RECYCLING OF DEAD LAPTOP BATTERIES FOR RENEWABLE ENERGY STORAGE SYSTEMS

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A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL/ELECTRONICS ENGINEERING, FACULTY OF ENGINEERING, UNIVERSITY OF BENIN, BENIN CITY, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B. Eng) DEGREE IN ELECTRICAL/ELECTRONICS ENGINEERING.

APRIL, 2024

CERTIFICATION

This is to satisfy that the project was jointly carried out by OKONTA PAUL CHUKWUNEKU with matriculation number ENG1805111, IKEBIAGBO CHUKWUEDUM JONATHAN with matriculation number ENG1805070, OKOLIE AUSTIN CHINEDU With matriculation number ENG1805108 AND ESENE MACAULAY JOHN with matriculation number ENG1805062 of the Department of Electrical/Electronics Engineering, University of Benin, in partial fulfilment for the award of the Bachelor of Engineering (B.Eng.) Degree in ELECTRICAL/ELECTRONIC Engineering.

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PROJECT SUPERVISOR

DEDICATION

We dedicate this project work first to the Almighty God for his merciful works in our lives. We also dedicate this project to our families for all their financial, moral and intellectual support throughout our journeys in the university.

ACKNOWLEDGEMENT

Our biggest thanks go to God Almighty for giving us the strength to start and finish our bachelor's degree in the Department of Electrical and Electronic Engineering, University of Benin. With his help, we were able to start and finish this project despite the obstacles encountered.

We would also like to thank our project supervisor, Engr Dr. N. Bello for patiently working with us on this project and giving us the opportunity and privilege to tap from his wealth of knowledge and experience. A big thank you also goes to the Head of the Department of Electrical and Electronic Engineering, Prof. K.O. Ogbeide for his mentorship and fatherly love for us the students of this great department.

To all academic and non-academic staff of the Department of Electrical and Electronic Engineering, we say thank you for making our stay here successful. Special thanks goes to our parents and guardians for their encouragement and support throughout our stay in the university. Without them we wouldn't have made it this far. Thank you to our friends who helped during our time of need. Their loving support saw us through the hurdles we faced.

Finally, thank you to everyone in the Electrical and Electronic Engineering Graduating class of the 2022/2023 session. The journey was not a smooth one, but we made it to the end. Congratulations!!!

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LIST OF ABBREVIATIONS

- BMS - Battery Management System
- RUL - Remaining Useful Life
- KWh - Kilo-watt hour
- IER - Institute for Energy Research
- IEA - International Energy Agency
- IRENA - International Renewable Energy Agency
- EV - Electric Vehicle
- Kg - Kilogram
- Wh/kg - Watt-hour per kilogram
- s, p - Series, Parallel

ABSTRACT

The investigation of second-life cases for abandoned lithium-ion batteries is a result of the rising demand for energy storage solutions as well as the environmental hazards caused by poorly disposed lithium cells. The objective of this study is to assess dead laptop batteries' potential as a substitute energy source by examining how well they function as energy storage devices in a renewable energy system.

In order to conduct the research, individual cells harvested from dead laptop batteries were gathered and sorted according to their capacity and condition. After that, several battery tests were conducted to evaluate the batteries' performance characteristics and remaining useful life.

After all tests were carried out, the viable cells harvested were used to construct a 10kilowatt-hour, 48V Lithium-ion battery pack. the pack was tested and deemed a suitable energy storage source.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Over the last few years numerous concerns have been raised over the efficiency of conventional power grid infrastructures, from issues of pollution to the inability of most grids to reach rural areas adequately, these inadequacies have led to a lot of attention being paid to distributed generation using a collection of renewable energy sources to supplement the capacity and reach of the conventional grid as well generate power for both personal and commercial purposes.

Globally the demand for renewable energy has been increasing parabolically in correlation to the decreasing cost of equipment as well as accessibility to relevant technologies. Recording a global growth of 50% in 2023, energy capacity from renewable energy sources are expected to reach even 7300 gigawatts(GW) over the next five years (IEA, 2024).

These recent developments has led to several challenges in the mass adoption of renewable energy such as high initial costs, capital costs, grid integration, energy storage and transmission, by virtue of that, countless hours of research has gone into making renewable energy sources more economical while also maintaining the elements of environmental sustainability they are most popular for offering.

Since renewable sources of energy often generate power at specific times of the day which may not correspond to peak demand periods, access to adequate power storage infrastructure at affordable costs is indispensable in the construction of any solar PV, wind or Fuel Cell installation. This forms the basis for this study by investigating the viability of used laptop batteries for the construction of battery packs thereby providing not only access to cost-effective power storage but also an opportunity to reduce lithium-ion battery wastes which are harmful to our environment.

1.2 PROBLEM STATEMENT

As earlier discussed, the increase in demand for renewable energy sources particularly that of solar photovoltaic cells has led to a corresponding increase in the demand for high capacity power battery packs to store enough energy to meet the necessary load requirements.

The cost of grade A and grade B batteries are often very expensive and discouraging to the average consumer often leading to a compromise for grade C batteries or worse, with less cycle life, discharge rates, depth of discharge, or even norminal voltages. This has put the average consumer in a tight position as he is forced to choose between high efficiency at an extremely high cost or a cell with barely any guarantee of it's performance.

