Electric Compressor System with Real Time Battery Monitoring

Muhammed Ahnas K I[1], Rishika Das[1], Arun Peter M J[1], Athul A[1], Reenu George[2], Jeena Joy[2]

[1]*Student, Department of Electrical and Electronics Engineering, Mar Athanasius College of Engineering Kothamangalam, APJ Abdul Kalam Technological University, Kerala, India*

[2]*Associate Professor, Department of Electrical and Electronics Engineering, Mar Athanasius College of Engineering Kothamangalam, APJ Abdul Kalam Technological University, Kerala, India*

Corresponding Author: dasrishika2021@gmail.com

Abstract*: Garbage trucks are an essential part of waste management, but conventional diesel-powered compression systems are a source of noise pollution, high fuel usage, and environmental degradation. Switching to electric compression systems provides a more efficient and environmentally friendly option by lowering fuel dependence, reducing noise, and enhance energy efficiency. One of the primary building blocks in this system is the Battery Monitoring System (BMS) that constantly monitors battery data like temperature, voltage, and current. Powered by an STM32 microcontroller, the BMS facilitates real-time observation and power distribution management for maximum efficiency, avoiding overcharging, overheating, and deep discharge. Apart from promoting battery life and system longevity, this cuts long-term expenses and ensures greater vehicle reliability. Installing an electric compressor system with a BMS greatly improves garbage truck efficiency while enabling cleaner and more sustainable waste management. As cities become more environmentally conscious, electric waste management systems are crucial in curbing pollution and encouraging energy-efficient urban infrastructure.

***Keywords*: Garbage Trucks, Electric Compressor Battery Monitoring System, STM 32.**

1. Introduction

Climate change and environmental sustainability are compelling urgent efforts at reducing carbon emissions and enhancing energy efficiency, especially in transport. Garbage collection as a municipal service has long been dependent on diesel-fueled trucks, which account for high fuel usage, noise pollution, and additional emissions during compaction processes. The trend towards electrification presents a cleaner, more energy-efficient alternative to solve these environmental issues while ensuring operational efficiency.

By minimizing the use of fossil fuels, electric trash compactor trucks reduce the adverse effects of conventional waste management processes on the environment. Performance enhancement is achieved aside from the BMS's safety feature, where it is designed to monitor vital parameters constantly, including voltage, temperature, and current. This allows the system to detect problems before they occur, thus preventing overcharging, over discharging, and thermal instability, which harm the efficiency and safety of the battery.

Installing an electric compressor on garbage trucks is a major breakthrough in waste collection technology. Not only does this work save fuel, resulting in cost reductions for municipalities, but it also lessens noise pollution, making city life quieter for citizens. Additionally, by reducing the environmental footprint compared to conventional diesel-powered trash cans, this work is in consonance with the principles of green urban waste disposal. It helps contribute to initiatives across the world that seek to lower carbon footprints in the public and private transport sectors. Generally, electric compressors as used in garbage trucks are a critical move towards constructing cleaner, more efficient cities.

2. Literature Review

This review explores the role of intelligent battery monitoring and the potential benefits of adopting these sustainable waste management solutions.

[1] Investigated energy estimation for lithium-ion batteries using a hybrid approach involving Gaussian mixture and Markov models for future load prediction. The method is aimed at accurately predicting the energy status of lithium-ion batteries by accounting for various uncertainties in load forecasting, thereby enhancing reliability in energy storage applications. The model's capacity to handle nonlinearities and varying load profiles offers robust estimation even in complex battery usage scenarios. The findings suggest potential improvements in energy management, particularly for systems requiring precise state of energy predictions.

[2] Focused on the development of BMS and State of Charge (SoC) estimation techniques tailored for electric vehicles. The study addresses the complexity of managing battery health, longevity, and performance through advanced SoC estimation and offers insights into developing effective BMS frameworks to support electric vehicle efficiency. By evaluating different estimation methods, the authors highlight challenges related to maintaining accurate SoC in diverse driving conditions. The work lays a foundation for improving battery lifespan and overall electric vehicle performance through enhanced BMS designs.

[3] Introduced an enhanced Coulomb counting method

designed to improve SoC and State of Health (SoH) estimation by integrating Coulombic efficiency metrics. This approach refines traditional Coulomb counting by adjusting for factors that can distort SoC accuracy, presenting a more accurate and reliable method for real-time SoC monitoring. The integration of Coulombic efficiency accounts for charge losses, thus reducing error in the SoC estimation. The research offers valuable insights into achieving higher accuracy in battery monitoring systems for both consumer and industrial applications.

