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Swappable BMS

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Approval

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Abstract

Electric Vehicles (EVs) are increasingly popular due to their lower maintenance costs compared to traditional gas-powered vehicles. However, one of the main drawbacks of current EVs is the charging time. To address this issue, we propose a battery swapping method that significantly reduces charging time. This allows users to replace depleted batteries with fully charged ones at designated docking stations. This system requires the development of an advanced Battery Management System (BMS) to ensure the health and protection of the battery packs. We explore the most efficient and practical methods for BMS design, focusing on maintaining optimal battery performance. Additionally, a control unit is necessary to manage multiple swappable battery packs, facilitating communication between the BMS and enabling charging and discharging processes.Furthermore, we discuss the integration of communication between the control unit and the docking station to ensure a smooth and efficient battery swapping experience.

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Acronyms

BMS Battery Management System

CAN Controller Area Network

EV Electric Vehicle

MCU Micro-controller Unit

EEPROM Electrically Erasable Read-Only Memory

SOC State of Charge

SOH State of Health

IC Integrated Circuit

ADC analog-to-digital converter

1. Introduction

In this chapter,we will explore the motivations behind initiating this project and identify the specific problems it aims to address.We will then outline the project's objectives and scope, detailing its unique aspects,potential beneficiaries, and possible applications.This chapter will conclude with a navigation guide for the subsequent chapters.

1.1 Motivation

EVs are at the forefront of the transition to sustainable transportation. According to data from Goldman Sachs Research, EVs are projected to constitute nearly half of global car sales by 2035.However,one of the primary challenges facing EV adoption is the time required for frequent recharging,which can lead to substantial downtime for drivers.For a long-distance drive, driver need to charge several times during the trip, and it will waste lot of time.An effective solution to this challenge is the implementation of a swappable battery system.By allowing drivers to exchange depleted batteries for fully charged ones, the time spent on charging can be drastically reduced.Moreover, with batteries being charged at dedicated charging stations, the costs associated with energy consumption can be optimized.

1.2 Problem Statement

The current model of single, non-swappable battery packs necessitates long charging times, contributing to "range anxiety" and limiting the practicality of EVs for users with immediate mobility needs.Existing BMSs are designed for these single, fixed battery packs, focusing on monitoring and protecting individual cells within a pack. However, they often fall short in addressing the unique challenges presented by multi-battery pack systems, particularly in vehicles designed for battery swapability. These challenges include managing the health and charge levels of multiple packs simultaneously,ensuring uniformity across different packs, and maintaining safety standards during the swapping process.

1.3 Primary Objectives

Primary objectives of our project can be listed as below.

- Designing BMS specifically for multi-pack, swappable lithium-based battery packs. This innovative BMS should address the safety, efficiency, and convenience challenges identified in current systems, making it a cornerstone technology for advancing the EV industry.

- Implementing a control unit within the BMS to ensure the batteries are exclusively used for their designated purpose in electric vehicles, maintaining system integrity and safety.

1.4 Project Scope

This project has three main scopes. The first is designing a new BMS specifically for the swapping battery packs.The second involves developing a controller unit,integrated into both the vehicle and docking station, that manages the charging and discharging of the batteries. Charging or discharging will only be possible when connected to this controller unit. The third scope involves ensuring that the new controller unit can communicate effectively with the control system of the docking station,which handles user authentication and other essential functions.

1.5 Novelty and the Uniqueness of the Project

Current BMSs typically use passive balancing, which dissipates excess energy from overcharged cells as heat, resulting in energy loss. Moreover, existing BMSs are limited in the number of parallel connections they can handle, restricting the overall current output.

Our proposed BMS offers the following key improvements:

- **Active Balancing:** By implementing active balancing, our system efficiently redistributes energy among cells, reducing energy waste during charging and discharging.

- **Increased Scalability:** AThe design supports more parallel connections, allowing for higher current output and better performance in large-scale applications.

