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ECO-FRIENDLY TRANSPORTATION: SOLAR CAR DESIGN FOR COMPETITION- PART III, ELECTRICAL SYSTEMS

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Abstract

This paper is the third part of a series focusing on the design and analysis of a solar car for competition. Specifically, it explores the electrical systems involved in the solar car design, including both high voltage (HV) systems like the Solar Array, Battery, and Motor, and low voltage systems such as the horn, display, driver interface systems, and the Controller Area Network (CAN bus). The study aims to develop a comprehensive understanding of the electrical architecture of solar cars, encompassing integration and communication between various components through the CAN bus. By examining the design, integration, and performance of these systems, this paper contributes to the advancement of eco-friendly transportation solutions and highlights the potential for renewable energy sources in the automotive industry. The project is undertaken by the Virginia Tech Solar Car team, as part of their participation in the solar car competition, demonstrating their expertise in sustainable vehicle design and innovation. In addition, the subsequent paper in this series (Part IV) will address the testing and validation phase of the solar car project. This paper will provide valuable insights into the practical verification of the solar car, detailing the implementation of the corresponding validation plan. By conducting rigorous testing and evaluation on physical prototypes, the performance and functionality of the solar car will be thoroughly assessed, ensuring its reliability and adherence to design specifications.

Keywords: solar car, electrical systems, solar array, CAN, battery, driver interface, high and low voltage

Introduction

The pursuit of eco-friendly transportation solutions has been a longstanding goal in the automotive industry, driven by the need for sustainable mobility and reduced environmental impact. In recent years, the development of solar-powered vehicles has emerged as a promising avenue towards achieving these objectives. Solar cars, propelled by electric drivetrains powered by solar photovoltaic modules or rechargeable batteries, offer a unique and renewable energy source for sustainable transportation. The concept of solar-powered vehicles dates back several decades, with early experiments and prototypes showcasing the potential of harnessing solar energy for propulsion. These pioneering efforts laid the foundation for the advancements witnessed today in the design and engineering of solar cars. Over the years, academic institutions and research organizations have played a significant role in pushing the boundaries of solar car technology, with numerous competitions held worldwide to evaluate the performance and efficiency of these vehicles. In this context, the Virginia Tech Solar Car team embarked on a project to design, analyze, and optimize mechanical and electrical subsystems of a solar car. The development of these subsystems followed a V-profile approach, where the subsystems are cascaded and integrated in a systematic manner. This approach ensures a coherent and synchronized design process, where the interactions between the subsystems are carefully considered to achieve optimal overall performance. Furthermore, the Virginia Tech Solar Car team collaborated closely with the corresponding system suppliers throughout the development process, collaborating to verify the design and incorporating their valuable feedback and knowledge into the design iterations. Need less to say, This opportunity brought real-world expertise and industry insights, enhancing the robustness and practicality of the design solutions. This paper focuses on the design and analysis of the electrical systems, encompassing both high voltage (HV) systems, including the Solar Array, Battery, Motor, and the low voltage systems, such as the horn, display, driver interface systems, and the Controller Area Network (CAN bus). The historical evolution of solar car design and the lessons learned from previous solar car competitions have been instrumental in shaping the approach and methodology has been employed in this project. Through a meticulous design process, incorporating state-of-the-art technology, adhering to competition regulations, and leveraging supplier collaborations, the Virginia Tech Solar Car team aims to develop an efficient and reliable solar car that maximizes energy utilization while ensuring optimal driver interface and overall system performance. The integration and communication of various components through the CAN bus is a crucial aspect of this project, enabling seamless coordination and control of the electrical subsystems.

By sharing the design methodology, challenges encountered, innovative solutions implemented, and the collaborative approach with suppliers, this paper aims to contribute to the broader body of knowledge in the field of solar car design. It also seeks to promote the adoption of eco-friendly transportation solutions, highlighting the importance of coordinated subsystem development and industry partnerships. Together, these efforts pave the way for a future where solar-powered vehicles will be likely dominant to play a significant role in achieving sustainable and environmentally conscious transportation. This paper serves as a continuation of Part I, which focused on the structural chassis design [1] and Part II which concentrated on Suspension, Steering, and Traction Systems design methodology [2]. Additionally, the final paper in this series (Part IV) will focus on the testing and validation phase, providing insights into how the solar car will be verified based on the corresponding validation plan.

1. Customer Needs and Target Setting

The electrical team identified customer needs and set target specifications by referencing the Formula Sun Grand Prix (FSGP) competition rules and regulations document (Innovators Educational Foundation [IEF], 2022). These rules provided the baseline requirements for each component of the vehicle. Additionally, the team established several additional requirements based on our specific electrical architectural decisions. One notable example is the inclusion of a driver user interface, which is not explicitly mentioned in the FSGP rules. We recognized the importance of providing a display to present data that could assist the driver in making informed decisions during the race. Therefore, we incorporated this feature into our design, going beyond the minimum requirements specified by the competition regulations.

By considering both the FSGP guidelines and our own supplementary requirements, we ensured that the electrical subsystem of the vehicle meets the demands of the competition while providing enhanced functionality and user experience. This approach allows us to address the specific needs of our team and contribute to the overall success of the solar car in the Formula Sun Grand Prix and similar competitions.

