“Study of the Economic Viability of Battery Second life”

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A Thesis submitted in partial fulfillment of the requirement for the degree of Bachelor of Science in Mechanical Engineering

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Candidate's Declaration

This is to certify that the work presented in this thesis, titled, "Study of the Economic Viability of Battery Second life", is the outcome of the investigation and research carried out by me under the supervision of Dr. Md. Rezwanul Karim, Associate Professor, Mechanical and Production Engineering Department, IUT. It is also declared that neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

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Recommendation of the Board of Examiners

The thesis titled "Study of the Economic Viability of Battery Second life" submitted by M.K. Nahyan Akanto, Student No: 180011106 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of B Sc. in Mechanical Engineering on May, 2023.

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Abstract

Lithium-ion batteries are now widely used in a variety of applications, from portable devices to electric cars and the integration of renewable energy sources, as a result of the growing demand for energy storage systems. However, given their short lifespan, questions about their economic viability and influence on the environment are raised. The idea of a "second life" for lithium-ion batteries has received a lot of interest lately as a means of overcoming these difficulties. By using batteries in new energy storage applications, this strategy seeks to extend the usable life of batteries past the scope of their original use. This study provides a thorough introduction to the second life idea for lithium-ion batteries, outlining its drivers, advantages, difficulties, and prospective applications. To find acceptable second-life applications, it investigates several methods for battery characterization, state-of-health assessment, and performance evaluation. The relevance of battery management systems and smart grid integration for ensuring effective operation and the best use of second-life batteries is also covered in the study. It also emphasizes the second-life approach's benefits for the environment and the economy, such as less waste produced and lower total expenses. The abstract also looks at new developments in the industry, including battery aging predictions, enhanced recycling methods, and sophisticated energy management approaches. Finally, it summarizes the necessity of uniform rules and regulations to support the use of second-life lithium-ion batteries in a safe and long-lasting manner. Overall, this study offers a thorough overview of the idea of a second life for lithium-ion batteries, demonstrating its potential to address issues with sustainability and affordability while assisting in the shift to a cleaner and more efficient energy future.

Keywords

Lithium-ion battery; Fast Charging; Charging protocol; Electrical Vehicles; Battery pack.

Abbreviation

AC	Alternating current
BMS	Battery Management System
CC-CV	Constant current - constant voltage
CCS	Combined Charging System
CEI	Cathode electrolyte interphase
CP-CV	Constant power - constant voltage
DC	Direct current
DCFC	DC fast charging
DEC	Diethyl carbonate
DMC	Dimethyl carbonate
DVA	Differential voltage analysis
EC	Ethylene carbonate
ECM	Equivalent circuit model
EIS	Electrochemical impedance spectroscopy
EV	Electric vehicle
FOM	Full order model
ICA	Incremental capacity analysis
LAM	Loss of active material
LCO	Lithium cobalt oxide
LFP	Lithium iron phosphate
LLI	Loss of lithium inventory
LMO	Lithium manganese oxide
LTO	Lithium titanium oxide
MCC	Multistage constant current
N/P	Negative-to-positive electrode
NCA	Lithium nickel cobalt aluminum oxide
NFRA	Nonlinear frequency response analysis
NMC	Lithium nickel manganese cobalt oxide
NMR	Nuclear magnetic resonance
P2D	Pseudo-two-dimensional
PCM	Phase change material
PDE	Partial differential equation
ROM	Reduced order model
SEI	Solid electrolyte interphase
SEM	Scanning electron microscopy
SOC	State-of-Charge

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Chapter 1: Introduction

1.1 Background of the study

Since 2010, the market for electric vehicles (EVs) has grown significantly, which has increased demand for lithium-ion batteries (LIBs) and electrochemical energy storage. The demand for LIBs is anticipated to double by 2025 and quadruple by 2030. The increased requirement for vital materials like lithium and cobalt, which are used in these batteries, is a result of the boom in demand for LIBs. However, given to the quick expansion, there are worries about future supply difficulties. While studies show that the supply of lithium is not likely to be seriously threatened in the near future, the availability of cobalt is a big concern. The majority of cobalt is produced as a byproduct of the mining of nickel and copper, with significant concentrations in Congo and refinery facilities in China. The supply of cobalt could be hampered by problems in certain areas brought on by governmental policy or sociopolitical instability. Additionally, because of the restricted processing capacity, the growing usage of nickel-rich cathodes in LIBs may make it difficult to source Class 1 nickel, which is necessary for cathode manufacture. Concerns regarding the depletion of resources and the effects on the environment are also increased by the anticipated proliferation of retired LIBs in the upcoming years. These elements work together to fuel growing concerns about the supply of essential components and the environmental effects of the predicted increase of defunct LIBs [1].

The manufacture of lithium-ion batteries (LIBs) must be significantly increased to meet the demand for electric vehicles and renewable energy storage around the world. However, questions about their extraction's ethical/environmental implications, price volatility, and accessibility of essential metals are raised. Additionally, as the number of LIBs rises, the number of end-of-life batteries will rise as well, creating a growing problem with battery waste. Unfortunately, due to weak standards, regulatory enforcement, and insufficient recycling programs, present techniques frequently result in landfill or incineration. Improper disposal releases pollutants such as heavy metals and hydrofluoric acid, endangering both human health and the environment.

To meet these issues, proper management of battery waste requires the creation of sustainable supply chains, enhanced recycling procedures, and stringent laws [2].

The problem of early recycling or disposal is one of the main reasons for investigating the second life of lithium-ion batteries. The usable life of these batteries ranges from 8 to 15 years, depending on the application and operating circumstances. After this time, they might still have a sizable amount of capacity and usefulness, nonetheless. Their economic worth can be increased by reusing them for different purposes, which will cut down on the need for fresh battery production and the impact it has on the environment as a whole.