1.6 Beneficiaries and Potential Applications

This project primarily targets future taxi drivers who may rely on EVs for their services. These drivers spend more hours on the road each day and their batteries are subject to frequent charging cycles, leading to quicker depletion. Implementing battery swapping methods can significantly benefit these drivers by minimizing downtime. Additionally, since these drivers typically operate within a limited geographic area, the need for numerous docking stations is reduced, making battery swapping a practical and efficient solution for their specific use case.

1.7 Navigation to the Chapters

The remaining chapters of this report are organized as follows: Chapter 2 provides a literature review of the project outlining the existing BMS, their charging and discharging methods and existing method in communication in vehicles. Chapter 3 details our methodology, including the proposed system architecture, analysis of alternative methods, risks and risk management plan, the estimated budget, task delegation among group members and timeline of the project; and Chapter 4 provides discussion and conclusions by summarizing the main findings of the literature review, feasibility of the project, impact of the project and further conclusions.

2. Literature Review

EVs are gaining popularity for their eco-friendliness and efficiency, but their reliance on high-capacity lithium-ion batteries necessitates a sophisticated BMS. This chapter examines the critical aspects of BMS, including battery monitoring, cell balancing, and communication protocols, to ensure optimal battery performance and safety.

2.1 BMS Requirements

EVs are increasingly favored for their fuel efficiency and eco-friendliness, appealing to automakers, governments, and consumers alike. Unlike traditional vehicles with internal combustion engines, EVs rely on battery-stored electric energy to power electric motors. As a result, EV batteries need to have high energy capacity and long life to maximize driving range. To meet these needs, lithium-ion batteries are commonly used in EVs due to their high energy density and efficient charging capabilities. However these batteries require more careful management system due to overcharged and undercharged of batteries.This requires the adoption of a proper BMS to maintain each cell of the battery within its safe and reliable operating range [1, 2].

2.2 Battery Monitoring

Key features of BMS are battery monitoring, cell balancing, safe charging and discharging,Galvanic isolation and communication interface [3]. When it comes to battery monitoring mostly focused on cell voltages measurements, SOC(state of Charge) measurement, current and cell temperatures.ICs(Integrated circuit) usually are able to measure voltage, temperature and current and use simple methods to estimate the battery's current State of Charge (SOC).There are analog front-end ICs and digital front-end ICs. Since decisions are made by MCU of BMS depending on monitored data, digital front-end ICs are more preferred. When selecting monitoring IC, there parameters to be considered according to application. They are Number of series cells (min, max), Vin (max), Features(Cell balancing, Integrated ADC, Multi-cell support, Open-wire detection, Overtemperature protection, Overvoltage protection, Separate MCU requirement..), Operating temperature range, Battery overvoltage protection (min, max) and Communication interface etc [4].

2.3 Cell balancing

Voltage variations occur within battery cells during charging and discharging, leading to imbalances. These imbalances are unavoidable due to differences in electrical and chemical properties, aging, production tolerances, internal impedance, and temperature variations. As a result, the battery's lifespan and charge potential are reduced, significantly affecting overall performance. Additionally, factors like temperature and passivation further decrease battery capacity, worsening with cell aging.Passive cell balancing and active cell balancing are two main techniques that are used in BMS [5]. Passive cell balancing method has low cost and easy implementation while the requirement for high power resistor, energy dissipation, and low efficiency are its disadvantages. Active cell balancing is low power dissipation and smaller equalizing time while high complexity of circuit and needed large space on circuit are disadvantages [6]. Proposed BMS is used active cell balancing considering low the power dissipation.

