Charging System
ARG25 Fall Technical Report
December 15, 2023
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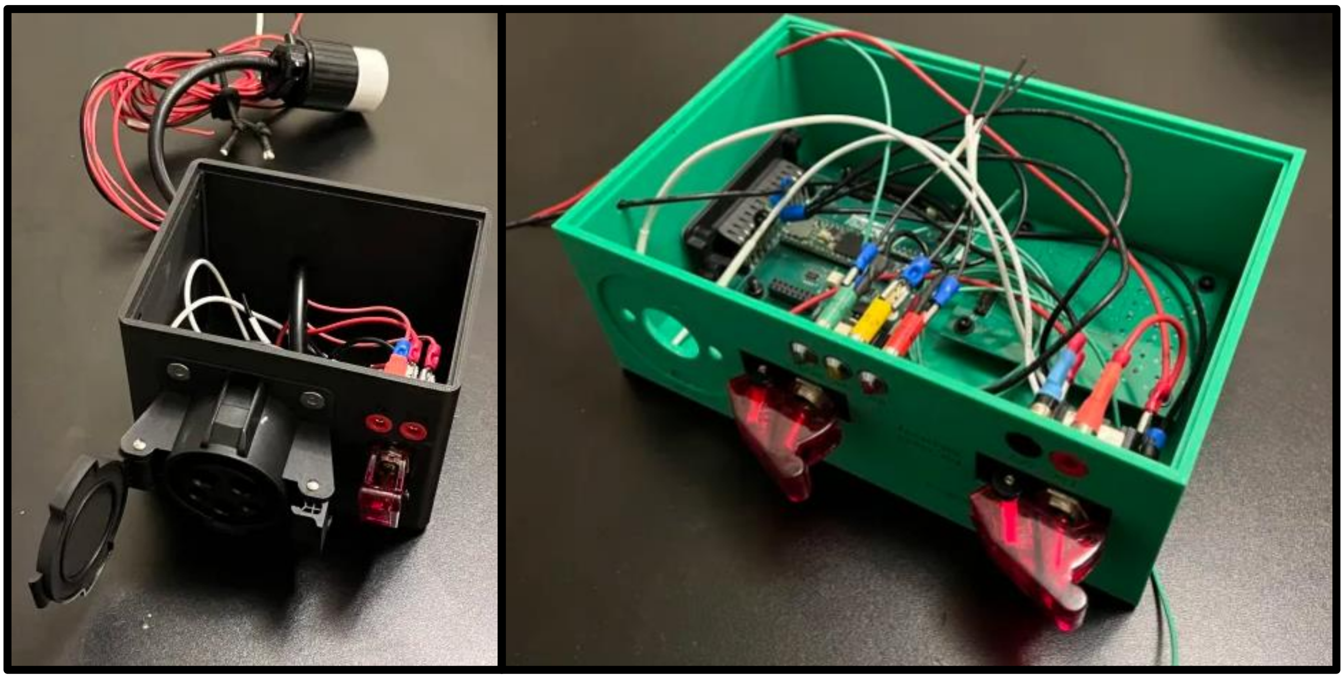

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0. Introduction

The charging system safely transmits electrical power from the building to the accumulator. This system is composed of the cart, charging harness, and any data cables needed for testing.

This system interfaces with AC input source, the accumulator's charging port, and safety systems such as the full shutdown circuit path. Note that although we do NOT need this system ON the car, it IS required to drive the car. Safety-critical aspects are everywhere here as the system includes and deals with high voltage, voltage shutdown sensors and logic, a requirement to feed steady current, thermal isolation and cooling.

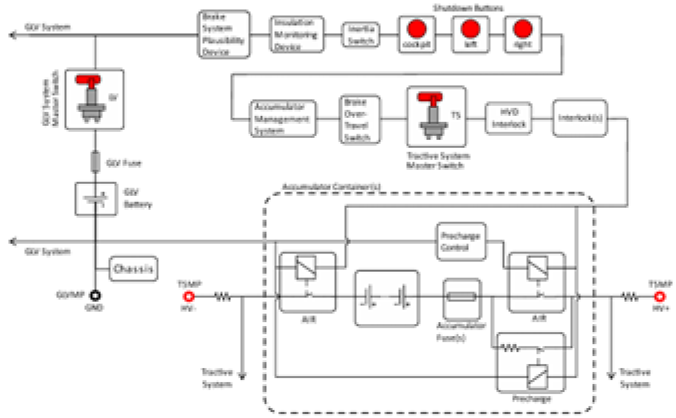
The key design parameters include high voltage protection, voltage shutdown sensors and logic, steady current regulation, thermal isolation, and its cooling. The inspection will test for charge level 2 to ensure that it is safe to charge the accumulator at the charging station.

1. Applicable FSAE Rules

Notice that anything in bold is a rule that the charging system design engineer is directly responsible for. All rules not in bold are either required practices or good engineering practices to keep in mind for the charging system. A copy of the 2025 rules is available for reference [15].

EV.2.1	ESF must have full architecture described of the charging system
EV.3.3.2	Max voltage must not exceed 600V DC at any time
EV.4.4	Adhere to Grounded LV Rules
EV.4.9	All TS components need to be flagged with an ISO 7010-W012 sticker
EV.4.10.1	**Teams must have a Hand Cart to transport their Accumulator Container(s)**
EV.4.10.2	**The Hand Cart must be used when the Accumulator Container(s) are transported on the competition site EV.11.4.2 EV.11.5.1**
EV.4.10.3	**The Hand Cart must:** **a. Be able to carry the load of the Accumulator Container(s) without tipping over** **b. Contain a minimum of two wheels** **c. Have a brake that must be:** **- Released only using a dead man type switch (where the brake is always on until released by pushing and holding a handle) or by manually lifting part of the cart off the ground** **- Able to stop the Hand Cart with a fully loaded Accumulator Container**
EV.4.10.4	**Accumulator Container(s) must be securely attached to the Hand Cart**
EV.5.2	Electrical Configuration
EV.5.8.2	**Two TSMPs must be installed in the Charger EV.8.2 which are:** **a. Connected to the positive and negative Charger output lines** **b. Available during charging of any Accumulator(s)**
EV.6.3	Wiring
EV 6.4	Connections

EV.6.5 Voltage Separation
EV.7.1.6 Grounding



EV.8.1.1	**All features and functions of the Charger and Charging Shutdown Circuit must be demonstrated at Electrical Technical Inspection. IN.4.1**
EV.8.1.2	**Chargers will be sealed after approval. IN.4.7.1**
EV.8.2.1	**The Charger must be galvanically isolated (AC) input to (DC) output.**
EV.8.2.2	**If the Charger housing is conductive it must be connected to the earth ground of the AC input.**
EV.8.2.3	**All connections of the Charger(s) must be isolated and covered.**
EV.8.2.4	**The Charger connector(s) must incorporate a feature to let the connector become live only when correctly connected to the Accumulator.**
EV.8.2.5	**High Voltage charging leads must be orange**
EV.8.2.6	**The Charger must have two TSMPs installed, see EV.5.8.2**
EV.8.2.7	**The Charger must include a Charger Shutdown Button which must:** **a. Be a push-pull or push-rotate emergency stop switch** **b. Have a minimum diameter of 25 mm** **c. Open the Charging Shutdown Circuit EV.8.4.2 when operated to the OFF position** **d. Hold when operated to the OFF position** **e. Be labelled with the international electrical symbol**
EV.8.3.1	**The Charging Shutdown Circuit consists of:** **a. Charger Shutdown Button EV.8.2.7** **b. Battery Management System (BMS) EV.7.3** **c. Insulation Monitoring Device (IMD) EV.7.6**
EV.8.3.2	**The BMS and IMD parts of the Charging Shutdown Circuit must:** **a. Be designed as Normally Open contacts** **b. Have completely independent circuits to Open the Charging Shutdown Circuit. Design of the respective circuits must make sure that a failure cannot result in electrical power being fed back into the Charging Shutdown Circuit.**
EV.8.4.1	**When Charging, the BMS and IMD must:** **a. Monitor the Accumulator** **b. Open the Charging Shutdown Circuit if a fault is detected**

EV.8.4.2	**When the Charging Shutdown Circuit Opens:** **a. All current flow to the Accumulator must stop immediately** **b. The voltage in the Tractive System must be Low Voltage T.9.1.2 in five seconds or less** **c. The Charger must be turned off** **d. The Charger must stay disabled until manually reset**
EV.11.5	Charging
IN.4.1	Inspection Items

2. Technical Overview

This section focuses on providing further design-specific context for how both the FSAE rules and the team goals will be reflected in the design of the charging system. It is also imperative to highlight that this design requires critical safety mechanisms such as the shutdown circuit and its related paraphernalia to make charging the vehicle safe. Though this should be understood implicitly, the charging system must be safe with all wiring and other design elements in accordance with FSAE rules and Good Engineering Practice standards.

As an addendum to all of the following, the system should be refined enough to have any member learn with ease the correct procedure to charge the pack. This does NOT mean everyone will have authority to do so but that the procedure for charging should not be difficult.

Design-Specific Benchmarks

1. The charging system will be composed of four components, the HV cluster enclosure, the LV cluster enclosure, the system-level enclosure, and the charging cart. The HV and LV clusters house electronics and their interactive components. By rules requirements they will be separate enclosures but can reside in the same system-level enclosure, which will be separate from the charging cart. The cart itself will carry the accumulator.
2. The system-level enclosure case will be designed so that debris will not be ingested by the cooling system, and will be a watertight, cube-like case with rolling wheels.
3. The HV and LV clusters must contain at least:
    a. TS Master Switch (Referred to as the TSMS)
    b. Shutdown Board Fault indicators for:
        i. IMD
        ii. BMS
    c. GLV Master Switch (Referred to as the GLVMS)
    d. Reset indicator and button for the Shutdown board
    e. 12V Battery switch
    f. E-Stop interrupting shutdown circuit
    g. J1772 EVSE Charging Level 2 Receiver
    h. TS- and TS+ 4mm banana jacks
4. Manufacturer specs for the Brusa charger the team owns is the driving force that dictated a new charger must be chosen for ARG25. The ARG25 minimum pack voltage is higher than 450V, which is above the maximum charging voltage that the ARG24 charging system can currently charge to through the Brusa charging unit [1]. This new device will be called the “charging unit” throughout this report.
5. The main frame of the cart will be raised from 6” wheels to 10” wheels.
6. RapidHarness will be used to map out the harnessing and wiring of the charging system before manufacture.

7. The interactions with the accumulator will be through a connector chosen by the vehicle harness designer for ARG25. However, the following connections will be provided to the vehicle:
    a. HV+
    b. HV-
    c. CAN HI
    d. CAN LO
    e. BMS FAULT
    f. SHUTDOWN
8. The charging cart will be updated to reflect its construction in real life as opposed to the current bounding-box model available in the drive.
9. The charging unit will have a safe connection to the 240 Volt EVSE charging system at both Cornell facilities and at the Formula SAE competition.
10. Detailed documentation will be created for both assembly in ARG25 and for future reference for charging designers in future years.
11. Cable routing will be neat and cabling will be enclosed in loom. All connections will be crimped using the proper tooling.
12. Wire sizes should be specified in the design. All wire sizing should be adequate to transmit the needed current with some specified safety factor.
13. The maximum voltage that must not exceed 600V DC at any time [15].

Testing-Specific Benchmarks

1. The charging unit will have a safe connection to the 240 volt wall outlet in the GM Laboratory space in the Engineering Learning Laboratory.
2. The charger unit and the other elements will be wired and mounted on some type of board so that bench tests can be made [2].
3. The charger will be able to take a connection to a portable gasoline generator, which will provide 240 volt, 10 kilowatt power for remote charging [2].
4. It is not expected that EMI would be an issue with charging but should be considered and a test plan will be written to have evidence to support this [2].
5. The charging system should be tested at full charging capacity to ensure that overheating does not occur when it is mounted in the case or enclosure [2].
6. Charging output should be tested to make sure it meets requirements for voltage, stability, and power [2].

3. History of Past Designs

Mechanical

In the past 4 years, the charging architecture had to be designed from scratch and implemented by the summer. Since the switch to electric vehicles in 2019, there has been three main transport solutions.

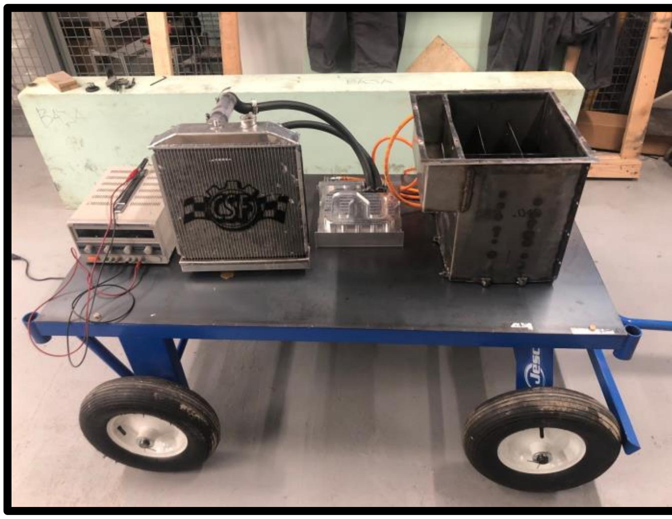


Figure 3a: 2019 Systems

Figure 3b: 2020 Systems

The first is the 2019 design in figure 3a by Alex Siskovic (ays28) [14]. This was a single level cart with a deadman's mechanism in the form of the pull handle being at a parallel angle to the cart floor. This was changed in 2020 to the 80/20 based design by Rishi Kansara (rkk58) seen in figure 3b [13]. Notice that the deadman's mechanism was never built as the COVID-19 pandemic halted progress. In 2021, John Dowd (jhd85) lowered the main platform by 12" and added a more reliable and easier to use deadman's switch, as can be seen in figure 3c [4]. Furthermore, John switched to the 6" wheels since "vibration was a problem for the cart, with screws rattling loose quite easily resulting in the rapid unscheduled disassembly of the 80/20 components."

Figure 3c: 2021 Systems

In the next two years, the cart chassis remained the same with only mounting changes. In 2022, Arushi Nety (apn29) added holes for mounting a few components on top of the cart [6]. Following this, in 2023, Dhruv Mittal (dm885) added mounts for the Brusa charger on the inferior side of the top shelf, and a radiator with its fan was mounted via welded tabs on the radiator on the handle side of the charging cart. The powerhouse and the DCDC were also mounted to the bottom as seen in figure 3d [5].