1.3 AIM

The aim of this project is to build a 10 kilowatt-hour, 48v lithium-ion battery pack using cells obtained from dead laptop batteries

1.4 OBJECTIVES

The specific objectives of this research work are as follows:

- To build an efficient battery pack with fair cycle life and depth of discharge.
- To understand the importance of Battery Management Systems (BMS) and Balancers in the operation of battery packs.
- To investigate the advantages of lithium-ion battery chemistry over various other battery chemistries.
- To learn the individual characteristics of each cell required to make a battery pack run properly.

1.5 METHODOLOGY

1. **Battery Collection**: This involves the acquisition of old laptop batteries from local computer repair shops, junk yards and merchants who deal in trading scraps.
2. **Cell Extraction**: This involves the breaking of the plastic covering of the batteries
3. **Cell Testing**: During this stage, the extracted cells are tested to ensure they are suitable for use.
4. **Cell Sorting**: After the testing, the cells are sorted according to their capacities, temperature and internal resistance.
5. **Cell Selection**: Depending on the application we are using the battery pack, as well as the total capacity required we select a range of cell capacities for the configuration.
6. **Determine Cell configuration**: When building battery packs a combination of series and parallel connections are employed to meet the required specifications.
7. **Balance the Cell Configuration**: At this stage we try to ensure that each column of cells are of equal combined capacity, this is done using an excel sheet.

1.6 RELEVANCE OF WORK

Only about 5% of the world's lithium batteries are recycled compared to 99 per cent of lead car batteries recycled in the United States. Recycling lithium batteries, however, can be hazardous. Cutting too deep into a cell or in the wrong place can result in it short-circuiting, combusting, and releasing toxic fumes (IER, 2023), that being said it is of utmost importance for more lithium cells to be taken out of landfills, junk yards and back into viable use.

In conclusion, building a 10kWh, 48V battery pack using recycled laptop batteries is a feasible and environmentally friendly approach to energy storage. However, it requires careful planning and design, as well as rigorous testing and selection of the batteries. The use of a battery management system and modular and scalable design can help to ensure safe and reliable operation of the pack. By using recycled batteries, it is possible to reduce the environmental impact of battery production and reduce waste.

CHAPTER 2: LITERATURE REVIEW

2.1 REVIEW OF OTHER RELATED WORKS

Building a 10kWh, 48V battery pack using recycled laptop batteries is a topic that has gained attention in recent years due to the growing interest in renewable energy and the need for efficient energy storage solutions. This literature review will examine various aspects of this topic, including the feasibility of using recycled laptop batteries, the design and construction of the battery pack, and the potential benefits and challenges of this approach.

One of the main advantages of using recycled laptop batteries is their potential to reduce the environmental impact of battery production. According to a report by the International Renewable Energy Agency (IRENA), the production of batteries for renewable energy systems can have a significant environmental footprint due to the extraction and processing of raw materials (Robert R. 2020) By using recycled batteries, it is possible to reduce the demand for new materials and reduce waste.

However, there are also challenges associated with using recycled laptop batteries. One of the main challenges is the variability in the quality and capacity of the batteries. Laptop batteries are typically designed for a specific device and may not have the same performance characteristics as a battery designed for energy storage applications. Additionally, the batteries may have been subjected to different levels of use and abuse, which can affect their performance and reliability.

The rapid growth of the battery market, driven by the electrification of the transport sector and the increasing demand for renewable energy storage solutions, poses challenges for waste management and recycling infrastructures. Traditional manufacturing strategies need to be adapted to the unique characteristics of battery recycling. A study conducted in collaboration with Northvolt AB focused on planning a battery recycling unit to identify challenges and unique features of battery recycling. The research found that while traditional manufacturing strategy categories are applicable to recycling environments, operational considerations must address uncertainties in discarded product inflow, variations in battery chemistry, and the need for a flexible process to accommodate future disruptions. Key managerial implications for battery producers include simplifying disassembly processes, implementing intelligent labeling systems, and advocating for industry standards to facilitate recycling efforts(Ingrid K & Jenny L, 2018).

In response to the study's findings, it is crucial for battery producers to recognize the specific challenges and requirements of battery recycling. By addressing uncertainties in discarded product inflow and adapting to the diverse battery chemistries encountered in recycling processes, manufacturers can enhance the efficiency and sustainability of their recycling operations. Implementing flexible processes that can accommodate future disruptions is essential for long-term success in battery recycling. Moreover, simplifying disassembly procedures, developing intelligent labeling systems, and advocating for industry standards are key strategies that can streamline and improve the recycling process for battery producers.

Reusing products is a suggested step toward sustainability. However, how customers used End-of-Use (EoU) or End-of-Life (EoU/L) products during their initial lifecycles and what their EoU criteria determine how profitable it is to reuse them. Future reusability is influenced not just by consumer behaviour but also by product design elements like durability. The purpose of this paper is to investigate the possible reusability of laptop batteries by analyzing a data set of Lithium-ion batteries. Because of their excellent dependability and energy economy, this kind of rechargeable battery is well-liked. As a result, it's critical to comprehend these batteries' lifespan and enhance the recycling procedure. This article simultaneously links the reusability evaluation to the degradation process and customer behaviour through time(Sabbaghi M et al, 2015).

(Lall P., and Zhang H. 2016) focuses on the evaluation and prediction of the remaining useful life of flexible batteries used in foldable wearable electronics. The authors discuss the importance of accurately predicting the RUL for battery management systems to ensure reliable operation and timely maintenance, as well as for battery second-life applications.