[4] Provide an overview of online, implementable SoC estimation techniques for lithium-ion batteries. The work categorizes methods based on computational feasibility and application potential in real-time battery management, emphasizing adaptability for dynamic and diverse usage environments. The approach facilitates the integration of SoC estimation methods into real-time systems, making them suitable for applications with high demands on energy accuracy. The authors advocate for systems that balance accuracy with computational efficiency to meet practical constraints in battery management.

[5] Reviewed challenges and recommendations for lithium-ion battery SoC estimation and management in electric vehicles. The analysis addresses the limitations faced in accurate SoC prediction under varied conditions and offers strategic recommendations for advancing BMS frameworks to meet the evolving demands of electric vehicle technology. By identifying gaps in current SoC estimation methods, this work serves as a guide for future research on improving BMS efficiency. The comprehensive review emphasizes the importance of adapting BMS designs to accommodate the specific requirements of electric vehicles.

[6] Critically assessed SoC estimation methodologies applicable to electric vehicles. The study discusses the pros and cons of various techniques, including model-based and data-driven approaches, and offers insights into how these methods can be optimized for better SoC estimation accuracy in electric vehicle applications. The comparison aids in identifying suitable estimation methods based on specific application needs, particularly in real-world driving conditions. The authors emphasize the need for hybrid techniques that combine accuracy and efficiency to achieve optimal battery performance.

3. BMS for Garbage Trucks

The efficient operation of electric garbage compactor trucks relies on a well-integrated BMS and a motor control system. The BMS ensures safe, reliable, and optimized battery performance by continuously monitoring key parameters such as voltage, current, and temperature. Simultaneously, the Motor Control System regulates the compaction mechanism, ensuring effective waste compression and power efficiency. The following sections explore the selection of a suitable control unit, the implementation of the BMS, and the role of the motor control unit in enhancing the overall efficiency, reliability, and sustainability of electric garbage trucks.

A. Comparing Controlling Unit

The Microcontroller unit (MCU), microprocessor unit (MPU), and central processing unit (CPU) are three control units that are used in battery management systems with varying levels of power consumption and performance. MCU is the lowest power consuming and cheapest, and it can be used for low-level functions, while MPU can be used for higher level computation for complicated applications. CPU with the maximum processing capacity can be used for complicated systems where real-time data analysis is needed but is power and cost intensive.

1) Microcontroller Unit (MCU)

The MCU is a compact integrated circuit designed to perform dedicated control tasks efficiently. It combines a processor, memory, and input/output peripherals on a single chip, making it ideal for real-time monitoring and essential battery management functions. Due to its low power consumption, cost-effectiveness, and ease of implementation, the MCU is widely used in electric garbage compactor trucks, ensuring efficient and reliable battery performance without excessive energy usage.

2) Microprocessor Unit (MPU)

The MPU offers greater computational power and flexibility than the MCU and is suited for applications that require advanced processing. It is most suitable for complex SoC estimation algorithms and real-time data processing, well suited for high-speed computation and advanced battery management. However, its higher cost and power consumption may not be suitable in cost-sensitive or power constrained environments such as electric garbage trucks.

3) Centralprocessing Unit (CPU)

The CPU offers the most processing capability of the three and is best suited for very advanced battery management systems that need real-time processing and advanced data analysis. It can support advanced hybrid SoC estimation methods and handle a lot of data.[2] Even though it is the most powerful, the CPU comes with greater costs and power consumption and is therefore less suited for low-cost applications like electric garbage compactor trucks, where cost efficiency is the top priority.

B. Battery Monitoring System

BMS plays an important part in continuously monitoring and regulating the most important battery parameters, such as voltage, current, and temperature. Its primary role is to prevent hazardous conditions such as overcharging, deep discharging, overheating, and short circuits, all of which have an effect on battery performance and life. By tracking these parameters with high precision, the BMS maintains the battery within safety margins, optimizing its performance and reducing risks. BMS deployments have real-time diagnostics, predictive maintenance, and fault detection capabilities, enabling early fault detection for reducing downtime and maintenance costs.