Active cell balancing is crucial for the longevity and efficiency of high-capacity lithium-ion batteries in EVs.Among the main methods for active cell equalization capacitor-based [7], inductor-based [8], and DC-DC converter-based [9] the latter is the most suitable for high-capacity cells. Capacitor-based balancing struggles with large energy transfers, making it inadequate for our needs. Inductor-based balancing, while better, lacks the precision required for accurate voltage control in high-capacity applications. Given these limitations, we have chosen the DC-DC converter-based approach for our BMS. This method efficiently handles high currents and provides precise voltage balancing. Typically, it involves using a separate DC-DC converter for each cell [9], which can be complex and costly. To streamline this, we propose using a single DC-DC converter with a switch matrix, allowing us to sequentially balance each cell. This method, documented by Texas Instruments [10] , [11], has proven effective in large-scale applications. Our project will scale this design to meet the demands of high-capacity cells, ensuring both efficiency and precision in our BMS.

2.4 Communication

Communication Protocol is a protocol used to transfer signals, data stream, or both between two devices in the BMS for EVs, this helps efficient exchange of Data from battery packs and main controller [12]. Modbus RS232 and Modbus RS485 protocols are well known because of their recognized reliability history, which falls in line with the implementations that need a BMS. Modbus RS232 is easy to use and cheap but with a small data transfer rate and short communication distance [13]. Modbus RS485 offers extended range and faster data rates, which makes it ideal for use-cases needing distances as well Nevertheless, the best choice between these two might be automotive often found within Controller Area Network (CAN) bus for producing tool strategies. The CAN protocol is famous for its robustness and real-time data exchange sometimes also combined advanced error-handling mechanisms making this one of the best choices in an EV environment since those vehicle system requires fast communication and very dynamic circumstances [14]. Its capacity to efficiently handle multiple nodes along with its fast communication make it ideal for modern BMS implementations.

As summary, a well-designed Battery Management System is essential for maximizing the efficiency and longevity of EV batteries. This chapter has covered the key elements of effective battery management, including monitoring, balancing, and communication, which collectively contribute to the reliable and safe operation of electric vehicles.

3. Methodology

In this chapter we will discuss on methodology based on following subtopics: Project Architecture, Resource Requaments, the Budget, Task Delegation, Time line, Project Deliverables.

3.1 Project Architecture

There are 16 LiFePO4 cells are connected in series and each cell has 3.2V nominal voltage. Battery monitoring IC is used for measuring voltage, current and temperature which are sent to main microcontroller (MCU). Measured voltage and current are used for balancing purposes and SoC estimation. According to temperature of each cell MCU make decision to avoid overheating of cells to prevent cell damaging. As previously describe unbalanced cells should go through equalization process to avoid overcharging and undercharging which are caused to life time reduction of cells. Considering power efficiency of balancing, we are going to use active cell balancing with buck converter method. MCU decides which cells should discharge and which cells should charge using monitoring data received. By continuously monitoring cells can be equalized to avoid overcharging and undercharging. MCU controls the MOSFET switches of charging and discharging. We have included active charging limiter to protect battery pack to avoid over current charging.

Fuel gauge ICs in BMS play a crucial role in monitoring and estimating the state of charge (SoC), state of health (SoH). Fuel gauge IC continuously monitor the battery's voltage, which is essential for estimating the SoC. This IC track the charge/discharge current using shunt resistors or other methods, which is crucial for calculating the remaining battery capacity. In our proposed designing has a fuel gauge IC which uses coulomb counting method to estimate SOC directly connected to MCU. EEPROM (Electrically Erasable Programmable Read-Only Memory) is used to store and retrieval of critical data related to the battery and the BMS operation. In the EEPROM we store data that are CAN bus address, security and authentication data, cell balancing data and battery characteristics. Its non-volatile memory and that makes it ideal for storing information that must be retained across power cycles and used for long-term monitoring, diagnostics, and maintenance.

Since high current go through BMS board, there is need of isolation communication circuits away from high current to prevent direct electrical connection between different parts of a circuit, allowing signals to pass between them without transferring harmful currents or voltages. Galvanic isolation is proposed for our BMS for protecting low-voltage control systems and users from potentially dangerous high voltages, thereby preventing electric shock and equipment damage. At the BMS we have included redundancy system by providing backup for critical functions such as voltage monitoring, current measurement, and temperature sensing, redundancy mitigates the risk of system failure, ensuring continuous operation even in the event of a hardware or software fault.