The paper provides a comprehensive review of the battery lifetime prognostic technologies, focusing on recent advances in model-based, data-driven, and hybrid approaches. The authors analyze the details, advantages, and limitations of these approaches, comparing their performance in predicting the remaining useful life of flexible batteries.

The authors also discuss the challenges and opportunities in battery lifetime prognostics, highlighting the need for further research and development in this area. They emphasize the importance of considering the specific degradation mechanisms and operating conditions of flexible batteries when developing RUL prediction models.

The growth and profitability of the EV battery recycling sector has the potential to make or break the pace of the vital electrification of the transport sector. The potential value creation for EV battery recycling, at $95 billion per year by 2040, is massive and is attracting attention from automotive OEMs, battery OEMs, and investors(Brönmark R, & Holm B, 2023).

(Hartono H, et al, 2017)focuses on evaluating the performance of power banks that are equipped with recycled laptop batteries. The study involved testing the power capacity of power banks fitted with recycled laptop batteries, specifically type 18650 cells. The research included selecting batteries based on physical appearance, cleaning pole connections, testing voltage, and monitoring temperature during the charging process.

The study's findings showed that there was no explicit testing done on the power capacity of power banks equipped with recycled laptop batteries. Nonetheless, the study shed light on the steps involved in evaluating and readying these recovered batteries for use in power banks. The study highlights the need for appropriate testing and evaluation to guarantee the dependability and performance of power banks equipped with recycled batteries and highlights the possibility of reusing used laptop batteries for sustainable energy storage solutions.

(Pascal M. et al, 2021) opines that the electric vehicle battery recycling industry needs to scale up today in order to keep pace with the exponential increase in production. Production waste from battery manufacturing currently accounts for over half the volume of material to recycle. Waste from the battery production process includes high-value materials containing lithium, nickel and cobalt lost at various stages during the process.

End-of-life batteries correspond to the overall volume of batteries available for recycling after a service. This means there is a direct correlation between available volumes and the volume of batteries manufactured 10 years ago. This stream of waste batteries is therefore very limited at present since very few EVs were sold in 2010. It will progressively account for most of the material available for recycling in the years after 2030.

Developing battery recycling activities is also about promoting new skills and encouraging an ecological shift that creates new job opportunities. According to a recent study into how to achieve a well-balanced transition in the French automobile industry, conducted by the Foundation Nicolas Hulot (June 2021), battery recycling will create 9,000 jobs in 2030-2035. An earlier study by the Centre for European Policy Studies (Drabik E and Rizos V, 2018) estimates that collecting, dismantling and recycling batteries creates 15 jobs for every 1,000 metric tons of lithium-ion battery waste.

Recycling electric vehicle batteries is an environmental and strategic imperative. The market for recycling electric vehicle batteries is growing exponentially: from 200,000 metric tons of EV batteries eligible for recycling in 2021 to 7 million metric tons in 2035, representing metals with a value in excess of €15 billion. The market is particularly buoyant in China while it is expanding in Europe and should follow suit in the USA in a few years.

Veolia plays an active part in this ecological transformation which boosts the mobility of tomorrow. The company has signed a deal with Renault that covers construction of a battery recycling plant in France, using streams of materials sourced from Renault vehicles. Discussions have also taken place with gigafactory operators intending to establish partnerships for recycling their production waste.

In conclusion, effective strategies for dealing with used batteries of new energy vehicles are crucial for the sustainability of the transport sector and the environment. The growth and profitability of the EV battery recycling sector has the potential to make or break the pace of the vital electrification of the transport sector. The job-creation potential of battery recycling activities is significant, creating new job opportunities and promoting new skills. Recycling electric vehicle batteries is an environmental and strategic imperative, and the market for recycling electric vehicle batteries is growing exponentially. Veolia plays an active part in this ecological transformation, and the company has signed deals with major automobile manufacturers for the recycling of their batteries.

Lastly, Before recycling used lithium-ion laptop batteries, testing and sorting work is needed through charge and discharge tests. For current lithium-ion battery charge and discharge tests, the battery is discharged through a resistor. Thus, the energy in the process is all dissipated. In this paper, an energy-recycling battery test system model is introduced. In the system, a Li-ion 18650 battery can be charged at a constant current mode and a constant voltage mode and discharged at a constant current mode, which are realized by PWM-controlled DC-DC converters. The modes are automatically switched through a controller. In the discharging process, energy is transferred from the under-test battery to a storage battery, which can also serve as a charging source instead of the DC power supply to recycle the energy. The system is simulated using Matlab Simulink. Its test accuracy and energy-transferring efficiency is considerable. According to the simulation results, the system can save about 50% energy overall in one charge and discharge cycle (zhou J et al, 2017)

2.2 HISTORY AND EVOLUTION OF LITHIUM-ION BATTERY PACKS

2.2.1 Early Beginnings (1970s-1980s)

The notion of lithium-ion batteries initially surfaced in the early 1970s, thanks to ground-breaking investigations conducted by scientists like Akira Yoshino, M. Stanley Whittingham, and John Goodenough. These scientists' investigations into diverse materials and chemical compositions set the groundwork for the creation of rechargeable lithium-ion batteries.

Whittingham created the first lithium-ion battery prototype in the 1970s, employing metallic lithium as the anode and titanium disulfide as the cathode. However, the possibility of lithium dendrite growth, which might result in short circuits and possibly fires, made the usage of metallic lithium unsafe.

