CHAPTER 1

INTRODUCTION

1.1. INTRODUCTION

A battery pack is a collection of individual batteries or cells arranged in a specific configuration to provide a portable and compact power source. These packs are designed to store and deliver electrical energy for a variety of applications, ranging from small electronic devices to electric vehicles and renewable energy systems.

Battery packs typically consist of interconnected cells, each contributing a specific voltage and capacity to meet the desired power requirements. The arrangement of these cells can vary based on the intended application, and it often involves series and parallel connections to achieve the desired voltage, capacity, and current specifications.

The design of a battery pack considers factors such as energy density, power density, voltage levels, and safety features. Battery management systems (BMS) are often integrated into the pack to monitor and manage individual cell performance, ensuring balanced charging and discharging, temperature control, and overall pack health.

As the demand for portable electronic devices, electric vehicles, and renewable energy storage continues to grow, the development and optimization of battery packs play a crucial role in enhancing energy efficiency, reliability, and safety across various industries.

We developed the compact battery pack with structural safety and high cooling performance based on numerical simulation for electric vehicle applications. The most important requirement in EV battery pack is high specific power, which makes lightweight design of battery pack essential, robust and lightweight module frame, which binds dozens of batteries together, was designed to minimize the deformation of batteries in case of swelling or explosion. Efficient cooling system was also achieved through the Pugh decision matrix with computational fluid dynamic analysis, to have a uniform temperature distribution and a minimized pressure drop within the pack under normal charging/discharging conditions.

1.2 OVERVIEW

In Simulink, you can model battery packs using various techniques like equivalent circuit models or electrochemical models. These models help simulate the behaviour of the battery pack, such as voltage, current, and capacity. It's a powerful tool for analysing and optimizing battery performance in different applications.

Battery pack modelling in Simulink involves creating a mathematical representation of the behaviour and characteristics of a battery pack. This modelling helps in understanding and predicting the performance of the battery pack in different scenarios.

There are different approaches to modelling battery packs in Simulink. One common approach is using equivalent circuit models. These models represent the battery pack as a combination of resistors, capacitors, and current sources. By adjusting the values of these components, you can simulate the behaviour of the battery pack under different loads and conditions.

Another approach is using electrochemical models, which capture the internal electrochemical processes happening within the battery. These models consider factors like chemical reactions, diffusion, and ion movement. By simulating these processes, you can gain insights into the battery's behaviour and performance.

Simulink provides various blocks and libraries specifically designed for battery pack modelling. These blocks allow you to easily create and simulate battery models, analyse their performance, and optimize their design. You can also incorporate these models into larger system simulations to assess the overall performance of a system powered by a battery pack.

Battery pack modelling in Simulink is widely used in various industries, including automotive, renewable energy, and portable electronics. It helps engineers and researchers understand battery behaviour, optimize battery pack designs, and develop efficient battery management systems.

CHAPTER 2

LITHIUM ION BATTERIES

2.1. INTRODUCTION LITHIUM-ION BATTERIES

A battery is a device that stores chemical energy and converts it into electrical energy. It consists of one or more electrochemical cells, which are composed of positive and negative electrodes, separated by an electrolyte. When a battery is connected to a circuit, a chemical reaction occurs within the battery, causing electrons to flow from the negative electrode (anode) to the positive electrode (cathode), creating an electrical current. Lithium-ion batteries have several key properties:

A lithium-ion or Li-ion battery is a type of rechargeable battery which uses the reversible intercalation of Li+ ions into electronically conducting solids to store energy. In comparison with other rechargeable batteries, Li-ion batteries are characterized by a higher specific energy, higher energy density, higher energy efficiency, longer cycle life and longer calendar life. Also noteworthy is a dramatic improvement in lithium-ion battery properties after their market introduction in 1991: within the next 30 years their volumetric energy density increased threefold, while their cost dropped tenfold.

FIG 2.1. Lithium-ion battery

Electrochemical storage system, also known as batteries, are gaining popularity due to limited reserves of conventional resources for energy generation. Varying nature of renewable sources like wind and solar energy has led challenge for storing the energy until consumers needs it. In 2017, more than GW of batteries are manufactured around the globe. Most popular type of batteries are Lithium-ion batteries due to their high energy density, relatively low self-discharge and low maintenance. Performance revolution of lithium-ion batteries has led the development of Plug-in Hybrids Electric Vehicle (PHEV) and Electric Vehicle (HEV). One of the areas in which electrification is gaining popularity is in the field of electric vehicles. Increased level of electrification gives features like frequent start-stop with fuel saving, regenerative braking, motor assistance, etc.[The performance of EV is mainly depending on design of battery pack which must be capable to deliver enough current for the motor for an extended period of time. Since, one battery provides quite low voltage and capacity, in an EV, Hundreds of batteries are connected in series and parallel to make battery pack which provides the required voltage and amp hours (Ah).