1.1. Powertrain Customer Needs

The Powertrain team identified key customer needs pertaining to the integration and operation of SolarCar's high voltage (HV) systems, including the Solar Array, Battery, and Motor. Additionally, ensuring the safety disconnection of HV systems, both manually and in response to faults, was a critical requirement (Appendix A).

To address these customer needs, we determined that measuring power flow within the system would serve as an effective metric for evaluating the design's success. Consequently, we established targets that encompassed all fault scenarios outlined in the competition rules and regulations. By measuring the conductors in the circuit, we could validate the desired outcomes and ensure compliance with the specified criteria. By focusing on these engineering characteristics and meeting the identified customer needs, the Powertrain team has developed a robust and reliable powertrain system for SolarCar. Our design prioritizes the integration of high voltage components, as well as the implementation of safety measures, to guarantee optimal performance and adherence to competition requirements.

2.1.2. Driver Interface Requirements

To establish the main requirements for the driver interface, a systematic approach was employed by decomposing the system into smaller, more manageable subsystems. This facilitated brainstorming and allowed for a comprehensive analysis of each component. The identified subsystems include:

- Data Transportation: This subsystem focuses on the efficient transfer of information throughout the vehicle, enabling the driver to receive critical data for decision-making purposes.

- Data Display: The driver interface should present relevant and essential information to the driver in a clear and easily understandable manner. This subsystem ensures that the displayed data is readily accessible and visible to the driver during operation.
- Vehicle Control: The driver interface should provide the necessary controls for operating vehicle lights, horn, and other low voltage peripherals. This subsystem ensures that the driver has convenient access to control these functionalities.

By systematically analyzing these subsystems, a robust list of requirements was developed, encompassing various aspects of the driver interface system. Each design iteration must be cross-referenced against these requirements to ensure compliance and functionality (Appendix A, Fig A1 , A2). Some driver interface requirements are binary in nature, such as the presence or absence of displayed data. Additionally, certain target specifications are dictated by the Formula Sun Grand Prix (FSGP) rules, including parameters like car light brightness and horn loudness. By addressing these driver interface requirements, the design team aims to create a user-friendly, intuitive interface that enhances the overall driving experience while adhering to competition regulations.

2. Concept selection

2.1. Powertrain

2.1.1. Electric motor

The electric motor is a critical component of the powertrain system in the solar car, providing power, efficiency, and compliance with competition regulations. The direct drive motor used in our project was selected with respect to its power output, torque characteristics, and compatibility with the vehicle design, Figure 1, 2. It is fitted directly onto the rear wheel, eliminating the need for a separate transmission, and improving efficiency and mechanical simplicity. The motor's design focuses on optimal performance and energy efficiency, considering weight reduction strategies for enhanced vehicle performance and range. Through a program of testing and validation with the supplier, the motor has proven to deliver reliable and consistent performance under various operating conditions. Its compliance with competition regulations ensures a fair competition among participating teams.

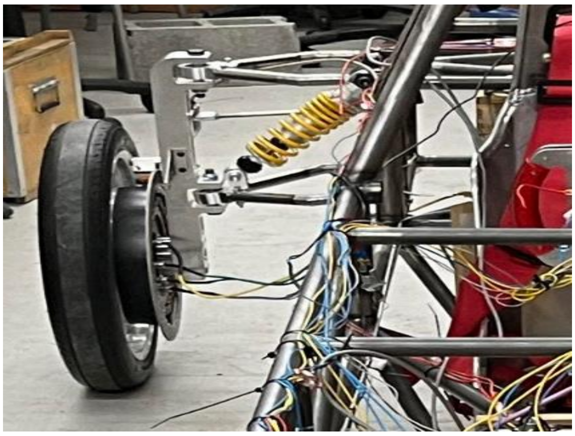

Figure 1: electric direct drive motor fitted on rear wheel

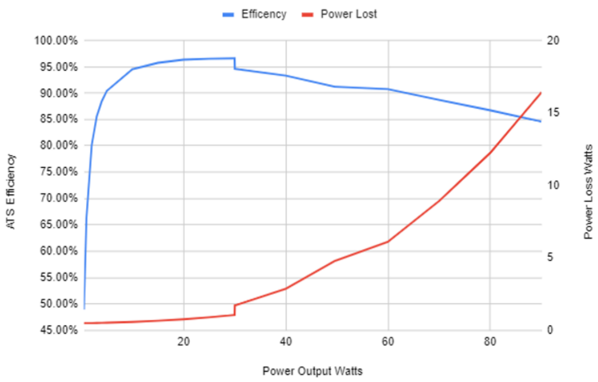

Figure 2: The electric motor power efficiency curves

2.1.2. Maximum Power Point Tracker (MPPT)

During the concept generation phase, we explored various solutions for power storage restriction in the high voltage system. As a result, we selected the Prohelion Control Module and Elmar MPPT as key component of our final solution facilitates an efficient utilization of solar energy by extracting the maximum power from the solar panels and regulating the charging process in different light conditions. One outstanding requirement involves interfacing high voltage systems and prioritizing the solar array over the battery, while ensuring that the MPPT would stop charging when the battery reached full capacity.

2.1.3. Solar arrays

Solar panels play a crucial role in harnessing sunlight and providing power to the electric drivetrain of the solar car, Figure 3. They are responsible for generating electricity during peak sunlight hours as well as storing energy in the battery pack for use when sunlight is not available or insufficient.