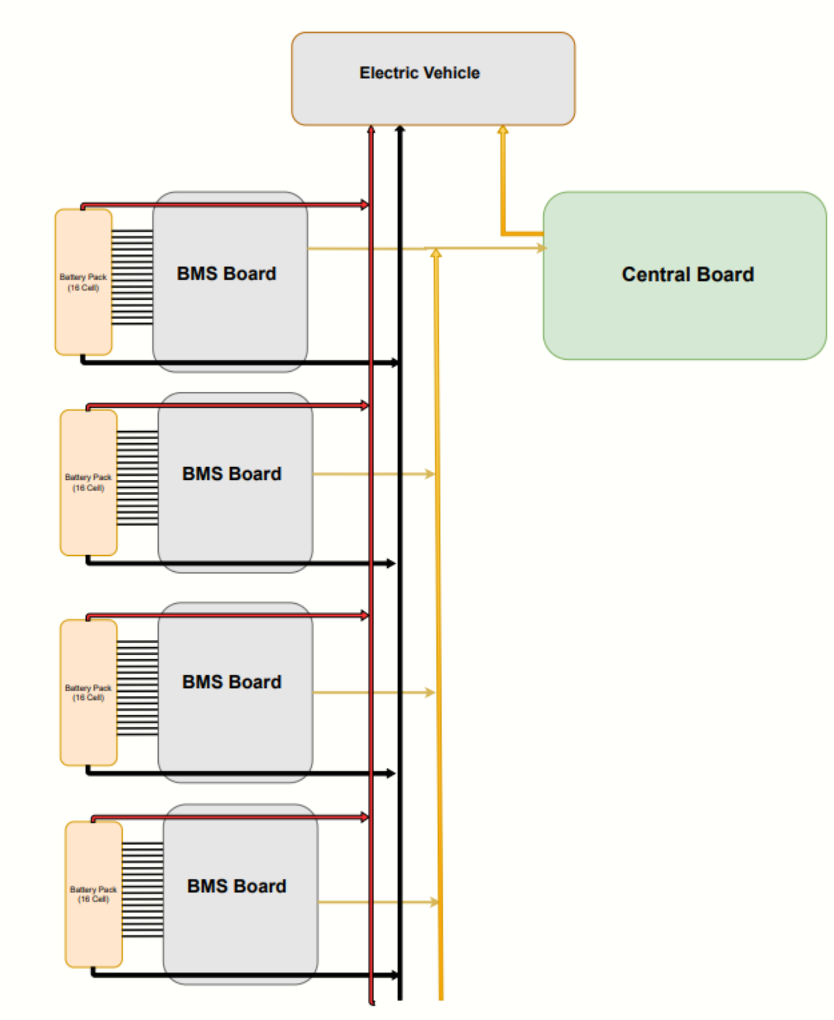


Figure 3.1: BMS Architecture in the vehicle.

To increase the capacity of batteries used in EV, few battery packs are connected in parallel. Parallelly connected packs are controlled by central controller which need to design in our project scope. BMS of each pack communicate through can CAN BUS and RS485 protocols to achieve robust communication and industry standards. Same central controller board are used at docking station to connect the battery pack. But two central controllers have two different features which are programmed accordingly.