Rechargeable battery packs often contain a temperature sensor, which the battery charger uses to detect the end of charging. Interconnects are also found in batteries as they are the part which connects each cell, though batteries are most often only arranged in series strings.

When a pack contains groups of cells in parallel there are differing wiring configurations which take into consideration the electrical balance of the circuit. Battery regulators are sometimes used to keep the voltage of each individual cell below its maximum value during charging so as to allow the weaker batteries to become fully charged, bringing the whole pack back into balance. Active balancing can also be performed by battery balancer devices which can shuttle energy from strong cells to weaker ones in real time for better balance. A well-balanced pack lasts longer and delivers better performance.

For an inline package, cells are selected and stacked with solder in between them. The cells are pressed together and a current pulse generates heat to solder them together and to weld all connections internal to the cell. Rechargeable battery packs often contain a

temperature sensor, which the battery charger uses to detect the end of charging. Interconnects are also found in batteries as they are the part which connects each cell, though batteries are most often only arranged in series strings.

"lithium-ion battery is a lightweight, high-power battery used in computers and mobile phones. It comes in several shapes, although a flat rectangle is most common. It is lighter than the nickel cadmium battery and the nickel metal-hydride battery. That makes it useful for devices that should be lightweight. Lithium-ion batteries work by the movement of lithium ions through a membrane (thin sheet that allows some substances to pass through). They are different from lithium batteries. Lithium batteries contain lithium metal and are not rechargeable (primary cells). Lithium-ion batteries do not contain lithium metal (only lithium compounds) and are rechargeable (secondary cells). They also do not last forever. Traditional lithium-ion batteries will have an average of 600 charge cycles. Some newer versions such as lithium iron phosphate and lithium titanate can last for 3000 cycles or more.

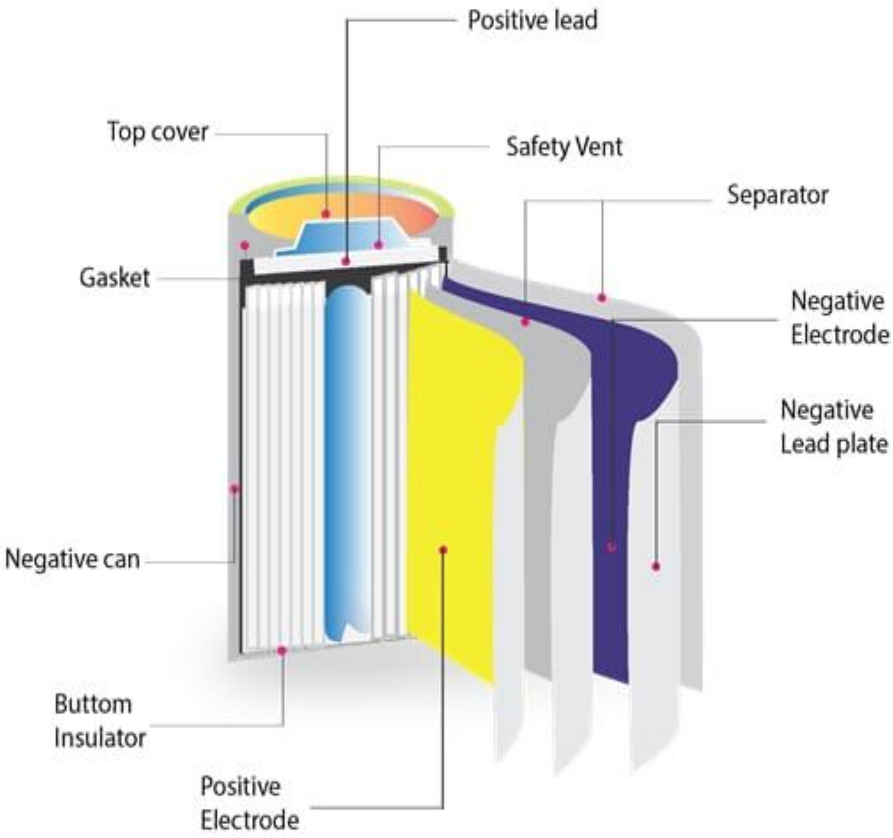


FIG 2.2. construction details of lithium-ion battery.