The SunPower C60 solar cell, a monocrystalline silicon solar cell that are known for their high efficiency, durability, and excellent performance in converting sunlight into electricity is employed in this project. These panels are typically comprised of multiple photovoltaic cells connected in series or parallel configurations to achieve a desired voltage and power output. The solar panels are strategically positioned on the car's surface to maximize exposure to sunlight and optimize energy generation.

2.1.4. Battery modules

The battery pack consists of four main elements: battery module, CMU, control module, and BMU, Figure 4. The selection of batteries for the pack involves considering factors such as energy density, weight, and efficiency to ensure optimal performance and range for the solar car. Efficient energy storage and management between solar panels and batteries are essential for achieving sustainable and reliable operation. In this project, we utilized the Prohelion battery pack, which comprises 18650 Li-Ion batteries connected in a configuration of 29s14p. This series-parallel connection increases overall voltage and capacity of the battery pack, aligning with the requirements commonly seen in electric vehicles.

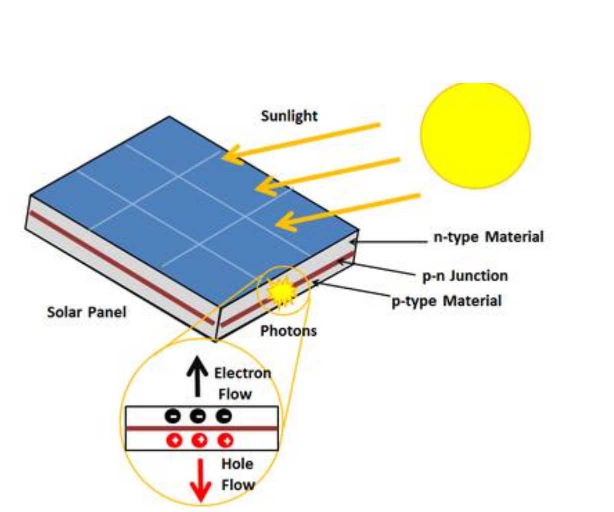

Figure 3: solar panel

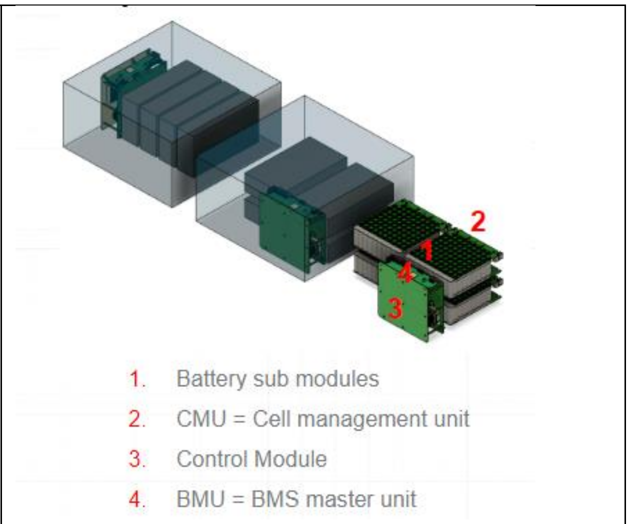

Figure 4: solar car battery pack description

Placing the battery pack in the front of the solar car provided several advantages, including improved airflow and ventilation around the batteries, which aided in preventing overheating. Additionally, this placement facilitated easier access for cooling mechanisms such as fans or cooling ducts, enhancing the overall cooling efficiency. However, it is necessary to consider other factors during the design process. The location of the battery pack in the front affected the weight distribution of the vehicle, potentially impacting handling, and stability behavior. To address this, the drive system was positioned in the back, allowing for a balanced weight distribution. While this configuration slightly compromised crashworthiness performance and increased drag force, these considerations are balanced through specific structural design modifications.

2.2. Low Voltage System

During the concept generation phase for the low voltage system, we developed an initial layout for the driver interface system, as shown in Figure 5. Alongside our chosen concept, we explored two alternative options. The first involved using relays or an Arduino to control the low voltage peripherals, while the second utilized the supplemental battery to power the fan and horn instead of the main battery.

In our chosen design architecture, all components of the low voltage system will be powered by the main battery and controlled directly by the driver through easily accessible switches on the steering wheel. The supplemental battery serves as a backup power source for vehicle electronics in case of a battery fault and during vehicle startup. We select this design for its simplicity, cost-effectiveness, and suitability as a minimum viable product.