2.2.2 Modern Lithium-Ion Batteries (2000s-Present)

Since the 2000s, lithium-ion batteries have proliferated and are now found almost everywhere, powering everything from consumer gadgets to energy storage systems and electric vehicles (EVs).

Key developments in recent years include:

- The rapid adoption of lithium-ion batteries in the EV market, is driven by the need for sustainable transportation solutions and advancements in battery technology.
- Continued improvements in energy density, with lithium-ion batteries now reaching energy densities of over 300 Wh/kg, making them more compact and lightweight.
- Advancements in fast-charging capabilities, reducing charging times and improving user convenience.
- The emergence of solid-state lithium-ion batteries, which offer the potential for even higher energy density, improved safety, and longer lifespan.

- Ongoing research into alternative anode and cathode materials, such as lithium-sulfur and lithium-air batteries, could further improve the energy density and performance of lithium-ion technology.

As the demand for energy-efficient and environmentally friendly power sources continues to grow, the evolution of lithium-ion battery technology remains a critical area of research and development, shaping the future of portable electronics, electric vehicles, and energy storage systems.

2.3 APPLICATIONS OF LITHIUM-ION BATTERY PACKS

Lithium-ion batteries have a wide range of applications in various industries due to their high energy density, long lifespan, and efficient power delivery. These batteries are commonly used in electronic devices, medical equipment, electric vehicles, and renewable energy systems.

In the electronics industry, lithium-ion batteries are used to power mobile phones, laptops, tablets, and other portable devices. They are also used in medical equipment such as pacemakers due to their long lifespan and high energy density.

In the electric vehicle industry, lithium-ion batteries are used to power electric cars, buses, and bikes. They are preferred over other types of batteries due to their high energy density, long lifespan, and fast charging capabilities.

In renewable energy systems, lithium-ion batteries are used to store energy from solar and wind power systems. They are preferred over other types of batteries due to their high energy density, long lifespan, and fast charging capabilities.

Lithium-ion batteries are also used in emergency power backup systems, portable power banks, and surveillance or alarm systems in remote locations. They are preferred over other types of batteries due to their high energy density, long lifespan, and efficient power delivery.

Researchers are continuously pushing the limits and boundaries of current Li-Ion technology by experimenting with new ways to improve the energy capacity and safety measures of these batteries. From using relatively cheaper and safer materials like Silicon and Vanadium oxides to creating 'nanostructures' within the battery cells, scientists are working towards creating a battery that is more energy-efficient, more cost-efficient, and much safer than its current form.

In summary, lithium-ion batteries have a wide range of applications in various industries due to their high energy density, long lifespan, and efficient power delivery. They are commonly used in electronic devices, medical equipment, electric vehicles, and renewable energy systems.

2.4 COMPONENTS USED IN THE PROJECT

1. 18650 Lithium battery Cells are often found inside laptop batteries, these are the cells used for this fabrication

Figure 2.1: 18650 Lithium battery cells: Individual energy storage units

2. 18650 Spacers are used to isolate the bodies of each individual cell in order to prevent a short circuit

Figure 2.2: 18650 Spacers

3. Nickel Strips are used for making parallel and series battery connections

Figure 2.3: Nickel Strips

4. Soldering Lead is used for joining metal parts

Figure 2.4: Soldering Lead

5. Glue is Used to attach the Kapton tapes

Figure 2.5: Glue

6. 14S Battery Management System monitors and controls the charging and discharging of the entire battery pack

Figure 2.6: Battery Management System

7. Spot welding machine Used to spotweld the nickel strips onto the battery terminals safely

Figure 2.7: Spot welding machine

8. Vero Board is the circuit board used for paralleling each 1Kwh pack to one another

Figure 2.8: Vero Board

9. 14S Balancer ensures that each battery is fully charged at the same time

Figure 2.9: 14s Balancer: Used

10. $4mm^2$ Black and Red flexible wire acts as the negative and positive terminals of the pack

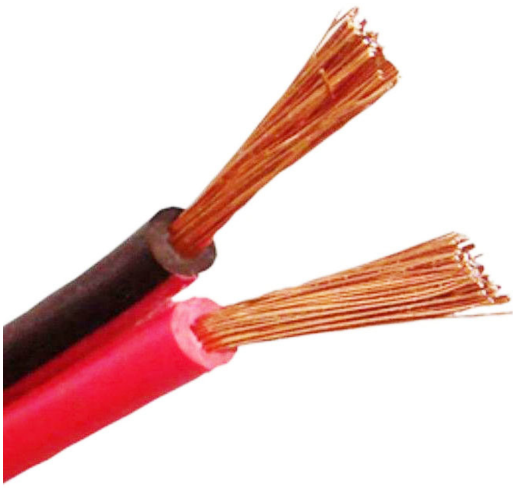

Figure 2.10: Flexible wire:

