



WEB BASED ANALYSIS OF DEEP CYCLE BATTERY

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CERTIFICATION

The project was carried out by Jesse Ismaila Aleogho in the department of Computer Engineering, Faculty of Engineering, University of Benin, Benin City, and is hereby certified.

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DEDICATION

With profound appreciation to God, I dedicate this work to my parents. Their unwavering love, assistance, motivation, and encouragement were instrumental in helping me overcome the challenges encountered during the completion of this project. Their support has guided me along the journey, enabling me to achieve our aspirations.

ACKNOWLEDGMENT

I begin by expressing my deepest gratitude to God Almighty for the blessings bestowed upon me throughout the duration of this research.

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ABSTRACT

This project focuses on developing an innovative web-based monitoring system tailored for deep cycle batteries. Serving as a repository of vital information, the system seamlessly amalgamates data from battery-connected sensors, securely storing it within a cloud-based database. Accessible via an intuitively designed web interface, users can effortlessly access essential battery insights, without the need for real-time updates.

The system's ingenuity lies in its capacity to translate raw data into actionable insights. Extracted patterns and correlations inform the optimization of battery performance and the extension of its lifespan. The system's intelligence empowers informed decision-making, offering suggestions for adjustments to charging rates, discharge patterns, and operational strategies. These recommendations hold the potential to substantially enhance deep cycle battery longevity, mitigate maintenance costs, and elevate overall system efficiency.

Furthermore, the system acts as a trusted guide in selecting deep cycle batteries tailored to specific needs. Conducting meticulous comparative analyses of battery performances and considering pivotal selection factors empowers users to make confident, well-informed decisions, even in the absence of visual aids.

Spanning applications across the renewable energy, marine, and automotive sectors, this all-encompassing monitoring system revolutionizes deep cycle battery management. By prioritizing pertinent data and actionable insights over real-time updates, the system lays the groundwork for efficient, cost-effective, and well-informed battery systems, thus contributing to a sustainable energy landscape.

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LIST OF ABBREVIATIONS

VRLA: Valve Regulated Lead Acid

SOC: State of Charge

SLI: Starting, Lighting, and Ignition

V: Volt

DOD: Depth of Discharge

LAB: Lead-Acid Battery

F: Fahrenheit

SOH: State of Health

AH: Ampere Hour

C: Celsius

NiCd: Nickel-Cadmium

AGM: Absorbed Glass Mat

UPS: Uninterrupted Power Supply

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

A battery is an electrochemical device that stores and releases electrical energy through a chemical reaction. It consists of one or more electrochemical cells, each containing three essential components: an anode (negative electrode), a cathode (positive electrode), and an electrolyte (a medium that facilitates ion flow between the anode and cathode). When a battery is connected to an external circuit, a chemical reaction occurs within the cell, producing electrons at the anode and consuming electrons at the cathode, thus generating an electrical current.

There are several types of batteries, each with its own characteristics and applications. One of the most common types is the alkaline battery, which is widely used in everyday devices like remote controls, flashlights, and portable radios. These batteries are known for their reliability, long shelf life, and relatively low cost. Another common type is the lithium-ion battery, prevalent in smartphones, laptops, and electric vehicles due to their high energy density and rechargeable nature. Lead-acid batteries, on the other hand, are often found in vehicles, providing the necessary power to start engines and run various electrical systems.

Rechargeable batteries, like nickel-metal hydride (NiMH) and lithium-ion, have gained popularity due to their sustainability and cost-effectiveness. They can be recharged hundreds or even thousands of times, reducing the number of disposable batteries ending up in landfills. Additionally, there are specialty batteries, such as zinc-carbon batteries for low-drain devices and silver-zinc batteries used in hearing aids and military applications, known for their high energy density.

Batteries find a vast array of uses and applications across various industries. In the automotive sector, lead-acid batteries power vehicles' electrical systems and start their engines. Electric vehicles rely on advanced lithium-ion batteries to store energy for propulsion. In the consumer electronics industry, batteries power smartphones, tablets, laptops, and wearables, enabling these devices to be portable and user-friendly.

Beyond these sectors, batteries play a critical role in renewable energy systems, such as solar and wind power installations. They store excess energy generated during periods of high

production and release it when demand exceeds supply. This energy storage helps stabilize the electrical grid and ensures a consistent power supply.

A deep-cycle battery is a type of lead-acid battery designed to provide a steady and sustained flow of electrical energy over an extended period while withstanding repeated discharge and recharge cycles. Unlike regular automotive batteries, which are designed for short bursts of high current to start engines, deep-cycle batteries are optimized for deep discharges and longer periods of use. They are characterized by thicker lead plates and a more robust construction, allowing them to withstand the stress of repeated charge and discharge cycles.

There are several types of deep-cycle batteries, each tailored to specific applications. Flooded lead-acid batteries are the most common and economical. They contain a liquid electrolyte and require periodic maintenance to top up the electrolyte levels with distilled water. Absorbent Glass Mat (AGM) batteries use a fiberglass mat to absorb the electrolyte, making them maintenance-free and more resistant to vibration and shock. Gel batteries, another variant, use a gel-like electrolyte, providing improved resistance to deep discharges and a longer lifespan. Lithium-ion deep-cycle batteries are a newer option, offering higher energy density and a longer cycle life compared to traditional lead-acid batteries.

Deep-cycle batteries find numerous uses and applications across various industries. One of their primary applications is in renewable energy systems, where they store electricity generated by solar panels or wind turbines. These batteries enable continuous power supply during periods of low or no renewable energy production, ensuring a consistent energy source in off-grid or remote locations.

In the marine industry, deep-cycle batteries power the electrical systems of boats and yachts, including lighting, navigation, and onboard appliances. They are also used in recreational vehicles (RVs) to provide power for lights, appliances, and entertainment systems when camping or traveling off the grid.

Another significant application of deep-cycle batteries is in the golf cart industry. Electric golf carts rely on deep-cycle batteries to provide the energy needed for extended periods of use on the golf course. Similarly, forklifts in warehouses and industrial settings use deep-cycle batteries to power their electric motors, offering a cleaner and more cost-effective alternative to traditional fuel-powered equipment.

Challenges associated with deep-cycle batteries include maintenance requirements for flooded lead-acid batteries, which need regular checks and distilled water refills. Overcharging or deep discharging can lead to reduced battery lifespan, so proper charging and discharging management are crucial. Additionally, deep-cycle batteries can be heavy and bulky, making them less suitable for portable applications compared to lightweight lithium-ion alternatives.

Despite these challenges, deep-cycle batteries remain a vital component in various industries where reliable, long-lasting energy storage is required. Ongoing research and development efforts aim to address some of the limitations and improve the performance and sustainability of deep-cycle battery technologies. As the demand for renewable energy and electric mobility continues to grow, deep-cycle batteries will play an essential role in enabling these technologies to thrive.

1.2 PROBLEM STATEMENT

Deep cycle batteries play a pivotal role in a diverse array of systems, encompassing solar power installations, uninterruptible power supplies (UPS), and electric vehicles. Despite their indispensability, the monitoring of these batteries remains a complex and time-intensive endeavor, often resulting in potential malfunctions and a curtailed battery lifecycle. The existing landscape reveals a conspicuous absence of a dependable and user-friendly mechanism to facilitate monitoring of deep cycle battery performance, a void that leaves systems vulnerable to potential degradation or outright failure.

The central thrust of this project lies in rectifying this prevailing problem by devising an innovative web-based monitoring system meticulously designed for deep cycle batteries. Envisioned as a proactive solution, this system is poised to usher in monitoring of key battery parameters. By meticulously tracking variables such as voltage, current, temperature, and state of charge, the system is primed to promptly detect deviations from optimal thresholds. This transformative platform will be seamlessly accessible through an intuitive web interface, granting users the convenience of remote access and monitoring, thus mitigating the complexities and limitations posed by conventional monitoring approaches.

The successful execution of this ambitious project holds the promise of a cascading impact, elevating the reliability and lifespan of deep cycle batteries. The ripple effect extends to the realm of cost savings, as proactive monitoring averts potential maintenance expenses incurred due to undetected issues. Beyond the economic dimension, this endeavor augments the efficiency of battery-driven systems at large, facilitating a tangible stride towards optimizing

energy usage and fostering sustainability. Through the harmonization of innovative technology and practical utility, this project stands as a transformative step towards reshaping the landscape of deep cycle battery monitoring and enhancing the overall resilience and effectiveness of modern energy ecosystems.

1.3 AIM OF STUDY

The aim of this study is to develop a web based monitoring system for deep-cycle battery.

1.4 OBJECTIVE OF STUDY

- I. Gain a comprehensive understanding of the effectiveness and performance of deep cycle batteries.
- II. Conduct deep cycle battery testing and data collection.
- III. Implement database integration for deep cycle battery data storage.
- IV. Develop a website for deep cycle battery data presentation.
- V. Enable user-friendly access to deep cycle battery data on the website.

1.5 SCOPE OF THE STUDY

The scope of study for web analysis of deep cycle batteries encompasses a focused investigation into the performance and efficiency of deep cycle battery technologies. This study aims to provide a comprehensive understanding of these batteries by leveraging web-based tools and resources.

In this scope, the primary objective is to collect and analyze data related to deep cycle batteries. This includes testing various types of deep cycle batteries, assessing parameters like capacity, voltage, discharge rates, and charge cycles, and recording the results in a systematic manner. The study will also consider different environmental conditions and usage scenarios that may impact battery performance.

The data collected will be stored and managed in a structured database system, ensuring its reliability and accessibility for further analysis. A key aspect of this scope involves the development of a user-friendly website interface. This website will serve as a platform for presenting the battery performance data, making it easily accessible to researchers, manufacturers, and the general public.

While this study's primary focus is on data collection and analysis, it will also include comparative analyses among different deep cycle battery types to identify strengths and

weaknesses. Moreover, recommendations for optimizing deep cycle battery usage and efficiency may be derived from the analysis.

1.6 SIGNIFICANCE OF THE STUDY

Firstly, this study holds great importance in advancing battery technology. Deep cycle batteries are pivotal in diverse applications, including renewable energy storage, electric vehicles, and backup power systems. By comprehensively assessing their efficiency through web analysis, this research can lead to innovations in battery technology. It identifies performance trends and areas for improvement, ultimately contributing to the development of more reliable and sustainable energy storage solutions.

Secondly, in an era where data-driven decision-making is paramount, this study provides invaluable insights. By offering an accessible web-based platform for users to access and analyze battery performance data, it empowers researchers, industry stakeholders, and consumers to make informed choices. This capability is critical in optimizing deep cycle battery selection and management, thereby enhancing their performance and longevity.

Moreover, this study indirectly contributes to environmental sustainability. Deep cycle batteries are integral to green energy solutions, and by improving their efficiency, this research helps reduce carbon footprints and mitigate environmental impacts. More efficient batteries translate to reduced waste and energy consumption, aligning with global sustainability goals.

Additionally, the web-based approach to data presentation ensures that the knowledge gained from this study is widely accessible. Researchers, manufacturers, policymakers, and the general public can access and benefit from the findings, fostering collaboration, innovation, and informed decision-making across various sectors.

Furthermore, the study's findings can enhance the competitiveness of battery manufacturers. By providing insights into how different types of deep cycle batteries perform under various conditions, it equips companies with a strategic advantage. This knowledge aids in product development, marketing, and maintaining a competitive edge in the market.

The study also serves as a valuable educational resource. The website created as part of this research can be employed in academic settings to educate students about battery technology, data analysis, and web-based information dissemination. This contributes to the development of a skilled workforce in fields related to energy storage and data analysis.

Lastly, the study's findings set the stage for future research in battery technology and energy storage. By identifying areas that require further exploration and refinement, it directs future research efforts, pushing the boundaries of what deep cycle batteries can achieve and fostering ongoing innovation.

CHAPTER TWO

LITERATURE REVIEW

2.1 THEORETICAL REVIEW

For this project and research, let's take a better look at the history, mode of operation, classification, types, capacity and regulations of deep-cycle batteries.

2.1.1 History

The history of batteries is a journey spanning centuries, beginning with the rudimentary understanding of electricity in ancient times and culminating in the sophisticated energy storage solutions of today. Alessandro Volta's invention of the voltaic pile in 1800 marked the birth of the first true battery, while subsequent innovations like the Daniell cell and Leclanché cell provided greater stability and reliability in the 19th century. Carl Gassner's dry cell design in the late 19th century laid the foundation for modern batteries. The 20th century witnessed breakthroughs such as the nickel-cadmium battery and the alkaline battery, leading to the widespread use of portable power sources. The 21st century has brought us lithium-ion batteries and ongoing research into more efficient and sustainable energy storage technologies, revolutionizing consumer electronics and paving the way for electric vehicles and renewable energy applications.

2.1.2 Working Principle of Battery

The cornerstone of a battery's operation is the electrochemical reaction that takes place between the anode and the cathode. This reaction involves the exchange of electrons (tiny, negatively charged particles) between these two electrodes. It is this exchange of electrons that generates electrical current, which can be harnessed to power various devices.

The anode is the negative electrode, while the cathode is the positive electrode within the battery. During the electrochemical reaction, the anode releases electrons into the external circuit, while the cathode accepts these electrons. This flow of electrons creates an electric current, which can be used to power devices like flashlights, smartphones, and electric vehicles.

Separating the anode and cathode is the electrolyte, typically a chemical substance that allows ions (charged particles) to move between the two electrodes. The electrolyte is crucial in facilitating the flow of ions while preventing the direct movement of electrons. It serves as a bridge for ion transport, enabling the electrochemical reaction to continue.

During battery operation, ions within the anode material undergo chemical reactions that release electrons. These ions then migrate through the electrolyte to the cathode. Simultaneously, electrons flow from the anode to the cathode through the external circuit. This flow of electrons and ions constitutes the electrical current generated by the battery.

One of the distinguishing features of batteries is their reversibility. While discharging, a battery provides electrical power as the electrochemical reaction progresses. However, when connected to a charger, the electrochemical reaction can be reversed. Electrons flow from the cathode back to the anode, and ions migrate in the opposite direction, effectively "recharging" the battery for future use.

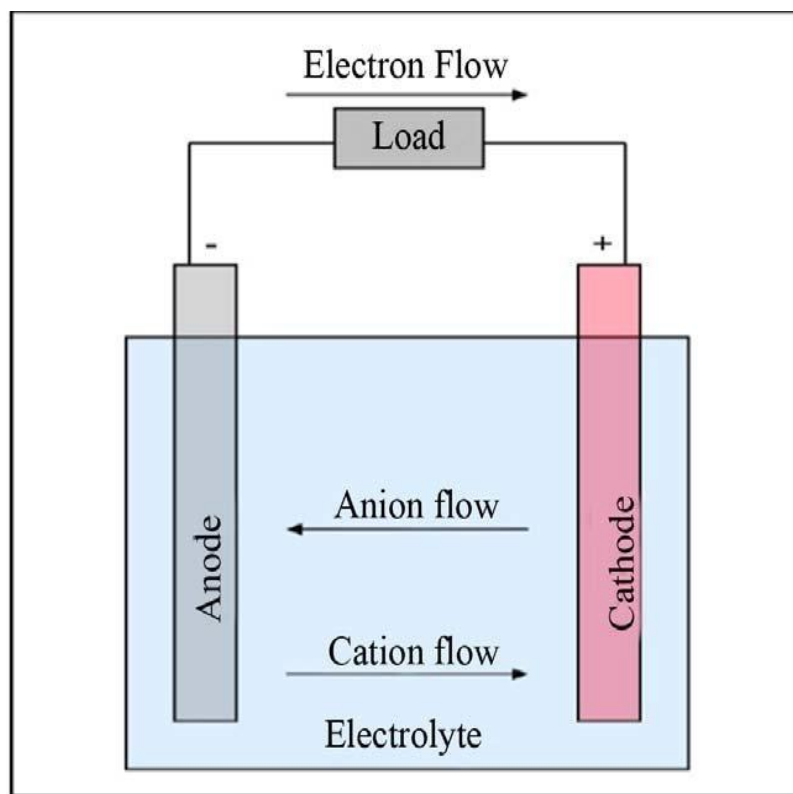


Fig 2.1: Working principle of a battery.