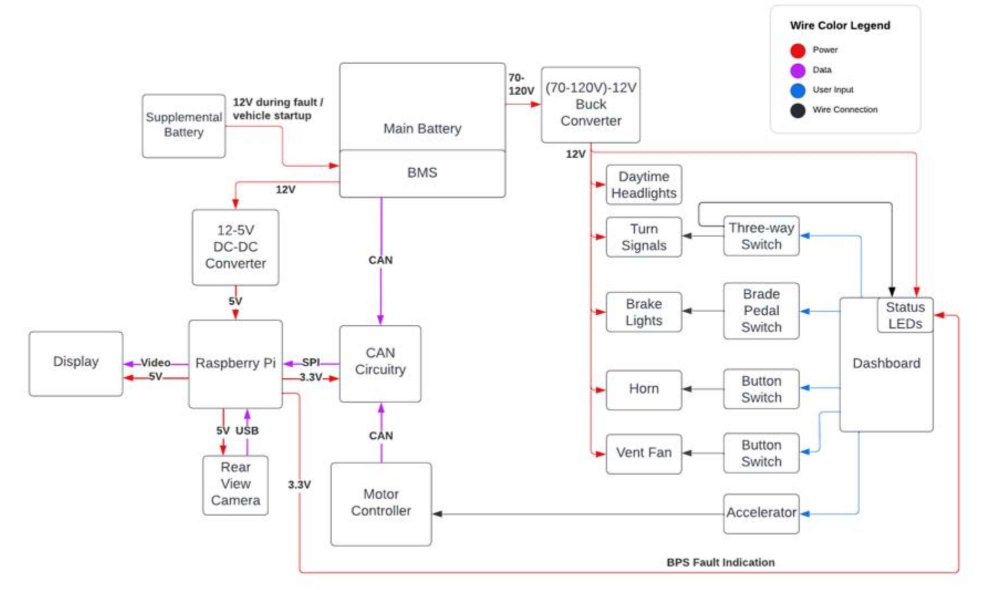

Figure 5: High-Level Diagram for the driver interface system layout

The power consumption of the low voltage systems is a critical factor in achieving the desired endurance for our solar-powered vehicle. As our primary goal is to maximize power to the motor, it is essential to calculate the power requirements of the low voltage electronics, Figure 6.

Part	Power draw	Efficiency
LED 1157 (x11)	6-33W	
Motor Controller	0-50W (19.2W nominal)	~98% efficient
MPPT	~0-50W	99.5% efficient MAX
Raspberry Pi	2.85W (idle)	
Driver Display	2.4W	
USB webcam (Logitech)	2.5W	
main battery DC-DC converter	1.9-7.1W	~91%
12-5V DC-DC converter	1.2W	~85%
MAX (W):	**118.25**	
AVG (W):	**77.15**	
Motor	0-2.5kW (Depending on load)	
TOTAL (W):	**960**	
MIN. MOTOR (W):	**841.75**	
AVG. MOTOR (W):	**882.85**	

Figure 6: Power Consumption of Low Voltage System

3. Analysis, Prototyping, and Testing

3.1. Low Voltage Systems Design

3.1.1. Lights/Peripherals

The low voltage system includes lights and peripherals, with LED bulbs has chosen for their power efficiency and simplified implementation, Figure 7. Each lighting system operates on a 12-volt power source and is protected by fuses to prevent excessive current flow. The headlights are always on when there is power in the motor and do not have a switch. Brake lights are controlled by a brake switch that closes the circuit when the brakes are applied. Turn signals utilize a three-way switch with separate pins for left and right signals, each powering four bulbs. An LED flasher pulses the 12-volt signal to create the flashing effect. Additionally, a double pole switch and another LED flasher enable the turn signal system to function as emergency hazard lights, activating both left and right signals simultaneously [3].

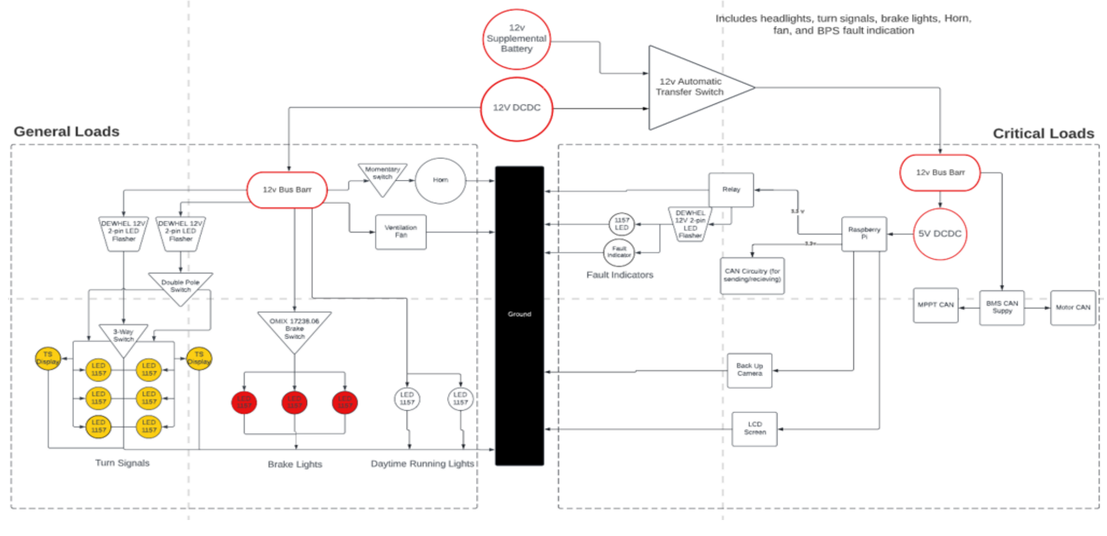

Figure 7: Low Voltage System Diagram

The horn and ventilation fan are both powered by a 12-volt source, which also powers the lights. The fan draws in external air and directs it towards the driver's face. The horn is operated by a momentary switch on the steering wheel. When the switch is pressed, power is sent to activate the horn, and when released, the circuit is opened. The BPS fault indicator, on the other hand, is powered by the supplemental battery. When a battery fault is detected, the Raspberry Pi sends a signal to a relay, which activates the BPS fault indication lights using power from the supplemental battery [4]. The flashing lights serve as an indicator to the driver and others outside the vehicle of a battery system fault.