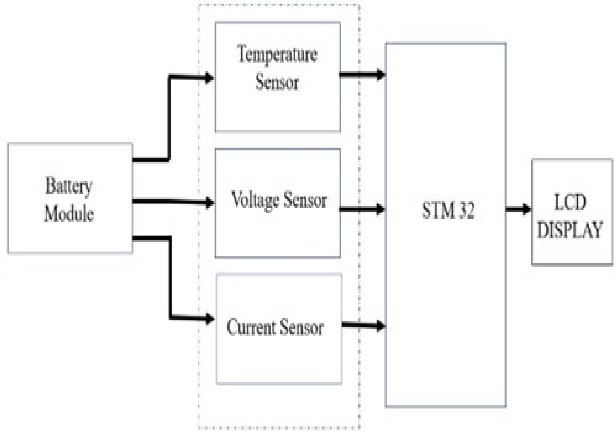

Fig. 1. Block diagram of BMS

Figure 1 illustrates a BMS, which tracks a battery pack by tracking critical electrical parameters through three sensors: a temperature sensor, current sensor, and voltage sensor. The temperature sensor tracks excess heat, keeping the battery within safe thermal ranges. The current sensor guards against over current states by tracking the flow of electricity, while the voltage sensor ensures battery voltage within safe ranges. This sensor information is transmitted to a display unit for real-time monitoring. This arrangement prevents battery failure, ensures safety, and enhances efficiency in applications such as electric vehicles, renewable energy storage, and industrial power systems by giving critical information on operations.

C. *Motor Controlling Unit*

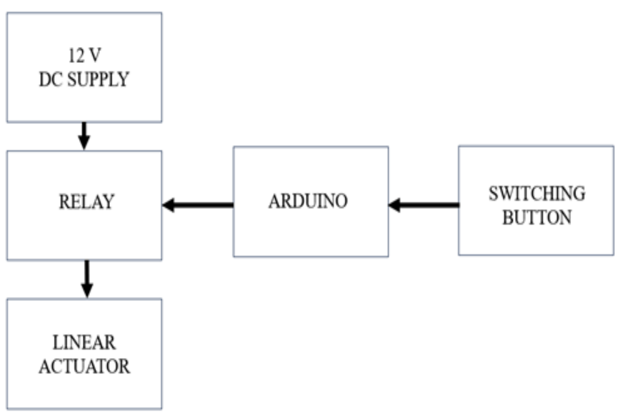

Fig. 2. Block diagram of MCU

Figure 2 illustrates a motor controlling unit (MCU) that controls the operation of the linear actuator, displacing the piston for waste compaction. The system consists of a 12 V DC power source, an Arduino controller, a relay, and a switch button. Upon activation of the button, the button triggers the Arduino, which supplies power to the relay. The relay is an electric switch that facilitates the flow of power from the 12 V DC source to the linear actuator. The linear actuator converts electrical power to linear motion, facilitating controlled piston movement for waste compression.

4. Simulation and Results

A. *Cell Characteristics*

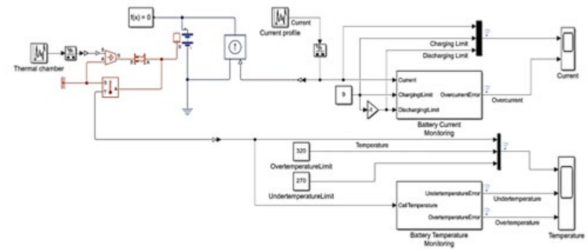

Fig. 3. Simulation circuit of cell characteristics

Figure 3 illustrates the MATLAB simulink model for the monitoring of temperature and variations of current in the cell. Also, this will assist in understanding whether the cell temperature and current exceed the threshold values provided. It includes,

1) Temperature Source

The thermal chamber unit would probably mimic an external environment to expose the battery to various temperature conditions. This may be employed to check how the management system and the battery react to changing temperatures. The system is a representation of thermal control and monitoring components that change temperature according to an input signal.

2) Current Profile and Battery Current Monitoring

The current profile unit is used to simulate the current flowing through the battery, which could represent charging and discharging cycles. The battery current monitoring unit checks the current against predefined charging limit and discharging limit values. This unit gives over current error, indicating if the current exceeds safe operational limits, potentially protecting the battery from excessive charge or discharge currents.