Utilizing lithium-ion batteries after their initial lifespan also offers chances for cost savings. Even while these batteries might not be able to handle the severe demands of grid-scale energy storage or electric car applications, they can nevertheless deliver adequate performance for less demanding jobs like stationary energy storage, backup power, or off-grid applications. Second-hand batteries can increase access to energy storage technology by providing a cheaper alternative to new batteries, especially in developing countries or for low-income groups [1].

However, using lithium-ion batteries for a second life is not without difficulties. To guarantee the feasibility and dependability of second-life applications, it is crucial to properly control battery degradation over time, capacity fading, and safety problems. Intelligent battery management approaches and battery health monitoring systems are being created to correctly determine the state and capacity of second-life batteries. Research into battery chemistry and design is also being done to improve the performance and security of batteries in secondary applications.

1.1.1 Fundamentals of Battery Second life

1. Battery Degradation: Understanding and controlling battery degradation is one of the key components of a battery's second life. Lithium-ion batteries endure capacity fading, elevated internal resistance, and other degradative processes that restrict their performance through time and use. To decide whether the battery is suitable for a second life use, this degradation must be carefully evaluated and regulated.

2. Battery Health Assessment: Determining if a battery is suitable for a second life requires evaluating its health and condition. To assess the battery's condition and determine how much longer it will last, a variety of diagnostic procedures can be utilized, such as examining its capacity, impedance, voltage behavior, and cycle life. To find batteries that can be used in second-life applications, a battery health assessment is helpful.

3. Repurposing and Application Flexibility: The capacity to reuse batteries for various purposes is another key idea in battery second life. Batteries can still be of great use in secondary applications like stationary energy storage, backup power, or off-grid systems even if they no longer match the strict specifications of their original application, such as electric automobiles. One crucial component of a battery's second life is the adaptability to change and repurpose batteries for various tasks.

4. Battery Management Systems (BMS): Maximizing the performance and safety of batteries in second-life applications depends on effective battery management systems. Individual battery cells or modules are balanced, charged, and discharged under the supervision of a BMS. In addition to ensuring peak performance, it also guards against overcharging and over-discharging and shields the batteries from potential dangers like a thermal runaway.

5. Safety Considerations: Safety must always come first when working with second-hand batteries. There may be a higher danger of safety events like a thermal runaway or short circuits when batteries deteriorate and age. To guarantee the secure operation of second-life batteries and reduce any potential dangers, appropriate safety processes, testing, and monitoring systems are necessary.

6. Circular Economy and Sustainability: By increasing battery life and lowering waste, the battery's second life is in line with the principles of the circular economy. Batteries can be reused, saving important resources and reducing the environmental impact of battery production, as opposed to recycling or premature disposal. To create a more sustainable energy storage environment, it is essential to emphasize sustainability and circularity in battery reuse.

7. Technological Advancements: The viability and success of battery second life are influenced by ongoing developments in battery technology, including improved materials, chemistry, and cell designs. The goal of research and development is to increase battery performance, cycle life, and durability to enable extended usage in second-life applications.

8. Regulatory Frameworks and Standards: It is essential to establish precise regulatory frameworks and standards for battery second life to guarantee its security, dependability, and quality. These frameworks include instructions for the evaluation, certification, and safe management of used batteries, making it easier for them to be incorporated into different applications and leveling the playing field for market participants.

9. Economic Viability: The economic viability of reusing batteries must be taken into account when discussing battery second life. To make sure that second-life solutions provide cost-effective alternatives to new battery installations, factors including the price of purchasing second-hand batteries, refurbishment or reconfiguration costs, and the value proposition of the resulting energy storage system must be assessed.

Understanding and resolving these foundations will help battery second life be implemented successfully, providing a sustainable and financially sound method of extending the life of lithium-ion batteries while also encouraging a more efficient and circular energy storage environment.

1.1.2 Battery Management System

Any energy storage device or battery pack must have a battery management system (BMS). It is in charge of keeping an eye on, managing, and safeguarding the batteries to ensure their best performance, longevity, and security. When many cells or modules are connected in series or parallel, the BMS is crucial to optimize the efficiency and dependability of the batteries.

Monitoring and balancing the state of charge (SOC) and state of health (SOH) of individual battery cells or modules is the main responsibility of a BMS. To precisely assess the health and condition of the batteries, it gathers real-time data on voltage, current, temperature, and other factors. The BMS can make wise judgments about charging and discharging procedures by analyzing this data, ensuring that the batteries run within their safe operating parameters.

Additionally, the BMS shields the batteries from hazards and malfunctions. It includes safety features like temperature management, overcharge protection, over-discharge protection, and short-circuit protection. A circuit diagram of BMS (Battery management system) is shown in [Figure-1]. The BMS can take necessary steps to reduce the risks in the event of abnormal operating circumstances or failures, such as disconnecting the malfunctioning cell or turning on thermal management devices to prevent thermal runaway.

In general, a good BMS is necessary for maximizing the effectiveness, security, and lifetime of battery systems. It allows for the effective use of the stored energy in batteries, guards against damage or early deterioration, and assures dependable performance in a variety of applications, such as renewable energy storage systems and electric vehicles.