3.1.2. GUI

The GUI, or graphical user interface, is an essential component of the driver interface system, Figure 8. It displays important information to the driver during a race, such as speed, battery voltage, and charging status. To create this interface, a web application is developed using a Raspberry Pi, which is connected to a display embedded into the steering wheel. The web application reads CAN data in real time and displays it to the driver. A test script was also created to simulate CAN data, which was used to verify the accuracy of the driver interface in real-time.

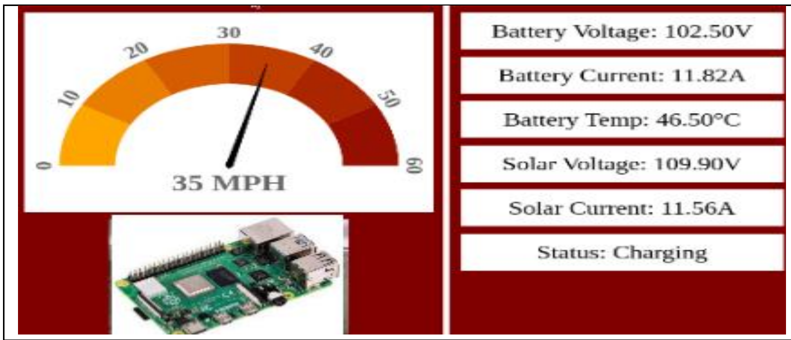

Figure 8: Current graphical driver interface

3.1.3. CAN Circuitry

CAN circuitry plays a crucial role in enabling data transmission within the car. CAN Circuitry refers to the hardware components and circuitry that are involved in implementing the CAN (Controller Area Network) communication protocol. It includes elements such as transceivers, controllers, and wiring that enable the transmission and reception of data over the CAN bus. Appendix B displays CAN circuitry (hardware) test set up and validation [5]. The test confirmed that the Raspberry Pi successfully received and transmitted CAN packets as intended.

3.1.4. Main battery management system (BMS) Control

The main battery management system (BMS) is responsible for monitoring and managing the main battery pack in the solar car. It ensures the safe and efficient operation of the battery by monitoring parameters such as voltage, current, temperature, and state of charge. It balances the cells, protect against overcharging or over discharging, and detect and respond to any faults or abnormalities in the battery pack. Additionally, the BMS control interfaces with other systems in the car, such as the powertrain and low voltage system, to coordinate the overall operation and optimize energy usage. Through its comprehensive monitoring and control capabilities, the BMS control enhances the performance, reliability, and lifespan of the main battery pack, contributing to the overall success of the solar car.

Prohelion BMS had several features that made it suitable for the solar car .The BMS supports communication via CAN bus, which is a widely used and reliable protocol for data transmission in automotive applications. This allows for seamless integration with both the batteries and the vehicle's systems. The BMS includes three 12V, 3A contactor drives with feedback. Contactors are used for high-current switching, such as connecting and disconnecting the battery pack. The inclusion of feedback ensures accurate monitoring and control of the contactors. The BMS features a resistive pre-charge circuit with fault detection. Pre-charging is a vital step in safely connecting the battery pack to the rest of the vehicle's systems, and the fault detection capability helps detect any issues during this process. Isolation Rating: The BMS has an isolation rating of 1kV DC, indicating that it provides sufficient isolation between the battery pack and other vehicle components for safety purposes. With dimensions of 195 x 55 x 30mm and a mass of 150g, it can be advantageous for integration into a solar car where space and weight considerations are important. The BMS consists of two components: multiple Cell Management Units (CMU), which measure and control the individual cells in the battery pack; and a single BMS Master Unit (BMU) which interface between the CMUs and the vehicle.

3.2. Powertrain

The powertrain solution for the solar car project involves the use of a Prohelion control module (BMU) and Elmar MPPT, Figure 9. The control module provides functionalities such as isolating the solar array and battery from the motor, activating an emergency stop in case of excessive current, and ensuring safe operation. The MPPT, on the other hand, limits the maximum current to 12A, prioritizes energy delivery from the solar array over the battery, and prevents overcharging by deactivating through the CAN bus.

To manage fault conditions and power flow on the main high-voltage bus connecting the Solar MPPTs, BMS, and Motor Controller, the powertrain design incorporates multiple high voltage contactors and fuses. A microcontroller is employed to control the connection and disconnection of the contactors, ensuring system safety. The contactors, fuses, and wires are selected to handle a continuous current of approximately 30A. The contactors are designed to handle a current twice the maximum current of the fuses, ensuring they do not get overloaded [6]. Fast-acting fuses with a current rating of 100A are employed on the main bus to break in case of a short circuit, providing protection. For the low voltage systems, there are no lower current fuses for the DC-DC Converter. Overall, this powertrain solution considers interactions between the high-voltage components and incorporates safety measures through contactors, fuses, and a microcontroller, ensuring reliable and efficient operation of the solar car's powertrain. The high voltage diagram is schematically depicted in Appendix C.