Figure 3d: 2023 Systems

An important shortcoming to note of the Brusa in 2023 was that it became difficult to properly cool. The charging unit could not take the full capacity of current that the J1772 could deliver, and two main attempts were made to fix this. A semi-successful attempt was in the form of attaching a thermal strap to the Brusa itself, but a fan on the radiator seen in figure 4 proved most effective. Dhruv Mittal (dm885) noted that “[f]or someone working on the charger next year, the real task would be improving Brusa cooling so it can easily take the high current from the J1772,” indicating that this issue was not entirely solved.

Figure 3e: J1772-P

Figure 3f: J1772-J

In regards to the rest of the changes for this year, there were enclosures built for the rest of the charging equipment that were located on top of the shelf as seen in figure 3g, unlike how the wiring was left mostly in bundles and set on the cart in 2022.

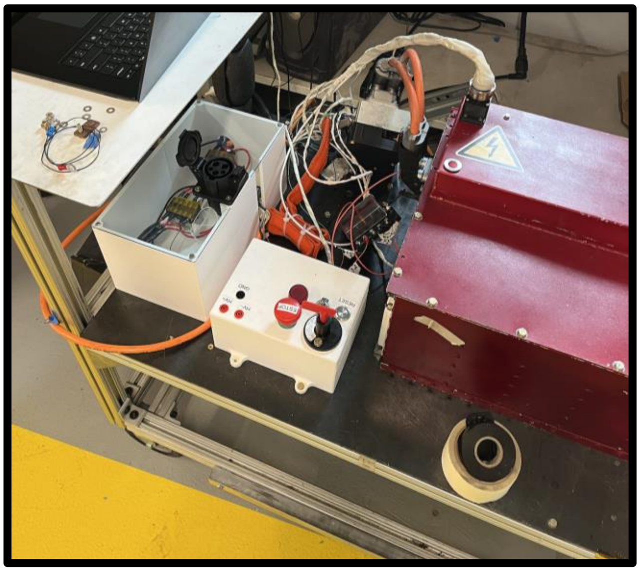


Figure 3g: 2022 Systems

In 2024, Lexi Stoff updated enclosures for the connectors and their paraphernalia, however did not change the cart chassis design more than adding mounting holes. The new enclosures can be seen in figure 3h [16].

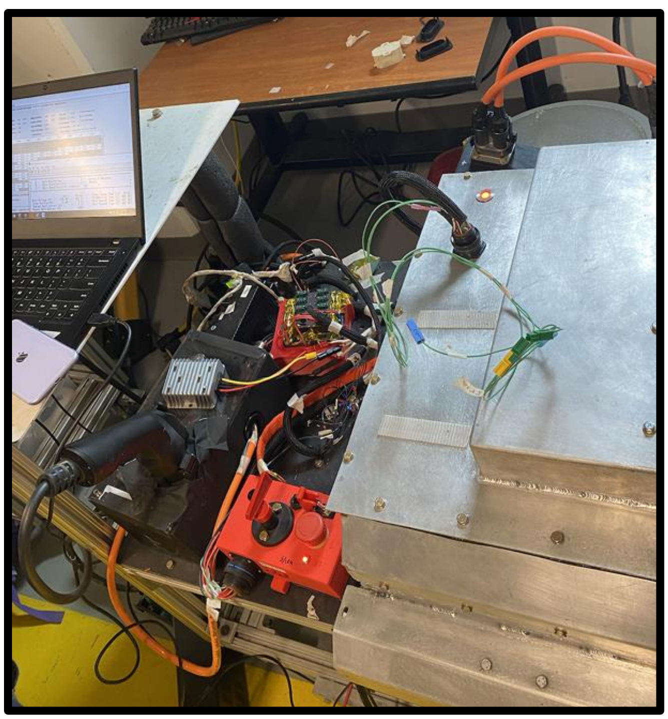


Figure 3h: 2024 Systems

The first charging unit chosen, the Brusa NLG513, was a decision by Jackson Luce in 2019 [6]. This was chosen from an array of chargers available from Brusa and was specifically bought with the idea that there was going to be troubleshooting help available since this was used by other FSAE teams.

It is important to note that the Orion BMS2 was used in conjunction with the charging system, which meant that the charging unit chosen had to be compatible with the already in-hand BMS [6]. Both the Orion BMS2 and the Brusa NLG513 were used from 2019 until 2024, where Noah Abramson (na325) chose to replace the BMS with his custom design. This makes switching the Brusa charging unit to an Elcon (TC) branded charging unit easier than it would have been in 2024 when it was first attempted.

The reason behind the first attempt to switch from the Brusa was because the "ChargeStar" software it relies on is much more difficult to understand and get support for than with the new alternative found under the branding "Elcon" or, natively, "TC." Emails back and forth, as will be mentioned later in the report, often receive a same-day response with Elcon staff, and although FSAE teams and individuals on the internet such as Wolftronix offered great help to understand and effectively use the Brusa, it is simply easier to rely on the manufacturer for concrete information about the device [5]. There are other reasons, including to the pack voltage change for 2025 that dictates a mandatory change in charger, but that will be explained in the Design section.

Moving away from the charging unit, level 1 charging, or more simply, plugging the charger into the regular 120VAC outlet one uses for daily use electronics in the USA like laptops, was replaced with level 2 between 2021 and 2022 by Nick Thomas (nat44) and Arushi Nety (apn29). This consists of using the EVSE J1772 plug offered at the comp site that provides 30A at 240VAC [6]. This will be kept along with the addition of the AVC2.r board in 2023 by Dhruv Mittal (dm885) [5].

The AVC2.r abstracts the process of sending a specific PWM signal to the J1772 to essentially a black box. Sending such a signal has been necessary since the J1772 will NOT provide current simply by plugging it into a closed HVIL (high voltage interlock) loop. This $50 board removes the need to worry about programming and replicating functions that specify what amperage is required from the J1772 as well as what state the charger is in. I attempted to replicate the board to see if it would be an advantage to not using something purchased off the shelves, more of that will be available in the Design section. Note that this process was done by the Orion BMS before.

It is important to highlight failures of the past such as how the shutdown circuit in ARG23 was incomplete, something only discovered after competition was over.

A more pressing manner was the time it took to charge. In December of 2024, according to Jason Heller (jmh469), ARG24's charging took "5-8 hours to go from empty to full and charged at like max 1A" (figure 3i). This is something that should change, as will be further detailed in the Testing Validation subsection under the Data section.

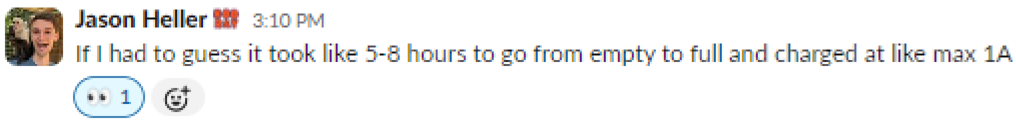


Figure 3i: Powertrain Lead for 2024 Car on 2024 Charging time

Another failure is the attempt to move to the Elcon charging unit architecture in 2024, abandoned due to the added complexity and faulty documentation at the time. There was simply not enough time to fix documentation mistakes of the past and to try something new and unexplored.

This lack of documentation also persists through 2024 (albeit less and less each year) as the wiring data stored in the forms of excel sheets in the team's google drive is not accurate to the physical charging system. These sheets were planned to be referenced and used, especially to build with RapidHarness mockups of the ARG24 charging harness, although the process was transformed into creating this sheet from scratch via continuity tests. In the wise words of Arushi, "continuity testing really makes the world go around" [6]. More information will be available on that in the Design section.

4. Data

Setting Design Criteria

The majority of the design parameters stem from a mix of the FSAE rules and team priorities in qualitative manners. This includes the form factor, the safety mechanisms, and the transportation of the system described in the Technical Overview section.

The data driven metrics that the team has not yet met are in the forms of an improvement in charging time, temperature, and the ability to collect charging data as could be done with the Orion BMS now that the switch has been made to the Elcon system.

This consists of charging up to 600V using Level 2 charging and being able to charge the car faster than it can charge with regenerative braking. The charging system also must not be the failure point in which the system needs to shut down from overheating concerns. Finally, CAN messages and flags will be read by both the BMS and by a reader of choice.

Validating System Design

After communicating a desire to see cooling metrics from the manufacturers of the charging unit, Elcon, an email was received with the following graph seen in figure 4a and the explanation from Sayyed A. Bashir as follows, where Sayyed provides that

" We have this chart which basically says that the charger will provide maximum output until the internal temperature reaches 85 deg C at which time the output will start decreasing until it reaches 90 deg C where it will stop charging until it cools down and starts up again."

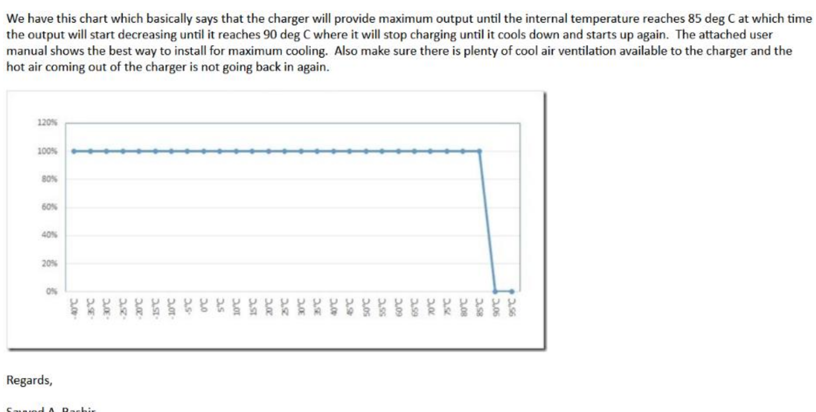


Figure 4a: Charging Data from Elcon staff

This, of course, must be taken with a grain of salt. Although it is imperative to trust people, a healthy amount of skepticism shows that it is very easy to replicate this same graph with hand inserting in 28 values into an excel table and plotting it with the appropriate units.

This makes validating the thermal reliability of the design something that must be trusted but verified, and so this will be one of the many tests that data needs to be collected on after the modules are all built and the pack assembled in Janman.

Testing plans should be written during and before Janman to set the exact numbers and figures that are desired to be compared to the Elcon's performance, however the most important one is that the temperature does not rise above 60 degrees Celsius, as this is often where most electronics on the car should shut off automatically. There was, initially, a plan to test the Elcon charging unit to its limits and ensure the cooling was sufficient by adding a load to the outputs, however this concept was never finalized because of two main reasons. The first is that a formidable and safe load that will take 450-600V costs more money than leadership was willing to spend. The second is that a cheaper option that would be built in house would not implement the same safety standards and would be an undesirable risk to spend time and money on for a testing process. Ultimately, making or buying such a load was deemed to be beyond the scope of the resources on this team at the moment.

In regard to charging speed, the system needs to provide continuous charging power. As a 6.6kW unit, this needs to take advantage of the 240VAC at 30A from the EVSE charger and use it to the team's advantage in charging the pack. Although the pack can take 600V at a maximum of a 20A charge, the charging unit can only provide 11A at 600V, something that is a quick calculation of 6.6kW/600V=11A using the relation for electric power P/V=I. Note that the datasheet defines an output capability of either 14A or 680V maximum [3].

Tuning the System

Tuning the system, electrically, requires the accumulator to be complete. The mechanical design can be updated and has been, as per the Technical Overview section describes. A lot of the mechanical changes have already been implemented and are listed here:

1. Switching the wheels from 6" to 10"
2. Testing fitment of individual switches and devices before printing all of their mounting locations together.
3. Printing the first revision of the HV and LV enclosures.
4. Testing the assembly fitment of the HV and LV components in their enclosures.

Electrical tuning will come in the form of having numerous amounts of testing plans written before and during Janman to address the following, listed in order of importance.

1. Does the shutdown circuit work as intended? Will a short cause the system to power off in the required amount of time?
2. Will the charging system reliably charge at a mandated CCCV (constant current and constant voltage) without throwing errors?
3. Will the charging unit overheat to inoperable parameters before the rest of the system? Is the cooling fan data provided in figure 9 from the manufacturer reliable?

4. Will the system be truly waterproof when enclosed in its
    a. System enclosure
5. Will the electronics be truly water resistant when enclosed in its
    a. HV enclosure
    b. LV enclosure
    c. ECU Enclosure

Each method of testing will require different tools depending on the action required, however a multimeter, probes, and a way to read CAN messages will help tremendously.

Continuous Assumptions

With a system interacting and handling high voltage as its primary function, there are certain components that cannot be made in house. The charging unit, for instance, has to be a black box to a certain degree, as one would void any warranty by taking it apart. This mandates a certain level of assumptions that the logic inside such a unit, be it the Brusa or the Elcon brands, will be able to safely handle the current and voltage that is advertised on their datasheets.

Near the beginning of this semester, there were tests performed to make sure that one could communicate with the Elcon charging unit [8]. From this, it will be assumed that one can trust the error flags generated by the Elcon as well as its ability to shut down if no messages are being received after the specified timeout in the datasheet.

Elcon Tests

The Elcon was explored early in October and followed the test procedure "jp928_CH25_(Test Procedure 1)_2024-10-04" [8]. The most important item in these tests was to be able to prove that, via CAN, the Elcon messages could be read. Using the FlexCAN library for Arduino and the ARG24 ECU, a test harness displayed in figure 4b was created to interface with the Elcon from a computer using the Arduino's serial monitor to visualize real time CAN messages.

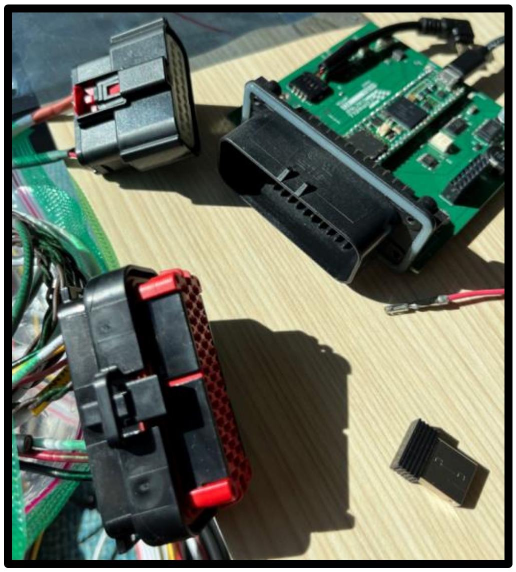


Figure 4b: Charging Data Harness, first version

Specific pinouts and schematics can be found in the procedure document. The manner in which these tests were performed is that first, the charging unit was plugged into the 240V outlet using a NEMA L14-30P connector, bypassing the J1772.