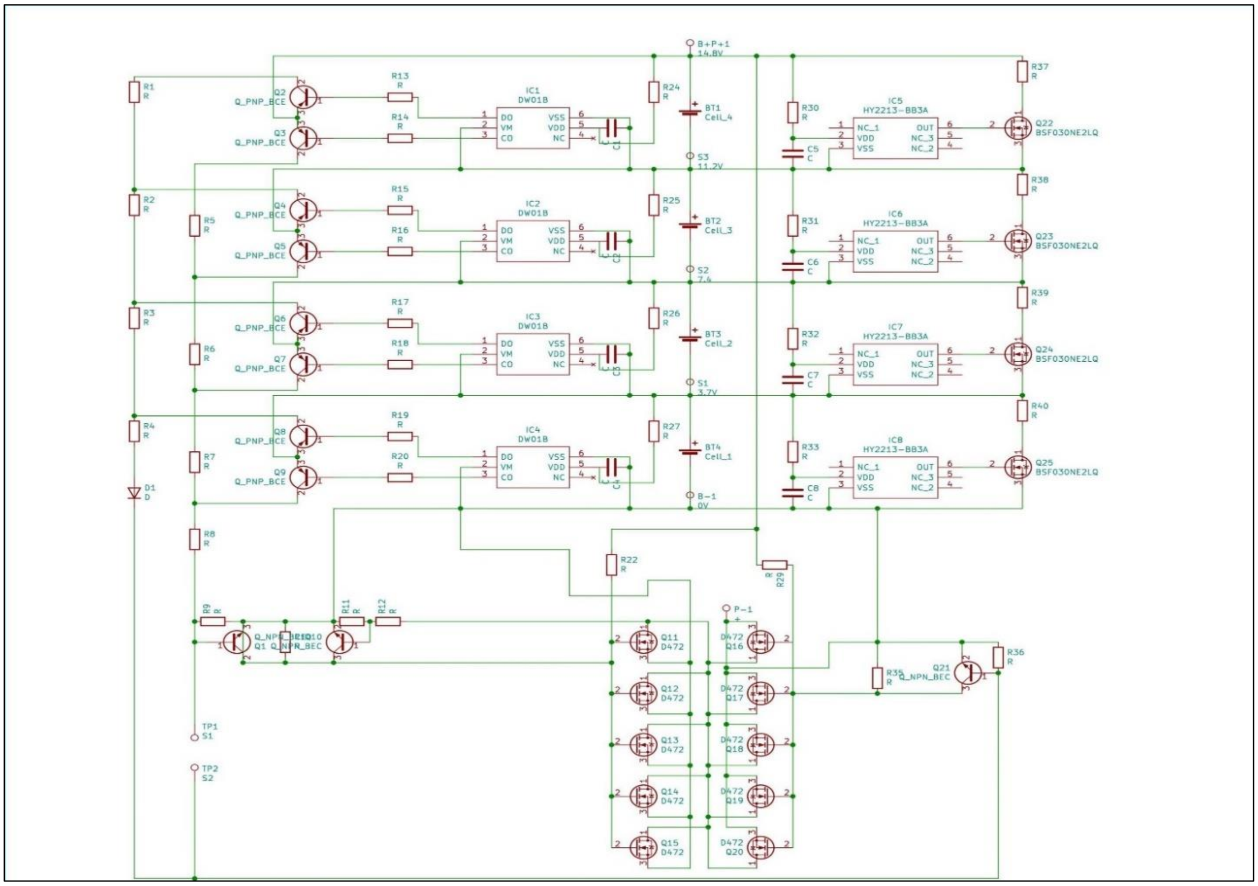

Figure 1 Circuit Diagram of Battery Management System (BMS) [3]

1.2 Present State of the Problem

The second life of lithium-ion batteries has been shaped in recent years by several innovations. Including used batteries in renewable energy systems, such as by connecting them to solar or wind installations, can increase storage capacity and improve the efficiency with which renewable energy sources are used. The creation of standardized methods for battery evaluation and repurposing aids in expediting the process and assuring quality and consistency. A wider adoption of this idea is made possible by the investigation of new business models, such as battery leasing or rental programs, and the development of regulatory frameworks to facilitate second-life utilization.

An intriguing opportunity to address environmental issues, encourage resource sustainability, and uncover commercial value is provided by the second life of lithium-ion batteries. We can lessen waste, lessen the need for new battery production, and develop a more sustainable and circular economy by prolonging the lifespan of existing batteries and reusing them for further uses. However, for the successful application of second-life use, it is essential to address the issues of battery deterioration, capacity fade, and safety. The second life of lithium-ion batteries has the potential to become a significant component of the energy storage landscape and contribute to a more efficient and sustainable future with continuous study, technological development, and supportive regulations.

1.2 Objectives

The long-term objective of this study is to attain an energy source by recycling existing batteries which is both economically and environmentally viable. So, the objectives set are below:

- To design a battery pack that is cost effective and environment friendly
- To design a battery pack that is efficient (takes less time to charge) and delivers overall better performance than conventional battery

1.3 Thesis Organization

This study begins with an introduction (Chapter 1) that provides background information on battery second-life, fundamentals and present state of the problem. Followed by a review of previous battery recycling methods in Chapter 2, the procedure for collecting batteries is briefly discussed along with a full literature analysis of previous experiments and other studies. Chapter 3 provides a full discussion of the design of the battery pack and the work procedure. An experimental analysis of the battery pack created for this study is presented in this chapter. The experimental outcomes and analyses are detailed in Chapter 4. Finally, Chapter 5 provides a review of the findings and recommendations for additional research.

Chapter 2: Literature Review

Lithium-ion batteries (LIBs) are increasingly in demand for use in electric vehicles and auxiliary energy storage systems that enable the use of renewable energy sources. This increase in demand necessitates a corresponding increase in manufacturing, which ultimately results in a significant number of squandered LIBs. Electric vehicles (EVs) powered by lithium-ion batteries (LIBs) are developing as a promising alternative, and the decarbonization of the transportation industry is essential for lowering global greenhouse gas emissions. Due to industry and legislative backing, consumer demand for EVs, and other factors, the LIB market is anticipated to increase exponentially over the next ten years. Pyrometallurgical, hydrometallurgical, and direct recycling procedures can be used to classify the existing recycling techniques [4].

Lithium-ion battery (LIB) technology has grown significantly since it was first commercialized in 1991, overtaking previous battery technologies as the primary option for powering portable electronic gadgets. Since LIBs have so many benefits, including their compact size, lightweight, high voltage, high energy density, extended lifespan, wide temperature range, and lack of memory effect, they are perfect for a variety of uses, including energy storage systems, electric vehicles (EVs), and portable devices. To ensure the long-term expansion of the LIB business, proper recycling and supply diversification are required [5].