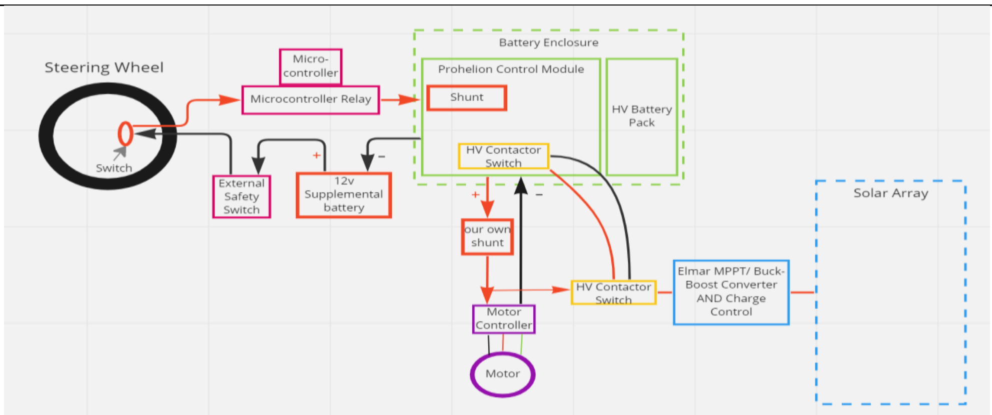

Figure 9: High level powertrain diagram

Conclusion:

In conclusion, the design and development of a solar-powered car electrical systems encompassed various aspects, including powertrain, low voltage systems, battery management, and control modules, and the graphical user interface (GUI). Throughout the project, careful consideration was given to maximizing power efficiency, optimizing energy storage, and ensuring the safe and reliable operation of the vehicle. The powertrain design incorporated with Prohelion control module and Elmar MPPT, which provided essential functionalities such as solar array and battery isolation, emergency stop capabilities, and efficient energy delivery. The selection of these components aligns with the goal of achieving optimal power flow and fault management on the main high-voltage bus, connecting the solar MPPTs, BMS, and motor controller.

For the low voltage systems, a comprehensive layout is developed, taking into account factors such as power consumption, component selection, and driver interface. The utilization of LED bulbs for lighting systems and the integration of accessible switches on the steering wheel demonstrated the focus on efficiency, simplicity, and user-friendliness. The battery management system (BMS) played a crucial role in monitoring and safeguarding the battery performance. The CMU and CAN communication facilitates effective control and data transmission within the vehicle, enabling real-time monitoring and fault detection. The GUI played a crucial role in enhancing the driver's experience and providing important information in real-time. By leveraging technologies such as a Raspberry Pi and a web application, a comprehensive and intuitive driver interface was created. This interface displayed vital information such as speed, battery voltage, and charging status, allowing the driver to monitor the car's performance during races or everyday use. Real-time data obtained through the CAN bus enabled accurate and timely updates on the GUI, contributing to informed decision-making and enhanced safety. The project successfully integrated key components, ensuring the synergy between high voltage and low voltage systems. The utilization of CAN bus communication, strategic placement of components, and adherence to safety standards were critical in achieving a functional and reliable solar-powered car. However, there are still opportunities for further enhancements and optimizations. This project demonstrated the feasibility and potential of solar-powered cars as a sustainable transportation solution. The knowledge gained and lessons learned throughout the design and development process will serve as a valuable foundation for future endeavors in the field of renewable energy-powered vehicles.

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Appendix A. Electrical Customer Needs, Target Setting

Powertrain (Battery, Motor, Solar Array) and User Interface

Electrical Customer Needs

#	Description	Weighting
1	The battery protection system shall be able to isolate the battery, motor, and solar array during a fault	5
2	The user shall be able to isolate the same systems above by the driver or externally	4
3	The battery box shall be equipped with a forced ventalation which directs air away from the driver	3
4	The wires off the main bus shall be properly fused	3
5	The powertrain systems shall be properly connected to ensure safe power transfer	4
6	The battey capacity shall be greater than the average between a sample of teams	1
7	The solar array power capability shall be greater than the average between a sample of teams	1
8	The Motor shall be capable of achieving 50 mph under small load conditions	3
9	The Motor shall be capable of reversing	3
10	The battery, motor, and solar array shall be connected by a single bus	4
11	The driver shall be able to read the current vehicle speed	3
12	The driver shall be able to read the current battery temperature	3
13	The driver shall be able to read the current battery current	3
14	The driver shall be able to read the current battery voltage	3
15	The driver shall be able to read the current light and turn signal status	2
16	The driver shall be able to have rear vision of behind the vehicle	2
17	The driver shall be able to see the current BPS (battery protection system) fault status	5
18	The driver shall be able to trigger the main power switch	5
19	The driver shall be able to control the motor speed with an accelerator	5
20	The driver shall be able to turn on functioning vehicle turn signals	2
21	The driver shall be able to turn on functioning front headlights	2
22	Brake lights shall turn on when the vehicle brake is toggled	2
23	The driver shall be able to toggle the emergency hazard signal where all turn signals flash	2
24	The driver shall be able to use a functioning horn	2
25	There shall be a functional ventilation system for the driver	2

10/7/2022
Our customer is Eashan and the SolarCar Team
Adeel Aziz, Gunnar Copeland, Joey Dias, Anthony Etzler, Vincent Garcia, Austin Honey, Jianyu Hua, Hanshin Lee, Jack Michaud, Clay Mowry, Harry Rui, Kyle Shah, Danny Stover, Ryan Vargo