Figure 4c: L1430-P Connector

This was done as it is not necessary for the Elcon to be provided with specifically and only the J1772. As long as 240VAC is provided, the charging unit will function.

From here, the custom USB harness connected the ARG24 ECU to a PC. The Molex 150 connector was plugged into the charging unit from the ARG24 ECU. From here, the Arduino code for charging was uploaded and the serial monitor began to show CAN messages. Four things were tested in this state, each time in between resetting the ECU by reuploading the code.

1. Will the Elcon shut down after a set amount of time of not receiving messages?
    a. The answer recorded was yes, at five (5) seconds.
2. Can a CCCV value be mandated and understood without mandating to begin charging?
    a. Yes. This was confirmed by receiving messages of what CCCV the charging unit was set at since the Elcon provides status CAN messages.
3. Does the conversion from numeric to hex work as described in the datasheet?
    a. Yes, this works as follows:
    b. Bits 1 and 2: 600V*10 to Hex = 0x17 0x70
    c. Bits 3 and 4: 11A*10 to Hex = 0x00 0x6E
    d. Bit 5: Flags
        i. 0x00=enable
        ii. 0x01=disable
4. Does the LV source output 12V?
    a. No, the LV source outputs 14V. This is a discrepancy with that indicated in the datasheet, that states 12V at 5A. There is a heat shrink label on the wiring that states that this is instead 14V 60W maximum.

5. Design for ARG25

The design for ARG25 is based around a portable, efficient, and safe combination of electrical and mechanical components. This design was chosen, especially the portable aspect, to move onto the optimization phase of charging. It is now year six as an electric team and four years past COVID-19 restrictions, so there should be no excuse to leave the charging system at its minimum requirements. Moving the charging components to a sealed case will do just that. It is not required by rules but it will allow the team to have more peace of mind that the system will always be safe and protected from the elements. This will also free up space in the charging cart itself to store tools, egress materials, or all of the other items like water that we end up lugging to line up for technical inspection. The new tires are already contributing to these efforts, making it easier to move the cart around. The added height that comes with new wheels on the charging cart does not affect the center of gravity enough to make it unstable. Finally, as mentioned in the previous sections, the charging unit is being moved to the Elcon, which is in the best interests of simplifying the charging process moving forward, given that good documentation is left behind.

As described in the Technical Overview section, this will be packaged in four major components. Each is described in this section with as much detail as possible. To be clear, the greatest challenge for this design was the lack of *CORRECT* documentation. This is not a complaint against future designers as they simply had bigger fish to fry, like getting the car driving. This will no longer be the case moving forward, as any changes made either in the spring semester and in the coming summer will be documented thoroughly- this will be my biggest fish to fry, in a sense.

The primary influencer of this design was to design to consider the orientation and the airflow of the Elcon charging unit. According to the datasheet, [3], the Elcon must be mounted on a horizontal surface with the fan facing down, or on a vertical surface. specifies that the Elcon cannot be mounted on a horizontal upper surface with the fan facing up, as visible in figure 5a.

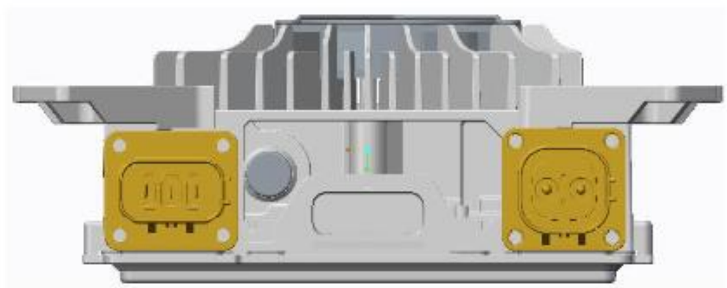


Figure 5a: Forbidden orientation of install for the Elcon

As per the support team, they do not seem to know the reasoning as to why this orientation must be avoided in figure 5b.

Re: HVIL on Elcon 6.6 kW Chargers Question

Joaquin,

We don't know the reasoning. This is the directive from the factory. All I can think of is that hot air collects at the top of an enclosed space and the fan will force that hot air back into the charger.

Regards,

Sayyed A. Bashir

ELCON / Electric Conversions
515 N. 10th Street, Sacramento, CA 95811
www.elconchargers.com www.zivanusa.com

Figure 5b: Elcon staff does not know why the orientation is unacceptable

Initial Design

Different approaches in the initial design consisted of mounting all components of the system to the charging cart, of using a non-rolling and thin aluminum case for these components, and of having a single box for all non-accumulator components. Ultimately, the latter was chosen and thus the first system design is shown in figure 5c.

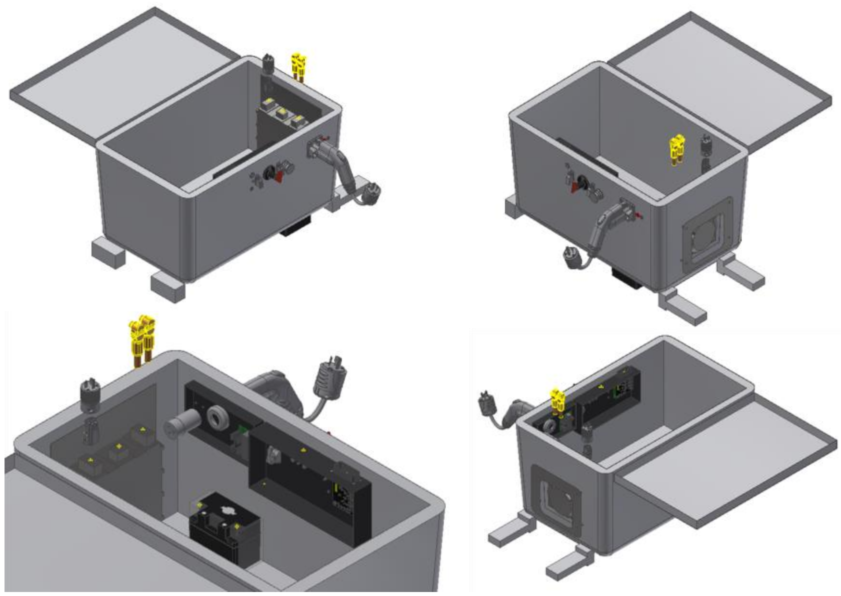


Figure 5c: ADR revision of the charging system enclosure

Changes before Janman and after FDR

The revised plan is to place the Elcon, fully enclosed with all of the other system electronics in their respective enclosures, into the waterproof case. The Elcon will be placed with the orientation such that the fan is facing down, and it will be lifted off of the base of the case with standoffs.

When charging, the case will be opened up if it gets too hot. A small latch or lift bar will be attached to keep the case open in these scenarios, and to avoid accidentally closing the lid.

Figure 5d shows the concept design for the new orientation in the bin. This design contains the bounding box areas inside and out of the selected container, shown with the given dimensions in figure 5e.

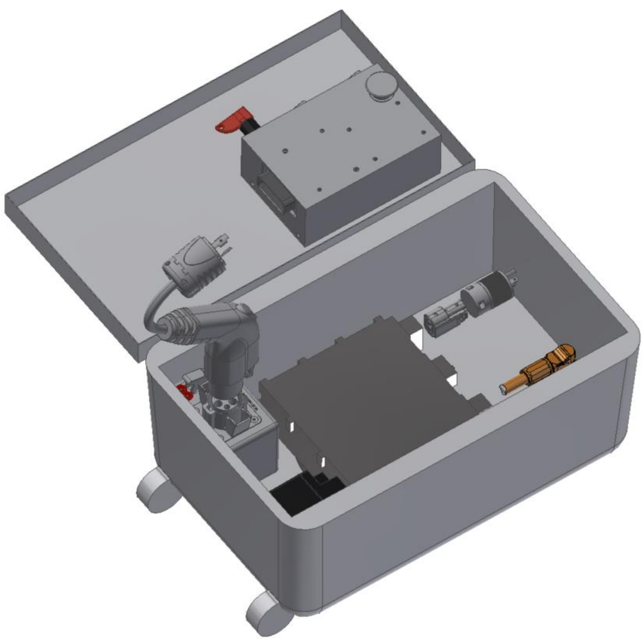


Figure 5d: FDR revision of the charging system enclosure

Figure 5e: Charging system enclosure case

3D Scan and Thermals

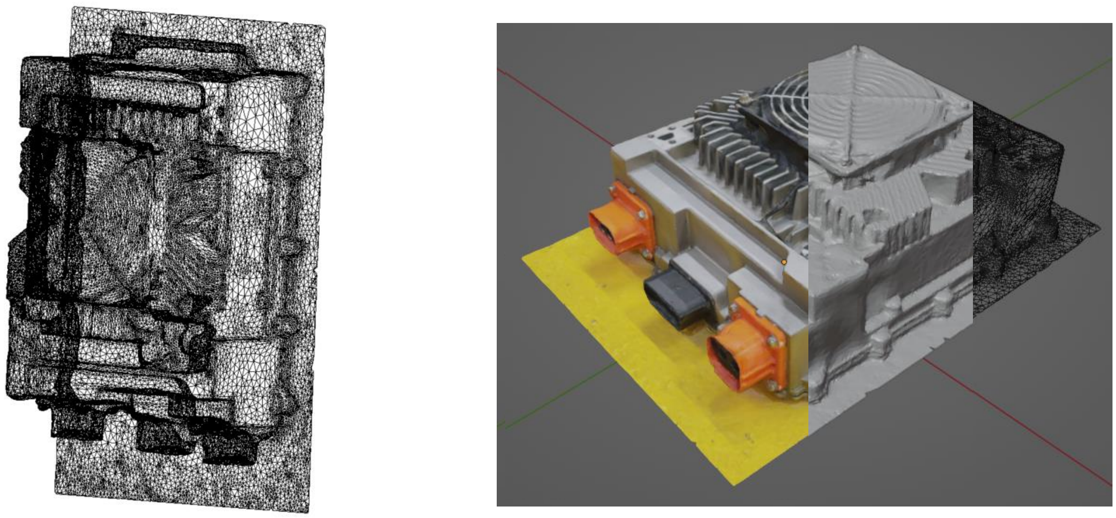


Figure 5f: Elcon charging unit imported to CAD after 3d scan

After it was decided that doing tests by loading the charging unit was not feasible, the next approach was to use the surface area of the charger to estimate the heat dissipation. To move forward with this, the Elcon was scanned in 3D to attempt to automate the process. This model was very large and cumbersome, something that must be simplified by hand later in the spring semester (figure 5f). This analysis will only be done if physical testing disproves the data provided to the team by Sayyed from the Elcon staff from figure 5a.

LV Cluster Enclosure

The initial approach to the housing was to combine the control panel box from 2024's design since that will save both the wiring and the J1772 receptacle, the shutdown board, and the ECU all in one place, which are the enclosures for the orange dots in figure 5g. The DCDC, denoted by the green dot, would also have been placed in that box but has been deemed unnecessary this year. The Elcon outputs a LV supply to power the items that that the DCDC was used to power in the past. The Purple item is the fuse board which will be in its own enclosure far from the other electronics once it arrives.

Figure 5g: ARG24 Enclosures and Systems

A few iterations of panel fitments were tested as each component arrived so that the box would be built progressively. This was primarily the product of parts being cheaper to source off of amazon than McMaster, which meant that although there were datasheets for most components, there were no CAD files available to make assemblies in inventor. This sprouted a number of test fits by printing small panel cutouts for each component as seen in figures 5h-5j.

Figure 5h: ARG24 ECU connector test fit

Figure 5i: RST Button test fit

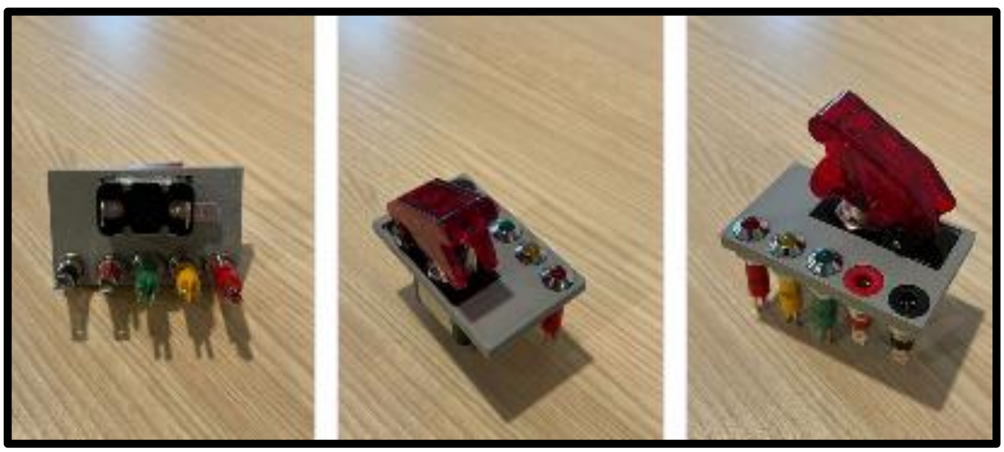


Figure 5j: LV Switch, LEDs, and Banana Jack test fits

After most components arrived, a first revision of the enclosure was printed. This first revision, pictured in figures 5k-5p, was mostly finalized. A few items are going to be altered but nothing will require a full redesign.