To recover precious materials, LIB recycling uses a variety of physical and chemical procedures, including pyrometallurgical and hydrometallurgical treatments. The decision to recycle LIBs is based on whether the environmental advantages of recovered materials surpass the environmental costs of the recycling processes. To increase recycling efficiency, different procedures can be combined, such as leaching and precipitation or heat treatment, leaching, and precipitation. Overall, pyrometallurgical techniques are frequently utilized in LIB recycling because of their simplicity, short process chain, and scalability [6].

Electric cars (EVs) have greater environmental performance and lower net carbon emissions have spurred EV adoption. However, Plug-in Hybrid Electric Vehicles (PHEVs) are not included in this study because it only examines plug-in Battery Electric Vehicles (BEVs) in the UK. It is crucial to take into account the difficulties and opportunities associated with recycling and reusing LIBs from decommissioned BEVs to promote the circular economy and maintain environmental sustainability [7].

To build battery systems for a low-carbon future, there will need to be a large diversification in cell chemistry, form factors, and scale. This will present issues for thermal management, aging, safety, ethical material sourcing, recycling, and disposal. To increase the lifespan of LIBs, they may find a second usage in systems like stationary Battery Energy Storage Systems (BESS) [8].

Due to its higher overcharge tolerance and safer performance, the LiFePO4 battery is regarded as being safer than the LiCoO2 battery. Pure electric buses frequently employ it, especially in situations where a high level of passenger safety is required. Innovating and producing new energy vehicles requires careful consideration of safety, which affects both national regulations and public perception. The NFPA issued the Lithium-Ion Batteries Hazard and Use Assessment to encourage research on LIB fires, emphasizing the significance of addressing fire concerns related to LIBs [9]. The possibility of repurposing old electric vehicle (EV) batteries in stationary applications is covered in this section. The economic, technological, and environmental benefits of battery recycling are emphasized, and the need for more study before general implementation is highlighted. It is anticipated that the global market for second-hand batteries will expand, presenting the potential for numerous businesses. The purpose of the review is to assess the environmental advantages, technical performance, and economic viability of reusing EV batteries in various applications [10]. Due to the widespread use of electric cars (EVs), many EV batteries have reached their end of life (EOL), although they still have significant energy. Utilizing this potential can reduce waste and environmental problems [11]. Major OEMs including Nissan-Renault, BMW, Tesla, and Daimler are paying more attention to battery reuse. According to a study, the global market for used batteries could grow to 26 GWh by 2025. Reusing EV batteries benefits the environment as well as offers a different source of income. This study examines capacity declines, the internal resistance increases, and cell-to-cell variability to assess the performance of second-life batteries for residential demand response and power smoothing applications [12]. The use of electric and hybrid vehicles is rising, and there is interest in using their batteries to support the grid. Battery recycling could increase storage capacity, but reliability issues including degradation and failure raise questions [13]. Establish a comprehensive methodology that takes into account the economics, technical viability, and battery status to assess the suitability of batteries for use in second-life applications. Additionally, it emphasizes the automation of several assessment components for seamless transitions. The goal is to hasten the decision-making process and make it simpler and quicker for EV batteries to transition to a second life [14]. Lithium-ion batteries and electric vehicles (EVs) are essential for decarbonizing transportation. OEMs and the environment can both benefit from the continued usage of retired EV batteries for energy storage. On the other hand, there is little research on battery aging and performance in second-life applications [15]. The usage of electric vehicle (EV) batteries with a 20% capacity loss for energy storage is investigated in this study. Despite modest initial earnings, businesses are experimenting with a variety of projects, focusing on battery management and the circular economy. Technology, communication systems, and Battery Management System considerations for remanufacturing enterprises are all covered in the study [16]. The best way to increase the sustainability of lithium-ion batteries is to move away from elements that are crucial and toward low- or no-cobalt substitutes. There are advantages to recycling batteries for energy storage systems, but this slows down metal recycling. Reuse and recycling trade-offs require more research because recycling has received less attention [17]. Fast-charging stations can use renewable energy resources like photovoltaic (PV) and battery storage systems to consume less grid electricity. With costs ranging from $38 to $147/kWh, second-hand batteries (SLBs) provide a practical answer. SLB performance and viability are impacted by battery chemistry and in-vehicle use. SLB degradation and capacity fading are influenced by DOD and charge/discharge rates, with lifetimes varying from 3 to 15 years. various SLBs have various roundtrip efficiencies, which are typically 80–85% [18]. Environmental concerns are causing the transportation sector to switch over quickly to electric vehicles. But a sizeable amount of retired lithium-ion batteries from these cars will be created. To address this, recycling or reusing the batteries can reduce negative effects on the environment and the economy while boosting the economy and lowering the demand for new batteries [19]. Li-ion batteries and a PV inverter are used in the plug-and-play technology of the suggested system. It includes a LabVIEW-based GUI for controlling and monitoring battery parameters in a home microgrid, as well as an embedded system using an Arduino microcontroller. The findings of the experiment are discussed [20]. With the worldwide stock of electric vehicles expected to reach 56 million units by 2030, their acceptance has increased significantly as a result of their democratization. Due to the vast number of spent batteries, this development does present an environmental concern, which has prompted the investigation of second-life battery uses for energy storage and other projects [21]. Significant cell-to-cell differences in LIB packs from EVs necessitate module or cell refurbishment. The second lifespan of LIBs is impacted by first-life aging conditions; degradation mechanisms include active material loss and a decrease in lithium inventory. The purpose of the study is to evaluate this dependence and identify the degradation processes [22]. Although lithium-ion batteries (LIBs) have many uses, their longevity is currently constrained by manufacturing techniques. For their second life, batteries must be grouped if they perform similarly. Due to a lack of historical data and nonlinear and unpredictable battery depletion, quick clustering solutions utilizing data-driven and machine-learning techniques are required [23]. Applications for Second-Life and Vehicle-to-Grid (V2G) connections are two areas of research for enhanced EV/PHEV batteries. V2G makes it possible for EVs to feed electricity into the grid, although coordination and battery deterioration problems persist. Battery life is extended through second-life solutions, which is good for the environment. Impacts on the economy and environment need to be examined further [24].

