wissen.de/die-oelkrise-der-1970er-schock-und-transformation/.

List of abbreviations

ANSI .... American National Standards Institute

CAD .... Computer-Aided Design

CAE .... Computer-Aided Engineering

CAM .... Computer-Aided Manufacturing

CC .... Constant Current

CV .... Constant Voltage

DIN .... Deutsche Industrie Norm

EMV .... Elektromagnetische Verträglichkeit

EN .... Europäische Norm

f. .... folgende Seite

HV .... High Voltage

IEC .... Inernational Electrotechnical Commission

Inc .... Incorporated

KI .... Künstliche Intelligenz

LED .... Light Emitting Diode

LV .... Low Voltage

PDF .... Portable Document Format

PNG .... Portable Network Graphics

PTC .... Positive Temperature Coefficient

TÜV .... Technischer Überwachungsverein vgl. .... vergleiche

z. B. .... zum Beispiel

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Use of artificial intelligence-based tools

Artificial intelligence (AI) based tools were used in this work. Table **??** provides an overview of the tools used and their respective purpose.

Tabelle A.1: List of AI-based tools used

Tool	**Description of Use**
Mercedes-Benz Direct Chat	Assistance with phrasing and spell checking (see entire thesis)
DeepL	Translation of the thesis
ChatGPT	Content structuring, summarization and technical formulation (see entire thesis)