3) Temperature Monitoring and Limits

The battery temperature monitor tracks the temperature of the battery. The temperature is measured against two boundaries, overtemperature limit and under temperature limit. These boundaries prevent the battery from running outside a safe temperature range. The monitoring device provides overtemperature error and under temperature error signals, which trigger if the temperature exceeds the specified boundaries, alerting the system to potential thermal problems.

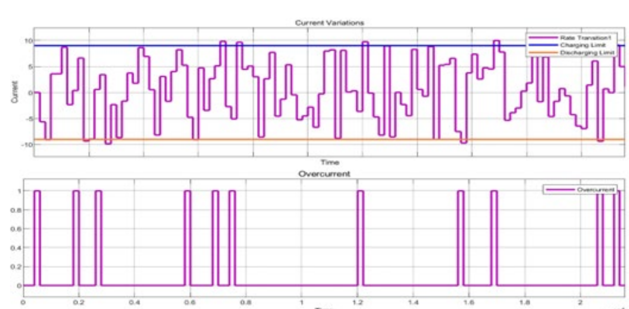

Fig. 4. Variations in current

The first graph in Figure 4 indicates the variations of battery current with time with charging and discharging limits as horizontal lines. The charging limit is the maximum current allowable for charging, which is set at +9 units. The discharging limit is the maximum current allowable for discharging, which is set at -9 units. The current varies between positive (charging) and negative (discharging) values, depending on the battery's charging and discharging cycles. If the current goes beyond these limits (either above the charging limit or below the discharging limit), it becomes a safety risk to the battery.

The second curve in Figure 4 represents over current events. At the time of occurrence of the pulse, it indicates an overcurrent state, i.e., the current has exceeded the safe limits of operation.[5] The over current state is triggered whenever the current exceeds the charging or discharging limit, as marked by spikes in the plot. The sporadic overcurrent indications imply that the battery witnessed both charging and discharge currents over safe levels at various times throughout the simulation.

Figure 5 illustrates the battery cell temperature over time with clearly defined temperature limits. The highest temperature limit is 320 units, which is the maximum temperature for safe operation. The minimum temperature limit is 270 units, where the minimum temperature for safe operation. The temperature varies within these limits to mimic environmental or operational variations. Every occurrence in which the temperature rises above or falls below these limits is a potential threat to the safety and efficiency of the battery. Fault signals are generated when the temperature of the battery exceeds the higher limit or falls under the lower limit. This monitoring system is important for ensuring proper temperature levels for safety since extreme temperatures cause performance degradation, damage, or safety hazards. Through continuous temperature monitoring, the system quickly alerts users to deviations, allowing fast action to avert overheating or over-cooling and ensuring the battery's reliability.

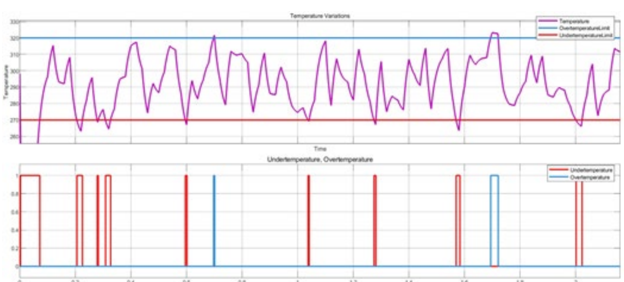

Fig. 5. Variation in temperature

B. Cell Balancing

Cell balancing is the act of balancing charge levels in the individual cells of a battery pack. Figure 6 illustrates the cell balancing simulation circuit. Cells in multi-cell batteries might have minor differences in capacity, internal resistance, and charge levels, which eventually result in imbalances. This imbalance can decrease the overall performance and life of the battery because the weaker cells will restrict the usable capacity. Cell balancing is used to make all cells have the same SoC [7] , keeping the pack both efficient and safe. Two methods of cell balancing are employed: passive balancing, which converts surplus energy into heat, and active balancing, which transfers energy from one cell to another.