Chapter 3: Methodology

3.1 Experimental Procedure

To ensure the proper integration and optimal performance of the batteries, the approach for creating a battery pack utilizing second-hand lithium-ion batteries requires several crucial procedures.

First, a thorough analysis of the second-life batteries is done to determine whether or not they are appropriate for the desired application. Through methods like capacity testing, impedance analysis, and visual inspection, this assessment examines the battery's remaining capacity, health, and safety qualities.

The next step is to sort and choose the appropriate batteries depending on their specs, such as voltage, capacity, and internal resistance. The selection of batteries for the battery pack is made after careful sorting to guarantee that they will work consistently and have an appropriate amount of energy storage.

Each battery is carefully tested and characterized after sorting to understand its behavior and performance. Testing for capacity, cycle life, internal resistance, and voltage stability are included in this. The information gathered from these tests enables the selection of the ideal battery mix for the battery pack and guarantees that any potential constraints or degradation problems are taken into consideration.

The design and configuration of the battery pack are then chosen based on the particular needs of the application. The basic design configuration is shown in the [figure-5], this model concept is used to connect the batteries during this study. During the design process, variables including voltage, capacity, series or parallel connections, and thermal management issues are taken into account. The purpose of this procedure is to maximize the battery pack's efficiency, security, and longevity.

For efficient administration and control, the battery pack must incorporate a strong and capable Battery administration System (BMS). The BMS keeps track of and manages the batteries charging, discharging, and balancing processes to ensure their safe functioning and lengthen their lifespan. A series parallel connection BMS model is shown in the [Figure-2], which connects 4 batteries with the BMS to ensure the correct voltage and current capacity to be produced. To protect the batteries and improve their performance, it has functions including overcharge protection, over-discharge protection, cell balancing, and temperature monitoring.

The safety of the system is rigorously verified and certified after the battery pack is designed and the BMS is integrated. A proper BMS module is shown in [Figure-3], a similar connection module is used. To ensure compliance with industry norms and regulations, this involves putting the battery pack through stringent safety testing such as overcharge, over-discharge, short-circuit, and thermal runaway scenarios.

The motor shown in [Figure-4] was used to measure the output capacity of the battery pack that is shown in [Figure-6]. The motor was used to test the operating hour of the battery pack.

It's crucial to do field testing in actual environments to confirm the battery pack's longevity and functionality. In this step, the battery pack's operation in the intended application is monitored. Its energy storage capability, cycle characteristics, and overall system effectiveness are evaluated. The information gathered during the field-testing phase aids in optimizing the arrangement of the battery pack and addressing any potential operating issues.

Throughout the entire procedure, a cost analysis is done to see whether employing second-hand lithium-ion batteries for the battery pack is economically feasible. This research takes into account the price of purchasing the used batteries, the cost of refurbishing or reconfiguring the system, and the total worth of the resulting energy storage system.

Finally, to determine whether using second-hand batteries is sustainable, the environmental impact is assessed. When comparing the extraction of raw materials, energy use, and greenhouse gas emissions, the evaluation takes these factors into account.

This complex process allows for the methodical and thorough design, implementation, and validation of the battery pack manufactured from second-hand lithium-ion batteries. The methodology makes sure the battery pack satisfies the performance, safety, economic, and sustainability requirements, helping to create an ecosystem for energy storage that is more efficient and sustainable.

Finally, we are going to compare all the experimental data with an auto rickshaw battery to find the economic viability of this battery pack. If the experimental values and the cost comes lower than the conventional auto rickshaw battery cost, we can consider the battery pack is economically viable.

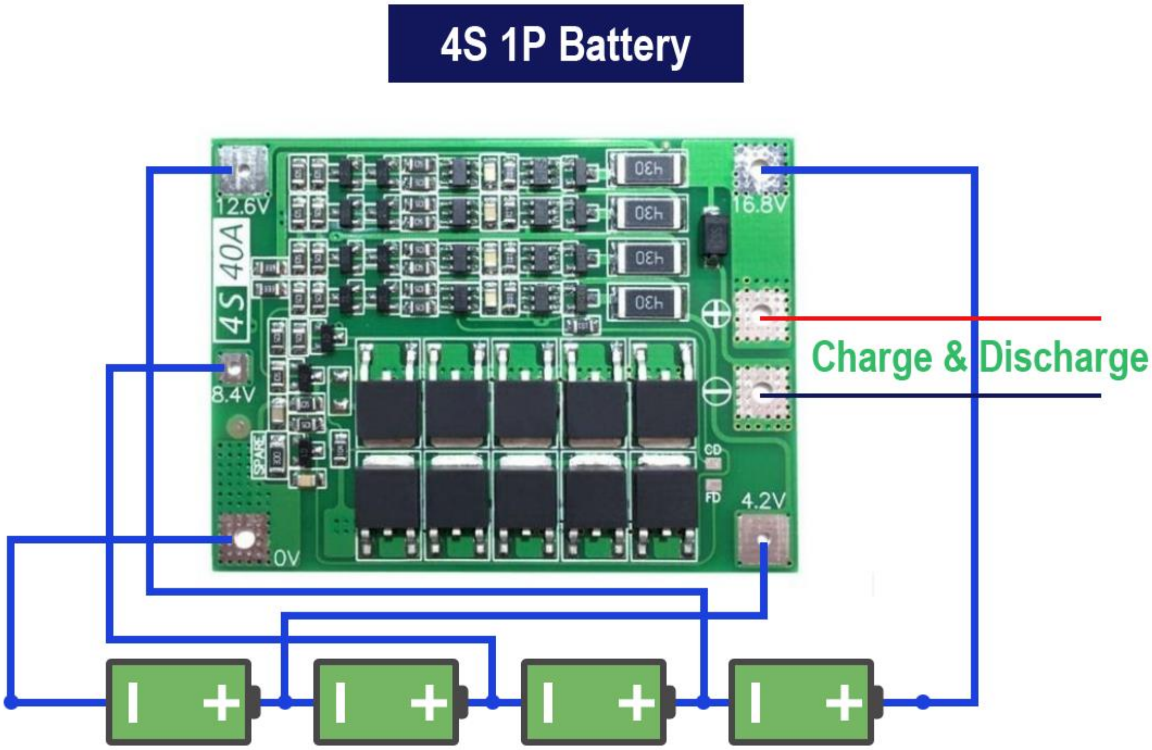

Figure 2 Battery Management System [3]