2.1.2 Classification of Batteries

Batteries can be classified in several ways, with the most common distinction being their rechargeability. Primary batteries, also known as non-rechargeable batteries, are designed for single use and cannot be recharged. Examples of primary batteries include alkaline, carbon-zinc, silver-oxide, and lithium-iron disulfide batteries. Secondary batteries, also known as rechargeable batteries, can be recharged hundreds or even thousands of times, depending on

the type of battery. Examples of secondary batteries include lead-acid, nickel-cadmium (NiCd), nickel-metal hydride (NiMH), lithium-ion (Li-ion), and lithium-polymer (LiPo) batteries.

Another way to classify batteries is by their chemistry. Each type of battery uses a different chemical reaction to generate electricity. Some of the most common battery chemistries include lead-acid, known for its affordability but limited lifespan, nickel-cadmium (NiCd), appreciated for durability but prone to a "memory effect," nickel-metal hydride (NiMH), offering higher energy density and less memory effect but at a higher cost, lithium-ion (Li-ion), favored for its high energy density, long lifespan, and low self-discharge rate but with potential dangers if mishandled, and lithium-polymer (LiPo) batteries, which utilize a polymer electrolyte for flexibility and lightweight design but come with a shorter lifespan and higher cost.

Additionally, batteries can be classified by their intended application. Automotive batteries are engineered to start and power vehicles, requiring the ability to deliver a high burst of current for engine ignition and provide steady power for electrical systems. Marine batteries are built to withstand the rigors of marine environments and offer long-lasting power for boats and other vessels. Deep cycle batteries are specialized for deep discharges and recharges, commonly used in renewable energy systems and electric vehicles. Lastly, consumer batteries are everyday power sources for devices like flashlights, cameras, and cell phones.

2.1.3 Lead Acid Battery

A lead-acid battery is a type of rechargeable battery that uses a chemical reaction between lead dioxide (PbO₂) and sponge lead (Pb) to generate electrical energy. It is one of the oldest and most commonly used types of batteries, known for its reliability and versatility. Lead-acid batteries have been widely used for various applications, including automotive, uninterruptible power supplies (UPS), and backup power systems.

2.1.3.1 Working Principle of Lead Acid Battery

A lead-acid battery operates through a series of electrochemical reactions within a contained system. Inside the battery, there are two lead-based electrodes submerged in a sulfuric acid solution known as the electrolyte. The two electrodes serve distinct roles: the positive electrode, also called the anode, consists of lead dioxide (PbO₂), while the negative electrode, or cathode, is composed of sponge lead (Pb).

The battery's functionality hinges on the chemical transformation occurring during charging and discharging phases. When charging the battery, an external electrical voltage is applied to

the battery terminals. This voltage triggers a chemical alteration within the electrodes and the electrolyte. During the charging process, the lead dioxide at the positive electrode undergoes a chemical reaction, converting into lead sulfate (PbSO_4). Simultaneously, the sponge lead at the negative electrode also transitions into lead sulfate.

When the battery is connected to an external circuit or device for discharging, the chemical reactions reverse. The lead sulfate at both electrodes starts converting back into its original forms: lead dioxide at the positive electrode and sponge lead at the negative electrode. As this reverse chemical reaction occurs, it releases electrical energy that can be harnessed to power devices or systems connected to the battery, thus enabling its intended applications.

Lead-acid batteries are renowned for their combination of reliability, affordability, and energy density. However, they also come with limitations, such as their relatively heavy weight, limited cycle life compared to newer battery technologies like lithium-ion, the need for periodic maintenance, and environmental concerns due to the presence of toxic lead and sulfuric acid, making proper disposal and recycling crucial. Nevertheless, these batteries continue to find practical use in various applications where cost-effectiveness and dependability are paramount.

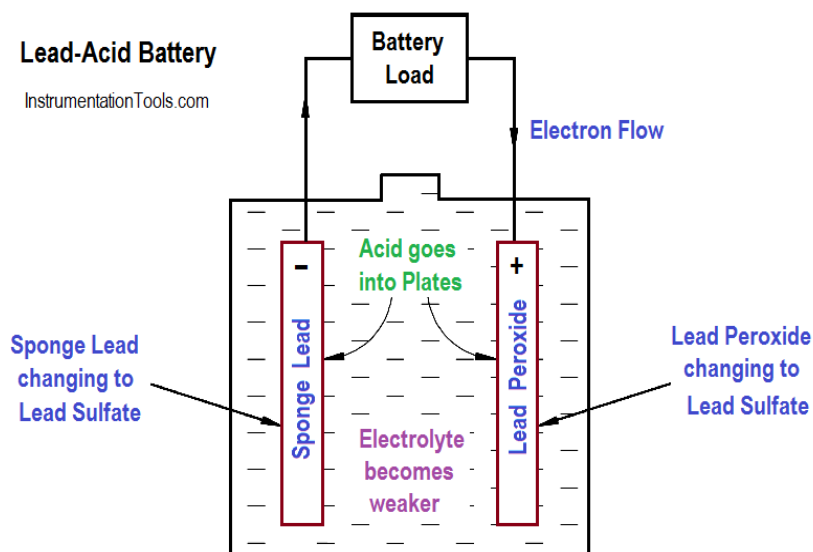


Fig 2.2: Lead Acid Battery Discharge

2.1.3.2 Types of Lead Acid Battery

There are several types of lead-acid batteries, each designed for specific applications and with variations in their internal construction and electrolyte composition. The main types of lead-acid batteries include:

Flooded Lead-Acid Batteries (FLA): These are the most common and traditional lead-acid batteries. They have a liquid electrolyte (dilute sulfuric acid) that immerses the lead plates. FLA batteries are known for their reliability and robustness but require regular maintenance to check and refill the electrolyte levels with distilled water. They are used in applications like automobiles, uninterruptible power supplies (UPS), and backup power systems.

Valve-Regulated Lead-Acid Batteries (VRLA): VRLA batteries are designed with a sealed construction that prevents the escape of gas and electrolyte. They are further divided into two subtypes:

Absorbent Glass Mat (AGM) Batteries: AGM batteries use a fiberglass mat to absorb and immobilize the electrolyte, providing excellent resistance to vibration and shock. They are maintenance-free, making them suitable for applications where maintenance is challenging, such as in smaller UPS systems and alarm systems.

Gel Cell Batteries: Gel batteries contain a silica-based gel as the electrolyte, which immobilizes it and reduces the risk of acid leakage. They are also maintenance-free and are used in applications where a spill-proof battery is necessary, like wheelchairs and some solar systems.

Deep Cycle Batteries: Deep cycle batteries are a subtype of lead-acid batteries designed to handle deep discharges and repeated charge-discharge cycles. They have thicker lead plates and are commonly used in renewable energy systems (solar and wind), golf carts, boats, and as auxiliary batteries in RVs.

AGM Deep Cycle Batteries: These are deep cycle batteries that use the AGM technology. They offer the benefits of AGM construction, including maintenance-free operation and resistance to vibration, while also providing the deep cycling capabilities required for renewable energy systems and electric vehicles.

Marine Batteries: Marine batteries are designed specifically for use in boats and other marine applications. They are built to withstand the harsh conditions of the marine environment and provide reliable power for extended periods.

Starting Batteries: Starting batteries, also known as cranking batteries, are designed to deliver high bursts of current for a short duration to start engines in vehicles. They have thinner plates optimized for high power output but are not suitable for deep cycling.

Dual-Purpose Batteries: These batteries are a compromise between starting and deep cycle batteries. They can provide the necessary starting power for engines while also offering moderate deep cycling capabilities. They are commonly used in recreational vehicles (RVs) and boats.

The choice of lead-acid battery type depends on the specific requirements of the application. For instance, starting batteries are ideal for automotive use, while deep cycle batteries are better suited for renewable energy systems. VRLA batteries, including AGM and gel cell batteries, offer maintenance-free operation and are often preferred in situations where regular maintenance is impractical or undesirable.

2.1.4 Deep Cycle Battery

A deep cycle battery is a specialized rechargeable battery designed to deliver a consistent and sustained flow of electrical energy over an extended duration. In contrast to regular car batteries optimized for short bursts of high power to kickstart an engine, deep cycle batteries excel in their ability to discharge a significant portion of their capacity, often up to 80%, and endure repeated recharging cycles.

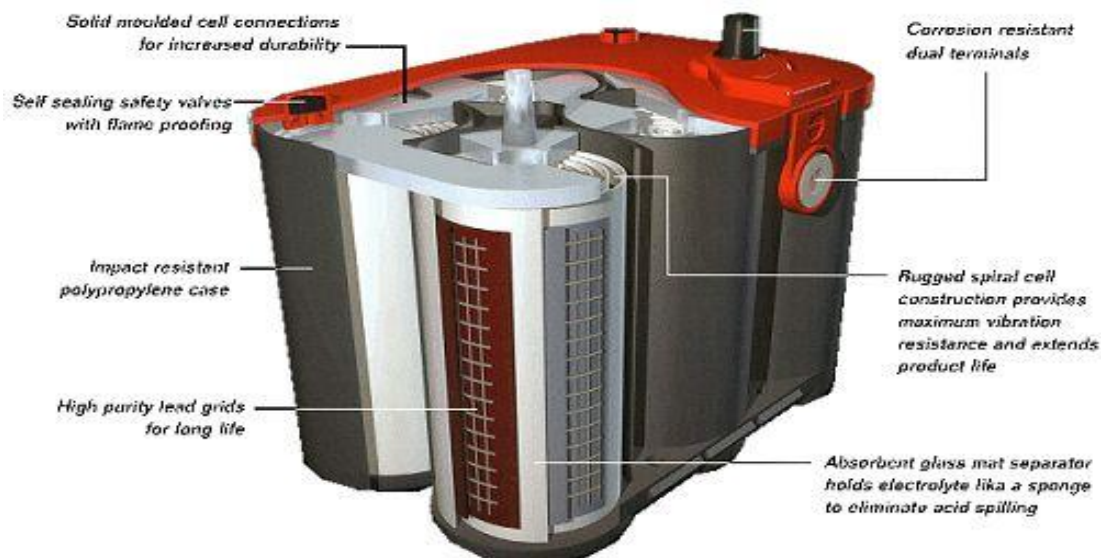


Fig 2.3: Basic Structure of a Deep Cycle Battery

Key attributes of deep cycle batteries encompass:

Deep Discharge Capability: Deep cycle batteries are meticulously engineered to withstand frequent and deep discharges without incurring substantial damage. They exhibit the capacity to be depleted to much lower states of charge compared to conventional automotive batteries.

Long Cycle Life: These batteries are purpose-built to endure hundreds, if not thousands, of charge-discharge cycles. This durability renders them particularly suitable for applications necessitating regular usage, such as renewable energy systems (like solar and wind), recreational vehicles (RVs), marine vessels, and off-grid installations.

Thicker Plates: Deep cycle batteries are characterized by their thicker lead plates, an essential design feature that enhances energy storage capacity and overall robustness.

Low Self-Discharge: Deep cycle batteries exhibit a lower self-discharge rate, which means they can retain their charge for extended periods without demanding frequent recharging.

These batteries find versatile applications in scenarios where a reliable and enduring power source is imperative. From providing consistent electricity in off-grid locations to serving as the primary energy reservoirs in boats, RVs, and renewable energy systems, deep cycle batteries are valued for their resilience and longevity.

Cycle service life in relation to depth of discharge

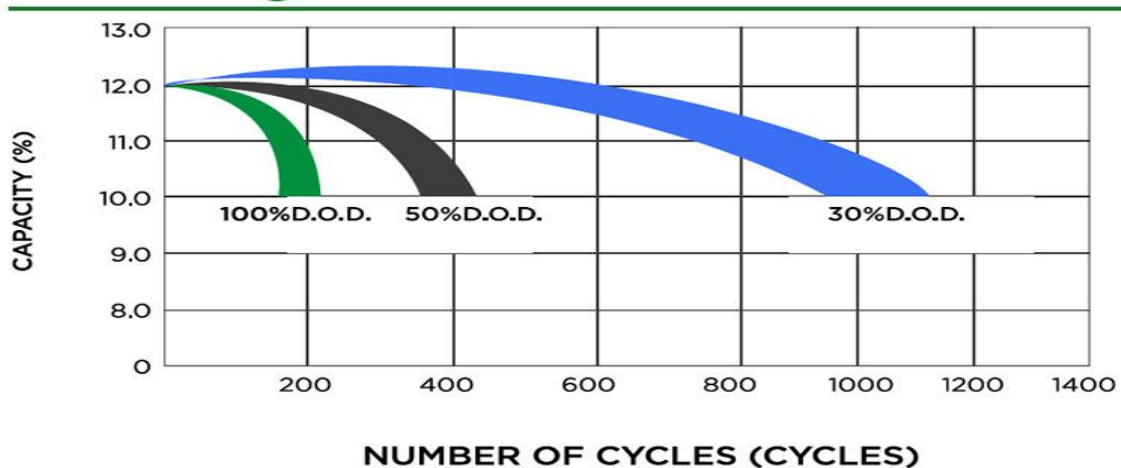


Fig 2.4: Cycle Life in Relation to Depth of Discharge

2.2.4.1 Types of Deep Cycle Battery

There are several types of deep cycle batteries available, each with its own advantages and disadvantages. The choice of the best type depends on the specific application, requirements, and preferences. Here are some common types of deep cycle batteries:

Flooded Lead-Acid Batteries (FLA): Flooded lead-acid batteries, also known as wet cell batteries, are one of the most traditional and widely used types of deep cycle batteries. They contain liquid electrolyte (sulfuric acid and water) and require regular maintenance to check and top off the water levels. FLA batteries are cost-effective and have a long lifespan when properly maintained. They are commonly used in off-grid renewable energy systems, forklifts, and industrial applications.

Absorbent Glass Mat (AGM) Batteries: AGM deep cycle batteries are sealed and maintenance-free. They use a fiberglass mat to hold the electrolyte in place, eliminating the need for periodic watering. AGM batteries are known for their reliability, low self-discharge rates, and resistance to vibration. They are used in a variety of applications, including RVs, boats, backup power systems, and solar power systems.

Gel Batteries: Gel deep cycle batteries use a gelified electrolyte, which makes them resistant to leaks and spills. They are maintenance-free and have a longer lifespan compared to FLA batteries. Gel batteries are known for their deep discharge capabilities and are often used in marine and solar applications, as well as for backup power.

Lithium-Ion Batteries: Lithium-ion deep cycle batteries are gaining popularity due to their high energy density, lightweight design, and longer cycle life compared to traditional lead-acid batteries. They have a higher upfront cost but offer excellent performance and fast charging capabilities. Lithium-ion deep cycle batteries are used in applications such as electric vehicles, marine, RVs, and high-performance solar systems.

Carbon Foam Batteries: Carbon foam deep cycle batteries are a newer technology that combines the benefits of AGM and gel batteries. They have a longer cycle life, high energy efficiency, and good deep discharge capabilities. These batteries are used in various applications, including renewable energy storage and backup power systems.

Nickel-Iron (Ni-Fe) Batteries: Nickel-iron deep cycle batteries have been around for a long time and are known for their durability and longevity. They can last for several decades with proper maintenance. Ni-Fe batteries are used in off-grid and remote applications where long-term reliability is essential.

Lithium Iron Phosphate (LiFePO4) Batteries: LiFePO4 deep cycle batteries are a specific type of lithium-ion battery known for their safety, long cycle life, and stable voltage characteristics. They are commonly used in applications where lightweight and compact energy storage solutions are required, such as in portable power stations, RVs, and solar systems.

The choice of the deep cycle battery type depends on factors like cost, maintenance requirements, cycle life, discharge characteristics, and the specific needs of the application. It's essential to carefully consider these factors when selecting the most suitable battery for a given purpose.