11. Liitokala Capacity Tester measures the capacity of each individual cell

Figure 2.11: Capacity Tester

12. Internal Resistance Tester is Used to measure the internal resistance of each cell

Figure 2.12: Internal Resistance Tester

13. Transparent Perspex is used To cover each module against dust and environmental factors

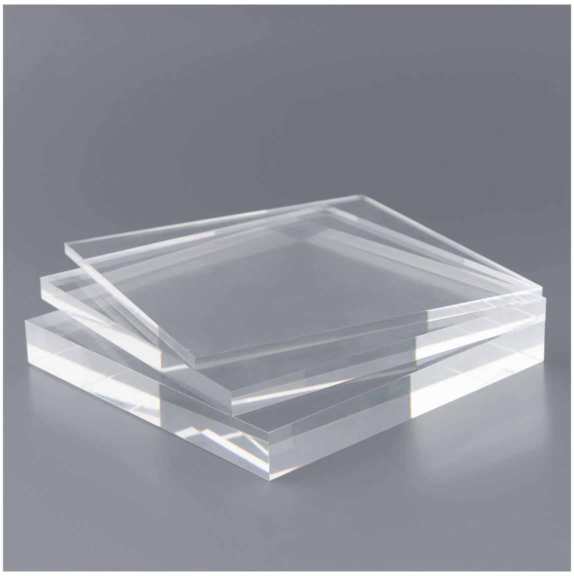

Figure 2.13: Transparent Perspex

CHAPTER 3: DESIGN METHODOLOGY

3.1 MATERIALS AND METHODS

To be able to build a battery pack of any capacity, certain materials, pieces of equipment and tools are necessary, coupled with the skills to use them. The methods and arrangement used depend on the capacity, voltage output and power needed.

3.2 MATERIALS

:

- Dead or salvaged laptop batteries
- Voltmeter
- Multimeter
- Wire Cutters
- Soldering iron and solder
- Spot welder
- Nickel strips
- Battery Management System(BMS)
- Balancer
- Busbars ($2.5mm^2$ copper wire)
- Kapton tape
- Fuse wires ($0.05mm^2$ copper wire)
- Cell spacers

- Connectors
- Vero Board
- Bolt($6mm^2$), 3inches Nut, and washers
- Transparent Perspex
- Internal resistance tester

3.3 METHODS

: Here, exclusive detail will be given on the methods, procedures and or steps which were carried out in building a 10 kWh, 48V lithium-ion battery pack.

3.3.1 Cell Harvesting, Collection and Preparation

A sufficient number of old laptop batteries are sourced and gathered. These laptop batteries typically contain the 18650 cells which are used for this project. An 18650 cell is a lithium-ion cell (can be of different chemistries) that tends to have a nominal voltage of 3.7V and range in capacity from 1800mAh to 3600mAh. The name 18650 is derived from its dimensions, 18mm width of the battery and 65mm length. These old laptop batteries are then disassembled carefully and safely in order to avoid damage to the cells and injury to the handler, the 18650 cells are extracted from their casings, and these cells are then visually inspected for signs of corrosion, damage or bulging (as shown in Fig 3.1). Damaged cells are disposed of.

3.3.2 Cell Testing

Tests are carried out on each individual cells in order to determine if the cells will be able to give out the output needed. These tests includes, capacity test, internal resistance test and self discharge test. The extracted cells are placed on a charger to increase it's voltage to the maximum which is about 4.2V. The fully charged cell is then place on a Liitokala capacity tester which checks the capacity of the cells., A Liitokala capacity tester is a multi-purpose device which can be used to check capacity, voltage and internal resistance


Figure 3.1: Some of the harvested cells

of the cell, it can also act as a charger for charging the cells (This is shown in Fig 3.2 and Fig 3.3 respectively).

In the self-discharge test, the cells are left for a couple of weeks, this is done to know the rate of discharge of each individual cell. Cells with a fast rate of discharge are kept aside not to be used for this project.

An internal resistance test is done to determine the internal resistance of each cell, it should be noted that cells with high internal resistance are not appreciated here because they have low power output and generate lots of heat due to power losses which makes them inefficient. In order to have a reference value for each cell to determine if the internal resistance is high or just right, a website ”secondlifestorage.com” was used to determine the standard values of internal resistance for each cell based on the manufacturer. The temperature of each cell is checked during testing (mainly when being charged), those with very high temperatures i.e. heaters are discarded.

An internal resistance tester is depicted in Fig 3.4

Figure 3.2: Capacity testing

Figure 3.3: Charging is done for cells which are too low to be detected by the capacity tester

Figure 3.4: Internal Resistance tester

3.3.3 Cell Sorting and Arrangement(Configuration)

During the capacity testing of these extracted cells, it will be observed that there will be variations in the values of capacities for these cells being that they are not new. These cells are then sorted out in groups based on their capacity, this is done to ensure better performance and safety.

Cell configuration is the arrangement of cells in a given way to be able to obtain the desired voltage and capacity required. Here the cells are arranged in parallel and series on a cell spacer. Series connection affects the voltage while parallel connection affects the capacity of the battery. In this case, the objective is to build a 10kWh, 48V battery pack. First of all, we have to get the configuration of a 1kWh, 48V battery, when this is done, placing ten(10) 1kWh batteries in parallel will form a 10kWh battery.

A single cell has an nominal voltage of 3.7V, to get the number of cells connected in series,

$$\frac{48}{3.7} = 12.9 = 13$$

Practically, to maintain stability and balance, an additional cell is added to a 48V battery pack. This extra cell contributes to maintaining constant voltage levels throughout the pack, preventing individual cells from being overcharged or undercharged, and improving longevity and overall performance. This brings the total voltage in the pack to

$$3.7 \times 14 = 51.8V$$

now we find number of cells required to be connected in parallel to achieve a 1kwh module assuming the capacity of a single lithium-ion cell obtained from the salvaged laptop battery is 1000mAh,

Capacity of the module = 1000Wh Voltage of the Module = 51.8V The capacity of an individual cell = 1Ah

$$\frac{1000Wh}{51.8V} = 19.3Ah$$

For design purposes, this number is rounded up to 20Ah

Number of Cells in parallel = $\frac{20Ah}{1Ah} = 20$

That is 20 cells connected in parallel.