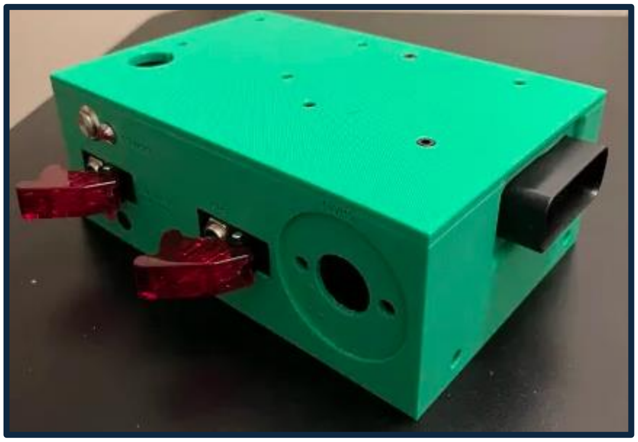


Figure 5k: LV Enclosure view 1

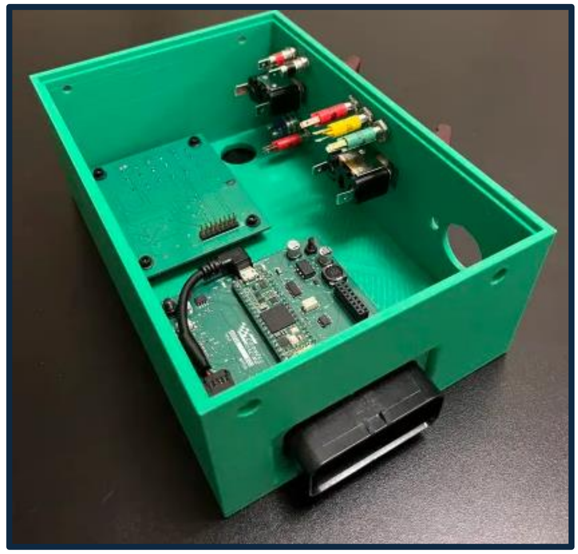


Figure 5l: LV Enclosure view 2

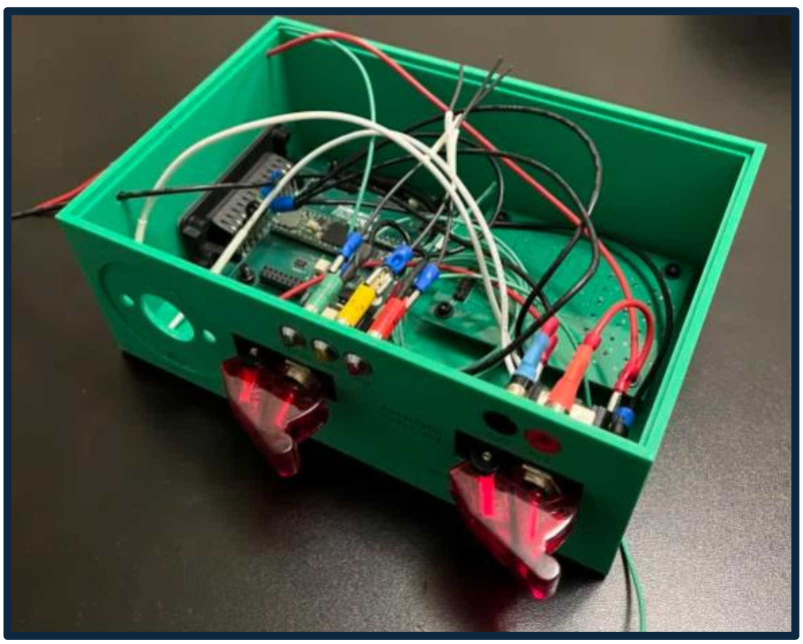


Figure 5m: LV Enclosure view 3

Figure 5n: LV Enclosure component fit

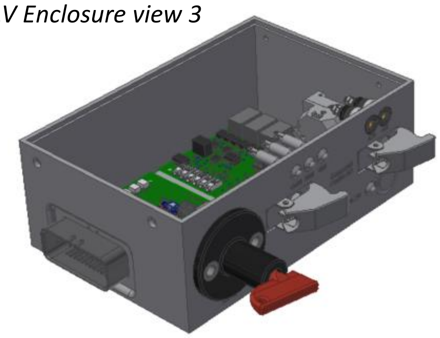


Figure 5p: LV Enclosure CAD

Note that the E-Stop arrived late and is not assembled until figure q, where it sits comfortably on the edge of the enclosure. The Hella switch that will be used for the GLVMS has still not arrived as of 2024-12-06.

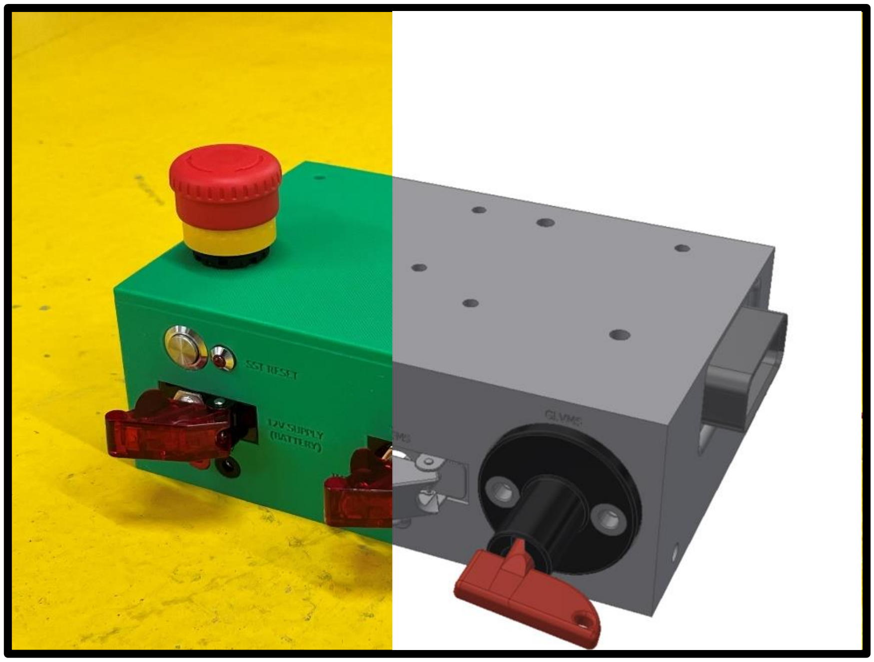


Figure 5q: LV Enclosure CAD and in-hand transition

The reprint will host minimal changes. Those changes are as follows, from [9].

1. The 3D printed standoffs for the Shutdown board will be added to the base with heat set inserts embedded. This eliminates the need for a positive reaction tool from outside the case.
2. Removal of the BSPD fault light. The BSPD fault will be high permanently when off the car. There is no point in making a separate charging shutdown board that does not have this feature so it will just be ignored.
3. Renaming of the “SST RESET” label to (SST next to the LED) and (RESET next to the button). This is to avoid confusion with the inverse relationship with the SST being on and the board needing to be reset.
4. Rewiring to short the Shutdown Board’s Charge pin to 12V.
5. Isolating the ECU to potentially another enclosure.

Shutdown Circuit

Main changes from ARG24 include that the fault indicators are integrated into the LV Cluster in ARG25 (figure 5r), as in ARG24 these are located on top of the ECU/SB box and done by hand in ARG25, outside of an enclosure (figure 5s).

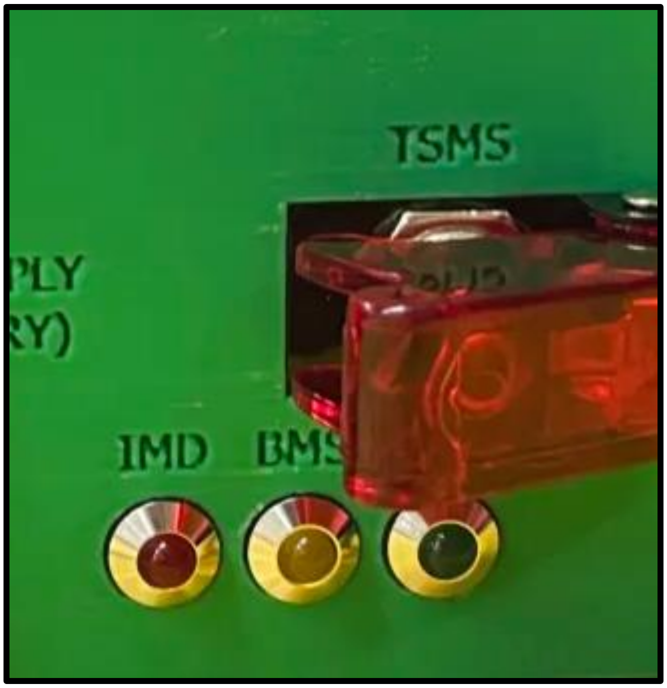


Figure 5r: ARG25 LV Enclosure Fault LEDs

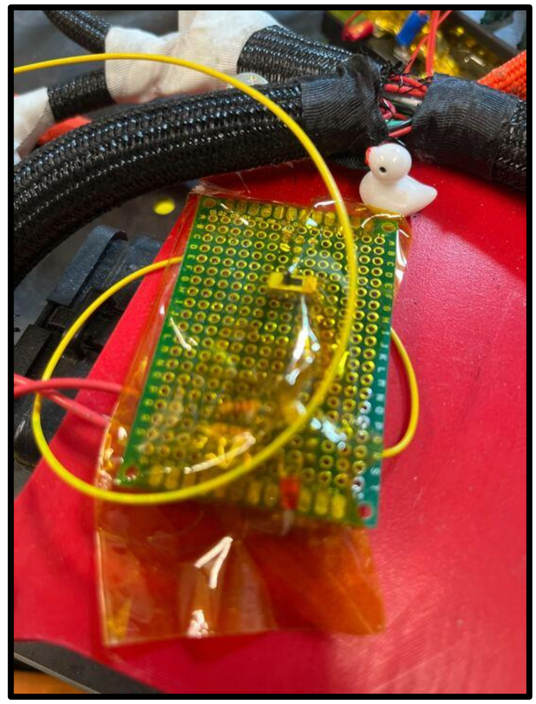


Figure 5s: ARG24 LV Fault LEDs

The rest of the shutdown circuit is highlighted yellow in figure 4t and should be referenced in the RapidHarness schematic instead of this report [11].

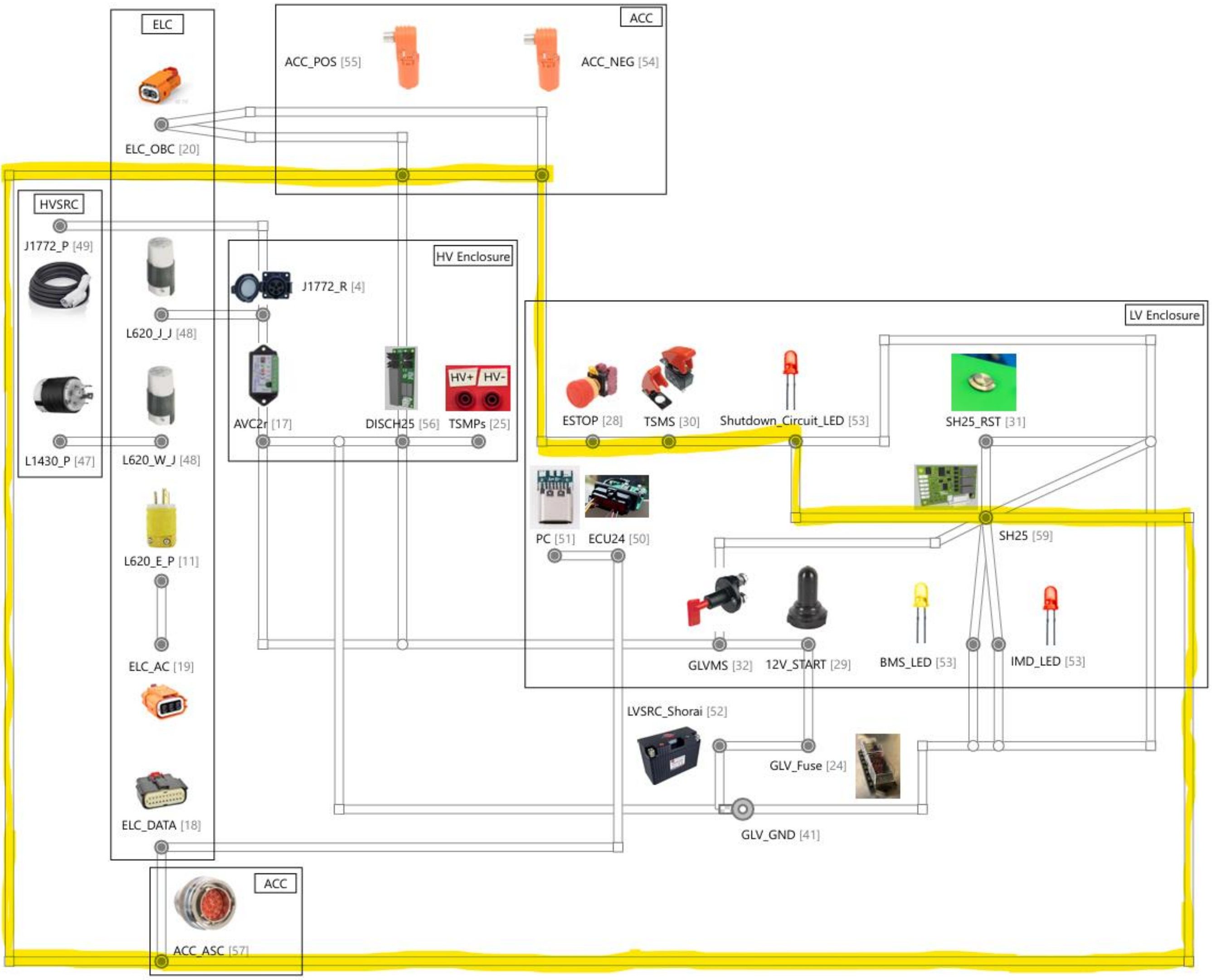


Figure 5t: Charging Shutdown Circuit

HV Cluster Enclosure

This enclosure houses the components of the blue dotted items in figure 5g and is purposely isolated from the LV components for safety. Note that this year there is no HVD as seen as the connector denoted by the blue square. Instead, two Amphenol SurLok connectors will be used that are unmounted on the charging system side.

Figure 5g: ARG24 Enclosures and Systems

In the same manner as the LV Enclosure, panel fitment was tested as each component arrived. Once again, the majority of these components were Amazon alternatives to McMaster parts, except for the J1772 recepticle and the AVC2.r board, which were both only on separate sellers and provided no CAD files. These tests with small panel cutouts for each component as seen in figures 5u and 5v.

**There is also a very satisfying video on the SDrive of the J1772 receptacle clicking into place into an interference fit from figure 5u in [12]!*

Figure 5u: J1772-J fitment view 1

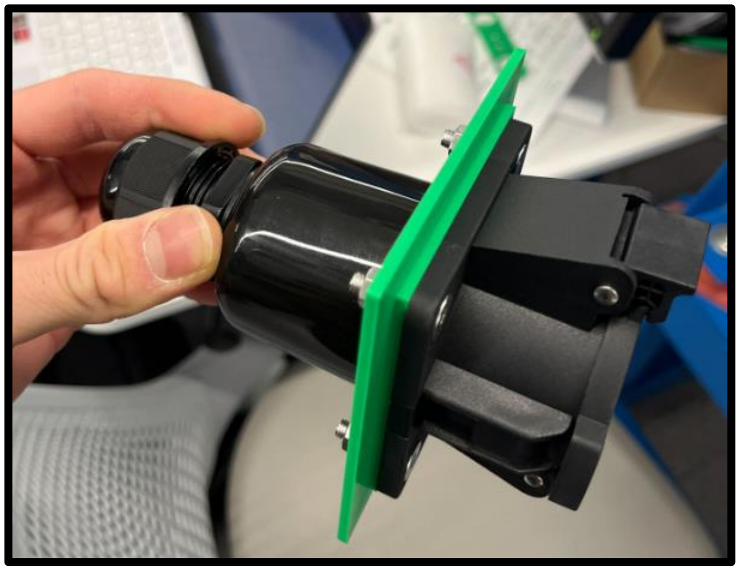


Figure 5v: J1772-J fitment view 2

Figure 5w: J1772-J Crimp ready locations

Once assembled, the only item left to still fit is the discharge board, as PCBs are currently in the process of testing and being revised. The board will fit without modifications, but the mounting posts are absent for the moment.