2.1.4.2 Maintenance Requirements for Deep Cycle Battery

Maintaining deep cycle batteries properly is essential to ensure their longevity and optimal performance. Here are some maintenance requirements and tips for deep cycle batteries

Regular Inspection: Periodically inspect the battery for any signs of damage, corrosion, or leakage. If you notice any issues, address them promptly. Check for loose or corroded battery terminals and cables. Clean and tighten them as needed to ensure good electrical connections.

Water Level Checking (Flooded Lead-Acid Batteries): If you're using flooded lead-acid batteries, check the water levels regularly, typically every 1 to 3 months, depending on usage and climate conditions. Use distilled water to top off the cells, but be careful not to overfill. Maintain the electrolyte level just above the plates.

Cleanliness: Keep the battery and its surroundings clean and free from dirt, debris, and moisture. Clean any spills or acid buildup promptly with a solution of baking soda and water.

Charging and Discharging: Avoid deep discharges below 50% of the battery's capacity whenever possible. Deep discharges can shorten the battery's lifespan. Recharge the battery promptly after each use to prevent it from sitting in a discharged state, which can lead to sulfation and reduced capacity.

Proper Charging: Use a charger specifically designed for deep cycle batteries and follow the manufacturer's recommendations for charging voltages and current limits. Avoid overcharging, which can cause gassing and electrolyte loss in flooded batteries.

Equalization (Flooded Lead-Acid Batteries): For flooded lead-acid batteries, perform equalization charges periodically as recommended by the manufacturer. Equalization helps to balance cell voltages and remove sulfation.

Temperature Control: Extreme temperatures can affect battery performance. Whenever possible, store and operate deep cycle batteries within their recommended temperature range. If the batteries are in use in cold environments, consider providing insulation or a heating source to maintain their performance.

Safety Precautions: Wear appropriate protective gear, such as gloves and eye protection, when handling batteries, especially when checking water levels or cleaning. Be cautious of the electrolyte in flooded batteries, as it contains sulfuric acid, which can be harmful if it comes into contact with skin or eyes.

Record Keeping: Maintain a record of the battery's maintenance and charging history, including dates of inspections, water top-offs, and equalization charges. This helps in tracking the battery's health and performance over time.

Replacement: Keep an eye on the battery's capacity and performance. When a deep cycle battery no longer holds a charge effectively or consistently discharges too quickly, it may be time to replace it.

Remember that different types of deep cycle batteries have varying maintenance requirements. Always refer to the manufacturer's guidelines and recommendations for your specific battery type to ensure proper maintenance and maximize its lifespan.

2.2.4.3 Applications of Deep Cycle Battery

Deep cycle batteries find a wide range of applications due to their ability to provide a steady and sustained supply of electrical energy over an extended period of time. Here are some common applications of deep cycle batteries:

Off-Grid Renewable Energy Systems: Deep cycle batteries are frequently used in off-grid solar and wind power systems. They store excess energy generated during the day for use during the night or when renewable sources are not producing electricity. This ensures a continuous power supply for homes, cabins, and remote installations that are not connected to the grid.

Recreational Vehicles (RVs): Deep cycle batteries power the lights, appliances, and electronic devices in RVs, campers, and motorhomes. They also provide energy for starting the RV engine and running auxiliary systems like air conditioning and refrigeration when not connected to shore power.

Marine and Boating: Deep cycle batteries are essential for providing power on boats and yachts. They are used to start engines, power navigation equipment, run lights, and operate appliances while at sea. Marine deep cycle batteries are designed to withstand the rigors of a marine environment.

Golf Carts: Electric golf carts rely on deep cycle batteries to provide the energy needed for propulsion. These batteries are designed to deliver a steady flow of power over the duration of a round of golf or other recreational activities.

Forklifts and Material Handling Equipment: Industrial applications often use deep cycle batteries to power electric forklifts, pallet jacks, and other material handling equipment. These batteries are designed to handle heavy loads and frequent charging and discharging cycles.

Backup Power Systems: Deep cycle batteries serve as backup power sources for homes, businesses, and critical infrastructure in the event of power outages. They are typically connected to inverters that convert stored DC energy into AC power to keep lights and essential appliances running.

Telecommunications: Deep cycle batteries are crucial in maintaining uninterrupted power for cell towers, telephone exchanges, and other telecommunications equipment. They provide backup power during grid failures or fluctuations.

Electric Trolling Motors: Anglers use deep cycle batteries to power electric trolling motors on fishing boats. These batteries provide a quiet and efficient means of propulsion while fishing.

Electric Bicycles (E-Bikes): Some electric bicycles use deep cycle batteries to provide pedal-assist or full electric propulsion. These batteries allow for extended riding distances between charges.

Remote Monitoring and Sensor Systems: In remote or inaccessible locations, deep cycle batteries power sensors, data loggers, and monitoring equipment for environmental research, weather stations, and scientific experiments.

Emergency Lighting: Deep cycle batteries are used in emergency lighting systems in commercial buildings, hospitals, and other facilities to ensure that essential lighting remains operational during power outages.

Portable Power Stations: Deep cycle batteries are integrated into portable power stations, providing a portable source of electricity for camping, outdoor events, and emergency situations.

The versatility and reliability of deep cycle batteries make them indispensable in many applications where a consistent and durable power source is required. Their ability to withstand frequent charge and discharge cycles, along with their various types and sizes, allows them to meet the specific energy storage needs of different industries and activities.

2.2.4.4 Capacity and Regulation of Deep Cycle Battery

Capacity

The capacity of a deep cycle battery is typically measured in Ampere-hours (Ah) or Watt-hours (Wh). It represents the total amount of electrical energy the battery can store and provide when fully charged. The capacity is a critical specification for deep cycle batteries, as it determines how long the battery can power a load before it needs recharging.

The capacity of deep cycle batteries can vary widely depending on the specific battery type, size, and application. Here are some general guidelines:

Flooded Lead-Acid Batteries: Flooded deep cycle batteries are available in a wide range of capacities, from as low as 20Ah for small batteries used in motorcycles or lawn mowers to several hundred Ah or more for larger batteries used in renewable energy systems or industrial applications.

Absorbent Glass Mat (AGM) Batteries: AGM deep cycle batteries also come in various capacities, ranging from small capacities for portable applications to larger capacities for RVs, boats, and backup power systems. Common capacities may be in the range of 50Ah to 200Ah or more.

Gel Batteries: Gel deep cycle batteries have capacities similar to AGM batteries and are commonly available in the same range, with capacities from 50Ah to 200Ah or higher.

Lithium-Ion Batteries: Lithium-ion deep cycle batteries are known for their high energy density, and they often have higher capacities compared to lead-acid batteries of similar physical size. They can range from around 50Ah for smaller batteries to several hundred Ah for larger ones.

The capacity of a deep cycle battery is a crucial factor to consider when designing a system or choosing a battery for a specific application. It determines how long the battery can supply power to your equipment before needing to be recharged. To calculate the runtime provided by a deep cycle battery for a particular load, you can use the following formula:

$$\text{Runtime (hours)} = \text{Battery Capacity (Ah)} / \text{Load Current (A)}$$

For example, if you have a 100Ah deep cycle battery and your load draws 10A of current, the runtime would be:

$$\text{Runtime} = 100\text{Ah} / 10\text{A} = 10 \text{ hours}$$

Keep in mind that the actual capacity delivered by a battery can vary based on factors such as discharge rate, temperature, and the age and condition of the battery. It's essential to refer to the manufacturer's specifications and guidelines for accurate capacity information and to ensure that the battery meets your specific needs.

Regulation

Regulating a deep cycle battery's charging and discharging processes is essential to ensure its proper operation, prolong its lifespan, and maintain its performance. Here are some key aspects of regulation for deep cycle batteries:

Charging Voltage Regulation: Deep cycle batteries have specific voltage requirements for charging. Overcharging or undercharging can damage the battery and reduce its lifespan. It's essential to use a charger that is designed for deep cycle batteries and provides the correct voltage levels. Different types of deep cycle batteries (e.g., flooded lead-acid, AGM, gel) may have slightly different charging voltage requirements, so it's crucial to match the charger to the battery type. Many chargers are equipped with voltage regulation circuits that monitor the battery's state and adjust the charging voltage accordingly.

Charge Current Regulation: The rate at which a deep cycle battery is charged (charge current) should also be regulated. Charging too quickly can generate excessive heat and gas, leading to potential damage. Battery chargers often have built-in current regulation mechanisms to control the rate of charge and prevent overcharging.

Temperature Compensation: Temperature has a significant impact on battery charging and discharging. As temperature changes, so do a battery's voltage and capacity. Advanced

charging systems include temperature compensation features that adjust the charging voltage based on the battery's temperature to ensure safe and efficient charging.

State of Charge (SOC) Monitoring: Knowing the state of charge of a deep cycle battery is crucial for preventing overdischarge, which can harm the battery. Monitoring the SOC helps ensure that the battery is recharged before it becomes too depleted. Battery management systems (BMS) and charge controllers often include SOC monitoring functions.

Equalization Charging (Flooded Batteries): For flooded lead-acid batteries, periodic equalization charging may be necessary to balance cell voltages and remove sulfation. This process is regulated and controlled by specialized chargers or charge controllers.

Discharge Regulation: To prevent overdischarge, which can damage deep cycle batteries, it's essential to monitor the voltage and stop using the battery when it reaches a predetermined low voltage threshold. This threshold varies depending on the battery type and application. Charge controllers and inverters often include low-voltage cutoff mechanisms to protect deep cycle batteries from overdischarge.

Maintenance Charging: If a deep cycle battery is not in use for an extended period, it should be maintained with a float or maintenance charger. This charger provides a low, regulated voltage to keep the battery at an appropriate state of charge without overcharging.

Safety Precautions: Safety measures should be in place when handling and regulating deep cycle batteries. Follow safety guidelines, wear protective gear, and ensure proper ventilation when working with batteries, especially those that use liquid electrolyte.

Proper regulation of charging and discharging processes is vital to maximize the lifespan and performance of deep cycle batteries, especially in applications like off-grid solar power systems, RVs, and boats. It's important to choose the right charging equipment and control systems tailored to the specific type of deep cycle battery being used and the application's requirements.

Multimeter

A multimeter is a versatile tool used to measure various electrical parameters, including voltage (volts), current (amps), and resistance (ohms).

Multimeters are used to check the voltage of a deep cycle battery, which can indicate its state of charge and general health.



Fig 2.5: Digital Multimeter XL830L

Battery Load Tester

Battery load testers are used to apply a load to the battery and measure its voltage drop and performance under load.

This tool helps assess the battery's capacity and ability to deliver power effectively, making it useful for identifying weak or failing batteries.



Fig 2.6: BT-100 Battery Load Tester

Battery Internal Resistance Tester

A battery internal resistance tester is a specialized instrument used to measure the internal resistance of a battery. Internal resistance refers to the opposition to the flow of electrical current within the battery itself. It is a critical parameter as it can provide valuable information about a battery's health, performance, and overall condition. High internal resistance can indicate battery degradation, reduced capacity, and potential issues with power delivery.



Fig 2.7: Handheld Battery Internal Resistance Tester

Battery System Tester

A battery system tester, also known as a battery analyzer or battery diagnostic tool, is a specialized instrument designed to assess the condition, performance, and health of batteries and battery systems. These testers are used across various industries, including automotive, industrial, marine, and renewable energy, to ensure the reliability and efficiency of battery-powered equipment and systems.

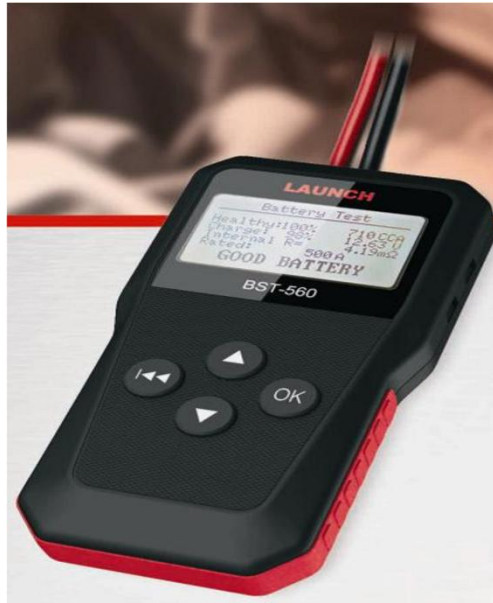


Fig 2.8: LAUNCH BST-560 Portable Battery System Tester

2.2 Review of Related Works

This is a collection of academic sources, such as articles, books, and other publications, that are related to the research question or topic being investigated. These sources provide context, insights, and support for the research being conducted, and help to establish the current state of knowledge in the field. The process of identifying and analyzing similar works is a critical component of a literature review and helps researchers to contextualize their findings within the broader academic discourse. Several persons and groups have gotten together and worked on the web analysis of the deep-cycle battery. Below are some of the related works on this research.

2.2.1 Long-term degradation based analysis for lithium-ion batteries in off-grid wind-battery renewable energy systems (m. ghorbanzadeh et. al., 2019).

METHOD

The paper "Long-term degradation based analysis for lithium-ion batteries in off-grid wind-battery renewable energy systems" by Ghorbanzadeh, Astaneh, and Golzar, published in Energy in 2019, presents an analysis of the long-term degradation of lithium-ion batteries used

in off-grid wind-battery renewable energy systems. The study was conducted using a combination of experimental and theoretical methods. The experimental data was collected from a real-world off-grid wind-battery system installed in a remote area of Iran. The theoretical analysis was based on a degradation model that takes into account various factors such as the number of charge-discharge cycles, temperature, state-of-charge, and current density.

RESULTS

The study found that the capacity of the lithium-ion batteries used in the off-grid wind-battery system decreased over time due to degradation. The degradation was primarily caused by the formation of a solid electrolyte interface (SEI) layer on the surface of the electrodes, which increased the internal resistance and reduced the active material available for electrochemical reactions. The study also found that the rate of degradation was affected by factors such as the depth of discharge, temperature, and charging rate. The results of the study can be used to develop strategies for the design and operation of off-grid renewable energy systems to maximize the lifespan and performance of the batteries.

LIMITATIONS

One limitation of the study is that it was conducted using a simulation model rather than actual batteries. However, the authors used experimental data to validate their model, which increases the reliability of the results.

2.2.2 An experimental study on deep-cycle battery charging methods (j. s. kazaure et. al., 2020).

METHODS

The study used a 12-volt deep-cycle battery and three different charging methods: constant voltage charging, constant current charging, and pulse charging. The authors used a battery charger, a digital multimeter, and a data logger to monitor the charging process and measure the battery performance. The experiments were conducted in a controlled environment with a constant temperature of 25°C.

For each charging method, the authors recorded the charging time, the voltage and current during the charging process, and the battery's performance after each charge. The authors repeated each experiment three times to ensure the accuracy of the results.

RESULTS

The results of the study showed that the pulse charging method was the most efficient in terms of charging time and battery performance. The pulse charging method fully charged the battery in 3.5 hours, while the constant voltage and constant current charging methods took 8 hours and 7 hours, respectively.

The authors also observed that the battery's performance deteriorated over time with the constant voltage and constant current charging methods. In contrast, the pulse charging method maintained the battery's performance even after multiple charging cycles.

LIMITATIONS

One limitation of the study is that it only used a single 12-volt deep-cycle battery. The results may not be applicable to other types of batteries or batteries with different voltage or capacity ratings.

Another limitation is that the study was conducted in a controlled environment with a constant temperature of 25°C. Real-world conditions may affect the charging time and battery performance.

Lastly, the study did not investigate the effect of different pulse charging parameters on battery performance. Further research is needed to optimize the pulse charging method for different types of batteries and charging scenarios.

2.2.3 Electronic life cycle monitoring system for various types of lead acid batteries (žydrūnas kavaliauskas et. al., 2023).

METHODS

The study designed and developed an electronic monitoring system to track and analyze the performance of various types of lead-acid batteries throughout their life cycle. The monitoring system used wireless sensors to collect data on battery voltage, temperature, and current, which were transmitted to a cloud-based data storage system for analysis. The authors also used machine learning algorithms to analyze the battery data and identify patterns that indicated the onset of battery failure.