Practically, we work with the average capacity gotten from the different cells and since there would be slight differences in the capacities of each cell we now have to balance each parallel column of cells in order to ensure that charging and discharging is done fairly uniformly across the module and by extension the entire battery pack (Fig 3.5).

3.3.4 Interconnection and Assembly of cells

The cells are connected together at one side of the battery pack by nickel strips according to its configuration using a spot welder, while at the other side of the battery pack fuse wires with busbars(copper wires) are used. It should be noted that nickel strips can be used on both sides but for easy repair and to prevent much damage in the case of a short circuit fault fuse wires are used.

3.3.5 Battery Management System(BMS) and Balancer

A battery management system is an electronics system that monitors every facet of a battery pack, it is most times referred to as the brain of the battery (Fig 3.6) The BMS is

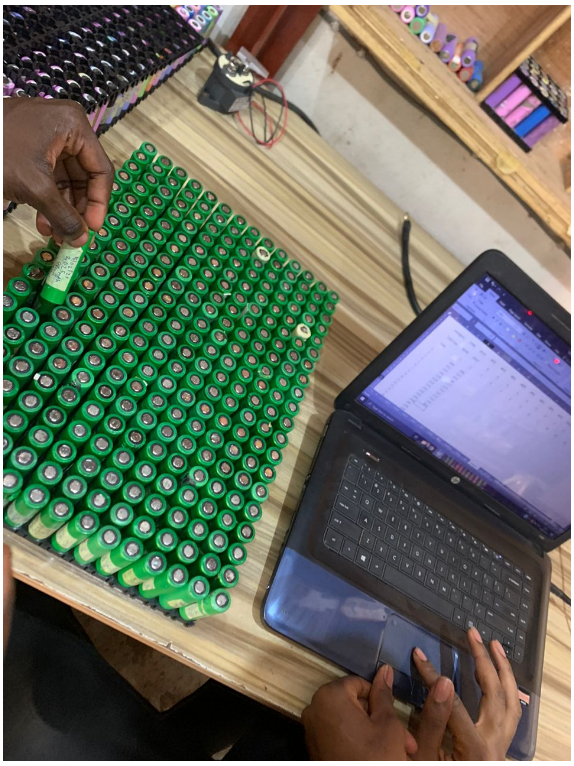

Figure 3.5: Module balancing in process

Figure 3.6: Battery Management System

very important in building a battery park due to the unsafe nature of lithium-ion batteries. Overcharging a lithium-ion cell can lead to Thermal Runaway. Thermal runaway occurs when the lithium-ion cell enters an uncontrollable self-heating state, here the cells generate heat at a rate faster than what it can dissipate which leads to combustion or explosion. The BMS helps to prevent this by stopping the battery from overcharging by cutting it off from the supply voltage when fully charged, it also controls discharge rates and isolates faulty cells.

A battery balancer is an electrical device that keeps the voltages of individual cells level, it does this by either discharging or charging the low or high cells until they all reach a uniform voltage.

There are three types of balancers which are,

- Resistive Balancer (Fig 3.8)
- Inductive Balancer
- Capacitive Balancer (Fig 3.7)

Figure 3.7: Capacitive Balancer

Figure 3.8: Resistive Balancer

3.3.6 Connection of the BMS and Balancer to the Battery Pack

The battery management system(BMS) and balancer to be used depend on the battery pack being designed, they should both be capable of accommodating the voltage and current given off by the battery. Now considering a single battery(module), a single battery with configuration 14S 20P has fifteen terminals (wires) with two main wires, one being positive and the other negative, the fifteen wires are connected straight to the balancer and BMS through connectors(Fig 3.9). The balancer only receives the fifteen wires from the battery but the BMS receives both the fifteen wires and the main negative wire of the battery, this enables the BMS to regulate and monitor the flow of current that enters and leaves the battery which allows for safe charging and discharging. It should be noted that the rating of the BMS and balancer determines the number of pins it has. So a BMS or balancer rated above 48V would have fourteen pins and more. The schematics of this is shown in Fig 3.10

Now in connecting the battery rack which has ten(10) Modules, a paralleling board which is a vero board is used. This board contains fifteen lines with fifteen connectors on it, each of the 15 wires from the battery is connected with the use of connectors to the paralleling board. The balancer and BMS are then connected to the paralleling board, this way the balancer and the BMS see the fifteen wires from the ten battery modules since all are connected to the paralleling board which serves as a busbar. In the connection, all the main positive terminals of batteries are connected to the positive busbar and all negative terminals to the negative busbar. The negative busbar is connected to the BMS just as how the negative terminal of a single battery module is connected.