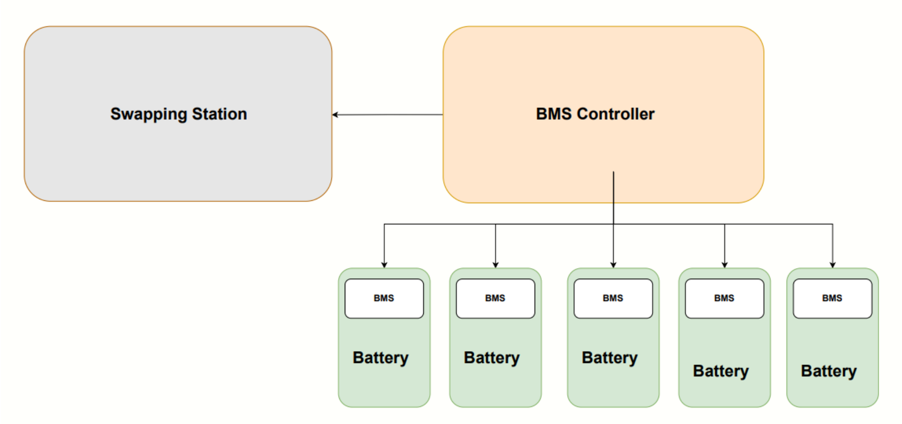


Figure 3.2: Docking Station Architecture

3.2 Resource Requirements

In this section, resource requirements are listed from each resources.

Hardware Resources

- Our project is hardware based project, hardware resources are as follows.
- STM32 Development Boards, Battery Packs, CAN Bus , RS485 module, Prototyping tools, Testing Equipment

Software Resources

- We need software tools for designing, programming and simulation purpose.
- STM32CubeIDE, Simulation tools, Altium Designer

Financial Resources

- Most of hardware resources need to buy and have to pay for the logitics sevices as well.

Logistical Resources

- Logistical resources are required for component sourcing, supply chain management.

Facilities

- Lab facility is need for testing and developing purposes.

3.3 The Budget

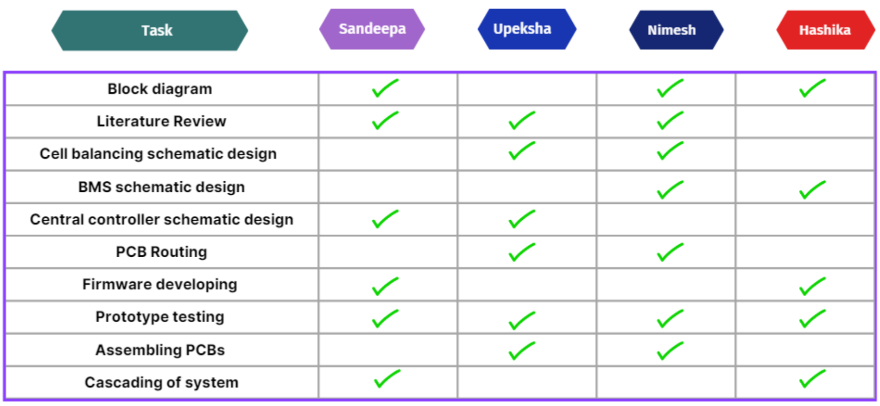
In Table 3.1 we present the estimated budget for the project. All the electronic components and PCB are imported from aboard, considerable proportion have to be for supply chain. We try minimize the prototyping cost aswell.

Table 3.1: Estimated Budget

Item	**Cost (USD)**
Electronic Components	140.00
PCB printing	150.00
Supply chain	60.00
Prototyping Testings	60.00
Total	**410.00**

3.4 Task Delegation

The task delegation chart shows how project responsibilities are divided among the team members. Each person is assigned specific tasks, ensuring that all aspects of the project are covered efficiently. This organized approach helps the team work together effectively toward the project's success.



Task	Sandeepa	Upeksha	Nimesh	Hashika
Block diagram	✓		✓	✓
Literature Review	✓	✓	✓	
Cell balancing schematic design		✓	✓	
BMS schematic design			✓	✓
Central controller schematic design	✓	✓		
PCB Routing		✓	✓	
Firmware developing	✓			✓
Prototype testing	✓	✓	✓	✓
Assembling PCBs		✓	✓	
Cascading of system	✓			✓

Figure 3.3: Task Delegation of project

3.5 Time line

In Figure 3.4, we illustrate the timeline for our project. We have marked November as the mid-evaluation deadline and March as the final evaluation deadline.