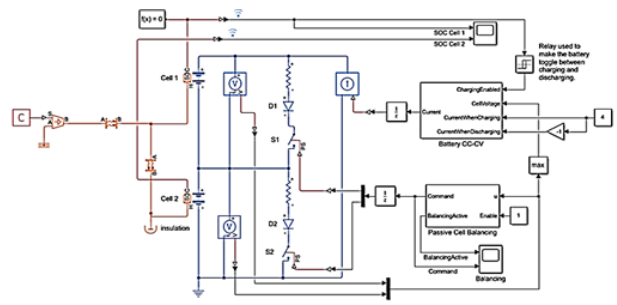

Fig. 6. Simulation circuit of cell balanncing

1) Battery

Figure 6 contains two cells in series, represented by" Cell 1" and" Cell 2". The SoC is monitored separately, allowing the BMS to manage each cell independently. "Insulation" is indicated to isolate and protect the cells, ensuring safely integrated within the circuit

2) Voltage Measurement

Voltage sensors (V) are connected across each cell to monitor individual cell voltages. These voltage measurements are essential for the passive cell balancing and charging system.

3) Diodes (D1 and D2) and Switches (S1 and S2)

Diodes (D1 and D2) and switches (S1 and S2) are used to control the flow of current during the balancing and charging processes. The diodes prevent reverse current flow, ensuring that the current only flows in the intended direction. The switches enable or disable specific circuit paths, allowing the system to switch between charging and discharging modes or activate balancing when necessary.

4) Current Sensor (I)

This sensor measures the current in the circuit, which is important for determining the charging and discharging rate of the cells. The current data is sent to the battery control unit for analysis.

5) Battery Control Unit (Battery CC-CV)

The BCU controls charging and discharging using a constant current-constant voltage (CC-CV) method. It takes input signals such as charging enabled, cell voltage, current when charging, and current when discharging. It also receives the SoC of each cell to adjust charging or discharging currents accordingly.

6) Cell Balancing Block (Passive Cell Balancing)

The Cell Balancing block handles passive cell balancing by redistributing charge from a higher SoC cell to a lower SoC cell to ensure both cells have similar charge levels. Enable allows for the balancing function to be turned on or off. Command dictates the specific balancing actions based on the SoC data from each cell.

7) Relay and Toggle Mechanism

A relay is used to toggle the battery system between charging and discharging modes. This ensures that the cells switch between charging and discharging based on their SoC and the overall system requirements.

8) Max and Inverter

A max function and an inverter are used for signal processing and control logic. The max block helps select the highest current or voltage value as needed, while the inverter modifies signal polarity for specific control actions.

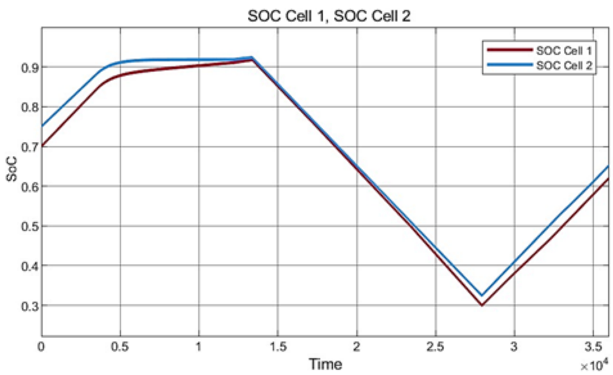

Fig. 7. SoC of cell 1 and SoC of cell 2

Figure 7 displays SoC in two cells, Cell 1 and Cell 2, during a given time frame for the charging and discharging actions. As energy is supplied, the SoC goes up when full charging has occurred, whereas during discharge, the SoC dips. Both Cell 1 and Cell 2 start at reduced SoC, with Cell 1 being slightly lesser than Cell 2. As time goes on, the SoC of both cells rises, which means that the cells are being charged. Cell 2's SoC increases a bit more quickly than Cell 1's, but the two cells end up with almost the same SoC at the end of this phase, reflecting some degree of balancing.

At about 1.5 x 104 seconds, the SoC of both cells levels off and begins to fall, indicating the start of the discharging period. Throughout this period, both cells discharge at roughly the same rate, with Cell 1 and Cell 2 following each other closely. The SoC of both cells continues to decrease, with both cells having a low SoC at around 3 x 104 seconds. This consistent discharge behavior is an indicator of the efficacy of the BMS in keeping uniform power consumption from both cells. Both cells begin recharging once they have reached the SoC bottom, and both their SoC increases again [6]. The cells recharge at approximately equal rates, indicating that the balancing algorithm is successfully keeping the cells' SoC levels uniform.