3.4 FINAL ASSEMBLY AND PACKAGING

With respect to the aim of this project, a single battery pack contains 280 cells with the configuration 14S 20P. This single pack is covered all over by a transparent Perspex which is tightened with bolts, nuts and washers, this acts as the enclosed casing that houses the cells. The vero board which connects the pack to the busbar, battery management

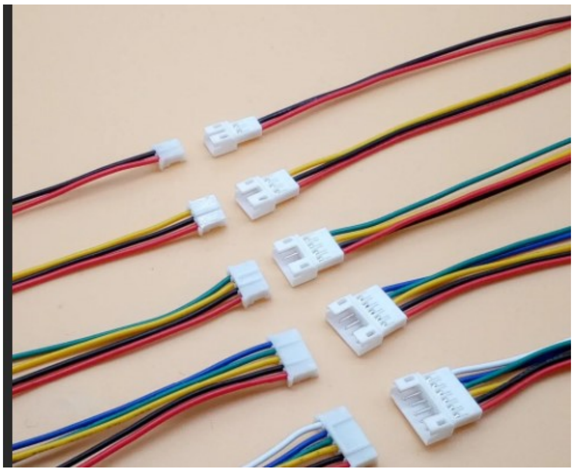

Figure 3.9: Connectors

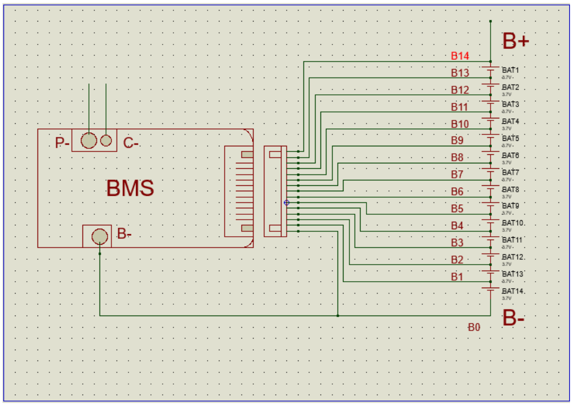

Figure 3.10: BMS Connection circuit diagram

system(BMS) and balancer is covered with kapton tape which is an insulating tape. The battery packs are then placed on a battery rack together.

3.5 SAFETY

In building a lithium-ion battery pack, certain safety measures must be taken in order to avoid damage to properties and harm to self as unsafe cells are used, such as;

- Insulate cells to stop them from short-circuiting, this can be done by covering the cell terminals with insulating materials (like Kapton tape).
- Cell Balancing: To achieve cell balancing, use a Battery Management System (BMS). When charging, keep an eye on each cell's voltage and make sure it's equal.

Some images of the desired design are shown in the figures below.

Figure 3.11: Pack showing the BMS, Balancer and Protection Relay

Figure 3.12: Full 10kWh Setup with Rack

Figure 3.13: 1kWh Battery Module

Figure 3.14: Side view

CHAPTER 4: CONSTRUCTION TESTING AND RESULTS

4.1 CONSTRUCTION

This project was built from useful cells of dead laptop batteries. The cell used was the lithium-ion (Li-ion) 18650 cell (18mm is the diameter of the cell, while 65mm indicates the length of the cell and 0 tells us it's circular in shape). The useful cells are placed on 14 by 20 spacers in the arrangement of 14 in series and 20 in parallel making it 280 cells mounted on the $18mm^2$ Insulated spacers. After testing was carried out on each cell and meeting the required specifications, the cells were attached one at a time.

The cells are connected in the arrangement of 14s and 20p; 14 cells in series going from the negative to the positive terminal of the batteries and 20 cells in parallel of same terminal. The cells are spot-welded carefully with nickel strips using the spot-welding machine from the positive to the negative terminals of the cells. This arrangement forms a pack of battery cells. Operating satisfactorily, the pack gives out approximately 1.5Ah as the range of cells used was within the range of 1000 to 2000mAh and has an estimated average of 1500mAh

4.1.1 SPOT WELDING AND SOLDERING

The spot welding was done on the terminals of the cells connecting the positive and negative terminals with the use of nickel strips. Soldering was done on the other end of the battery pack to connect the $0.05mm2$ copper wire to the terminals (negative to positive) of the battery which serves as a fuse, or a protective measure taken on the battery pack to isolate the connection when there is a short-circuit.

4.1.2 COUPLING

After the connection of the nickel stripes and fuse wires were done on the battery terminals with the use of the spot-welding machine and soldering iron, coupling takes place with the use of two rectangular perspex and $6mm^2$ bolts with 3 inches length nuts and washers to hold the two perspex having well-arranged battery cells on the spacers between them.

Figures 4.1 & 4.2 display the finished singular pack

Figure 4.1: Finished Singular Pack

Figure 4.2: Finished singular pack

4.1.3 CASING

9 other battery packs are made with the same previously stated process and arranged in a tall metallic casing. Each battery pack weighs about 13kg, making the total weight of 130kg for the 10 battery packs. The metallic case is employed in this scenario because it

can withstand and carry such a heavy load without any mechanical failure due to excessive stress. The case comprises 10 battery packs, a 14s balancer and a 14s BMS (battery management system)

4.2 TESTING AND RESULTS

Each cell of a battery pack was tested independently and underwent a Capacity test, an Internal resistance test, a Temperature test and a Self-discharge test. These tests are necessary tests carried out on each cell gotten from the dead batteries to determine the remaining useful life.

4.2.1 CAPACITY TEST

This test is carried out with the liito kala capacity testing machine where the cell is placed in the machine. This test checks the mAh (milliamp-hour) (capacity) of the cell. For this project, the accepted range for the cell capacity is about 1000mAh to 15000mAh. This is shown in Fig 4.3

Figure 4.3: liito kala capacity testing machine capacity test

4.2.2 INTERNAL RESISTANCE TEST

This test is carried out with the use of the internal resistance tester. This checks the internal resistance of each cell. For this project, the accepted internal resistance for each cell should be less than 130mohm. Within the range of 60mohms to 130mohms. Practically, the internal resistance of the reusable cells should not be more than 150% of the internal resistance of that same cell when it is brand new as shown in Fig 4.4.