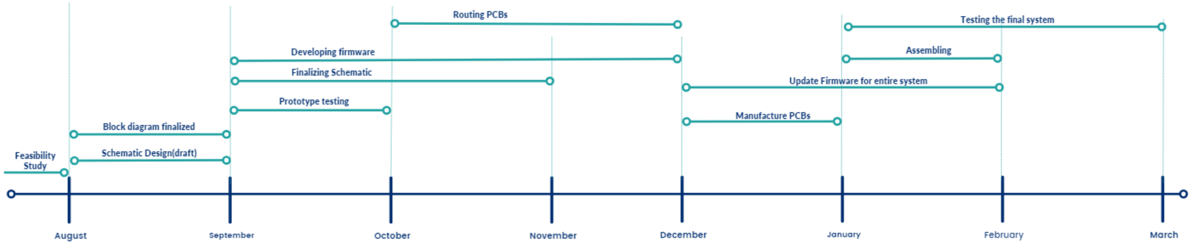


Figure 3.4: Timeline for the project

3.6 Project Deliverables

End of the project followings are delivered and we work on achieve those deliverables.

- **Unified Management System:** A fully integrated and scalable management system for overseeing multiple power packs, complete with real-time monitoring, control, and optimization capabilities.
- **Advanced Safety Protocols:** A set of rigorously tested safety protocols designed to protect against common hazards like overcharging and overheating, ensuring the system meets or exceeds industry safety standards.
- **Secure and Tamper-Proof System:** A robust, secure system architecture that includes encrypted communications, secure access controls, and tamper-detection features to prevent unauthorized access and ensure the integrity of operations.
- **User-Friendly Interface:** An intuitive and easy-to-use interface that simplifies system management, featuring clear visualizations, accessible controls, and comprehensive documentation.
- **Research Publication:** A high-quality research paper detailing the project's innovations and findings, prepared for submission to a top-tier conference or academic journal, highlighting the project's contributions to the field.

This chapter outlines the methodology for our project, detailing the architecture, resource requirements, budget, task delegation, and timeline. We have designed a robust BMS with active cell balancing, safety protocols, and secure communication. The system architecture includes 16 LiFePO4 cells, monitored by a Battery Management IC and a fuel gauge IC, with redundancy for reliability and galvanic isolation for safety. Resource requirements encompass hardware, software, financial, logistical, and facility needs, with an estimated budget of 410. The project timeline includes milestones for mid-evaluation and final evaluation. Our deliverables include a unified management system, advanced safety protocols, a secure system, an intuitive user interface, and a research publication for a top-tier conference or journal.

4. Discussion

The this chapter of the report includes the discussion of the project. First, this summarizes the main findings of the literature review which we discussed in chapter 2. Moreover, the feasibility of the project is explained under technical, financial and social aspects, ensuring our project is feasible. Next, the impact of the project is discussed further. Those impacts are applied to both local and global sections.

4.1 Main Findings of the Literature Review

As Key features of a BMS we need to consider about battery monitoring, cell balancing, safe charging and discharging, galvanic isolation, and communication interfaces. For the battery monitoring, digital front-end integrated circuits (ICs) are favored over analog ones due to their superior accuracy and ability to interface effectively with the MCU that makes critical decisions based on the monitored data.So by choosing a IC which which are compatible with our requirements such like Number of series cells (min, max), Vin (max), Features,Operating temperature range, Battery overvoltage,protection (min, max) and Communication interface , we would be able to achieve battery monitoring more effectively. By selecting an IC that meets our specific requirements,such as the number of series cells (min and max), maximum input voltage (Vin), key features (like cell balancing, integrated ADC, multi-cell support,etc), operating temperature range, and communication interface we can achieve more effective battery monitoring.