5. Design of Compactor System

A. Design of Battery System

1) Battery Details

- *Battery Type*: Li-ion
- *Nominal Voltage*: 3.7 V per cell
- *Capacity*: 1200 mAh
- *Required Number of Cells*: 3

The battery has a capacity of 1200 mAh, and the required number of cells is 3.

C-rate is calculated as,

$$C - Rate = \frac{Motor\ Current}{Battery\ Capacity} 0.5\ \mathrm{C} \quad (1)$$

B. Compactor System Design

1) Linear Actuator

- Permanent Magnet DC Motor
- Motor Diameter = 36 mm
- *Specifications*: 12 V, 1000 N, 2 A
- Linear Speed (V linear) = 7 mm/s
- *Force (F)*: 1000 N

2) Compactor Plate

- *Dimensions*: 0.5 m ×0.3 m = 0.15 m2
- *Material*: light steel with a thickness of 5 to 10 mm

3) Waste Bin

- *Dimensions*: 0.5 m × 0.5 m × 0.3 m
- *Plate Travel Distance*: 0.3 to 0.5 m

Available Pressure on the Compactor Plate

The pressure (P) can be calculated using:

$$P = \frac{F}{A} (2)$$

Where:

- Surface area of the plate is 0.15m2
- Applied force is 1000N

Substituting we get,

$$P = \frac{1000}{0.15} = 6000\ Pa\ (3)$$

Waste Density: 150–300 kg/m^3 compacted to 600–700 kg/m^3

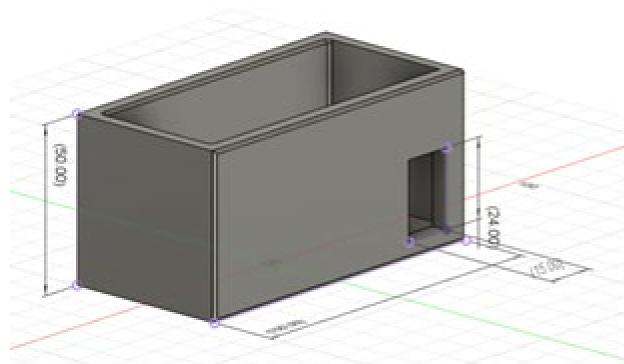

Fig. 8. Cabinet design

Figure 8 shows the cabinet where the waste is going to be collected and compressed.

6. Hardware

The hardware design of the system is an important feature that guarantees the effective functioning of the BMS and MCU in an electric garbage compactor truck. This section describes the main hardware components employed in the system, such as the STM32 microcontroller, linear actuator, cell monitoring circuit, and motor control circuit. The STM32 microcontroller, with its low power and scalable features, acts as the central processing unit, controlling data capture and system control. The linear actuator translates rotational motion into linear motion to facilitate the necessary movement for the operation of the compactor. The cell monitoring circuit protects the battery by monitoring voltage, current, and temperature all the time and providing real-time data on an LCD display.

Furthermore, the motor control circuit, which is constructed around an Arduino microcontroller and a 4-way relay system, offers accurate control of the forward and backward motion of the actuator, adding to the overall functionality of the system. These hardware elements combine to provide safe, efficient, and reliable operation of the electric garbage compactor truck.

A. Cell Monitoring System

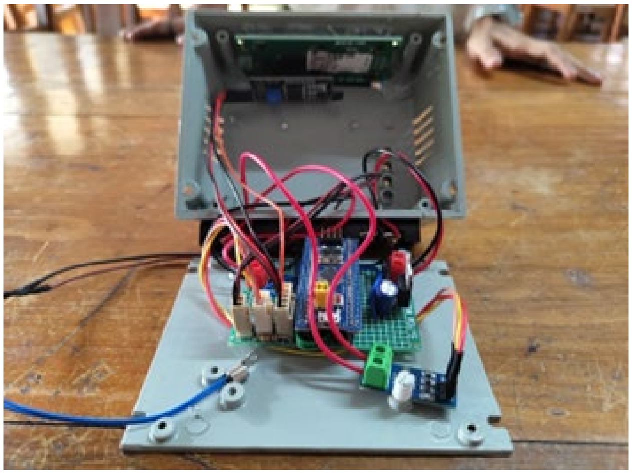

Fig. 9. Battery monitoring system

The cell monitoring system uses an STM32 microcontroller to monitor temperature, current, and voltage in real-time. A thermistor is used as the temperature sensor, which is connected to a temperature controller that converts changes in resistance into a voltage signal, which the STM32's ADC converts to find the temperature.