Electrical Engineering Characteristics

Customer Needs

#	Description	Customer Weighting (5-1)	1 Battery Size (kWh)	2 Solar Array Capabilities (W)	3 Speed (mph)	4 Coverage (%)	5 Power Flow (W)	6 Visible on Driver Dashboard (Yes/No)	7 Vertical Viewing Angle (degrees)	8 Horizontal Viewing Angle (degrees)	9 Visibility Distance (m)	10 Volume (dBA)
1	The battery protection system shall be able to isolate the battery, motor, and solar array during a fault	5	3	1	1	9	9					
2	The user shall be able to isolate the same systems above by the driver or externally	4	3	1	1	9	9					
3	The battery box shall be equipped with a forced ventalation which directs air away from the driver	3	3	1	1		1					
4	The wires off the main bus shall be properly fused	3	1	1	3	9	9					
5	The powertrain systems shall be properly connected to ensure safe power transfer	4	3	3	3	1	9					
6	The battey capacity shall be greater than the average between a sample of teams	1	9	1	1	1	1					
7	The solar array power capability shall be greater than the average between a sample of teams	1	1	9	1	1	3					
8	The Motor shall be capable of achieving 50 mph under small load conditions	3	1	1	9	1	1					
9	The Motor shall be capable of reversing	3	1	1	6	3	6					
10	The battery, motor, and solar array shall be connected by a single bus	4	1	1	1	3	9					
11	The driver shall be able to read the current vehicle speed	3	3	3	1		3	9				
12	The driver shall be able to read the current battery temperature	3	3	3			3	9				
13	The driver shall be able to read the current battery current	3	3	3			3	9				
14	The driver shall be able to read the current battery voltage	3	3	3			3	9				
15	The driver shall be able to read the current light and turn signal status	2	3	3			3	9	9	9	9	
16	The driver shall be able to have rear vision of behind the vehicle	2	3	3			3	9	9	9	9	
17	The driver shall be able to see the current BPS (battery protection system) fault status	5	3	3			3	9				
18	The driver shall be able to trigger the main power switch	5	3	3			3					
19	The driver shall be able to control the motor speed with an accelerator	5	3	3	1		3					
20	The driver shall be able to turn on functioning vehicle turn signals	2	3	3			3		9	9	9	
21	The driver shall be able to turn on functioning front headlights	2	3	3			3		9	9	9	
22	Brake lights shall turn on when the vehicle brake is toggled	2	3	3			3		9	9	9	
23	The driver shall be able to toggle the emergency hazard signal where all turn signals flash	2	3	3			3		9	9	9	
24	The driver shall be able to use a functioning horn	2	3	3			3					9
25	There shall be a functional ventilation system for the driver	2	3	3			3					
Absolute Score	------>		#REF!	#REF!	#REF!	#REF!	#REF!	#REF!	#REF!	#REF!	#REF!	#REF!
Importance Ranking	1st, 2nd, 3rd... ------>		2nd	4th	7th	5th	1st	3rd	6th	6th	6th	8th

Figure A.1: Electrical systems customer needs with corresponding weighting factor

Electrical Target Specifications Table

Customer Need #s	Eng. Characteristic	Importance	Units	Marginal Value	Ideal Value	Verification Measurement Device
1-24	Power Flow (W)	1st	W	0.00	0.00	Current/Voltage Sensors or Power meters
1,2, 4-10	Coverage (%)	5th	%	90.00	100.00	Logging in spreasheet
1-24	Battery Size (kWh)	2nd	kWh	4.93	5.50	Capacity Tests using high power loads; voltage/current monitoring
1-11, 19	Speed (mph)	7th	mph	35.00	40.00	Radar gun or speedometer
1-24	Solar Array Capabilities (W)	4th	W	927.50	1000.00	Current/Voltage Sensors or Power meters
11-17	Visible on Driver Dashboard (Yes/No)	3rd	Yes/No	Yes	Yes	Can the driver see it clearly
15,16,20-23	Vertical Viewing Angle (degrees)	6th	degrees	5.00	15.00	Human vision and protractor
15, 16, 20-23	Horizontal Viewing Angle (degrees)	6th	degrees	45.00	80.00	Human vision and protractor
15, 16, 20-23	Visibility Distance (m)	6th	m	30.00	30.00	Ruler
24	Volume (dBA)	8th	dBA	75.00	102.00	Decibel Meter

	---------- **VEHICLE DATA (VD)** ----------	
VD.1	The data circuitry shall transport and receive digital data to/from the main battery pack, motor controller, and solar MPPTs through the data processing unit at a minimum rate of 1 Hz per transmission	Danny
VD.2	The data processing unit shall control the motor torque based on the driver's acceleration input according to the motor's specified torque chart	Danny
VD.3	The data processing unit shall send requested data to the driver user interface at a minimum rate of 0.5 Hz	Adeel
VD.4	The data processing unit shall receive video from a rear vision camera	Danny
VD.5	The data processing unit shall determine when a battery fault condition has occurred and inform the driver user interface	Danny
	---------- **DRIVER USER INTERFACE (UI)** ----------	
UI.1	The driver Interface shall display battery pack power in Watts	Adeel
UI.2	The driver Interface shall display battery pack temprature in Fahrenheit	Adeel
UI.3	The driver Interface shall request data from the data processing unit	Adeel
UI.4	The driver Interface shall display speed in MPH	Adeel
UI.5	The driver interface shall display rear vison from the data processing unit	Adeel
UI.6	The driver interface shall display fault information when a fault occurs	Adeel
	---------- **LOW VOLTAGE SYSTEMS (LV)** ----------	
LV.1	The low voltage system shall have white daytime running lights operating whenever motor has power	Kyle
LV.2	The low voltage system shall have two amber turn signal lights for the front of the vehicle	Kyle
LV.3	The low voltage system shall have two amber turn signal lights for the sides of the vehicle	Kyle
LV.4	The low voltage system shall have two amber turn signal lights for the back of the vehicle	Kyle
LV.5	The low voltage system shall have brake lights for the back of the vehicle	Kyle
LV.6	The low voltage system shall include a high mounted center brake light	Kyle
LV.7	The low voltage system shall include a horn that meets the FSGP rules and regulations	Kyle
LV.8	The low voltage system shall include turn signals will also function as emergency hazard lights	Kyle
LV.9	The low voltage system shall have an exterior BPS fault indicator located above the center brake light	Kyle
LV.10	The low voltage system shall power the low voltage components required to turn on the car during vehicle startup	Danny
LV.11	The low voltage system shall power the battery protection system during a fault condition	Danny
LV.12	The low voltage system shall supply each low voltage component with the correct input voltage	Kyle
LV.13	All low voltage systems shall be protected during overcurrent situations	Kyle
LV.14	The low voltage system shall include outside air from intake vents directed at the driver's face	Kyle
LV.15	The turn signals shall include a status indicator for the driver	Kyle