Cell balancing is another key feature of the BMS, as voltage variations occur within battery cells during charging and discharging. These imbalances, caused by differences in electrical and chemical properties, can reduce the battery's lifespan and overall performance. Two main techniques for cell balancing are passive and active balancing.Passive balancing is cost-effective and easy to implement but suffers from high energy dissipation and lower efficiency. On the other hand, active balancing, which the proposed BMS will use, offers lower power dissipation and faster equalization times, although it comes with higher circuit complexity and space requirements. Among the active balancing methods(capacitor-based, inductor-based, and DC-DC converter-based) DC-DC converter based is the most suitable for high-capacity cells in EVs. The chosen DC-DC converter-based approach, which utilizes a single DC-DC converter with a switch matrix to sequentially balance each cell, ensures precise voltage control and efficient handling of high currents, making it the optimal choice for the BMS in this project.

As the communication protocols for our project, we considered RS485, RS232, and CAN bus. Given the need to connect multiple BMS units to a central control unit and the importance of real-time data exchange,we chose the CAN bus protocol.This choice ensures the scalability of the project while providing the fast communication required for efficient operation.

4.2 Feasibility and Risk Factors

This section outlines the project feasibility under technical, financial and social criteria.

4.2.1 Technical Feasibility

- When choosing monitoring IC, after considering parameters such as number of series cells, Vin, Features, temperature range, battery overvoltage protection, communication interface, we have planned to use BQ79656-Q1 by Texas Instruments.
- To balance the imbalanced cell voltages, we planned to use DC-DC converter-base active balancing technique by focusing on longevity and efficiency of high-capacity.
- Since several (two or more) battery packs are connected parallelly to vehicle, central controller is responsible on switching charging and discharging. To prevent high current surge on controlling circuits we proposed to Galvanic isolation between BMS and central controller.
- Same central controller is used in docking station. Therefore, MCU of central controller can be programmed accordingly whether it is used in vehicle or docking station.
- Robust communication between battery packs and central controller is important to keep the system without failures. Also, communication between vehicle and central controller have to keep industry standard protocol which reliable for any kind of vehicle. Therefore, CAN bus and RS485 are proposed to use in our design.

So, all our proposed tasks are technically feasible.

4.2.2 Financial Feasibility

- our project is reinforced by the fact that the major expenses, including electronic components, PCB printing, supply chain, and prototyping/testing, are fully covered by the sponsoring company, ensuring that the project remains within budgetary constraints and reducing the financial risk involved.

So, our project is financially feasible.

4.2.3 Social Feasibility

- From a social feasibility standpoint, EVs are increasingly popular due to their ability to improve fuel economy,lower fuel costs, and reduce emissions. As we discussed earlier, this project addresses a key challenge in EV technology,therefore it has significant market potential. However, a potential issue arises with the swappable batteries taken from docking stations could be subject to physical damage. This risk necessitates the implementation of new regulations to ensure proper handling and protection of the batteries.

So, our project is Socially feasible.

4.3 Impact of the Project

Our project is primarily focused on developing a swappable BMS tailored for local EV taxis, specifically targeting EV tuk-tuks. We plan to test and implement the system within this context. The BMS and control unit are designed with scalability in mind, allowing for the connection of multiple parallel battery packs. This flexibility enables the system to be extended for use in a wide range of global EVs.

From this chapter we outline main findings of literature review. Those findings helped us to select the most suitable methods for our project out of alternative methods. Then we checked whether those selected methods are feasible or not. Additionally we discussed how our project impacts globally as well as locally.

5 Conclusion

Electrical vehicles are becoming popular nowadays. As the charging time is the main problem of EVs, we proposed a battery swapping method that significantly reduces charging time. For that requires the development of an advanced battery management system. And a control unit is required to facilitate communication between BMS and enable charging and discharging processes. Also need the integration of communication between the control unit and the docking station. Through the literature review, we ensure that this approach has the potential to succeed. Finally, according to the analysis we have done throughout this report, we can conclude that our proposed solution is technically, financially, and socially feasible.

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