Figure 9 shows the cell monitoring system employed for electric compactor trucks. Current measurement employs an AC712 current sensor. Voltage measurement is carried out by a voltage divider circuit consisting of 100 kΩ (R1) and 10 kΩ (R2) resistors, where R1 is connected to battery terminal and R2 to ground (GND). This voltage divider decreases the battery voltage to a value appropriate for the STM32's ADC, which computes the actual voltage based on the voltage divider formula. The data after processing is shown on an LCD display, allowing real-time observation of the cell status. Temperature, current, or voltage that go beyond predetermined limits can be made to trigger alarms, switch on cooling circuits, or activate protection circuits. This will provide the best battery performance, safety, and efficiency. The readings from the voltage, current, and temperature sensors will be shown on the LCD display.

B. Motor Controlling Unit

An MCU based on a 4-way relay is designed with an Arduino microcontroller at the center is designed. This design enables accurate control of the movements of the actuator. Two switches are incorporated to drive the circuit: one switch is used for forward movement, and the other switch is used to trigger backward movement.

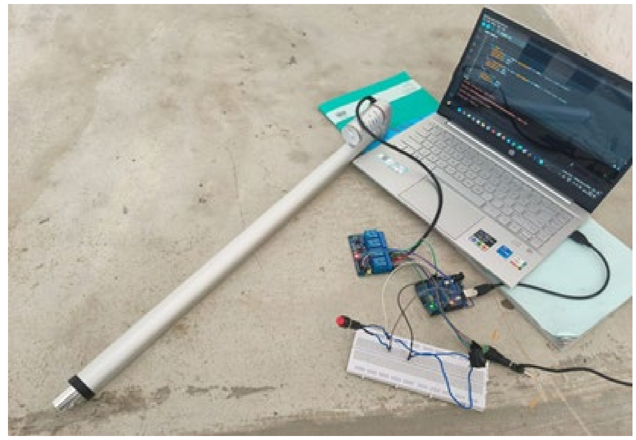

Fig. 10. Motor controlling unit

Figure 10 represent the MCU and its components respectively. This design not only provides straightforward control but also enhances the functionality of the system, making it suitable for various applications where directional movement of an actuator is necessary.

The reliability of the relay combined with the flexibility of the Arduino programming, further ensures efficient operation of the circuit. Figure 11 represents the forward motion of the piston where the Arduino is programmed with a specific logic that ensures smooth forward operation. When the forward motion switch is pressed, the actuator translates in one direction, permitting functions like extending or advancing. In contrast, operating the reverse motion switch turns the actuator's direction around, permitting retraction or reverse operations.

Fig. 11. Motor controlling unit

C. Final Hardware Setup

Figure 12 depicts the ultimate hardware integration of the electric compactor system with real time battery monitoring, which has been obtained by integrating the battery monitoring circuit with the compactor and motor control unit. The STM32 microcontroller interprets real time data from the NTC thermistor, AC712 current sensor, and voltage divider circuit to obtain precise monitoring of temperature, current, and voltage.

Fig. 12. Hardware setup

7. Conclusion

BMS for electric compactors in waste collection trucks is significant in improving battery performance, life, and overall environmental sustainability through accurate, real time state estimation. Based on the cost effective STM32 microcontroller, this system provides for real time accurate monitoring of voltage, current, and temperature, enabling proactive maintenance, optimized energy use, and maximum battery life. Its scalability and flexibility in its architecture render it suitable for use in a broad spectrum of applications, such as electric vehicles, industrial power systems, and renewable energy storage solutions. With growth in the global movement toward electrification and eco-friendly energy solutions on the rise, the BMS becomes an integral facilitator of energy efficiency, emissions minimization, and operational reliability. Through enhanced battery health and avoiding premature aging, this technology facilitates environmentally friendly practices, making electric powered systems sustainable, efficient, and viable for long term application in waste management and other areas.

References

[1] M. F. Niri, T. M. N. Bui, T. Q. Dinh, E. Hosseinzadeh, T. F. Yu, and J. Marco, ‘‘Remaining energy estimation for lithium-ion batteries via Gaussian mixture and Markov models for future load prediction,’’ J. Energy Storage, vol. 28, Apr. 2020, Art. no. 101271.