The outstanding items for this enclosure are as follows from [9]:

1. Adding mounting for the discharge board.
2. Adding harness wrap on the outgoing wiring when the HV enclosure is fully ready to be connected to the system. This includes the two SurLok connectors and an ASC connector for the Accumulator Interfaces.
3. Switch all mounts to heated inserts.

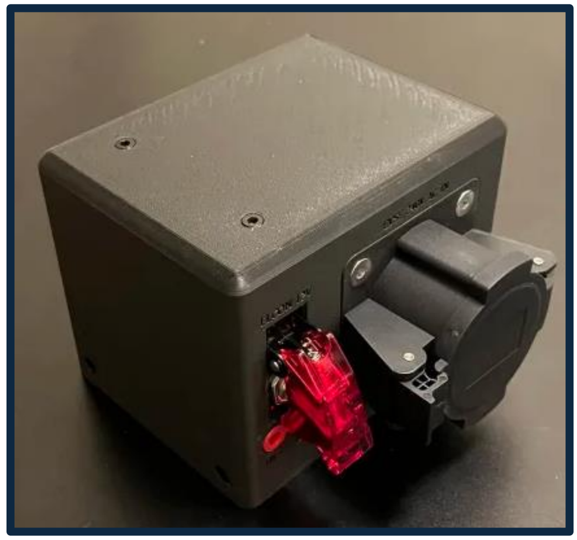


Figure 5x: Different views of the assembled HV Enclosure

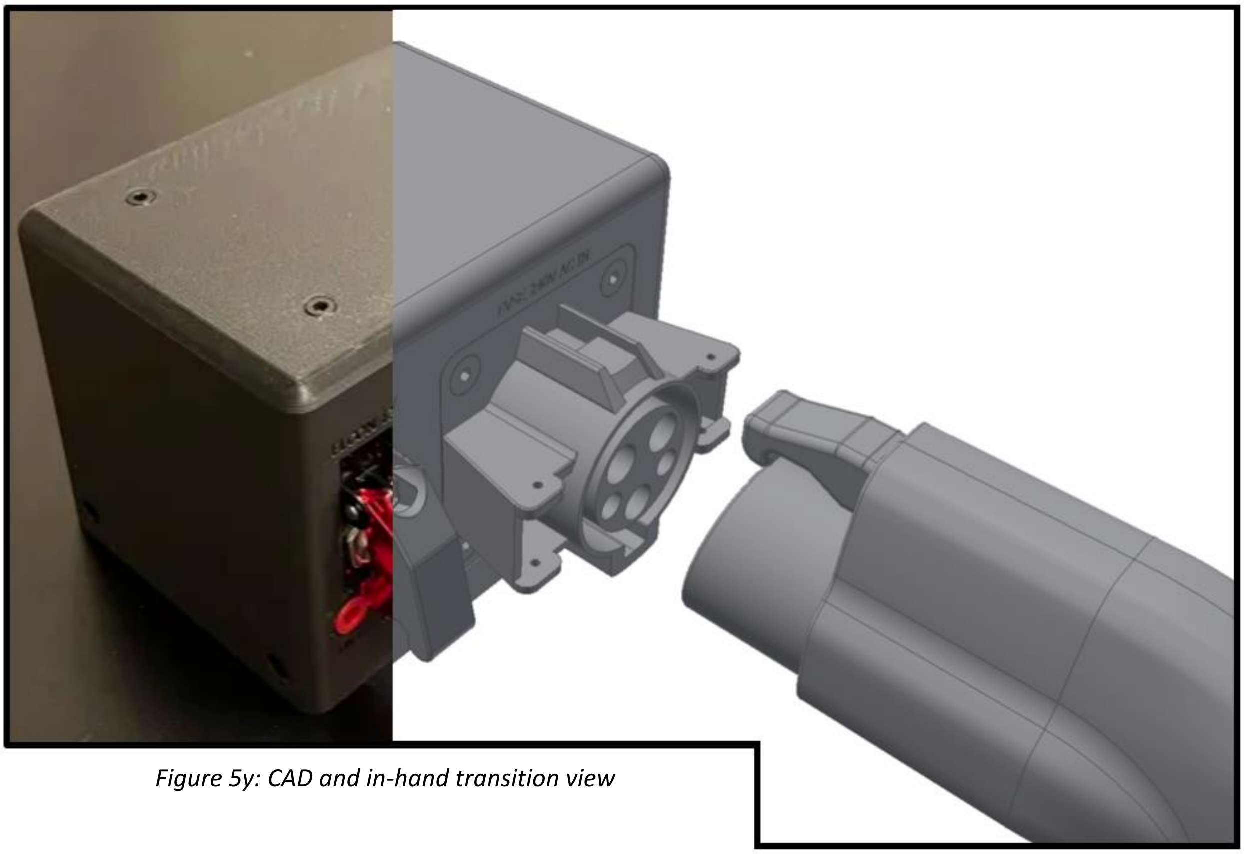


Figure 5y: CAD and in-hand transition view

Accumulator Interfaces

The accumulator connects to the charging system as described briefly in point 7 of the Design-Specific Benchmarks subsection of the Technical Overview section. The interactions with the accumulator will require an HV+ and an HV- connectors, pictured in figure 5aa, and a CAN HI, CAN LO, BMS FAULT, and SHUTDOWN signals from the ASC connector pictured in figure 5z.

Figure 5z: CAD and in-hand transition view

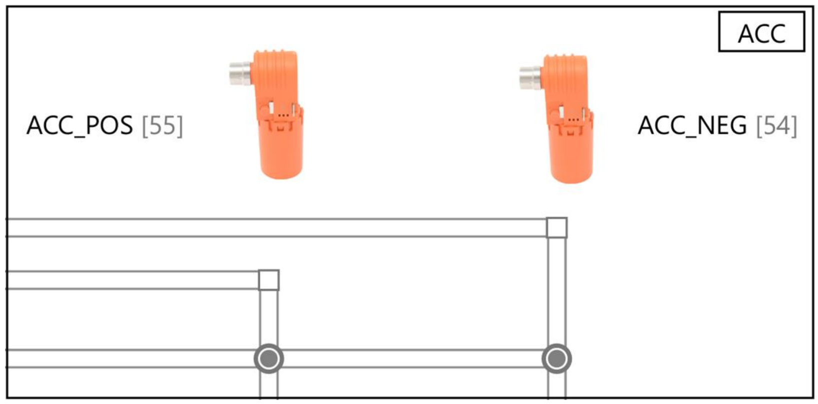


Figure 5aa: CAD and in-hand transition view

Charging Cart

The first and almost only change to the charging cart itself was to increase ground clearance, as has been an issue in the past already. The 6-inch wheels seen in figure 5bb are replaced by the 10-inch ones in figure 5cc.

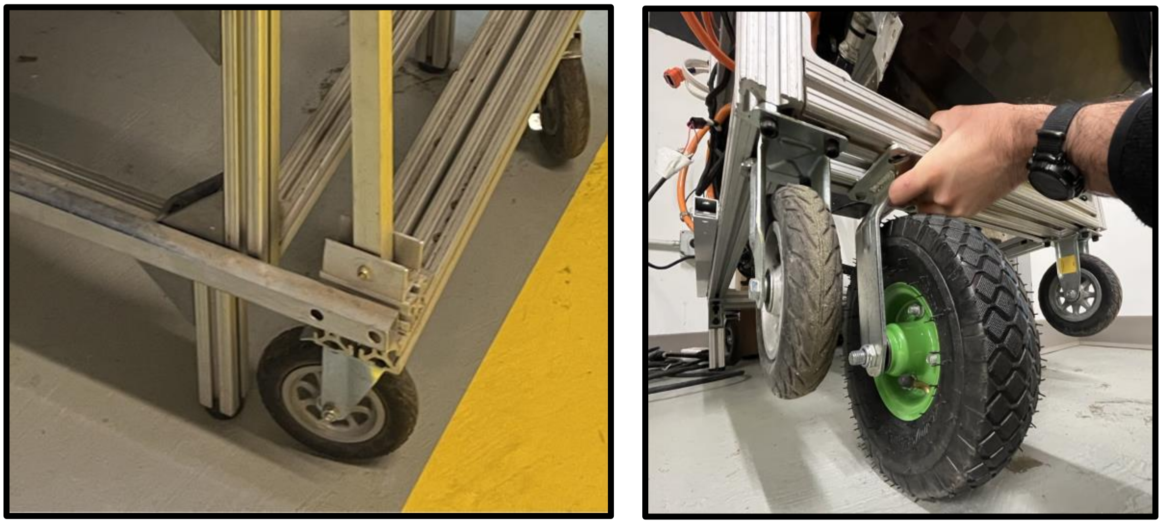


Figure 5bb: Tire size comparison

Figure 5cc: Cart height comparison

At first, semi-pneumatics were chosen to avoid having to deal with flat tires. This soon proved to be too expensive to be worth it and the hassle of changing a tire was deemed acceptable.

With the new tires, the deadman's lock drop legs needed to be pushed forward away from the casters to allow them to fully rotate 360 degrees. These legs were also raised to compensate for the added ride height of the wheels, as seen in figure 5dd and 5ee.

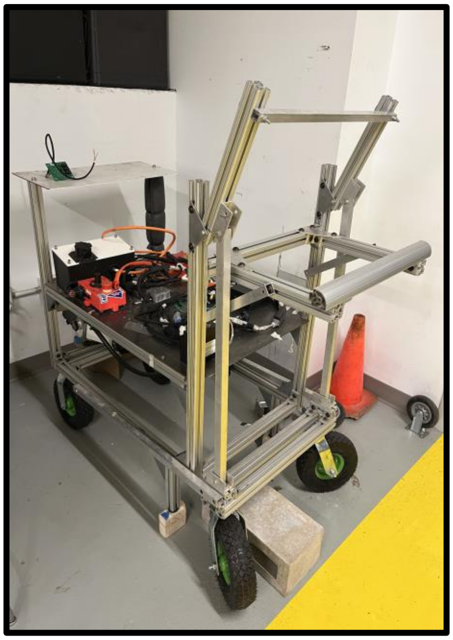


Figure 5dd: Cart on cinder and wood blocks

Figure 5ee: Cart on new posts

Finally, the CAD of the charging cart was updated from ARG24's design seen in figure 5ff to better represent what the cart looks like in reality as shown in figure 5gg.

Figure 5ff: ARG24 Reference Cart

Figure 5gg: ARG25 Reference Cart

Charging Procedure

To properly and safely charge the system, one needs to make sure they are not alone. Thirty amps is not to be taken lightly. Nobody should be charging alone or unsupervised at any time.

There will be a timesheet on the cart to properly measure the amount of time it takes to charge the pack for data collection, referenced as “the timesheet” in these procedures. Names of components are referenced from [11].

1. Write the time start of charging process on the log attached to the cart in a new row on the timesheet.
2. Properly secure the accumulator onto the charging cart.
3. Plug in the ELC_OBC.
4. Plug in the ELC_AC.
5. Plug in the ELC_DATA.
6. Provide 240VAC via plugging in the J1772-J receptacle from the EVSE’s J1772-P or by plugging in the L1430-P to the ELL source. Then plug the L620_E_P into the L620_J_J or the L620_W_J, respectively.
7. Open charging systems enclosure and remove the two large orange HV SurLok connectors (ACC_POS and ACC_NEG) and the ACC_ASC connector to the accumulator. These should then be connected to the accumulator in their respective receptacles.
8. Turn on the GLVMS to power the LV system.
9. Turn on the TSMS switch to close the shutdown circuit.
10. Write the time **start** of charging on the log attached to the cart in your row on the timesheet.
11. The BMS will take over charging procedure from this point forward.
12. Write the time **end** of charging on the log attached to the cart in your row on the timesheet.

If any faults are thrown, and the Shutdown_Circuit_LED turns off,

- ensure that the GLVMS is turned off and inspect what caused the fault. Then, turn it back on and inspect.

OR

- press the SH25_RST button to reset the SH25 and continue.

ECU Harness

The ECU harness's purpose is to be able to both read and write messages to the charging unit through CAN. Note that after FDR, charging will be on CAN 1 not CAN 0. This does not affect the design. Using the ARG24 ECU, the pins used to interface with the Arduino and the CAN capabilities of the ECU are shown in figures 5ii-kk. The Arduino code for programming this device is in [7].