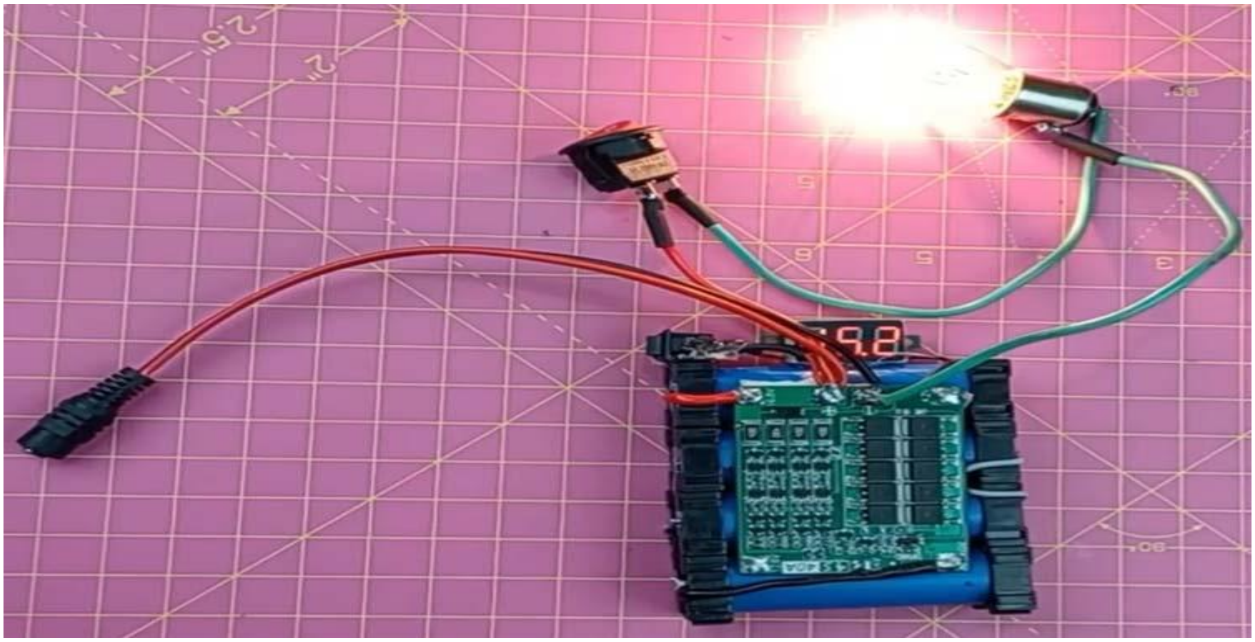

Figure 3 Battery-Pack-using-BMS-Module [3]

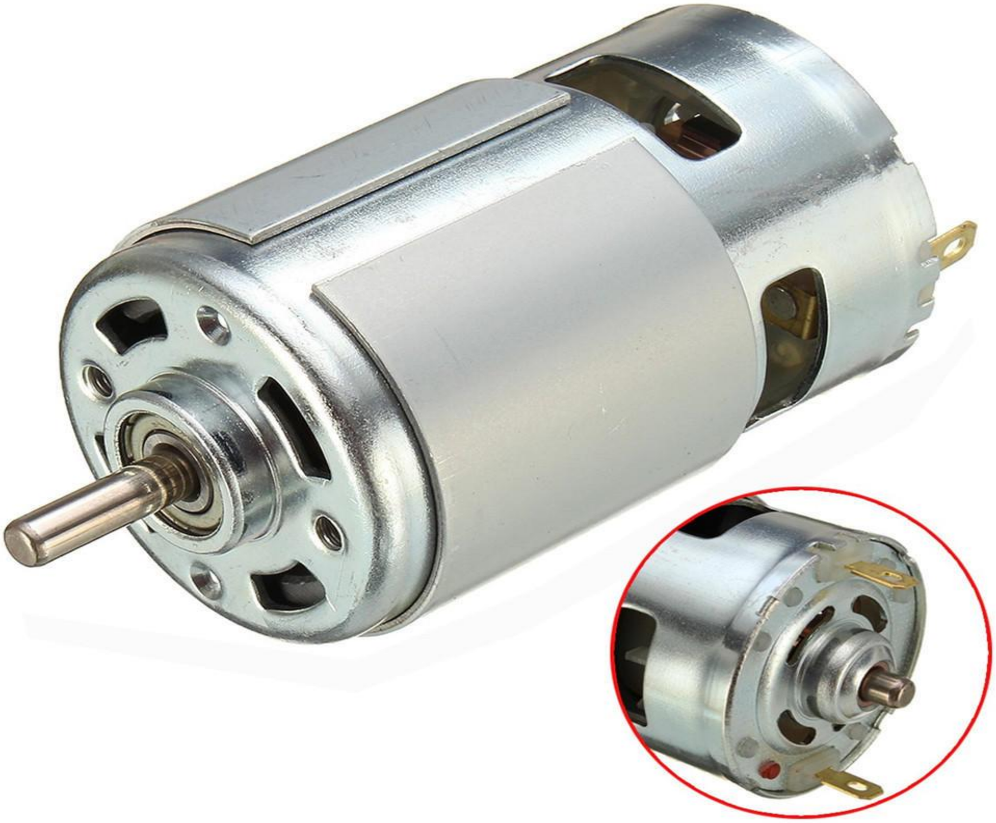

Figure 4 12Volt 21000 RPM DC motor [10]