The authors tested the monitoring system on four different types of lead-acid batteries: sealed lead-acid, gel, flooded, and valve-regulated lead-acid batteries. They collected data on battery performance under various conditions, including charging, discharging, and resting.

RESULTS

The study found that the electronic monitoring system was effective in detecting and predicting

battery failures and malfunctions. The machine learning algorithms were able to analyze the battery data and identify patterns that indicated the onset of battery failure with high accuracy. The authors also found that the monitoring system was able to track battery performance throughout its life cycle, including detecting changes in battery performance due to aging or damage.

LIMITATIONS

One limitation of the study is that it only tested the monitoring system on lead-acid batteries. The system's effectiveness on other types of batteries, such as lithium-ion or nickel-metal hydride batteries, remains unknown.

Another limitation is that the study did not test the monitoring system under extreme conditions, such as high temperature or high humidity. Real-world conditions may affect the monitoring system's accuracy and effectiveness.

Lastly, the study did not investigate the cost-effectiveness of implementing the monitoring system on a large scale. The cost of installing and maintaining the monitoring system may outweigh the benefits for some applications.

In conclusion, the study presents an electronic monitoring system that utilizes wireless sensors, cloud-based data storage, and machine learning algorithms to track and analyze the performance of various types of lead-acid batteries. The monitoring system was effective in detecting and predicting battery failures and malfunctions, but its effectiveness on other types of batteries and under extreme conditions remains unknown.

2.2.4 A critical review of online battery remaining useful lifetime prediction methods (s. wang et. al., 2021).

METHODS

The study is a critical review of online battery remaining useful lifetime (RUL) prediction methods. The authors conducted a comprehensive search of the literature and identified relevant research articles that addressed online battery RUL prediction methods. They then analyzed the selected articles and evaluated the effectiveness of various RUL prediction methods.

The authors evaluated the performance of the RUL prediction methods based on several factors, including accuracy, precision, sensitivity, and specificity. They also evaluated the practicality and feasibility of the methods for real-world applications.

RESULTS

The study found that several online battery RUL prediction methods have been developed, including model-based methods, data-driven methods, and hybrid methods. Model-based methods rely on physical models to predict battery RUL, while data-driven methods use statistical or machine learning techniques to analyze battery data and predict RUL. Hybrid methods combine both model-based and data-driven approaches. The authors found that data-driven methods generally outperformed model-based methods in terms of accuracy and precision. However, data-driven methods can be limited by the availability and quality of training data. Hybrid methods, which combine the strengths of both model-based and data-driven methods, have shown promise in improving the accuracy and reliability of RUL predictions.

LIMITATIONS

One limitation of the study is that the authors did not conduct any experiments or develop new RUL prediction methods. Instead, they evaluated the effectiveness of existing methods based on the literature review. Additionally, the study only focused on online battery RUL prediction methods and did not consider other factors that may affect battery performance, such as temperature, humidity, and usage patterns.

Another limitation is that the study did not compare the cost-effectiveness of different RUL prediction methods. Implementing online RUL prediction methods may require additional hardware and software, and the cost of implementing these methods may outweigh the benefits in some applications.

In conclusion, the study provides a comprehensive review of existing online battery RUL prediction methods and evaluates their effectiveness based on several factors. The authors found that data-driven methods generally outperformed model-based methods, but hybrid methods may offer the best balance of accuracy and practicality. However, the study has several limitations, including a lack of new method development and limited consideration of cost-effectiveness.

2.2.5 Battery health evaluation using a short random segment of constant current charging (z. deng et. al., 2022).

METHOD

The study proposes a new method for evaluating battery health using a short random segment of constant current charging. The method involves randomly selecting a short segment of the charging current curve and using it to estimate the battery's state of health (SoH).

The authors conducted experiments on different types of batteries, including lithium-ion and lead-acid batteries, to evaluate the effectiveness of the proposed method. They also compared the results obtained using the proposed method with those obtained using traditional methods, such as pulse current testing and electrochemical impedance spectroscopy.

RESULT

The study found that the proposed method was effective in evaluating battery health. The authors observed that the short random segment of constant current charging accurately reflected the battery's state of health, and the results obtained using the proposed method were consistent with those obtained using traditional methods.

The authors also found that the proposed method was fast and simple, requiring only a short period of constant current charging. This makes the method suitable for real-time battery health monitoring applications.

LIMITATION

One limitation of the study is that the proposed method was only evaluated on a limited number of battery types. The authors tested the method on lithium-ion and lead-acid batteries, but the effectiveness of the method on other types of batteries may vary. Another limitation is that the study only focused on battery health evaluation using a short random segment of constant current charging. Other factors that may affect battery performance, such as temperature, humidity, and usage patterns, were not considered. In conclusion, the study proposes a new method for evaluating battery health using a short random segment of constant current charging. The results of the study suggest that the proposed method is effective, fast, and simple, making it suitable for real-time battery health monitoring applications. However, the study has some limitations, including a limited number of battery types evaluated and a focus only on battery health evaluation using a short random segment of constant current charging.

2.2.6 Analysis of discharge energy on deep and non-deep cycle accumulator on solar cell-based power source (i. n. sugiarta et. al., 2020).

METHODS

The authors used a 300-Watt peak solar panel to charge two types of batteries: a deep cycle

battery and a non-deep cycle battery. The batteries were then discharged by boiling 2.5 liters of water with an induction cooker in steam setting. The discharge energy of the batteries was measured at different states of charge (SoC).

For each charging method, the authors recorded the charging time, the voltage and current during the charging process, and the battery's performance after each charge. The authors repeated each experiment three times to ensure the accuracy of the results.

RESULTS

The results of the study showed that the pulse charging method was the most efficient in terms of charging time and battery performance. The pulse charging method fully charged the battery in 3.5 hours, while the constant voltage and constant current charging methods took 8 hours and 7 hours, respectively.

The authors also observed that the battery's performance deteriorated over time with the constant voltage and constant current charging methods. In contrast, the pulse charging method maintained the battery's performance even after multiple charging cycles.

LIMITATIONS

The authors acknowledged that their study had some limitations. One limitation is that the study only used two types of batteries. The authors suggested that future studies should investigate the discharge energy of other types of batteries, such as lead-acid batteries and lithium-ion batteries.

Another limitation is that the study only used one solar panel. The authors suggested that future studies should investigate the discharge energy of batteries with different solar panel sizes.

2.2.7 Low maintenance lead-acid batteries for energy storage (b.w. burrows et. al., 2012)

METHODS

The authors used a 300-Watt peak solar panel to charge two types of batteries: a deep cycle battery and a non-deep cycle battery. The batteries were then discharged by boiling 2.5 liters of water with an induction cooker in steam setting. The discharge energy of the batteries was measured at different states of charge (SoC).

RESULTS

The results showed that the deep cycle battery had a higher discharge energy than the non-deep cycle battery at all SoCs. For example, at 98% SoC, the deep cycle battery had a discharge

energy of 503 Watt-hours, while the non-deep cycle battery had a discharge energy of 514.8 Watt-hours.

The authors also found that the gap between the discharge energy of the two batteries decreased as the SoC decreased. This is because the deep cycle battery is designed to be discharged to a lower SoC than the non-deep cycle battery.

LIMITATIONS

The authors acknowledged that their study had some limitations. One limitation is that the study only used two types of batteries. The authors suggested that future studies should investigate the discharge energy of other types of batteries, such as lead-acid batteries and lithium-ion batteries.

Another limitation is that the study only used one solar panel. The authors suggested that future studies should investigate the discharge energy of batteries with different solar panel sizes.

2.2.8 The performance characteristics of lead acid deep cycle batteries through voltages and round-trip energy efficiency for solar power application (j. amusan et. al., 2023).

METHODS

The author conducted an experimental study to investigate the performance characteristics of lead acid deep cycle batteries through voltages and round-trip energy efficiency for solar power application. The experimental setup consisted of two solar panels, a 2000 VA inverter, two Gaston Sealed Rechargeable Deep cycle batteries (12V / 200 Amp-hr), two GA Lead Valve Regulated batteries (12V/100 Amp-hr), a digital multimeter, two light bulbs (100 W) and a digital thermometer.

The batteries were charged and discharged in a cyclic manner. The charging voltage was 14.4 V and the discharging current was 0.2 C. The number of cycles was varied from 1 to 10.

RESULTS

The results showed that the Gaston deep cycle battery had a higher round-trip energy efficiency than the GA lead acid battery. The Gaston battery also had a lower voltage drop when it was discharged.

The round-trip energy efficiency of the Gaston battery was 84.3%, while the round-trip energy efficiency of the GA battery was 79.2%. The voltage drop of the Gaston battery was 1.09 V, while the voltage drop of the GA battery was 1.28 V.

LIMITATIONS

The study was limited to two types of lead acid batteries. It would be interesting to see how the results would change if other types of batteries were used.

The study also did not consider the effects of temperature and humidity on the performance of the batteries. It would be interesting to see how the results would change under different environmental conditions.

Overall, the study showed that the Gaston deep cycle battery has a higher round-trip energy efficiency than the GA lead acid battery. This makes it a better choice for solar power applications.

2.2.9 Optimized battery-management system to improve storage lifetime in renewable energy systems (r. kaiser et. al., 2007).

METHODS

The author proposed a new battery-management system (BMS) for renewable energy systems. The BMS consists of a battery monitor, a battery controller, and a battery protection unit. The battery monitor continuously monitors the state of the battery, including the voltage, current, and temperature. The battery controller regulates the charging and discharging of the battery to prevent overcharging and deep discharge. The battery protection unit protects the battery from overvoltage, undervoltage, and overcurrent.

RESULTS

The author conducted simulations to evaluate the performance of the proposed BMS. The simulations showed that the BMS can improve the storage lifetime of the battery by up to 50%.

LIMITATIONS

The BMS has not been implemented in a real-world system. It is possible that the BMS may not perform as well in a real-world system as it did in the simulations.

The BMS is designed for a specific type of battery. It may not be suitable for other types of batteries.

The BMS is not as sophisticated as some other BMSs that are available commercially.

2.2.10 Improving the life-cycle and soc of the battery of a modular electric vehicle using ultra-capacitor (a. s. sener et. al., 2019).

METHODS

The author proposed a hybrid energy storage system consisting of a battery and an ultracapacitor. The battery is used to store energy for long periods of time, while the ultracapacitor is used to store energy for short periods of time. The ultracapacitor is connected in parallel with the battery to provide a quick burst of power when needed.

The author conducted simulations to evaluate the performance of the hybrid energy storage system. The simulations showed that the hybrid energy storage system can improve the life-cycle and state of charge (SOC) of the battery.

RESULTS

The simulations showed that the hybrid energy storage system can improve the life-cycle of the battery by up to 50%. This is because the ultracapacitor can absorb the transient loads, which reduces the stress on the battery.

The simulations also showed that the hybrid energy storage system can improve the SOC of the battery. This is because the ultracapacitor can provide a quick burst of power when needed, which prevents the battery from being discharged too deeply.

LIMITATIONS

The hybrid energy storage system is more expensive than a traditional battery system.

The hybrid energy storage system is more complex than a traditional battery system.

The hybrid energy storage system requires more maintenance than a traditional battery system.

2.3 META ANALYSIS

S/N	TITLE	METHOD	RESULT	LIMITATIONS	REFERENCE
1	Long-term degradation of lithium-ion batteries	Ghorbanzadeh, Astaneh, and Golzar (2019) analyzed lithium-ion battery degradation in	Higher temperatures and rapid charging/discharging led to faster battery degradation. A	The study used a simulation model, though validated with experimental data, enhancing reliability.	Ghorbanzadeh, M., Astaneh, M., & Golzar, F. (2019). Energy, 166, 1194-1206. [DOI](https://doi

		off-grid wind-battery systems using both experiments from an Iranian setup and a theoretical degradation model incorporating factors like cycles, temperature, state-of-charge, and current density.	lower state of charge extended battery lifespan.		.org/10.1016/j.enegy.201.10.120)
2	An Experimental Study on Deep-Cycle Battery Charging Methods	Kazaure et al. (2020) conducted experiments on deep-cycle batteries with three charging methods: constant voltage, constant current, and multi-stage charging,	Multi-stage charging was the most efficient, with the shortest charging time and highest energy efficiency. Constant current had the longest charging time, and constant voltage led to the highest battery temperature.	Limited to one battery type; only three charging methods were explored.	Kazaure, J. S., Amuda, F. A., & Danladi, T. A. (2020). International Journal of Engineering and Innovative Technology (IJEIT), 9(8). [DOI](https://doi.org/10.17605/O SF.IO/CN34S)

		assessing charging time, energy efficiency, and battery temperature.			
3	Electronic Life Cycle Monitoring System for Various Types of Lead Acid Batteries	Developed an electronic monitoring system for various lead acid batteries, tracking voltage, current, temperature, and state of charge. Tested on different battery types.	Effective for monitoring battery performance, identifying issues, and optimizing charging/discharging.	Limited to laboratory experiments; calibration needed for different batteries; cost-effectiveness not explored.	Žydrūnas Kavaliauskas, Igor Šajev, Giedrius Blažiūnas, and Giedrius Gecevičius. (2023). Appl. Sci. 13(8), 4746.
4	A Critical Review of Online Battery Remaining Useful Lifetime Prediction Methods	Conducted a comprehensive review of online battery remaining useful lifetime prediction methods, discussing data-driven, physics-based, and hybrid methods.	Identified various online prediction methods with pros and cons, providing recommendations for future research.	Focused solely on online methods; selected literature may not cover all methods; no comparative evaluation.	Wang, S., Jin, S., Deng, D., & Fernandez, C. (2021). Frontiers in Mechanical Engineering, 7. [DOI](https://doi.org/10.3389/fmch.2021.719718)

5	Battery health evaluation using a short random segment of constant current charging	Proposed a battery health evaluation method using short random segments of constant current charging, detecting various battery faults.	Effective in fault detection, applicable to different battery types, and quick.	Limited to lab experiments; performance in real-world conditions not assessed; calibration required for different batteries and may not suit severely faulty batteries.	Deng, Z., Hu, X., Xie, Y., Xu, L., Li, P., Lin, X., & Bian, X. (2022). <i>iScience</i> , 25(5), 104260. [DOI](https://doi.org/10.1016/j.isci.2022.104260)
6	Analysis of discharge energy on deep and non-deep cycle accumulat or on solar cell-based power source	Analyzed discharge energy of deep and non-deep cycle batteries charged with a solar panel, comparing different charging methods.	Pulse charging was the most efficient, maintaining battery performance, and discharge energy was influenced by state of charge.	Only two battery types tested; no consideration of environmental factors.	Sugiarta, I. N., Suparta, I. N., Sudiarta, I. W., Teresna, I. W., & Narottama, A. A. N. M. (2020). <i>Journal of Physics: Conference Series</i> , 1450(1). [DOI](https://doi.org/10.1088/1742-6596/1450/1/012131)https://doi.org/10.1088/1742-

					6596/1450/1/012 131
7	Low maintenance lead-acid batteries for energy storage.	Examined discharge energy of deep and non-deep cycle lead-acid batteries at various states of charge (SoC).	Deep cycle batteries had higher discharge energy, especially at low SoC.	Limited to two battery types; no assessment of environmental conditions.	Burrows, B W, Sunu, W G, & Dick, B H. (2012). (https://doi.org/10.2514/3.62516)
8	The performance characteristics of lead acid deep cycle batteries through voltages and round-trip energy efficiency for solar power application	Conducted experiments on lead acid deep cycle batteries to assess performance through voltages and round-trip energy efficiency for solar power applications.	Gaston deep cycle battery had higher round-trip energy efficiency and lower voltage drop than GA lead acid battery.	Only two battery types tested; environmental factors not considered.	Amusan, J. (2023). <i>Scientia Africana</i> , 14.