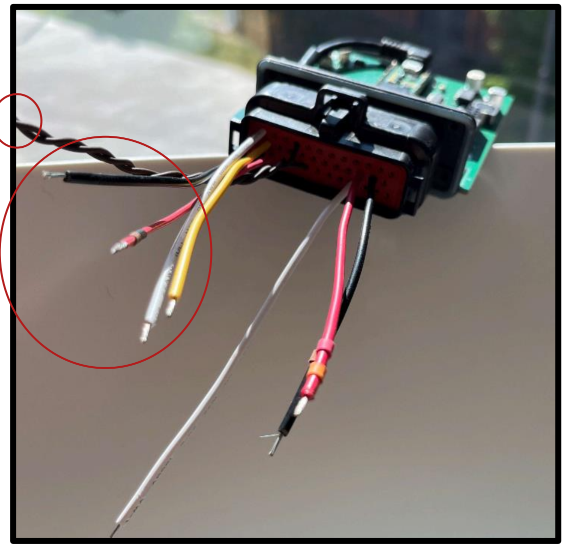


Figure 5ii: ARG25 Data Harness

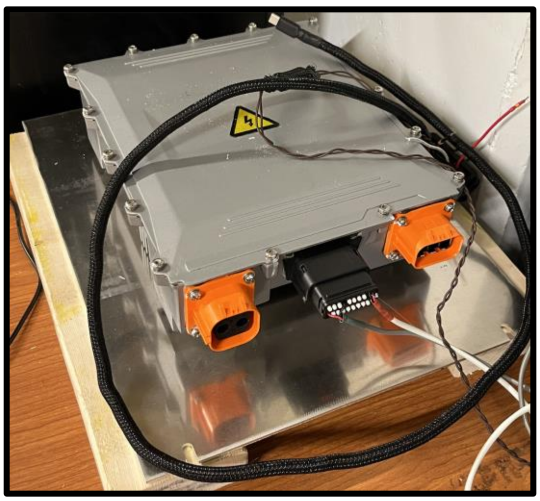


Figure 5hh: ARG25 Data Harness around Elcon

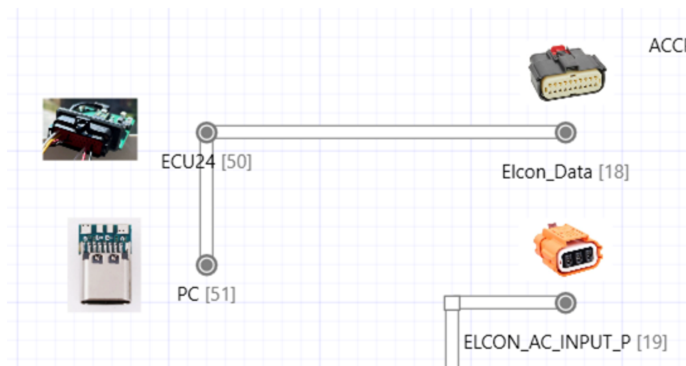


Figure 5jj: Data Harness Wiring to Elcon

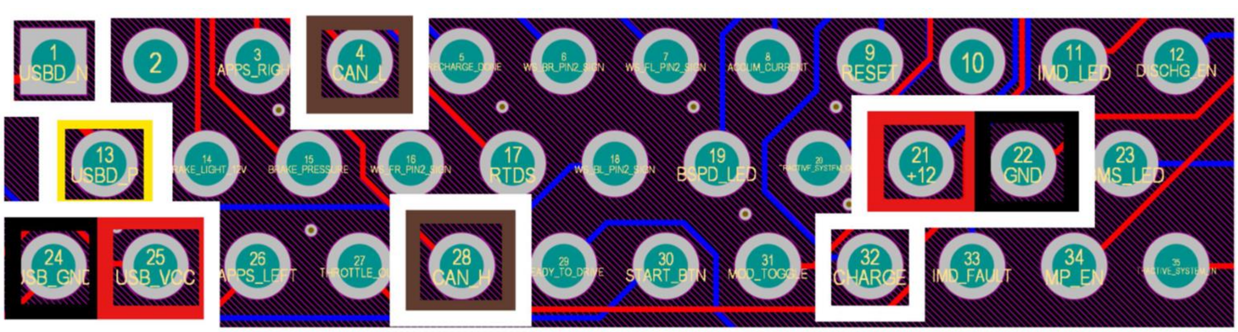


Figure 5kk: ARG24 ECU output pins for Charging Data Harness

Large Voltage HUD/Display

The primary purpose of this display is to ensure that the Elcon's charging unit's 14V output is correctly regulated and converted to 12V via a L7812CV mosfet. This is primarily a sanity check, as the electronics in the shutdown circuit and in the charging system can run off of 14V natively. The enclosure was designed to have room for wiring inputs and outputs in a linear configuration along with a snap fit for the voltage reader module. Unlike the HV and LV enclosures, there were no test fits as this was a small enough component that fit in its first assembly.

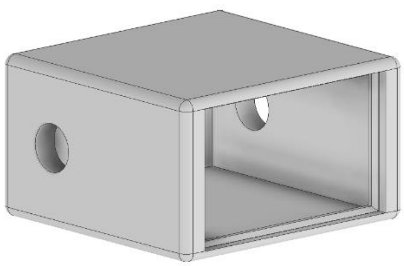


Figure 5ll: Display CAD

Figure 5mm: Display Assembley

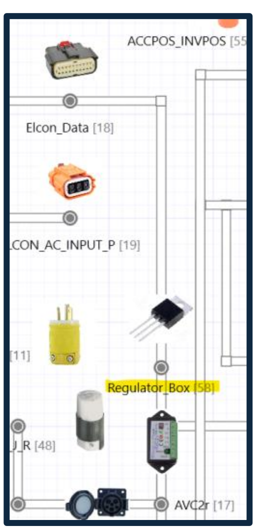


Figure 5mm: Display Harnessing (Outdated)

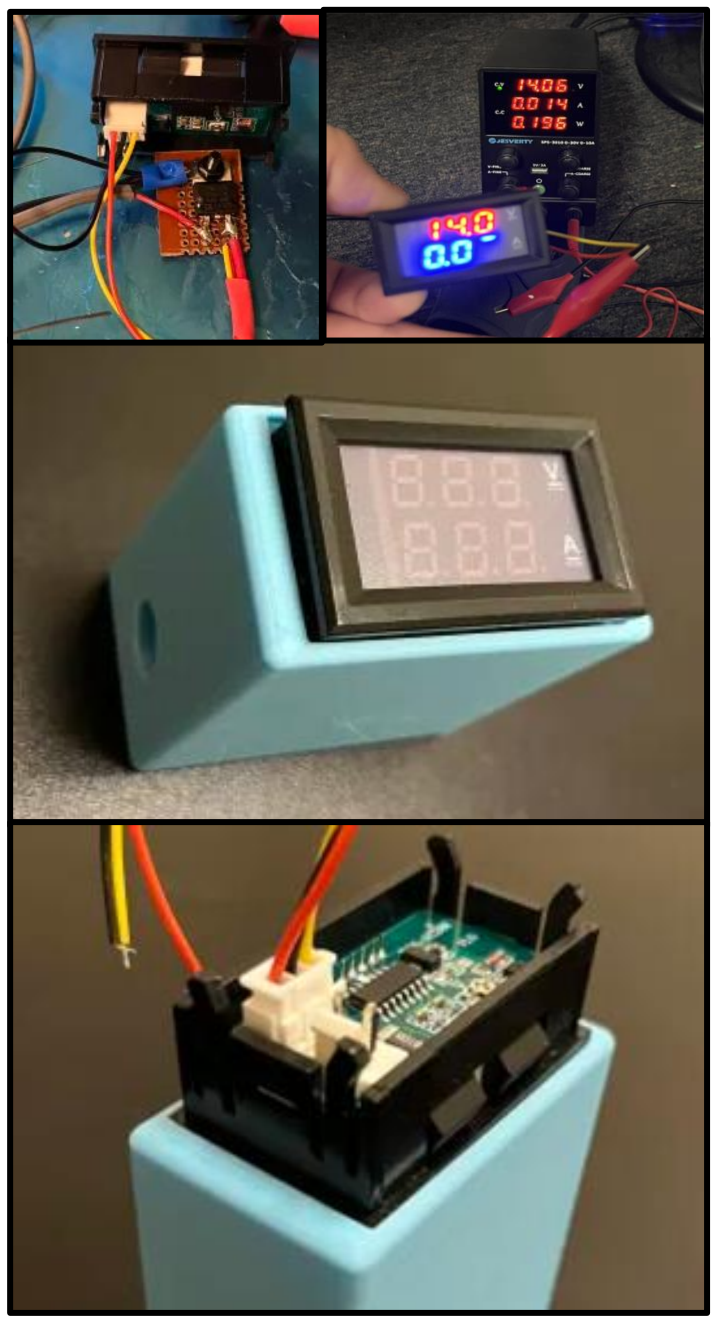


Figure 5nn: Display testing collage

Abandoned Project Attributes

Retrofitting Attempts

The ability to test charging on different battery types (i.e. ARG24 if time permits) No truly wild or exotic fasteners will be employed but the tabs on the HV and LV clusters were going to be out of the ordinary [2].

Redesigning the AVC2.r

This was considered to be redundant and would only benefit if the AVC2.r board was difficult to source or ship.

For the ARG 26 Designer

The most crucial component of this design is documentation. As simple as that may sound, all the small discrepancies between the written information and the actual working product will make the design exponentially more difficult if nothing is written down. This is also for future part designers. Most of your advice in designing this system will be provided in a detailed analysis of the design for ARG27, not from this small section in the report.

Long lead time items are also something to watch out for, however only on case-by-case basis. For instance, if a new charging unit needs to be ordered, often times that comes from sending an email and getting a quote, and then waiting for it to arrive.

Similarly, individual items like the required E-stop will be ordered for other parts of the team. Check LV and HV to make sure there are no extras or ask previous designers of the control panel or the roll hoop for the case of the E-stop.

6. *Materials and Manufacture*

Material Selection

- Systems Enclosure – Preferably IP67 rated but any waterproof case of the correct dimensions works.
- HV and LV Enclosures – PETG HF chosen over PLA as it can withstand more heat without warping. Competition tends to be in very hot places.
- Wiring: Minimum AWG sizes
  - 22G - SS
  - 16G - HV+ and HV-
  - 22G - 12V TS
- HV Poles use 10-2mm wiring
- Shrouding material will be plastic

Serviceability is going to be difficult when the harness is fully wrapped, so it is imperative to manufacture it correctly the first time. RapidHarness is a great tool to do this (albeit not a replacement for reliable continuity checks!).

If a specific datasheet for a component is desired, please check the BOM section for reference. For vendors, please look up the part number as supplier stock may vary.

Figure 4pp shows the high level overview of how the charging system works. Note that updates will not change this very much and for a more detailed, harness-level overview, one should follow the RapidHarness schematic shown in [11] and in figure 6b.

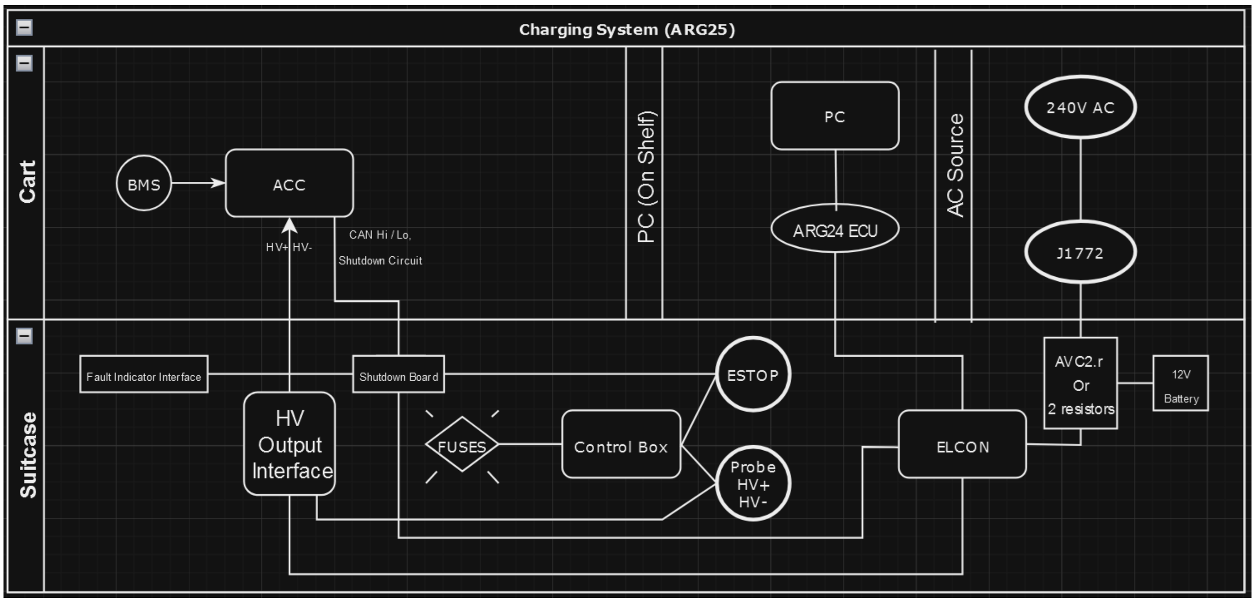


Figure 6a: Flowchart for ARG25 Charging System

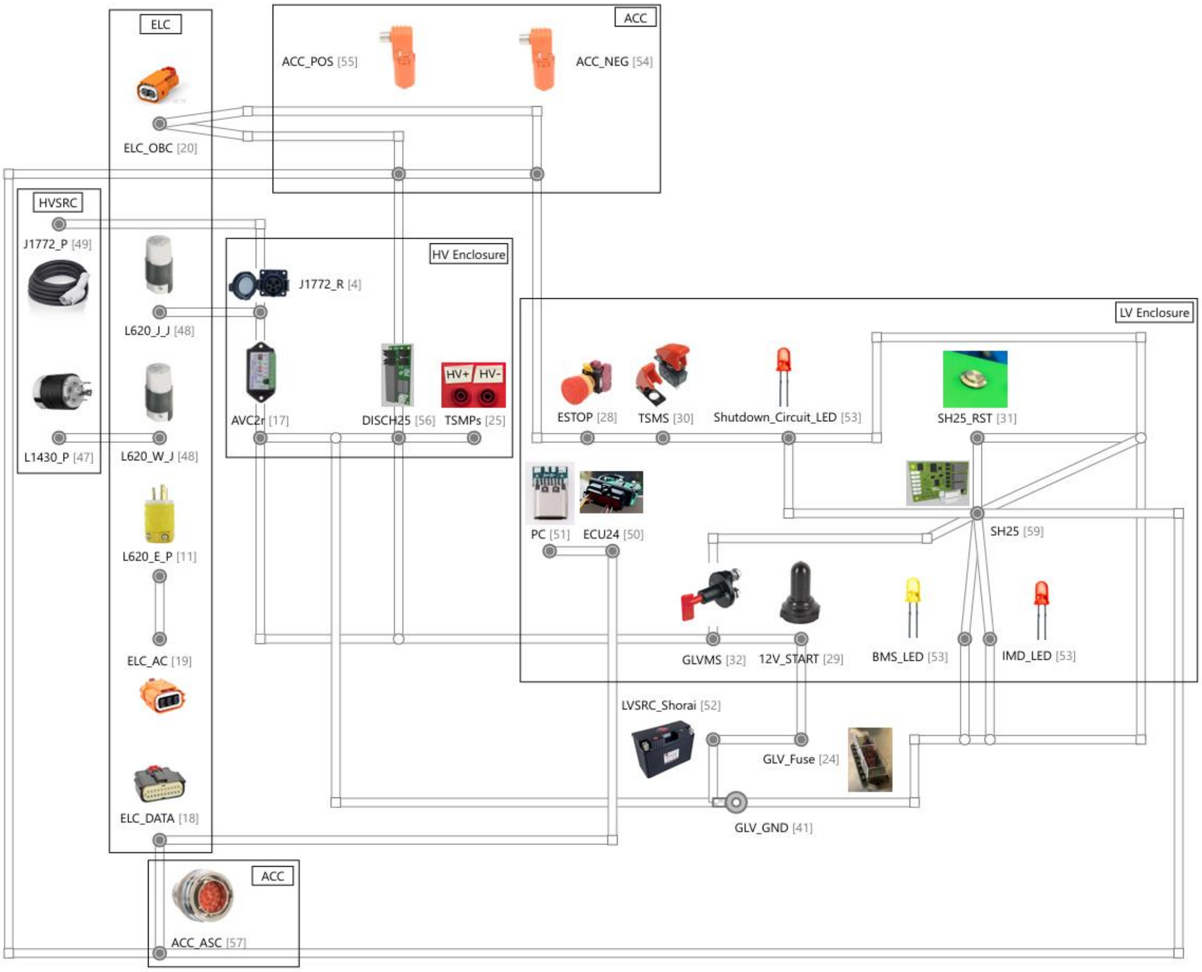


Figure 6b: ARG25 Charging System RapidHarness schematic

Janman Manufacture Process

The following items will be prepared before Janman to make manufacture easier.