Figure A.2: list of driver interface requirements

Appendix B: CAN Bus hardware setup and testing

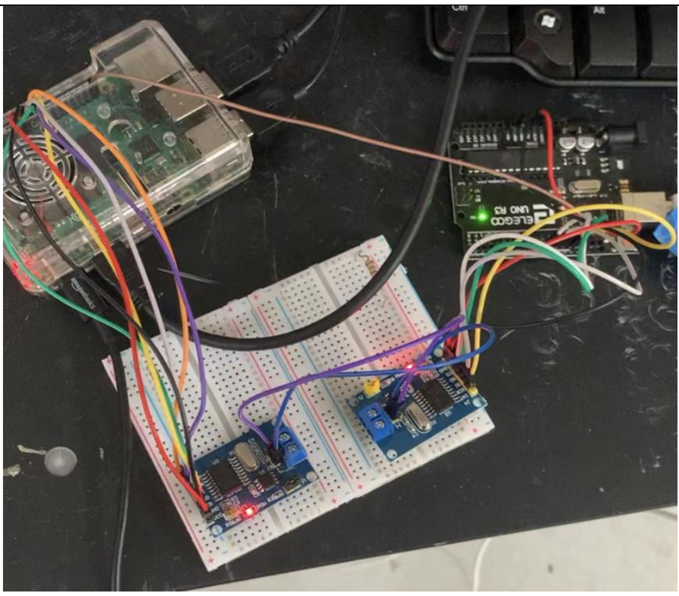

Figure B.1: CAN Hardware Test Setup

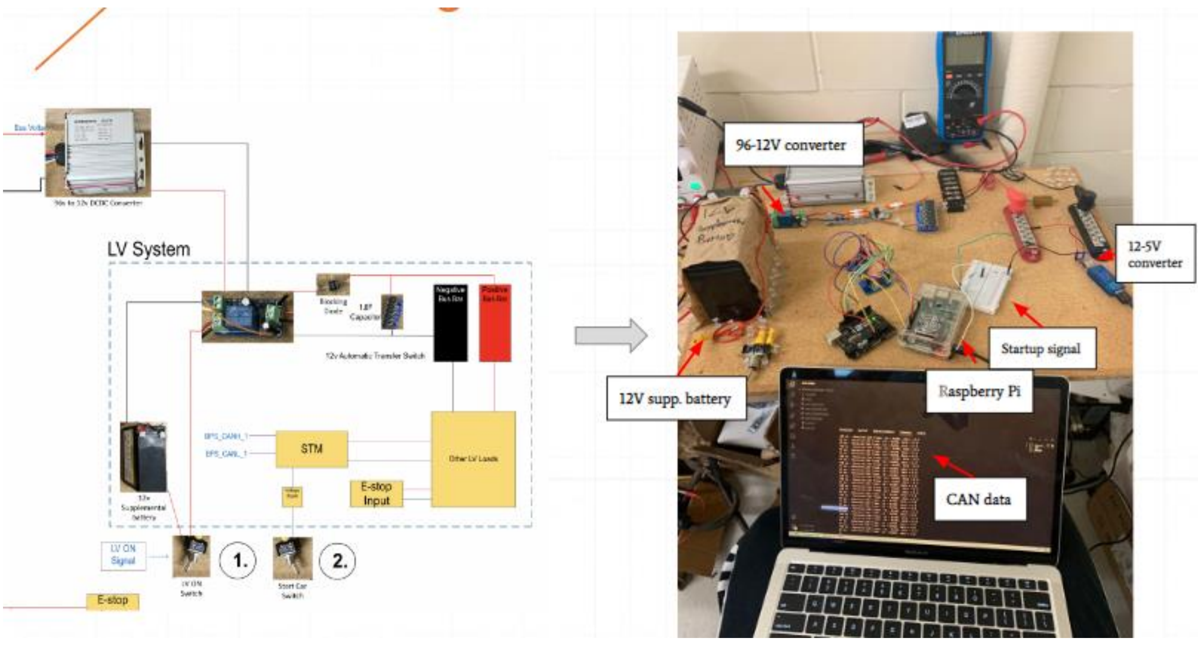

Figure B.2:CAN Bus Testing

Appendix C: High Voltage Diagram