9	Optimized battery-management system to improve storage lifetime in renewable energy systems.	Proposed a BMS comprising battery monitor, controller, and protection unit, simulated its performance, suggesting up to 50% storage lifetime improvement.	Simulations indicated improved storage lifetime.	Not tested in real-world systems; designed for specific battery type; less sophisticated than some commercial BMSs.	Kaiser, R. (2007). Journal of Power Sources, 168(1), 58-65. [DOI](https://doi.org/10.1016/j.jpowsour.2006.12.024)
10	Improving the life-cycle and SOC of the battery of a modular electric vehicle using ultra-capacitor.	Proposed a hybrid energy storage system combining battery and ultracapacitor, simulated its performance, suggesting battery life-cycle and state of charge (SOC) improvement.	Simulations indicated improved battery life-cycle and SOC.	More expensive and complex than traditional systems; increased maintenance required.	Sener, A. S. (2019). In 2019 8th International Conference on Renewable Energy Research and Applications (ICRERA) (pp. 611-614). IEEE.

CHAPTER THREE

METHODOLOGY

3.1 RESEARCH METHODOLOGY

In this chapter the system design approach to achieve to realise the project objectives is carried under the following sub headings:

Gather Equipment and Setup

Battery Testing

Designing Battery Data Collection System

3.1.1 Gather Equipment and Setup

The necessary equipment for battery testing, including a battery impedance tester, digital multimeter, digital multimeter, digital thermometer and battery system tester tools were acquired.

A controlled environment for battery testing with a stable temperature was set up.

Various Components and Tools Utilized During the Battery Testing Process

BTS Battery System Tester: This comprehensive tester evaluated various aspects, including the state of charge, state of health, voltage, and battery rating.

Load Tester: This tool provided fundamental battery parameters such as voltage, internal resistance, cold cranking amp (CCA), and ampere-hour (AH) capacity.

Multimeter: A versatile device that combined multiple measurement functions into a single unit, encompassing measurements of voltage, current, and resistance.

Battery Impedance Tester: Utilized for calculating the battery's impedance, this tool accomplished this by dividing the voltage within the battery circuit by its current.

DC Load Bank: Used to simulate various current loads, the DC load bank allowed us to assess the battery's performance under different load conditions.

Digital Battery Thermometer: This device played a critical role in determining the battery's temperature at any given moment, a vital parameter for battery assessment.

Battery Hydrometer: This instrument served the purpose of measuring the specific gravity of the electrolyte within the deep cycle battery, providing insights into the battery's state of charge.

3.1.2 Battery Testing

3.1.2.1 State of Health of the Battery (SOH)

To assess the battery's state of health (SOH), we utilized the Launch BST-760 Battery System Tester. It was imperative to configure the battery tester to the appropriate voltage range, which corresponds to the 12-volt rating of the battery under examination. We also configured the battery tester with the manufacturer-recommended settings for battery type (GEL cell deep cycle battery), FLOAT voltage range (13.6-13.8 volts), and CYCLE voltage range (14.4-18.0 volts). Subsequently, we connected the designated Kevin test clip from the tester to the battery and recorded the test outcome. According to the test report, the battery exhibited a state of health (SOH) of 100%, signifying its excellent condition.

3.1.2.2 Capacity Test

Industrial batteries are commonly rated in terms of their ampere-hour (Ah) capacity. A battery with a 200 Ah rating, for instance, is theoretically capable of supplying a consistent current of 2 amperes for 100 hours, 4 amperes for 50 hours, and so forth. This relationship is determined by the following equation:

$$\text{Life (Hours)} = \text{Ampere-Hour Rating (Ah)} / \text{Current Drawn (A)}$$

It's important to note that the capacity of deep cycle batteries diminishes as the demand for current increases, and extreme temperatures, both low and high, can also affect their capacity. Typically, batteries are evaluated using a discharge rate of c/10. In practical terms, if a battery has a capacity of 200 Ah, it will be tested by drawing a current of 20 amperes during the c/10 discharge rate assessment.

3.1.2.3 Voltage Test

Nominal voltage refers to the standard open circuit voltage under typical conditions. It's a value assigned to a circuit or system for the sake of easily categorizing its voltage class. The nominal voltage is the cumulative total of all the voltages of cells connected in series. The operational voltage of a circuit can vary from the nominal voltage but remains within a range that ensures the battery operates effectively.

$C/10 \text{ discharge (Ampere)} = \text{Battery capacity in Ah} / 10\text{Hrs}$

$= 200\text{Ah}/10\text{Hrs} = 20 \text{ Amperes}$

3.1.2.4 Cycle Performance Test

Cycle efficiency is a measure of a battery's performance, indicating the ratio between its discharging and charging capabilities. To determine cycle efficiency, a completely discharged battery undergoes a charging process with a $c/10$ charging current, and the time taken to reach a full charge is recorded. Subsequently, the fully charged battery is discharged with a $c/10$ discharging current, and the time it takes to deplete the battery is measured and documented. The cycle efficiency is then calculated as the product of the discharging current and time divided by the product of the charging current and time. For deep-cycle batteries, a typical cycle efficiency falls within the range of 80% to 90%.

3.1.2.5 Specific Gravity Test

Specific gravity serves as a crucial indicator for assessing the charge status of a cell or battery, and it is typically measured using a hydrometer. However, it's important to note that specific gravity measurements alone cannot determine a battery's capacity. During discharge, specific gravity decreases in a linear fashion as ampere-hours are depleted.

As a result, in a fully charged and steady-state operating scenario, as well as during discharge, monitoring the specific gravity of the electrolyte provides a rough estimate of the cell's charge level. Specific gravity gradually decreases during battery discharge until it approaches a value close to that of pure water, and it increases during the recharge process. The battery is considered fully charged when the specific gravity reaches its highest attainable value.

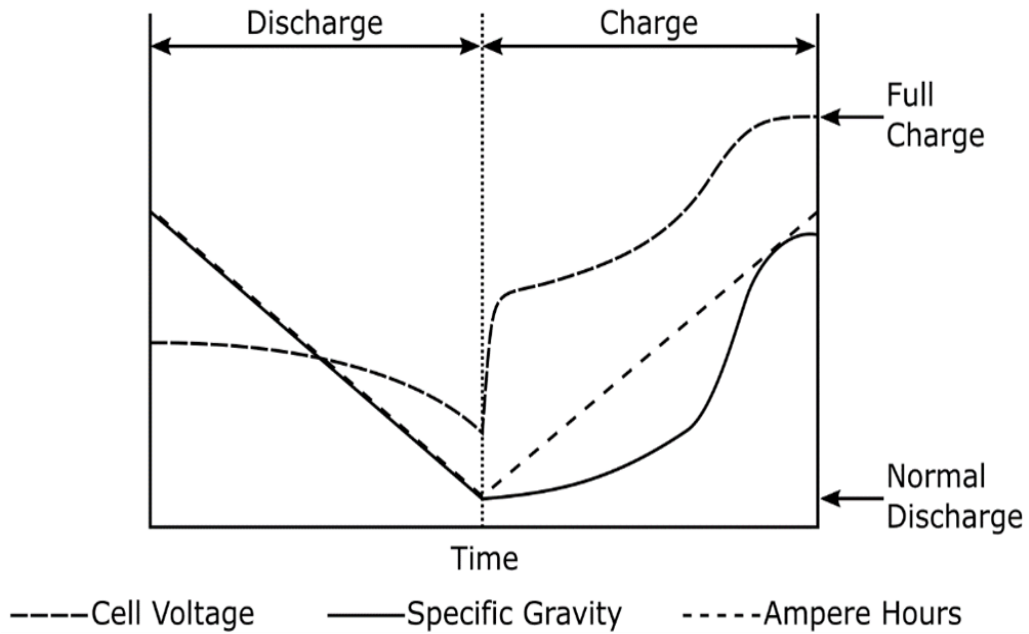


Fig 3.1: Changes in Voltage and Specific Gravity During Charge and Discharge

3.1.2.6 Maximum Depth of Discharge Test (DoD)

The Depth of Discharge (DOD) is a crucial factor that significantly impacts a battery's expected cycle life. The relationship between DOD and cycle life is nonlinear, meaning that as you reduce the depth of discharge, you can increase the number of cycles the battery can undergo. In simpler terms, if you're willing to tolerate the added size and weight, oversizing the battery can substantially enhance its cycle life by reducing the depth of discharge (DOD) in each cycle.

For a wide range of DOD values, typically spanning from 30% to 100%, the number of cycles a battery can provide is roughly proportional to the DOD. However, as the discharge level becomes shallower and approaches minimal levels, this proportional relationship starts to break down.

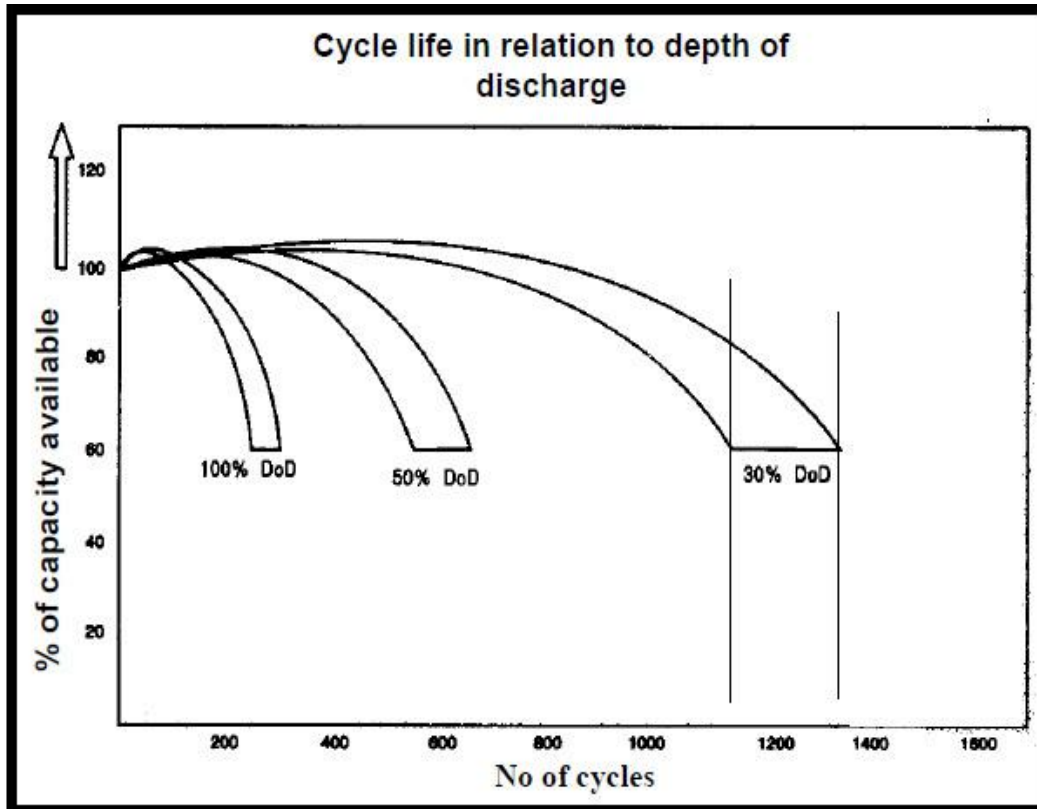


Fig 3.2: Discharging Performance

3.1.2.7 Battery Charging and Discharging

Battery Charging Procedure

The capacitor was adjusted to achieve the desired current reading on the DC ammeter. Since the battery's terminal voltage was changing very slowly, a slight modification in capacitance became necessary during the charging cycle, particularly around the 12-hour mark, to maintain the desired current rate.

In order to handle secondary currents ranging up to 20 amperes, we carefully selected a transformer with an appropriate rating. We arranged the batteries in a series configuration and closely monitored the individual voltages across them. The battery was charged and discharged at a rate of $c/10$, taking into consideration its 200Ah capacity. Consequently, a 20A charging current was introduced into the circuit.

The charging terminal voltage was calculated using the formula

$$V_T = V_b + (I_{\text{charge}} * R),$$

where V_b represents the battery voltage,

I_{charge} is the charging current, and

R signifies resistance.

Initially, the fully discharged battery had an open circuit voltage of 12.11 volts, and the specific gravity of the electrolyte was measured at 1160. Following the charging process, the final specific gravity of the electrolyte increased to 1220. Notably, the temperature during the battery charging process rose from 30°C to 38°C.

Battery Discharging Procedure

High-power rheostats were employed for discharging the battery, and the discharging circuits were configured as follows:

We utilized standard equipment to measure specific gravity, nominal voltage, and other relevant parameters. To discharge the 12-volt battery, a variable resistance was connected in series with it. It was necessary to adjust this resistance periodically to maintain a consistent discharge current at the rate of $c/10$.

The discharging terminal voltage was calculated using the formula

$$V_T = V_b - (I_{\text{discharge}} * R),$$

where V_b represents the battery voltage,

$I_{\text{discharge}}$ is the discharging current, and

R signifies resistance.

Initially, the fully charged battery had an open circuit voltage of 12.94 volts, and the specific gravity of the electrolyte was measured at 1250. After the charging process, the final specific gravity of the electrolyte decreased to 1100. During the battery discharge process, the temperature increased from 30°C to 31°C.

3.1.2.8 Temperature

The capacity of a battery, which indicates how many ampere-hours it can store, is influenced by temperature. It decreases as temperatures drop and increases as they rise. Most manufacturers recommend an operational temperature range of around 27°C (80°F) because batteries tend to perform most efficiently at this temperature.

For deep-cycle batteries, the standard recommendation is to maintain them at room temperature, typically between 25°C (about 77°F) and 27°C (approximately 80°F). When temperatures drop to approximately -22°F (-27°C), the battery's ampere-hour (AH) capacity can drop to about 50%. At freezing temperatures, capacity reduces by around 20%, while higher temperatures, such as 122°F (50°C), can increase capacity by approximately 12%. It's important to note that higher temperatures, especially above 100°F (38°C), can lead to increased internal discharge of batteries. In cold climates, battery capacity decreases, while in hot climates, the battery lifespan may be reduced.

During the charging process, it's normal for deep-cycle batteries to warm up, and they can still be used to power electrical devices during this time. However, if a battery becomes hot to the touch, it may indicate a potential issue, often related to overheating during charging or excessive use, requiring a cooling period.

When not in use or in storage, deep-cycle batteries should be stored at or below room temperature. Maintaining a stable temperature around the battery is crucial for its optimal performance. When charging the battery, the charger should be capable of adjusting the voltage per cell based on the battery's temperature, as colder temperatures require higher voltage for proper charging compared to warmer conditions.

3.1.2.9 Battery Load

The duration for which a battery can power a load depends on the magnitude of that load. In theory, if no load is connected to the battery, it could last indefinitely. However, this ideal scenario rarely occurs in practice.

In a simplified theoretical model, if a load connected to the battery requires 20 amperes (A), the battery might last approximately 10 hours. If the load demands 200A, the battery's duration could reduce to about 1 hour. And if an even higher load of 2000A is needed, the battery may only last for roughly 6 minutes. It's important to note that these are rough estimates, and real-world results often deviate due to various influencing factors, including temperature extremes, which can significantly affect battery performance.

Battery voltage also plays a role in this context. Common voltages for a 200Ah deep cycle battery are 12 volts (12V) and 24 volts (24V). For this particular project, a 12V battery was used.

3.1.2.10 Summary of Analyzing the Performance of the Deep Cycle Battery

Initially, we assessed the battery's state of health (SOH) and state of charge (SOC) using the BTS battery tester. The results indicated a 100% SOH and a 95% SOC, signifying that the battery was in excellent condition and fully charged, making it a "GOOD BATTERY."

We proceeded to confirm the battery voltage to ensure it matched the manufacturer's specifications. Our testing revealed that the battery's voltage was 12.57 volts. Additionally, we determined the Ampere-hour capacity.

Employing a load simulator, we simulated various energy consumption scenarios, specifically measuring the amount of charge the battery could deliver at 5A, 10A, 20A, 30A, 40A and 50A currents for 1 hour. Concurrently, we monitored the battery's temperature using a digital thermometer under these different operational conditions.