- RapidHarness wiring sheets printed out and laminated
- Cleaned up/decluttered charging area
- Foamboard bought to build harness
- If time permits, pre-cutting wires according to RapidHarness lengths and bundling

Janman activities include:

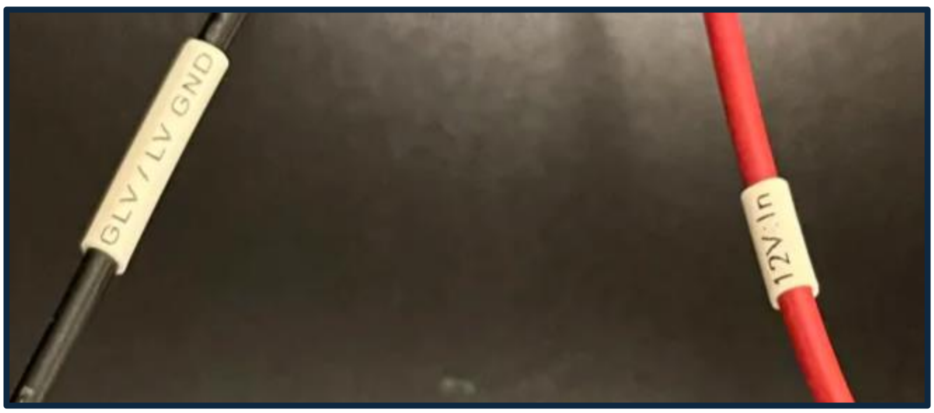
- Carrying out the testing procedures outlined in the Elcon Tests subsection of the Data section.
- Cutting and assembling any harnessing left that was not finished in December 2024.
- Proper labeling of any non-labeled looms will be added with the heat shrink label printer.
    - 

Figure 6c: Heat-shrink-labeled wires

- Documenting any changes after all testing plans are completed.

An extra item to test would be to see if the AVC2.r board can be replicated and thus converted into a PCB that the team can order for much cheaper along with the other LV boards. This is only to be done if all of the above tasks are finished.

BOM

The following BOM is taken from the BOM pdf available in [10].

Id	Type	Manufacturer	Part Number	Description	Quantity	Usage
4	Connector	Multicomp	DSI-EV32S-NC	SOCKET, EV, J1772, 32A; Product Range: IEC 62196-2 Type 1, SAE J1772 Series; Gender: Receptacle; Voltage Rating:...	1	J1772_R
11	Connector	Leviton	1448	Yl Dust Guard Plug 2PO 3WI 6-20P 20A250V | Leviton 1448	1	L620_E_P
17	Connector	SAE	AVC2r	J1772 Module	1	AVC2r
18	Connector	Molex	33472-2006	Conn Housing Sealed Housing Receptacle 20 POS 3.5mm ST Cable Mount Bag	1	ELC_DATA
19	Connector	Amphenol Industrial	HVSL633063A106I	female cable connector; 3 pole; straight; A-coded; 6, 00mm²; with HVIL	1	ELC_AC
20	Connector	TE Connectivity / AMP	2103177-5	Automotive Connectors Plug Assy, Key E, Ta Cpa, HVA280-2PHI Xe	1	ELC_OBC
24	Connector	SEI	R3-76		1	GLV_Fuse
25	Connector	2xBanana Jacks	VProbes	Banana Jack, 15A	1	TSMPs
28	Connector	Idec	YW1B-V4E02R	Emergency Stop Switch, 2NC, IP20 (Connection Box)/IP65 (Front Panel)	1	ESTOP
29	Connector	APM Hexseal	C1131/28	SWITCH BOOT; For Use With: Toggle Switches; Product Range: - 16F4923	1	12V_START
30	Connector	CW Industries	GT-4R	Switch Hardware Safety Cover Red 12mm 17.5mm 12.2mm	1	TSMS
31	Connector	Schneider Electric	ZB4BA26	Pushbutton, groping, waistband round, black, front ring silver, mounting Ø 22 mm, ZB4BA26	1	SH25_RST
32	Connector	Hella	GLVMS	GLV Master Switch	1	GLVMS
38	Wire	N/A	SS (Shutdown Circuit)			W1, W2
41	Ring Terminal	N/A	GND		1	GLV_GND
47	Connector	Legrand	L1430P	TURNLOK, PLUG, 3P4W, 30A, L14-30P, IP20; Connector Type: NEMA L14-30P; Current Rating: 30A; Connector Colour: Black,...	1	L1430_P
48	Connector	Hubbell Wiring Device-Kellems	HBL2323	Locking Connector 20A 250V 2P 3W Nylon Black/White	2	L620_J_J, L620_W_J
49	Connector	Leviton	EVJ40-25	Electric Vehicle Charging Kit J1772 Charge Conn 40A Max 25FT Cord	1	J1772_P
50	Connector	FSAE	ECU24		1	ECU24
51	Connector	Fysh	USB-C_P		1	PC
52	Connector	Interlight / Jacs Koopman	LFX14A1-BS12	Replacement for Shorai LFX14A1-B	1	LVSRC_Shorai
53	Connector	N/A	LED	Just a bright light	3	BMS_LED, IMD_LED, Shutdown_Circuit_LED
54	Connector	Amphenol	SLPPB35BSO1EH	SurLok Plus; Female Cable Connector; 8.0 mm Radsok; 270° Coded; 35 mm²	1	ACC_NEG
55	Connector	Amphenol	SLPPB35BSO0EH	SurLok Plus; Female Cable Connector; 8.0 mm Radsok; 90° Coded; 35 mm²	1	ACC_POS
56	Connector	FSAE	DISCH25	rev3	1	DISCH25
57	Connector	Amphenol	MS3476L16-26P	Conn Circular MIL-DTL-26482 PL 26 POS 16-26 Size PIN Contact Cable Mount	1	ACC_ASC
59	Connector	ch2233	SH25	Shutdown Board with D Sub Connector 5747841-4 (CHarness Connector 5747845-4)	1	SH25

Table 6d: BOM from RapidHarness [10]

7. Timeline

The timeline for the design and manufacturing of the charging system includes several key milestones: RapidHarness system prototype by August 30th, full cart CAD completed by September 6th, incomplete harness built for testing by September 13th, final design including ADR comments by November break, and the goal to charge the ARG24 pack reliably by the end of the Fall semester.

Timeline

Oct 4 ········ Elcon charger tests begins.
Oct 5 ········ System-Level ADR: All predicted harness wires cut to length (not 100% connectors).
········ Some enclosures are 3D printed. Finalized CAD model for the full cart is ready.
Oct 11 ········ Monocoque Freeze: Rapid harness construction complete.
Oct 15 ········ Manufacturing begins.
Oct 26 & 27 ········ Part-Level ADR.
Oct 31 ········ All required components are ordered.
Nov 27 - Dec 1 – FDR: ········ Final design including ADR feedback is complete.
········ All harness connectors installed.
········ All enclosures 3D printed.
Dec 13 - Jan 3: ········ Complete documentation for replicating the system.
························
Jan 10 ········ All Harnessing Complete and all first round test procedures written.
Jan 1x ········ Begin attempts to charge the ARG24 pack **reliably** and train members on the charging process.
Jan 20: ········ Remanufacture of any needed enclosures is complete.
Jan 20 - End of JanMan: ········ Compatibility testing to charge smaller segments for testing and R&D safely.
Feb 7 ········ Parts installed on the car.
Feb 21 ········ First drive of the vehicle.
Mid-Semester 2025 ········ Documentation! Updating remaining architecture redesigns or changes.

Timeline Changes	
2024-09-10	SDR – Document Creation
2024-09-26	PDR – Removed all sections before October 4th, 2024. Adjusted dates for ADR, FDR, Parts on car, and for First Drive.
2024-10-27	ADR – Removed section on “Nov 29 – Testing plan and checkouts completed.” and added section on “Elcon for ARG24 Architecture Design begins.”
2024-11-20	Highlighted that some parts are ordered and not arrived yet.
2024-11-25	Removed “Elcon for ARG24 Architecture Design begins” under January 20th
2024-12-03	Reformatted table for report compatibility, Added Jan 10, 1x, 20, and reworded some activity names.

Table 6e: Timeline for ARG25

8. References

Please note that this report is located on the S:Drive along with all of the supporting files. Files not mentioned are in the same directory as the report and all referenced below are in a subfolder named "resources." For ease of access, past reports have been copied into this subfolder. The main drive location is:
"S:\Reports\2025 Car\Fall Technical\Powertrain\Powertrain Peripherals\Peripherals_ChargingSystem"

[1] Brusanlg513 Manual, resources/Brusanlg513_manual.pdf.

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[5] D. Mittal, *Technical Report: HV Charging Systems*, Spring 2023. [Online]. Available: resources/ARG23_Sp23_TechnicalReport_HV_Charging_Systems_dm885.docx