How to increase the battery life:

The use of battery outside or beyond its limits decreases its life therefore to increase the battery life BMS plays an important role because all the limits are handled by BMS. For example, charging discharging, usage temp and various other parameters. Therefore, by following ways we can increase the battery life :Active balancing and Cell switching: these two things are controlled by BMS

therefore proper and efficient code and circuit should be made for the battery pack.Through optimized partial charging: Batteries have a limited lifespan because of degradation. This can be reduced by using optimized partial charging methods. Nowadays many electrical devices come with this feature. Due to limited lifespan, it becomes a costly method for the customer to fully replace the battery unit. To reduce this degradation, we can have an optimized partial charging method. In the optimized charging, method the battery is charged to a certain point and also discharges the battery up to certain limits. in this method we also have another method in which we charge according to the usage of the battery for example if a person is traveling only 50km a day then the battery can only be charged up to 75 to 80% and when he or she has to travel longer distance then only he can have fully charged battery it can also call as next day prediction. This all happens with the help ofintelligent BMS of the battery. This method increases battery life and battery performance.

Avoid charging to 100%: - we should always avoid charging to 100% or fully charge the battery. When we charge the battery to 100% it will create higher float voltage in the battery and will damage as well as decrease the performance. If someone want always a fully charged battery then he or she should take a battery in which battery works on the lower float voltage such as li-ion phosphate cells. They usually work on lower float voltage than the more similar li-ion batteries. Sometimes if there is no stopping method after 100% then overcharging occurs and this will accelerate the aging process of the batteries.

Limiting battery temperature: -

when we limit the working temp of the battery it increases the battery life and battery performance. For example, we should not charge the battery in cold temp also we should not discharge the battery at high temperatures. The temperature of the battery has to be at a particular temperature. The charging below 0 degrees Celsius will generate metal plating. And this metal plating is observed at the anode which will slowly generate internal short and result in producing heat. All this will make it difficult to handle and unstable. In many recent devices, there is a provision of stopping of charging and discharging when reached to the particular temperature.

Avoid the high charge and discharge rate:

Having large charging and the discharging ratewill generate more heat into the battery and will reduce the lifecycle and efficiency of the battery. A higher current rate is directly related to a higher stress rate in batteries.

Avoiding deep discharging:

Disking deeply will damage the battery soon or permanently. As mentioned earlier deep discharging will create metal plating and it will result in a short circuit. This makes the battery hard to handle and there may be a chance of explosion. Many BMS are made according to it in which discharging stops at a particular point.

Selecting the proper charge termination method:

In this we selected charge rate or a charger in which we require minimum termination of the current charge. Which will extent the battery life by avoiding 100% charge of the battery? For example, termination or stoppingthe cycle when current drops up to c/5. This is also similar or same to decreasing the float voltage to 4.1 V. in both cases the battery is not charged to 100% which is good for battery life**.**

How to slow down battery ageing:

1. Do not use of battery in high ambient temperature environment and also avoid exposure to direct sunlight.

2. Keeping battery inactive/discharged for long amount of time should be avoided, if such situation arises make sure to charge battery in between even if it is not required.

3. Do not charge the battery very frequently (keep a habit of charging the battery only after soc drops below 25%).

4. If the operation is critical replace battery after SOH drops below 90% otherwise after 50%.

2.2. PROPERTIES OF LITHIUM ION BATTERY

Lithium-ion batteries have several key properties:

1. High Energy Density: Lithium-ion batteries provide a high energy density, making them efficient for various applications, from portable electronics to electric vehicles.

2. Low Self-Discharge: These batteries have a low self-discharge rate compared to other rechargeable batteries, allowing for longer shelf life.

3. Long Cycle Life: Lithium-ion batteries typically have a longer cycle life, meaning they can endure more charge and discharge cycles before their capacity significantly degrades.

4. Fast Charging: They are known for their ability to charge quickly, especially compared to other rechargeable batteries.

5. Voltage Stability: Lithium-ion batteries maintain a relatively stable voltage throughout most of their discharge cycle.

6. Compact and Lightweight: These batteries are compact and lightweight, making them suitable for portable electronic devices.

7. No Memory Effect: Unlike some other rechargeable batteries, lithium-ion batteries do not suffer from memory effect, so there's no need to completely discharge them before recharging.

8. High Discharge Current: Lithium-ion batteries can provide high discharge currents, making them suitable for applications with varying power requirements.