We also conducted tests to assess the battery's impedance, which is a critical factor in evaluating its performance.

To complete our analysis, we measured the specific gravity of the battery's electrolyte using a hydrometer. This involved assessing the electrolyte's density, providing valuable insights into the battery's overall condition.

3.3 Designing Battery Data Collection System

The battery data acquisition system was employed to gather precise voltage, temperature, and State of Charge (SOC) measurements at predetermined intervals. This system was automated to remove the need for manual parameter monitoring, guaranteeing accurate logging timing, a critical requirement for the timely evaluation of data accuracy and observation efficiency.

The battery data acquisition system comprises two key components:

A data logger device driven by a microcontroller.

Specialized software for battery data acquisition.

The development of the Battery Data Acquisition Software followed a plan-driven software development approach. The Rational Unified Process (RUP) model, which emphasizes incremental delivery, was chosen for the development process. This involved iterative phases of requirements specification, analysis & design, and implementation & validation. The initial software prototype was developed in the first iteration and served as a reference for subsequent modifications, leading to the creation of a stable version.

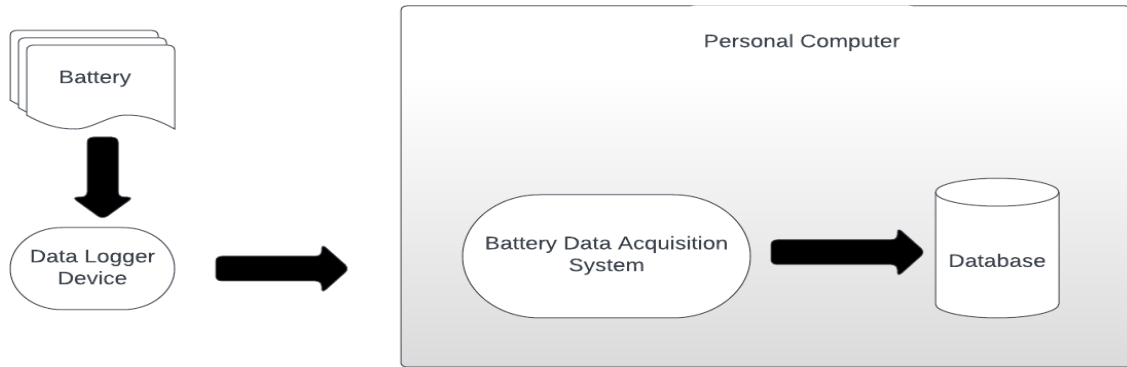
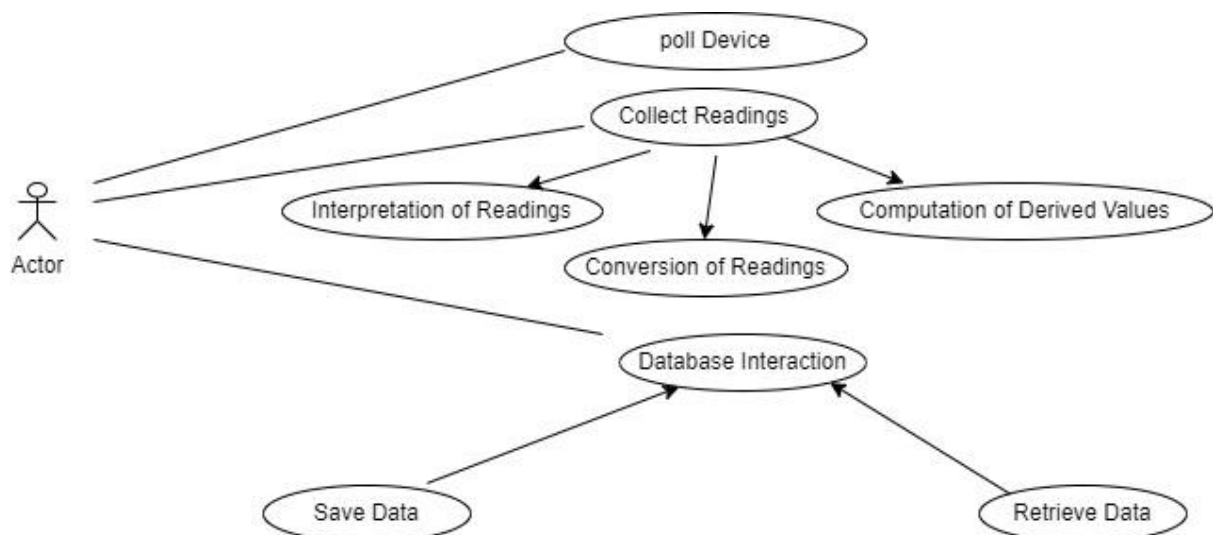


Fig 3.3: Block diagram of battery data collection system

During each iteration, various software engineering activities were carried out:

Requirement Specification

In this stage, both functional and non-functional requirements for the system were defined. Use case diagrams and specification tables were employed to model the system's requirements. The functional requirements encompassed key capabilities, such as communication with the data logger device, retrieval of temperature, voltage, and State of Charge (SOC) readings, interpretation and conversion of readings, computation of Depth of Discharge values, and interaction with the database for data storage and retrieval.



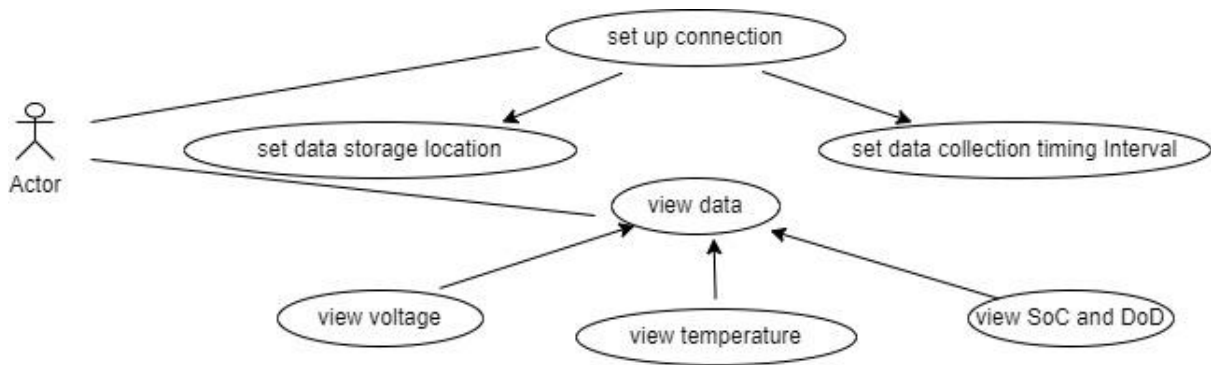


Fig 3.4: Use Case diagram of battery data collection system

Analysis and Design

Object-Oriented Analysis and Design methods were applied to the software development process. This approach facilitated the use of Universal Modeling Language (UML) diagrams to represent both static and dynamic aspects of the software. StarUML served as the Computer-Aided Software Engineering (CASE) tool for modeling. Static structure modeling involved components such as the Class Diagram, while dynamic behavior modeling illustrated interactions within the software and between users and the software using diagrams like the activity diagram.

In summary, the development of the Battery Data Acquisition Software followed a systematic approach, using RUP and iterative development to refine the software's requirements, design, and functionality. UML diagrams played a significant role in modeling various aspects of the software's behavior and structure, ensuring a well-structured and functional final product.

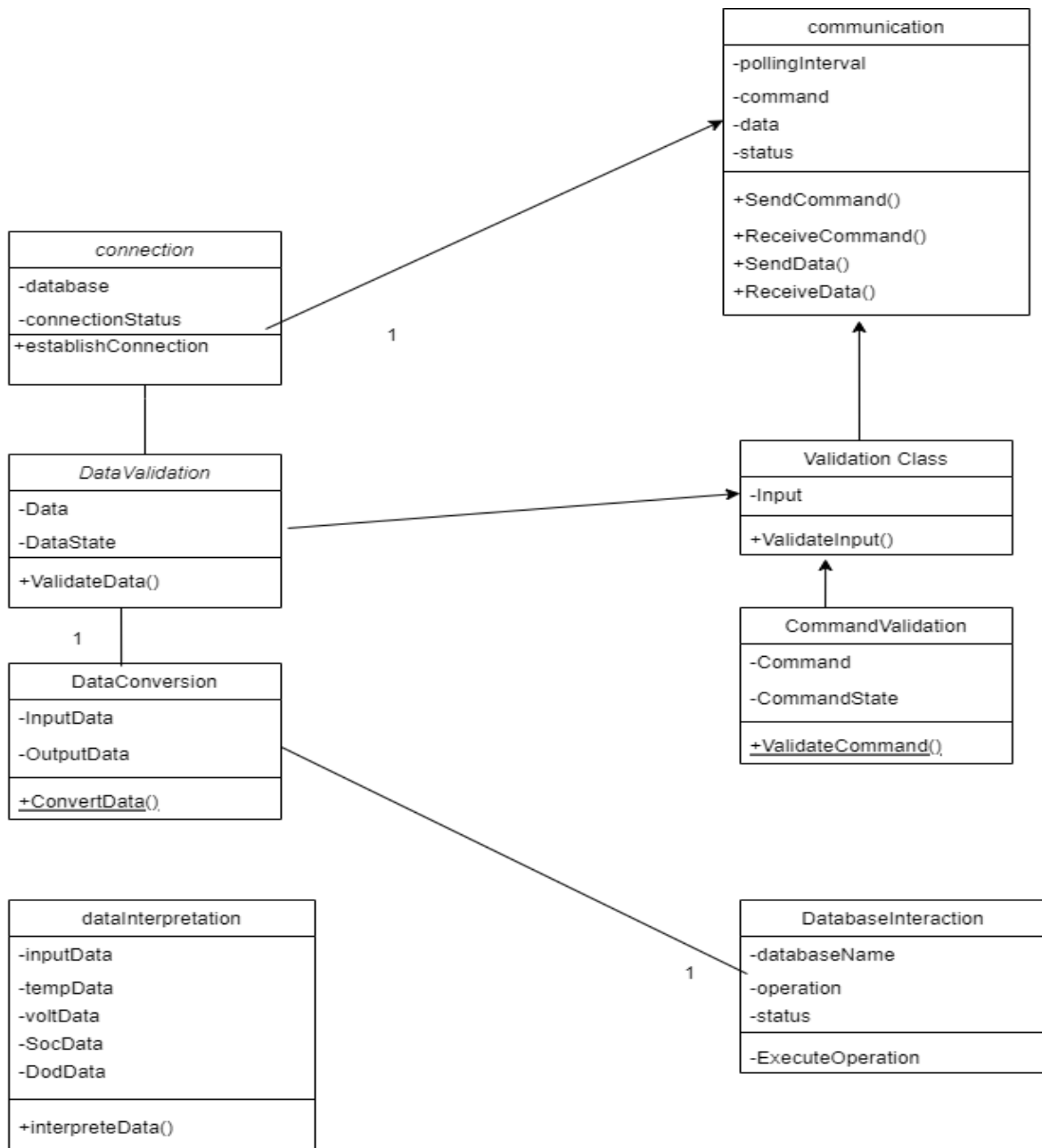


Fig 3.4: Class diagram of battery data collection system

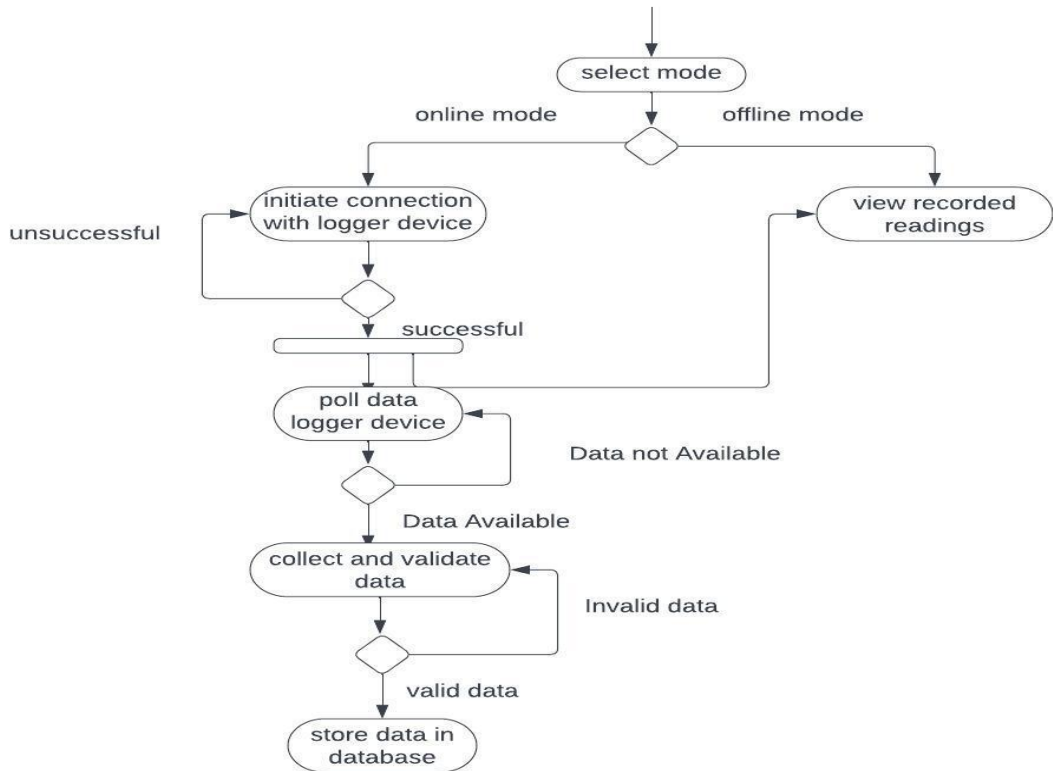


Fig 3.5: Activity diagram of battery data collection system

Database Design

The database design process involved the creation of an Entity-Relationship (E-R) Diagram. This diagram served as a blueprint for defining the database's entities and their respective properties.

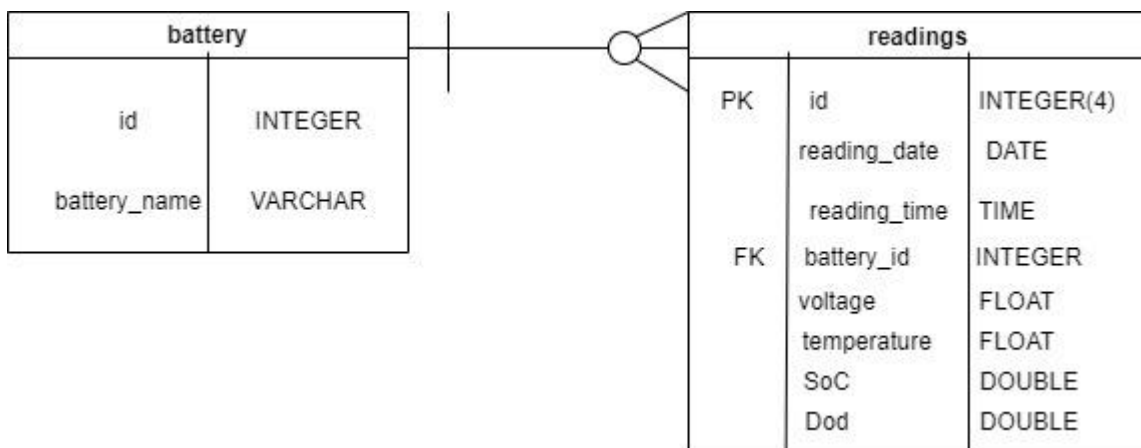


Fig 3.6: E-R diagram of battery data collection system

Software Implementation

The JavaScript and the React library served as a powerful platform for displaying values and conducting analysis of deep cycle battery data. They were used to create dynamic user interfaces, visualize data through tables, and provide updates for monitoring battery parameters like voltage, current, temperature, and state of charge. Additionally, JavaScript facilitates user interaction and customization while enabling integration with backend systems for more in-depth analysis. These technologies, being cross-platform compatible, ensure accessibility across various devices and browsers, enhancing the user experience for battery analysis applications.