[2] K. W. E. Cheng, B. P. Divakar, H. Wu, K. Ding, and H. F. Ho, ‘‘Battery management system (BMS) and SOC development for electrical vehicles,’’ IEEE Trans. Veh. Technol., vol. 60, no. 1, pp. 76–88, Jan. 2011.

[3] J. Lee and J. Won, ‘‘Enhanced Coulomb counting method for SoC and SoH estimation based on Coulombic efficiency,’’ IEEE Access, vol. 11, pp. 15449–15459, 2023.

[4] J. Meng, M. Ricco, G. Luo, M. Swierczynski, D.-I. Stroe, A.-I. Stroe, and R. Teodorescu, ‘‘An overview of online implementable SOC estimation methods for lithium-ion batteries,’’ in Proc. Int. Conf. Optim. Electr. Elec tron. Equip. (OPTIM) Int. Aegean Conf. Electr. Mach. Power Electron. (ACEMP), May 2017, pp. 573–580.

[5] M.A. Hannan, M.S. H. Lipu, A. Hussain, and A. Mohamed, ‘‘A review of lithium-ion battery state of charge estimation and management system in electric vehicle applications: Challenges and recommendations,’’ Renew. Sustain. Energy Rev., vol. 78, pp. 834–854, Oct. 2017.

[6] R. Xiong, J. Cao, Q. Yu, H. He, and F. Sun, ‘‘Critical review on the battery state of charge estimation methods for electric vehicles,’’ IEEE Access, vol. 6, pp. 1832–1843, 2018.

[7] D.N.T.How,M.A.Hannan,M.S.H.Lipu,andP.J.Ker,‘‘State of charge estimation for lithium-ion batteries using model-based and data-driven methods: A review,’’ IEEE Access, vol. 7, pp. 136116–136136, 2019.

[8] M. Zhang and X. Fan, ‘‘Review on the state of charge estimation methods for electric vehicle battery,’’ World Electr. Vehicle J., vol. 11, no. 1, p. 23, Mar. 2020.

[9] B. Yang, J. Wang, P. Cao, T. Zhu, H. Shu, J. Chen, J. Zhang, and J. Zhu, ‘‘Classification, summarization and perspectives on state-of-charge estimation of lithium-ion batteries used in electric vehicles: A critical com prehensive survey,’’ J. Energy Storage, vol. 39, Jul. 2021, Art. no. 102572.

[10] M.Naguib, P. Kollmeyer, and A. Emadi, ‘‘Lithium-ion battery pack robust state of charge estimation, cell inconsistency, and balancing: Review,’’ IEEE Access, vol. 9, pp. 50570–50582, 2021.

[11] Z. Wang, G. Feng, D. Zhen, F. Gu, and A. Ball, ‘‘A review on online state of charge and state of health estimation for lithium-ion batteries in electric vehicles,’’ Energy Rep., vol. 7, pp. 5141–5161, Nov. 2021.

[12] M. O. Qays, Y. Buswig, M. L. Hossain, and A. Abu-Siada, ‘‘Recent progress and future trends on the state of charge estimation methods to improve battery-storage efficiency: A review,’’ CSEE J. Power Energy Syst., vol. 8, no. 1, pp. 105–114, Jan. 2022.

[13] Y.-M. Jeong, Y.-K. Cho, J.-H. Ahn, S.-H. Ryu, and B.-K. Lee, ‘‘Enhanced Coulomb counting method with adaptive SOC reset time for estimating OCV,’’ in Proc. IEEE Energy Convers. Congr. Expo. (ECCE), Sep. 2014, pp. 1313–1318.

[14] O. Kadem and J. Kim, ‘‘Real-time state of charge-open circuit voltage curve construction for battery state of charge estimation,’’ IEEE Trans. Veh. Technol., 2023.

[15] Y.-S. Lee, M. Liu, C.-C. Sun, and M.-W. Cheng, ‘‘State-of-charge estima tion with aging effect and correction for lithium-ion battery,’’ IET Electr. Syst. Transp., vol. 5, no. 2, pp. 70–76, 2015.

[16] Y.Ko,K.Cho,M.Kim,andW.Choi,‘‘A novel capacity estimation method for the lithium batteries using the enhanced Coulomb counting method with Kalman filtering,’’ IEEE Access, vol. 10, pp. 38793–38801, 2022.