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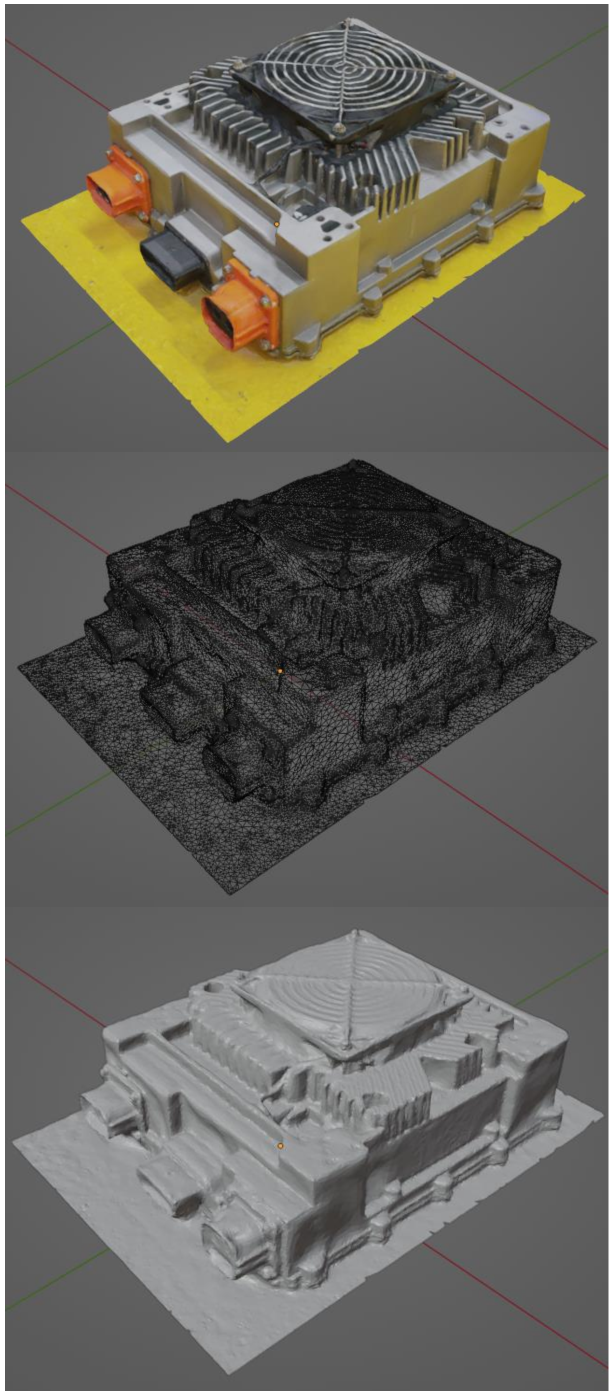
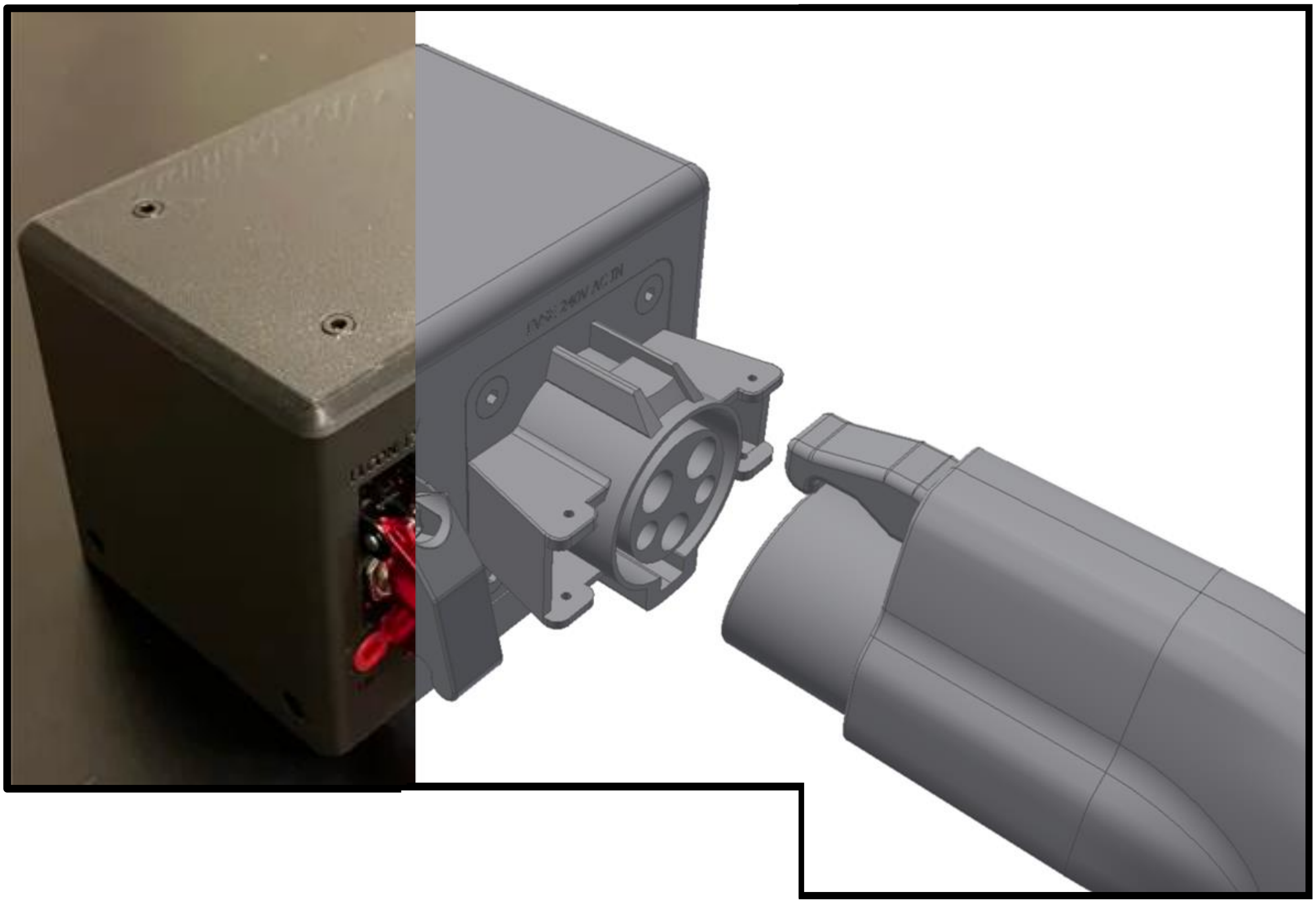
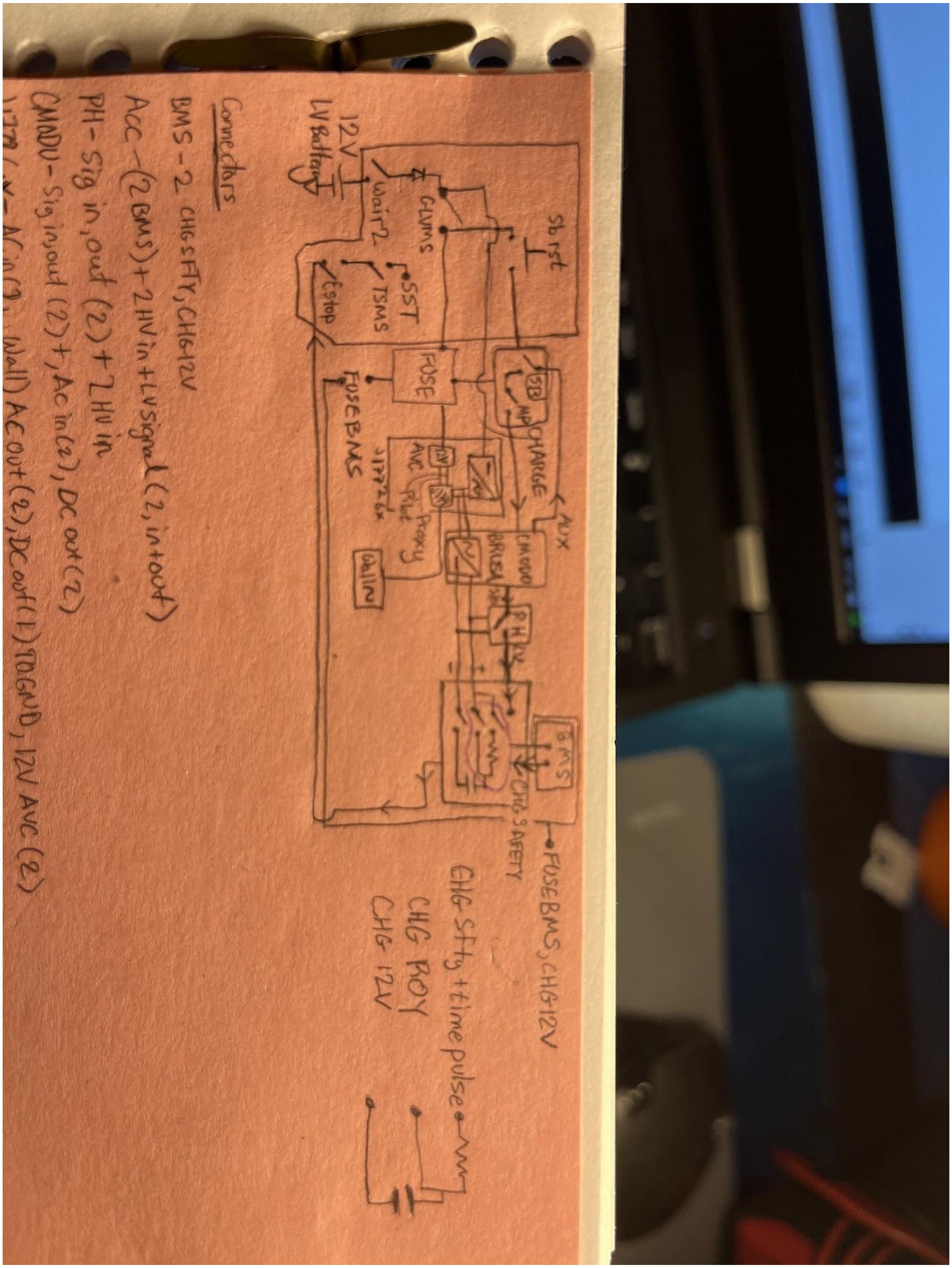
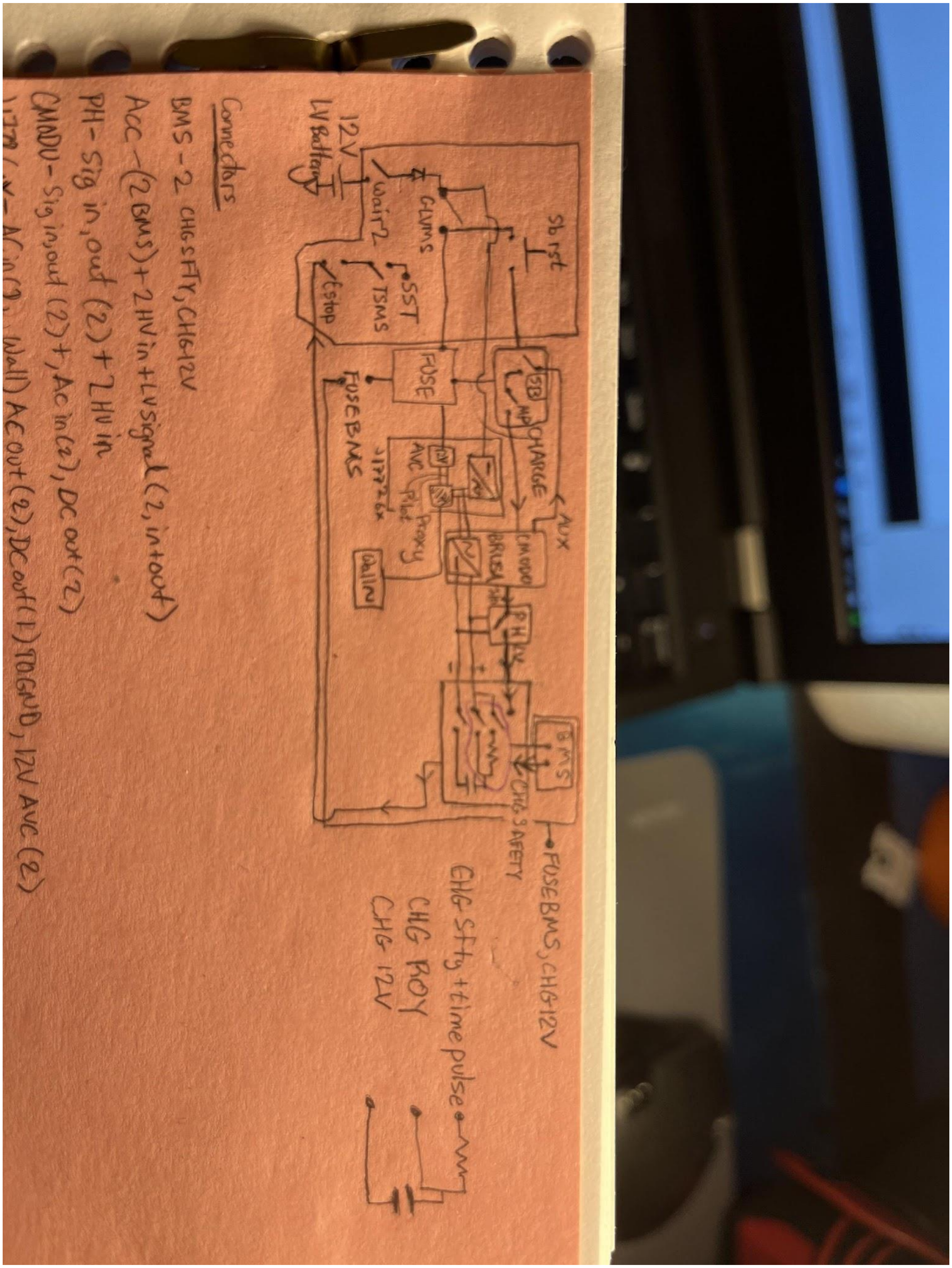
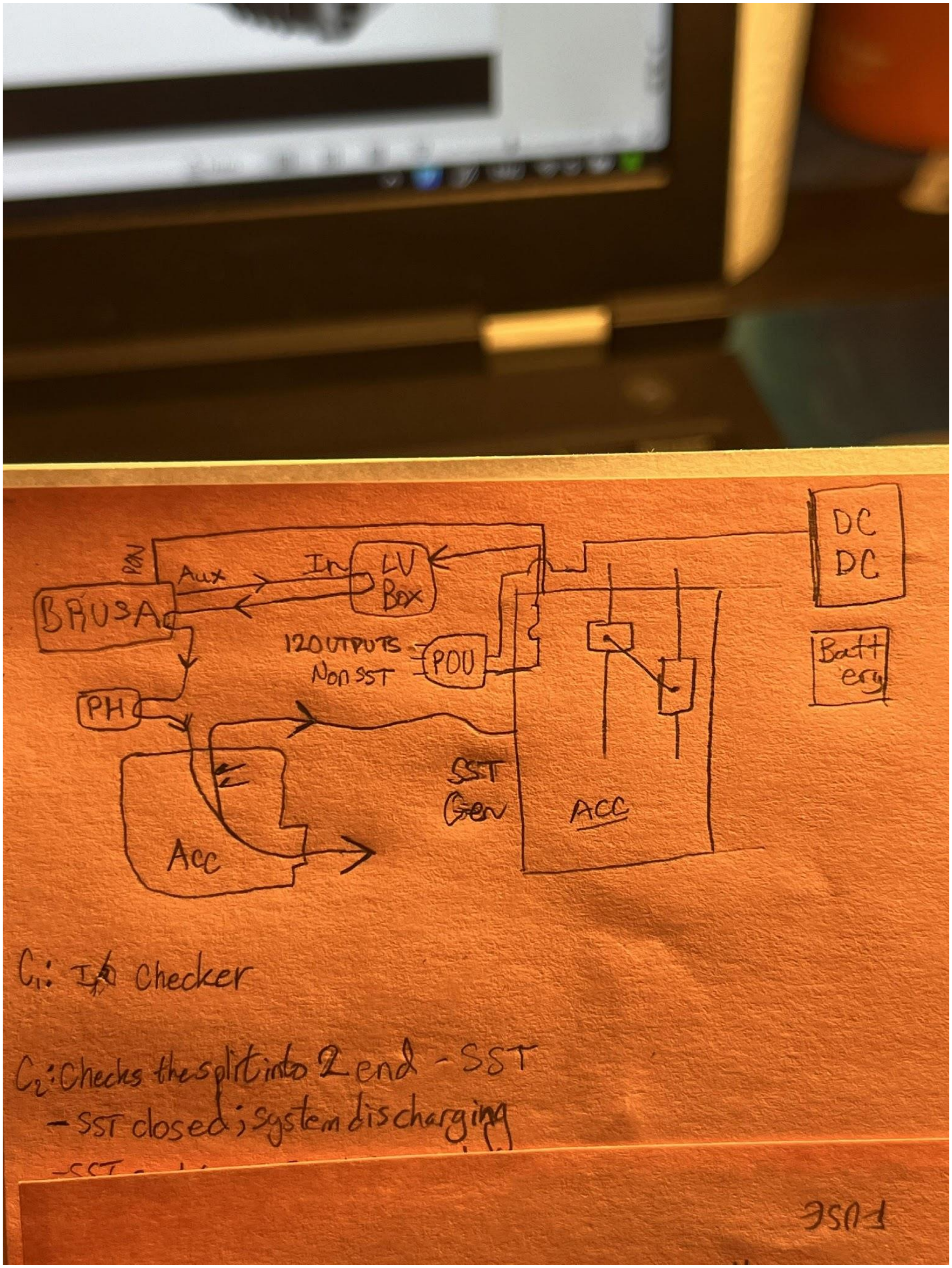
9. Appendix






Connectors
BMS-2 CHG SFTY, CHG 12V
ACC-(2 BMS)+2 HV in + LV signal (2, in + out)
PH-Sig in, out (2) + 2 HV in
CMODU-Sig in, out (2) +, AC in (2), DC out (2)
AC out (2), DC out (1) TO GND, 12V AVC (2)
12V LV Battery
SD rst
GLVMS
SST
TSMS
Estop
FUSE
FUSEBMS
CHARGE
AUX
CMODU
BRUSA
PH
BMS
CHG SAFETY
Wall
Pilot
Proxy
FUSEBMS, CHG 12V
CHG Sfty + time pulse
CHG RDY
CHG 12V


Connectors
BMS-2 CHG SFTY, CHG 12V
Acc-(2 BMS)+2HV in+LV signal (2, in+out)
PH-Sig in,out (2)+2HV in
CMODU-Sig in,out (2)+, AC in(2), DC out(2)
12V LV Battery
CHARGE
FUSE
FUSEBMS
BMS
AUX
CHG SAFETY
FUSEBMS, CHG12V
CHG Sfty +time pulse
CHG RDY
CHG 12V


DC
DC
LV
Box
In
Aux
BRUSA
12 OUTPUTS
Non SST
PDU
Batt
ery
PH
SST
Gen
ACC
Acc
C₁: I/O Checker
C₂: Checks the split into 2 end - SST
- SST closed; system discharging