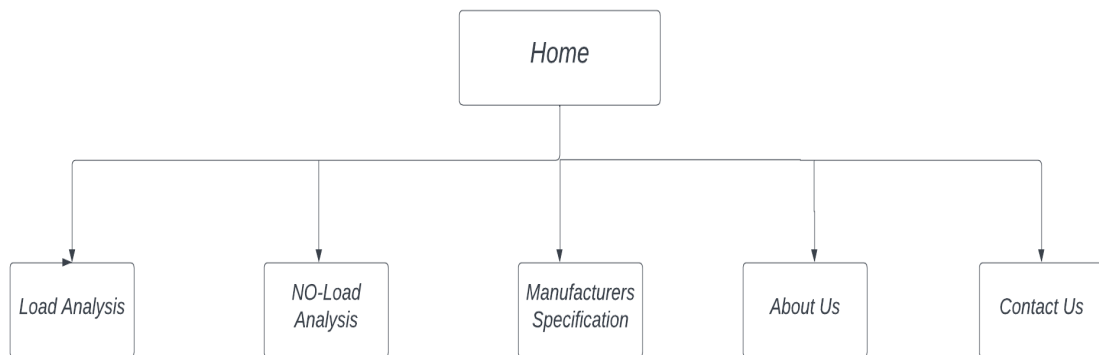


FIG 3.7: Web Flowchart

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 TEST RESULT

The battery being examined was a commercially available, industrial-grade deep-cycle battery commonly employed in solar home systems in Nigeria.

Charging and Discharging Test

Experimental data table during charging period

Initial voltage before the charge	12.14V
Initial Temperature	30°C
Initial Specific Gravity	1160
Charging Current	18A
Charging Date	22/08/2023

Table 4.1: Table displaying data collected during the battery's charging phase

The battery undergoing testing was subjected to charging and discharging at a rate of C/10 current. Prior to initiating the charging circuit, the battery exhibited an initial voltage of 12.14 volts (indicating a fully discharged state), an initial temperature of 30°C, and a specific gravity of 1160. Upon connecting the battery charging circuit, the voltage read 12.55 volts, the temperature remained at 30°C, and the specific gravity remained at 1160. Throughout the analysis of the lead-acid industrial battery, temperature, voltage, and specific gravity measurements were taken for each cell using a thermometer, digital voltmeter, and hydrometers, respectively.

The voltage, temperature, and specific gravity were incrementally increased and recorded every hour until the battery reached a fully charged state, which took approximately 11 hours to achieve. The data collected during the charging process is presented in the table below.

	Time (Hour)	Initial	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00
	Voltage	12.14	12.55	13.09	13.29	13.5	13.7	13.93	14.42	14.82	15.2
One	Specific Gravity	1160	1160	1160	1160	1160	1165	1165	1170	1175	1190
	Temp (°C)	30	30	29	29	29	30	30	30	30	34
Two	Specific Gravity	1160	1160	1160	1160	1180	1165	1165	1170	1170	1185
	Temp (°C)	30	30	29	29	29	30	30	30	30	34
Three	Specific Gravity	1160	1160	1160	1160	1180	1165	1165	1167	1170	1185
	Temp (°C)	30	30	29	29	29	30	30	30	30	34
Four	Specific Gravity	1160	1160	1160	1160	1175	1160	1160	1170	1170	1185
	Temp (°C)	30	30	29	29	29	30	30	30	30	34
Five	Specific Gravity	1160	1160	1160	1160	1185	1165	1165	1175	1175	1190
	Temp (°C)	30	30	29	29	29	30	30	30	30	34
Six	Specific Gravity	1160	1160	1160	1160	1185	1165	1170	1175	1175	1195
	Temp (°C)	30	30	29	29	29	30	30	30	30	34
Average Specific Capacity		1160	1160	1160	1160	1181	1164	1165	1171	1172	1188
Average Temp (°C)		30	30	30	31	31	31	31	32	33	34
Standard Deviation		0	0	0	0	0	1.86	2.88	2.91	2.5	3.72

Table 4.2: Charging rate of the deep cycle battery

Experimental data table during discharging period

Initial voltage before the charge	12.76V
Initial Temperature	30°C
Initial Specific Gravity	1210
Load	300W
Discharging Date	23/08/2023

Table 4.3: Table displaying data collected during the battery's discharging phase

Before initiating the discharging process, the battery exhibited an initial voltage of 12.76 volts (indicating a fully charged state), an initial temperature of 30°C, and a specific gravity of 1210. When the load was connected to the battery, the voltage dropped to 12.30 volts, the temperature decreased to 10°C, and the specific gravity remained at 1210. Subsequently, the voltage, temperature, and specific gravity gradually decreased and were recorded hourly until the battery reached a fully discharged state, which occurred over a span of 8 hours. The data collected during the discharging process is presented in the following table.

	Time (Hour)	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00
	Voltage	12.3	12.14	12.0	11.9	11.78	11.61	11.37	10.98	10.71
One	Specific Gravity	1210	1210	1200	1200	1185	1180	1170	1160	1160
	Temp (°C)	30	30	29	29	29	30	30	30	30
Two	Specific Gravity	1210	1210	1200	1195	1180	1180	1170	1160	1160
	Temp (°C)	30	30	29	29	29	30	30	30	30
Three	Specific Gravity	1210	1210	1200	1195	1180	1180	1170	1160	1160
	Temp (°C)	30	30	29	29	29	30	30	30	30
Four	Specific Gravity	1210	1210	1200	1190	1175	1180	1170	1160	1160
	Temp (°C)	30	30	29	29	29	30	30	30	30
Five	Specific Gravity	1210	1210	1200	1195	1185	1180	1170	1160	1160
	Temp	30	30	29	29	29	30	30	30	30

	(°C)									
Six	Specific Gravity	1210	1210	1200	1195	1185	1180	1170	1160	1160
	Temp (°C)	30	30	29	29	29	30	30	30	30
Average Specific Capacity		1210	1210	1200	1195	1181	1179	1169	1160	1160
Average Temp (°C)		30	30	29	29	29	30	30	30	30
Standard Deviation		0	0	0	3.44	3.73	1.86	1.86	0	0

Table 4.4: Discharging rate of the deep cycle battery

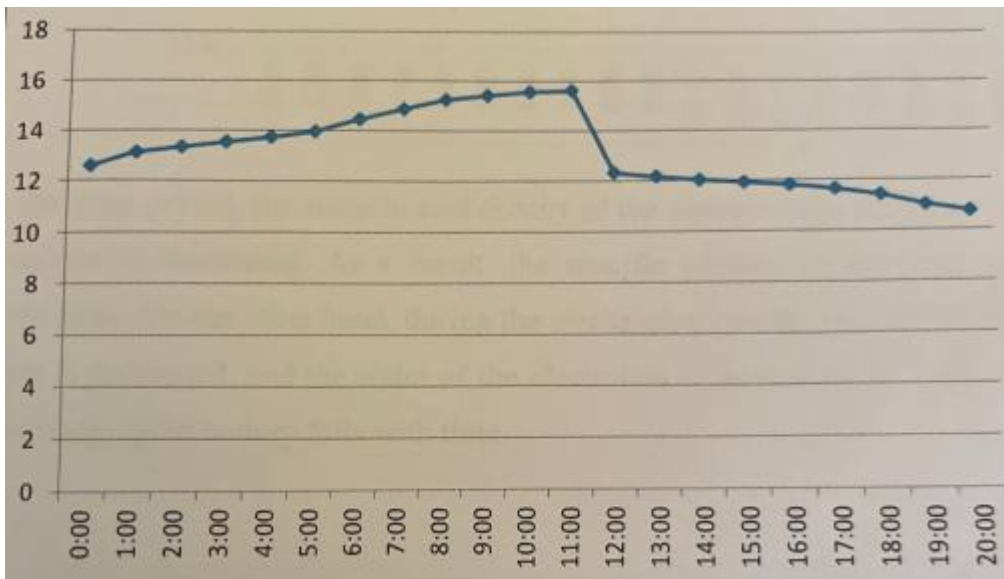
Discussion

As depicted in Table 4.2, the voltage exhibits relative stability during the second to fifth hours of the charging process. After five hours, there is a notable increase in battery voltage due to the occurrence of charging chemical reactions and the diffusion of plates into the primary electrolyte. This heightened voltage necessitates a higher charging voltage. After six hours of charging, gassing begins to form from the electrolyte. Around the ten-hour mark, the remaining lead sulfate is eliminated, and acid formation ceases. At this point, the electrical energy input is directed toward the electrolysis of water, splitting it into hydrogen and oxygen gases. Consequently, no further changes occur, and the voltage remains constant at approximately 15.53 to 15.58 volts for eleven hours.

Upon completing the charging cycle, the voltage of the industrial deep-cycle battery typically ranges from 15 to 15.8 volts. However, when the charging circuit is disconnected, the cell voltage rapidly drops to approximately 12.6 to 12.8 volts within ten to twelve minutes.

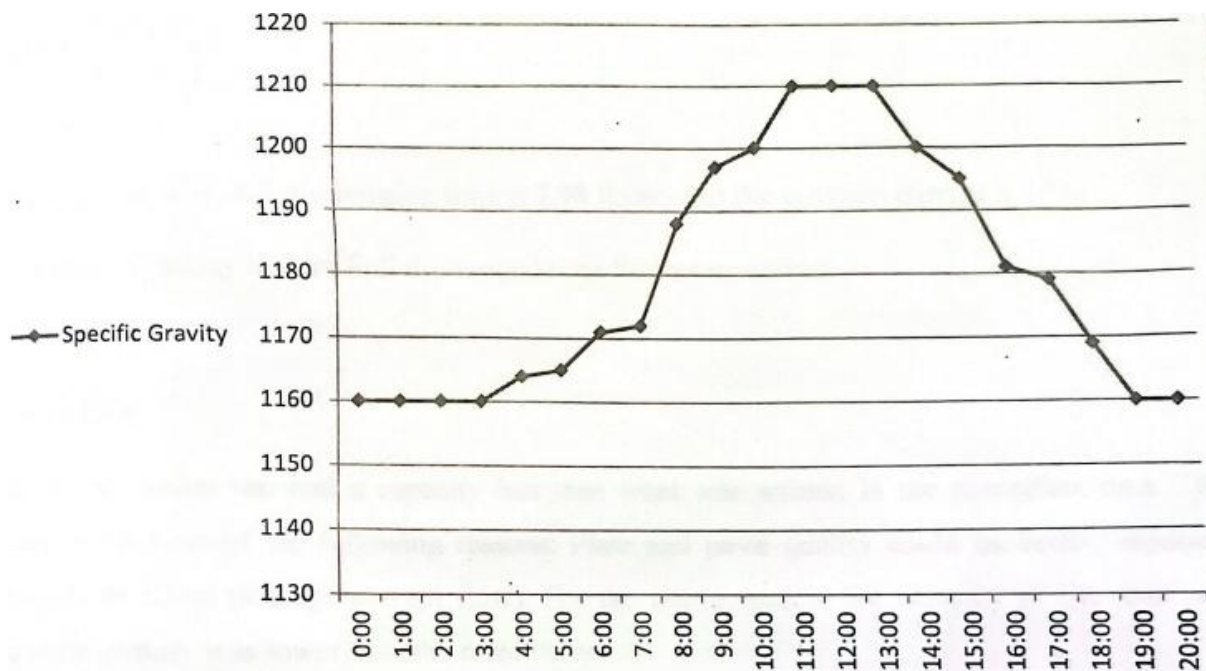
At the outset of the discharge process, the voltage experiences a swift decline from its final charge voltage. Subsequently, the rate of voltage decrease becomes more gradual, contingent upon the amount of current drawn from the battery. It is advisable to cease the discharge when the voltage of the lead-acid industrial battery reaches approximately 10.7 volts.

Charging and discharging profile of the deep cycle battery



Specific Gravity Test

The specific gravity of an industrial deep-cycle battery serves as an indicator of the cell or battery's charge status. It is regularly measured using a hydrometer, either during the process of reaching full charge or full discharge. Specific gravity increases in a linear fashion as the battery charges, and it decreases linearly during discharge. Monitoring the specific gravity of the electrolyte provides a rough estimate of the cell's charge level and reflects the battery's characteristics, serving as a measure of battery efficiency.



During the charging phase, the density of sulfuric acid in the electrolyte increases while the water content decreases, causing the specific gravity of the lead-acid battery to rise over time. Conversely, in the discharging phase, the density of sulfuric acid in the electrolyte decreases, and the water content increases, leading to a gradual decrease in the specific gravity of the deep-cycle battery.

Cycle Efficiency

The cycle efficiency of a lead-acid industrial battery is a measure of its performance, indicating the ratio of energy discharged to energy charged. It's calculated as the product of the discharging current and time divided by the product of the charging current and time, or simply as the ratio of discharging ampere-hours to charging ampere-hours. This efficiency is typically expressed as a percentage.

Based on the experimental data (referenced from tables 4.2 and 4.4), the discharging ampere-hour was found to be 143.64Ah, while the charging ampere-hour was 198Ah. As a result, the cycle efficiency is determined to be 72.55%, which is notably lower than the industry standard for lead-acid industrial batteries, typically exceeding 85%. This lower efficiency suggests that the tested battery's performance is suboptimal

State of Health (SOH)	100%
Voltage	12.57V
State of Charge (SOC)	95%
Measured	830A

Table 4.5: State of Health and State of Charge

Capacity Test

The capacity of a battery represents the amount of electricity it can deliver under specific conditions and is typically measured in ampere-hours (Ah). To illustrate, a battery with a 200Ah rating is theoretically capable of providing a constant 2A current for 100 hours, 4A for 50 hours, and so forth, as determined by the following equation:

$$\text{Capacity (in ampere-hours)} = \text{Life (in hours)} \times \text{Ampere-hour rating (Ah)} / \text{Ampere drawn (A)}$$

In our experimental setup, the battery took 11 hours to reach a full charge at a constant current of 18A. Therefore, the battery's capacity in Ah during charging can be calculated as:

$$\text{Capacity} = 11 \text{ hours} \times 18\text{A} = 198 \text{ Ah}$$

During the discharge phase, the battery discharged fully in approximately 7.98 hours, maintaining a constant current of 18A. Thus, the capacity during discharging was:

$$\text{Capacity} = 7.98 \text{ hours} \times 18\text{A} = 143.64 \text{ Ah}$$

It was observed that the tested battery had a capacity lower than what was indicated in the manufacturer's nameplate data. This discrepancy could be attributed to factors such as the quality of the battery plates and paste, as well as the need for potential improvements in the separator to address issues like leakage current flow. These factors contributed to the lower-than-rated capacity of the lead-acid industrial battery.