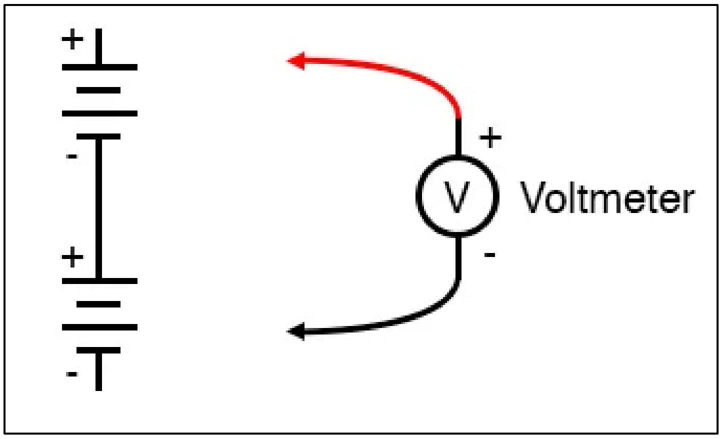

Figure 5 Basic circuit Diagram [11]

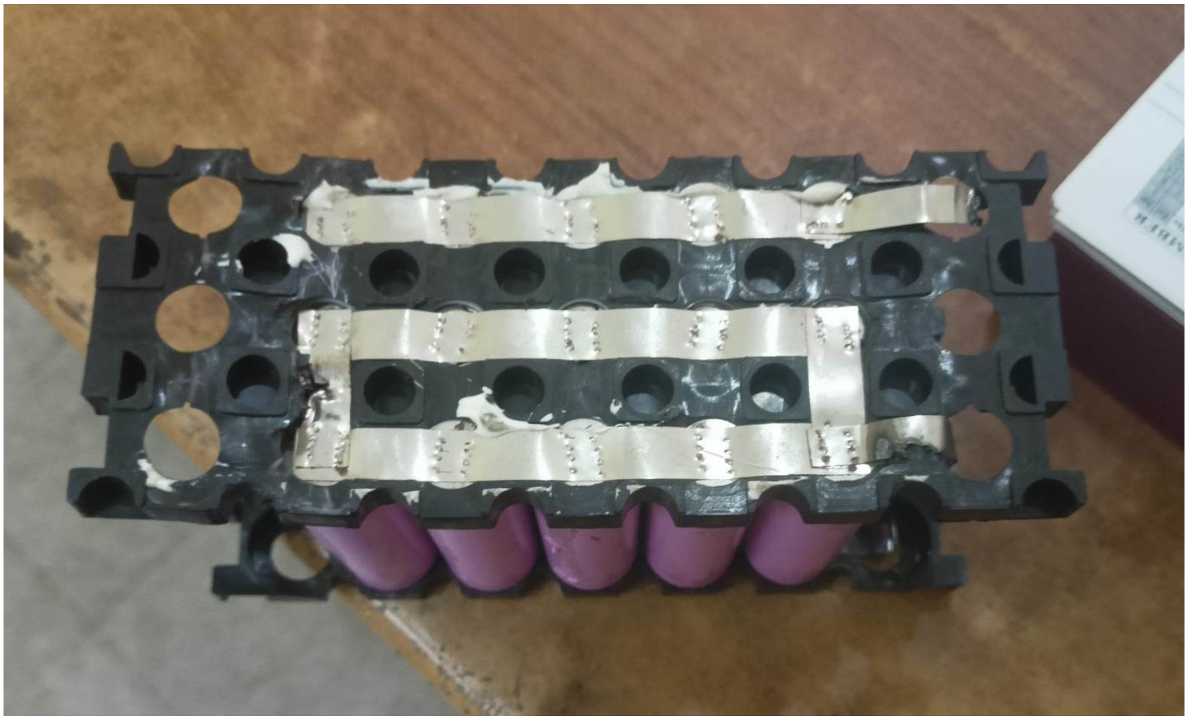

Figure 6 Battery Pack.

3.2 Materials for Experiment

Materials:

- Second life lithium-ion batteries
- Battery management system (BMS)
- Battery testing and characterization equipment (e.g., capacity tester, impedance analyzer)
- Voltage and temperature sensors
- DC motor
- Battery pack components (e.g., connectors, wiring, insulation materials)
- Safety equipment (e.g., gloves, safety glasses)
- Application-specific load or device
- Data acquisition system (optional)

The experiment's goal was to build a battery pack out of used lithium-ion batteries. By assessing the battery's remaining capacity, cycle life, internal resistance, and safety issues, the technique involves determining the battery's appropriateness. Based on the batteries' specs, including voltage and capacity, they were chosen and sorted. Each battery underwent extensive testing and characterization to ascertain its health and performance. The battery pack's design and configuration took into account variables including voltage, capacity, and thermal management to satisfy the needs of the intended application. The charging, discharging, and balancing of the batteries were monitored and managed by a suitable Battery Management System (BMS), which was integrated. Protection against overcharge and over discharge was one of the safety precautions put in place. Through field testing, which evaluated the battery pack's capacity, effectiveness, and behavior in actual use, the performance of the battery pack was confirmed. To ensure correct maintenance, monitoring and maintenance routines were devised, and environmental concerns were taken into account for the proper disposal of unsuitable batteries. The experiment revealed useful information regarding the viability and efficiency of using used lithium-ion batteries to build a practical and long-lasting battery pack.

Chapter 4: Results and Discussions

4.1 Experimental Data:

Battery No	Voltage (Volts)
1	3.35V
2	3.36V
3	3.38V
4	3.36V
5	3.05V
6	3.09V
7	3.10V
8	1.44V

Total output voltage of the battery pack	24.13V
Voltage rating in the motor	24V
Motor power	150Wh
Battery output current	150Ah
Battery output power	3.6KWh

We have an eight-cell battery pack available. Battery No Voltage (Volts) is 1=3.35V and Battery No Voltage (Volts) is 2=3.36V. 3=3.38V 4=3.36V 5=3.05V 6=3.09V 7=3.10V 8=1.44V. The battery pack's total output voltage is 24.13V, which is slightly more than the motor's nominal voltage rating of 24V. This implies that the battery pack is made to power the motor.