Figure 4.4: Internal Resistance Tester

4.2.3 TEMPERATURE TEST

This test is carried out with the use of a thermometer when the cells are in use or are undergoing capacity testing. The accepted temperature of the cells should be less than 60 degrees Celsius. This test is very important as it prevents us from using cells that can get extremely hot when they are being used which could likely lead to an explosion or a fire outbreak.The thermometer used is displayed in Fig 4.5.

Figure 4.5: Thermometer

4.2.4 SELF DISCHARGE TEST

The nominal voltage of a cell is 3.7V while the voltage of a cell at full charge is 4.2V. After a full charge, the cells are left alone for about 2 weeks and their voltage are measured again. The voltage of the cells that remained unchanged at 4.2V or a little below that with a difference of about 0.2 are classified under low self-discharge cells. The low self-discharge cells are used for the project. While High self-discharge cells which are cells that discharged below 3.9V and won't be used for the project.

Results from all tests carried out can be seen in Table 4.1

4.3 DISCUSSION AND FINDINGS

A sample of 14 cells was tested as shown on the table above meeting the test requirement. For the capacity test, the accepted value for the project are cells of capacity ranging from 1000mAh to 1500mAh and for the Internal resistance test less than 150mOhns while for the self-discharge test within 4.0 to 4.2 volt as the nominal voltage is 3.7 and finally temperature test less than 60degree Celsius. Battery cells that do not meet this requirement are taken aside and not used for this project. 280 cells having similar requirements as shown

S/N	Capacity Test(mAh)	Internal Resistance test(mohm)	Self discharge test(volts)
1	1092	110	4.2
2	1112	120	4.15
3	1048	105	4.2
4	1357	101	4.19
5	1420	128	4.15
6	1325	108	4.11
7	1021	95	4.2
8	1450	98	4.01
9	1380	107	4.05
10	1230	109	4.18
11	1270	97	4.2
12	1114	129	4.18
13	1150	119	4.15
14	1498	115	4.09

Table 4.1: Results from the Capacity test, Internal resistance test, and Self Discharge test

in the table above are selected to form a pack and consecutively, 9 other packs are made with this same procedure.

The weight of each pack is 13kg and 10 packs are stacked on the casing or battery stand. The total weight of the packs on the battery stand or rack is 130kg. Each pack produces a minimum of 1.5kWh and the total 10 packs produce approximately 15kwh.

The depth of discharge carried out on the battery was 88.9%. For lithium-ion batteries, the voltage at the low side is 2.85V while the voltage on the high side is 4.2V at the cell level. At the battery pack level, the voltage at the low side is 39.9V and the voltage at the high side is 58.8V. Discharging from 58.8V to 39.9V is 100% depth of discharge, but for this project, we discharged from 58.8V to 42V making our depth of discharge 88.9%. For the monitoring, a capacitive tester was connected to the battery packs with an LCD screen displaying the number of hours the battery worked, the current being drawn, the voltage of the battery and most importantly the capacity of the battery. After it was all done, the capacity was 13.5kwh drawn from the 10pack batteries.

To investigate the advantages of Lithium-ion Battery chemistry over other battery chemistries, we did a side-by-side comparison of one of our modules() with the AJC 12V, 100Ah Sealed Lead-acid Battery()

Figure 4.6: 1 kilowatt-hour lithium-ion Module

Figure 4.7: 12V,100ah lead Acid battery

Our 1kwh module weighs 13kg while the lead acid battery capable of providing 1.2kwh of energy weighs about 31.2kg, carrying out simple calculations we can see that the lithium battery provides 77 watts per Kg while the lead acid battery provides just 38.5 watts per Kg meaning that the Lithium battery has a much higher energy density.

CHAPTER 5: CONCLUSION

After several rigorous, designs, fabrications and testing as discussed in the earlier chapters, we have been able to achieve our Aims and objectives as outlined below;

- After construction was complete the battery pack was put on load testing and the actual capacity was seen as 13.5 kilo-watt hour at a debt of discharge of 88.9% meaning at full discharge the capacity would be 15.2 kilowatt-hour, this is done to compensate for the age of the cells used in production and at the same time provide the customer with efficient energy storage well above the rated capacity.

5.1 CHALLENGES

1. The first hurdle during the process was the uncertainty in the viability of the cells obtained from old laptop batteries as well as the possibility of damaging the good cells during cell extraction.
2. The range in capacities of recovered cells makes it a little more challenging to carry out the balancing processes and also makes it more difficult for the balancer to ensure all cells are charged fully at the same time.
3. The weight of the overall battery pack including the rack makes it very difficult to transport from one place to another.

5.2 RECOMMENDATIONS

1. Use as small a range of capacities as possible to carry out your design, which will make balancing the pack easier and enable the 14s balancer to function effectively.
2. To enhance the mobility of the battery pack, different form factor racks can be experimented with, for example, using a horizontal rack with wheels and a handle for easy movement.

3. Each section of the rack used to hold individual modules should be equipped with rollers similar to the ones used in drawers to make sliding in and out of modules for maintenance or replacement purposes.

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