4.2 Web-based Resource Management System

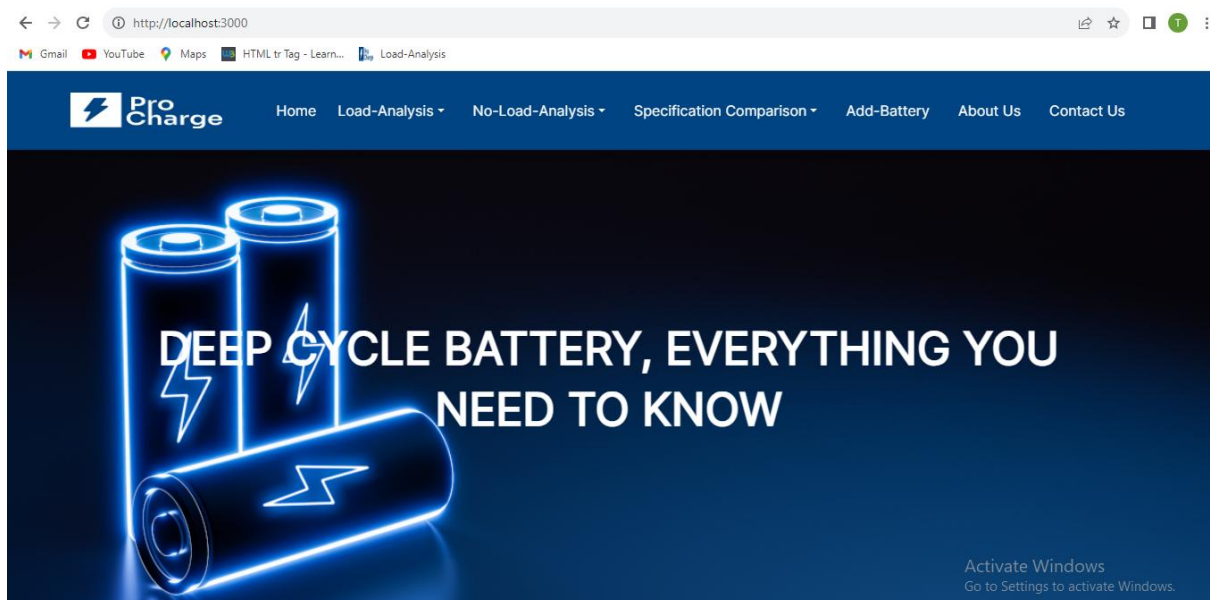


Fig 4.4: A Screenshot of the home page

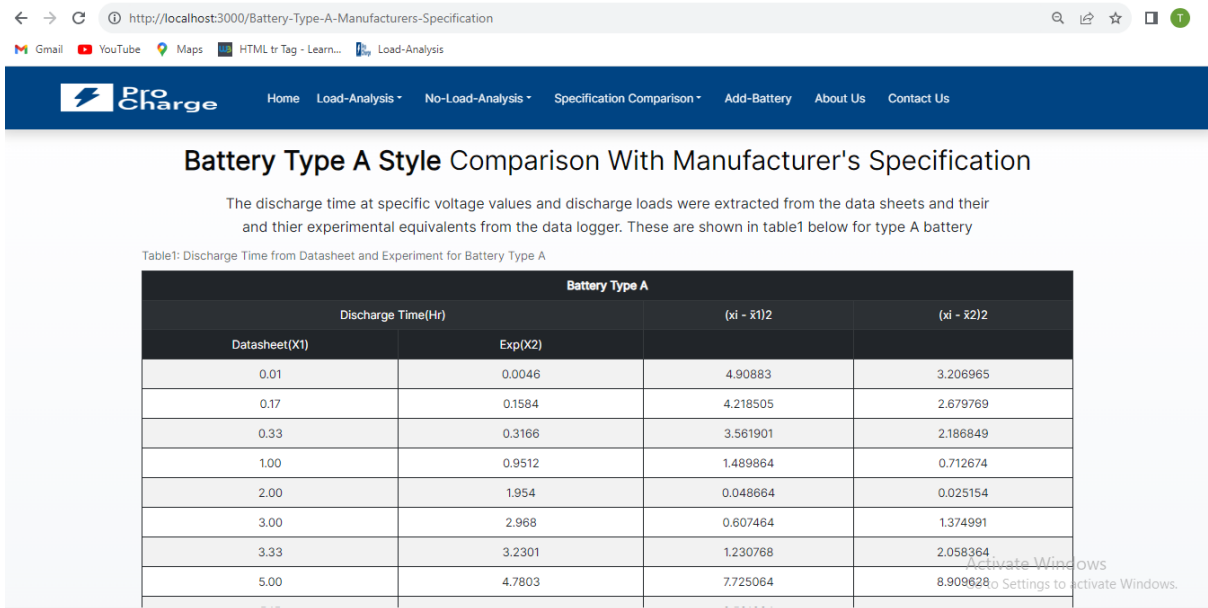


Fig 4.5: A Screenshot of the Specification Comparison Page

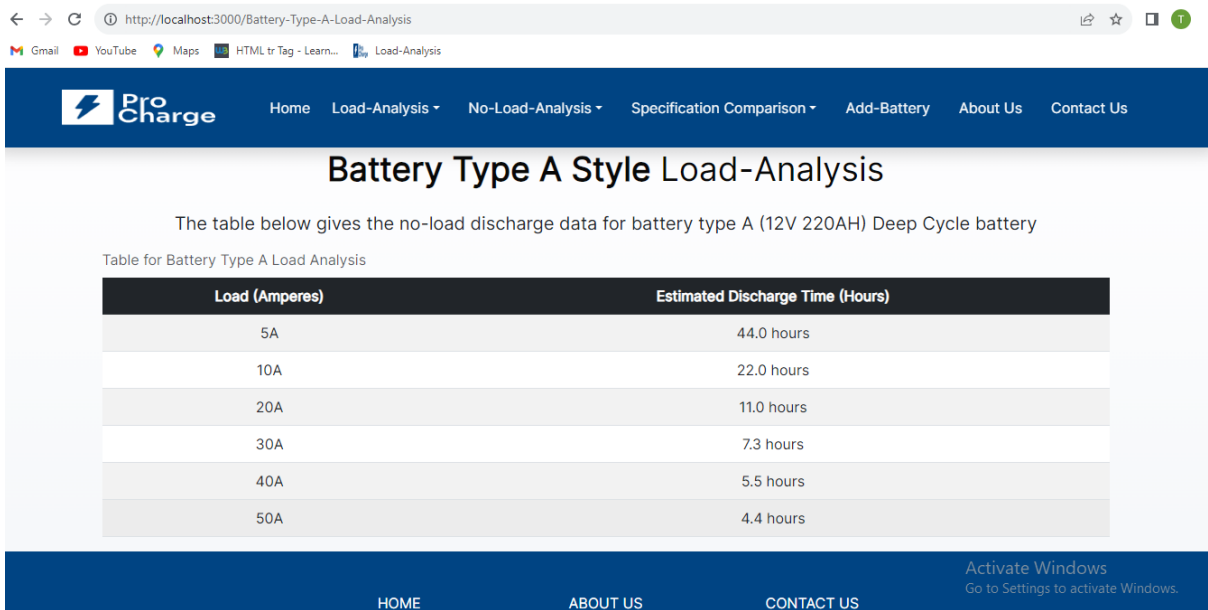


Fig 4.5: A Screenshot of the Load Analysis Page

Fig 4.6: A Screenshot of the No-Load Analysis Page

Fig 4.7: A Screenshot of the About Us Page

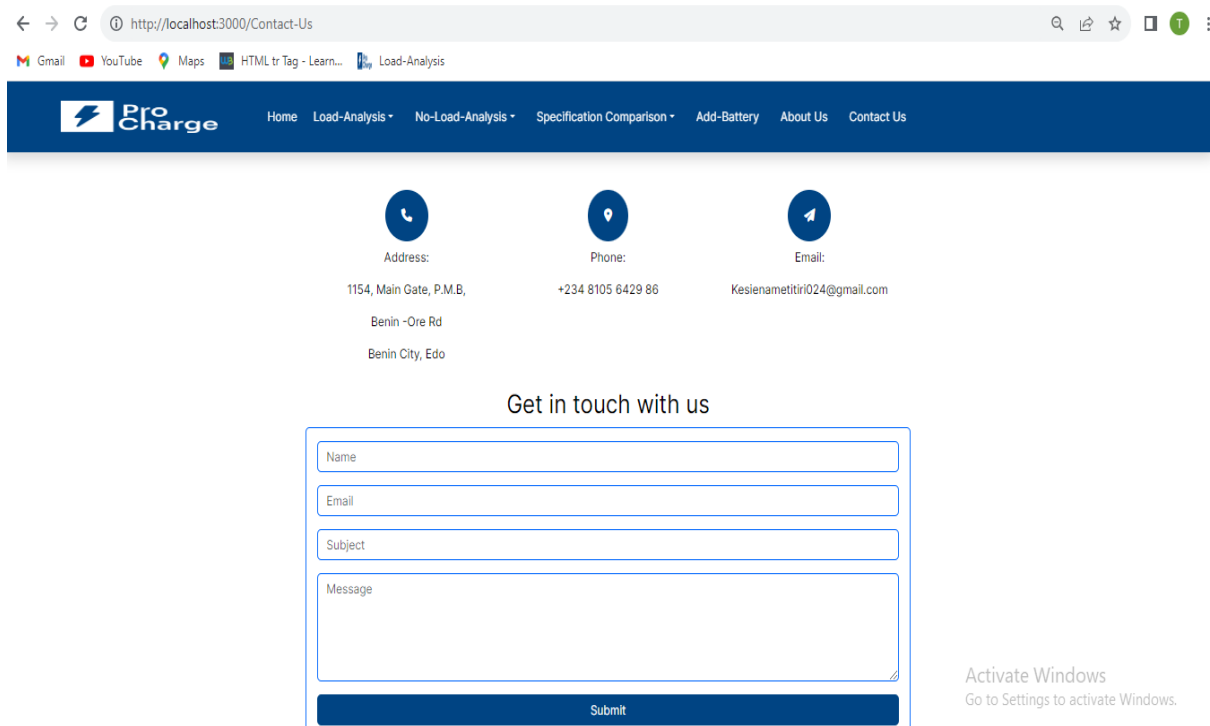


Fig 4.8: A Screenshot of the Contact Us Page

Figure 4.4 displays the homepage of the web-based system known as 'Pro Charge.' Within this system, Figure 4.5 stands out as it presents the 'Manufacturer's Specification Comparison' page, where test results are compared to the manufacturer's specifications to assess battery performance.

For a deeper insight into battery characteristics, Figure 4.6 is dedicated to 'Battery A No Load Analysis Information,' shedding light on the battery's behavior under no-load conditions. In contrast, Figure 4.5, titled 'Battery A Load Analysis Information,' offers detailed data about the battery's performance when subjected to various loads.

Additionally, Figure 4.7 introduces the 'About Us' page, providing valuable information about the project's author and background. To engage with the project author or convey feedback, Figure 4.8 represents the 'Contact Us' page, where website visitors can conveniently communicate their comments and complaints.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Industrial batteries, a type of lead-acid battery with robust positive plates, are specially designed for deep discharges, making them ideal for solar home systems. These systems require energy storage for day-to-night usage.

It's important to note that, for every 1000-watt inverter, a minimum of a 100Ah battery is recommended. For instance, a 6000-watt inverter would require at least three 200Ah batteries. During the charging and discharging processes, various parameters were meticulously observed and measured. While calculating voltage in other cells was not possible, hourly data on the battery's terminal voltage, specific gravity of different cells, and various cell temperatures were recorded and analyzed. Correlations and standard deviations for these parameters were established.

From the hypothetical data, it was observed that during the initial stages of charging or discharging, the cells were charged uniformly. However, after some time (around 2 to 3 hours), the charging profile of different cells became distinct, only to become uniform again in the final stage. The battery capacities were also determined, revealing that the tested batteries had lower capacities than their rated values.

Throughout the deep-cycle battery's charging and discharging cycles, strict guidelines were followed. Charging and discharging were carried out at a rate of C/10 or 0.1C charging current. Minimum and maximum terminal voltage limits were maintained at 10.5V during discharging and 15.8V during charging. The electrolyte level was carefully maintained at the optimum level. These tests were conducted in a university laboratory, providing the team with valuable insights into potential issues that may arise during battery analysis.

The importance of industrial batteries is steadily growing, particularly as renewable energy solutions gain prominence in addressing the world's impending energy challenges.

The study successfully accomplished its objectives and identified the specific challenge of limited access to independent databases for assessing the quality and performance of these batteries. Through a systematic experimental approach and the implementation of the BDA system, the research generated valuable data. This data can be highly beneficial to individuals,

companies, and future researchers interested in deep cycle batteries and their performance characteristics.

5.2 RECOMMENDATION

The proposed methodology for conducting this thesis comprised a structured sequence of steps and tests to assess battery efficiency and performance. As part of the battery analysis, it was recommended to conduct tests for both the State of Health (SOH) and State of Charge (SOC), utilizing the BTS-760 battery tester.

For a comprehensive evaluation of deep-cycle battery performance, a range of tests were suggested, including but not limited to the nominal voltage test, capacity test, cycle efficiency test, specific gravity test, and maximum Depth of Discharge (DoD) test.

While the research has successfully covered its stated objectives and scope, there is room for further exploration by considering alternative energy storage systems, such as lithium-ion batteries. Recent advancements in battery technology, not addressed in this study, present opportunities for additional investigation.

To enhance the research's credibility, future studies could involve testing multiple arrays of batteries, providing diverse data to validate overall results.

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APPENDIX

Battery Terminologies

Ampere-Hour: An ampere-hour, often abbreviated as amp-hour, signifies the flow of one ampere of current for one hour. It serves as a unit to measure the amount of electrical charge a storage battery can deliver before requiring a recharge.

Anode: This is an electrode within a polarized electrical device where conventional current enters the device.

Battery: A device that converts chemical energy into electrical energy, typically consisting of two or more electrically connected cells. In some cases, the term "battery" can also refer to a single cell, such as a household battery.

Available Capacity: This refers to the overall battery capacity, usually expressed in ampere-hours or milliampere-hours, available for performing tasks. It depends on various factors, including the quantity and density of electrolyte, temperature, discharge rate, endpoint voltage, and the battery's history.

Battery Types: Generally, batteries fall into two categories: primary and secondary accumulator/storage batteries. Primary batteries are designed for single-use, while secondary batteries can be recharged after partial or complete discharge, restoring them to their initial charged state.

Battery Capacity: The electrical output of a cell or battery during a service test before it reaches a specific final electrical condition. It can be expressed in units such as ampere-hours, watt-hours, or similar measurements. Watt-hours are calculated by multiplying ampere-hours by the battery voltage.

Battery Charger: A device or equipment capable of supplying electrical energy to recharge a battery.

Battery-Charging Rate: The current at which a storage battery is charged, typically measured in amperes.

Cathode: The electrode from which conventional current exits a polarized electrical device.

C_i (C-sub-i): This relates to the rated capacity, in ampere-hours, for a specific constant discharge current (denoted by 'i,' representing the number of hours the cell can deliver the

current). For example, C5 capacity indicates the ampere-hours delivered by a cell at a constant current for 5 hours.

Capacity: The quantity of electricity a battery delivers under specified conditions, typically measured in ampere-hours.

Cell: An electrochemical apparatus comprised of positive and negative plates, separators, and electrolytes capable of storing electrical energy. It serves as the fundamental building block of a battery when housed in a container with terminals.

Charge: In the context of a storage battery, it refers to the conversion of electrical energy into chemical energy within the cell or battery. Charging involves maintaining a unidirectional current opposite to the discharge current, effectively returning the cell or battery to a fully charged state.

Charge Rate: The current applied to a secondary cell during recharging, often expressed as a multiple of the cell's rated capacity. For instance, the C/10 charge rate for a 500 Ah cell equals 50 A (500 Ah divided by 10 hours).

Discharge: The withdrawal of small currents over extended periods, typically longer than one hour.

Dry Cell: A primary cell where the electrolyte is absorbed in a permeable medium or otherwise prevented from flowing. The term "dry cell" is commonly associated with cells like the Leclanché cell, a typical commercial type.

Electrode: An electrical conductor through which electric current enters or exits a conducting medium, whether it's an electrolytic solution, vacuum, solid, gas, or molten substance.

Electrolyte: A chemical compound that, when dissolved or fused in certain solvents, conducts an electric current. All electrolytes, in solution or molten form, produce ions that facilitate the flow of electric current.

End-of-Discharge Voltage: The voltage of a battery at the conclusion of a discharge cycle.

Energy: The capability to produce output, often expressed as capacity multiplied by voltage or measured in watt-hours.

Energy Density: The ratio of cell energy to weight or volume, typically measured as watt-hours per pound or watt-hours per cubic inch.

Float Charging: A recharging method in which a secondary cell remains consistently connected to a constant-voltage supply, maintaining the cell in a fully charged state.

Galvanic Cell: A combination of electrodes separated by electrolyte, capable of generating electrical energy through electrochemical processes.

Internal Resistance: The resistance encountered by the flow of electric current within a cell or battery.