Listed as 150Wh, or 150 watt-hours, is the motor power. This shows how much energy the motor uses during a single hour of use.

The output current of the battery pack is specified as 150Ah, or 150 ampere-hours. This shows how long the battery pack can provide a continuous current under certain conditions.

The output power of the battery pack is specified as 3.6KWh, or 3.6 kilowatt-hours. This is a reference to the battery pack's overall energy capacity. Overall, this analysis indicates that the battery pack is made to run a motor with a 24V rating and a 150Wh power requirement. The battery pack has a 150Ah capacity and a 24.13V total output voltage, delivering a 3.6KWh overall energy capacity. Now, considering the battery pack to be used for auto rickshaw battery. We need to compare the results with the current battery performance that's available in the market. Conventional Auto rickshaw battery costs around 20000 takas. And the motor capacity that's used for auto rickshaw is 1.5 KWh.

4.2 Theoretical Calculations for Finding the Viability:

From Experimental value;

Eight batteries are taken with output voltage of 3.35V, 3.36V, 3.38V, 3.36V 3.05V, 3.09V, 3.10V & 1.44V

Total output voltage of the battery pack= 24.13V

Voltage rating in the motor= 24V

Motor power= 150Wh

Battery output current= 150Ah

Battery output power= (24X150) watt =3.6KWh

The actual number of hour it can run=3.6/0.15=24 hr.

4.2.1 Comparing with conventional rickshaw

Running the battery for 13 hours straight.

Motor Output= 1.5KW

Total power required= (1.5X13) KWh= 19.5KWh

Power= VI

Voltage output required= (19500/140) Volts= 140Volts (approximate)

IF every battery 3 volts each

Battery required= 140/3= 47 batteries.

Cost per battery=75 taka

Total cost required= 75X45= 3525 taka

Other cost variables= 5000 taka

Total cost required to make battery pack= 8525 taka.

Auto Rickshaw battery normally costs 20000 takas in Bangladesh [12].

4.3 Discussion

The conclusions drawn from the experiment data and assumption calculations offer insightful information about the performance and capacity of the battery pack used to power an electric motor.

In the calculation, it was assumed that five batteries with a combined capacity of 140Ah and a voltage of 12V were wired in series to produce a voltage of 60V and 8.4kWh. 1.5 kWh was the specified motor power. These values were used to determine the motor's actual operating time, which was 5.67 hours. The motor's calculated range is 141.75 km when the assumed speed of 25 km/hr. is taken into account. This calculation highlights how crucial battery capacity is in affecting the motor's working time and range.

The experimental values, on the other hand, used eight batteries with various voltage readings. The battery pack's overall output voltage was measured at 24.13V, although the motor's rated voltage was 24V. The battery output current was 150Ah, while the motor power was listed as 150Wh. These figures led to an estimated battery output power of 3.6 kWh, which translated into a real operating period of 24 hours.

It is evident by comparing the theoretical calculations and experimental results that the calculation's assumptions did not correspond to the real-world scenario that the experimental data indicate. The experimental results showed that eight batteries were sufficient to produce the requisite power, but the assumption calculation predicted the requirement for 47 batteries. The importance of conducting practical trials and taking into account actual battery performance rather than depending only on assumptions is highlighted by this large disparity.

The theoretical calculations' cost analysis offered an estimate of the overall cost needed to construct the battery pack, which came to 8,525 takas. It is essential to take into account additional cost factors, such as the anticipated 5,000 takas in production, installation, and maintenance expenditures. The entire expected expense now stands at 13,525 takas. Comparatively, a typical auto-rickshaw battery in Bangladesh costs about 20,000 takas, which highlights the potential financial savings associated with using a battery pack built from used lithium-ion batteries.

The results from the experiment values and assumption calculations highlight the significance of taking into account actual battery performance and capacity when planning and evaluating the cost of a battery pack. Making decisions regarding the use of battery packs in electric vehicles can be made more accurately and reliably by conducting real-world experiments and assessing the performance of used batteries.

Chapter 5: Conclusion

Conclusion and Future Recommendations:

In conclusion, battery second life offers a valuable chance to increase the lifespan of lithium-ion batteries, helping to provide a more sustainable approach to energy storage. Utilizing second-hand batteries for stationary energy storage, backup power, and off-grid systems can help decrease waste, conserve resources, and have a minimal negative impact on the environment. Second-life batteries can be efficiently used while assuring optimal performance and safety by properly assessing, testing, and integrating battery management systems. To fully realize the promise of battery second life, issues such as battery degradation, varied characteristics, and regulatory frameworks must be resolved. The acceptance of second-hand batteries as a sustainable solution for our expanding energy needs will be fueled by continued improvements in battery technology, together with standardized procedures and recycling programs. In this study we wanted make a battery pack which can tackle the challenges that are currently facing in recycling lithium-ion batteries by using the second life method. For which the environmental hazard can be reduced. Also, we can use this battery pack that has an economical side by implementing this battery pack in Auto Rickshaw. Overall, we can say Battery second life concept is economically and environmentally viable.

Future battery reuse has a lot of potential across several fronts. Reusing second-hand batteries can offer a sustainable alternative to meet energy needs as the demand for energy storage rises. Better characterization and exploitation of second-life batteries will be made possible by developments in battery technology and the creation of effective battery management systems. Additionally, cutting-edge uses for second-life batteries, including grid-scale energy storage, infrastructure for charging electric vehicles, and the integration of renewable energy sources, present exciting prospects. The development of standardized procedures, rules, and recycling frameworks will also increase the viability and environmental advantages of battery second life as the circular economy takes pace. The proliferation of second-life applications will aid in the creation of a more sustainable and effective energy storage ecosystem, which will be facilitated by continuous research and development activities targeted at enhancing battery performance, longevity, and safety.

Chapter 6: References

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