CONCLUSION:

In conclusion, lithium-ion batteries are a widely used and versatile type of rechargeable battery. They offer high energy density, long cycle life, and are lightweight, making them ideal for various applications. However, it's crucial to handle them with care and follow proper safety guidelines to ensure their safe and effective use. So, whether it's powering our smartphones or driving electric vehicles, lithium-ion batteries play a significant role in our daily lives.

CHAPTER 3

BUS SELECTOR

3.1. INTRODUCTION TO BUS SELECTOR

The bus selector block in Simulink allows you to choose specific signals from a bus and extract them for further processing or analysis. It's like picking out the signals you want from a bundle of wires.

To use the bus selector block, you first need to connect it to the bus signal you want to extract signals from. Then, you can specify which signals you want to extract by using the block's parameter settings or by connecting it to other blocks that define the selection criteria.

Once you've set up the bus selector, it will output only the signals you've selected, making it easier to work with specific parts of the bus in your Simulink model.

Remember, the bus selector is a handy tool when dealing with complex bus signals that contain multiple signals. It helps you focus on the signals you need without cluttering your model.

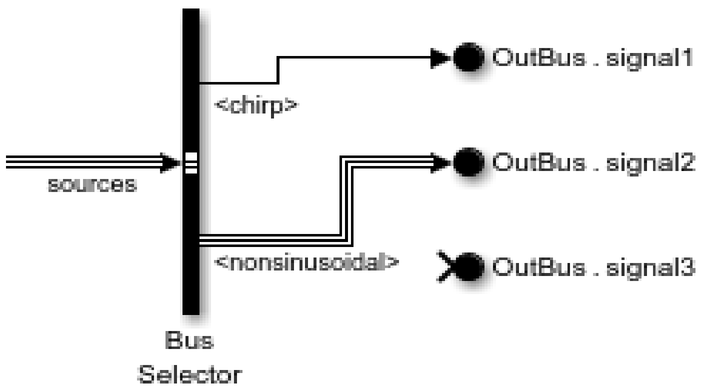


FIG 3.1 Bus selector

To create a bus selector in Simulink, follow these steps:

1. Create a Bus Signal: Use the Bus Creator block to create a bus signal by combining multiple signals.

2. Insert Bus Selector Block: Drag and drop a Bus Selector block from the Simulink Library Browser.

3. Connect Bus Creator and Bus Selector: Connect the output of the Bus Creator block to the input of the Bus Selector block.

4. Configure Bus Selector: Double-click on the Bus Selector block to open its block parameters. Specify the elements you want to extract from the bus by selecting or entering their names.

5. Connect Outputs: Connect the output ports of the Bus Selector block to the subsequent blocks or subsystems in your model.

A bus selector is a component used in MATLAB Simulink to extract specific signals from a bus. In Simulink, a bus is a group of signals bundled together into a single entity. The bus selector allows you to pick and output specific signals from this bundle. If you have a bus containing information about a car (speed, temperature, etc.), but you only need the speed information for a particular part of your model, you can use a bus selector to extract just the speed signal from the bus. In essence, the bus selector simplifies the handling of complex data structures by letting you focus on specific elements within a bus rather than dealing with the entire bundle of signals.

Bus selector parameters:

1. soc

2. current

3.1.1 SOC [STATE OF CHARGE]:

SOC stands for the remaining battery capacity as a percentage to the total in the same situation. 100% stands for the battery fully charged to its total capacity, and 0% stands for battery fully discharged. Accurate SOC estimation plays a vital role in monitoring existing capacity state, to further guarantee the safe and healthy operation of the battery. Two approaches are developed for SOC estimation, which is categorized as direct estimation approach and model-based approach. For the direct estimation approach, based on the direct measurements of battery current and voltage, SOC is mainly calculated by two different ways named Ampere-hour (Ah) or coulomb counting method and open circuit voltage (OCV) based method. Ah method is a general and simple method to calculate SOC.

Since charging or discharging current can be easily measured, Ampere hour (Ah) method becomes a straightforward choice for SOC estimation. However, Ah method is highly dependent on the current measurements, error accumulation over the time will significantly affect the estimation accuracy. Besides, it is difficult to determine the initial SOC accurately in real-time applications especially when the battery is only charged within a limited range, e.g., 10%90%. Calibrations of initial SOC and current become the challenging issues to adopt Ah method for SOC estimation. It has been proposed that there exists a one-to-one nonlinear relation between the battery SOC and OCV.

Although high estimation accuracy of battery SOC can be achieved by the OCV method, the resting time has become a major limitation for OCV-based SOC estimation. It generally takes a long time to reach equilibrium after disconnecting the load current (for example for LiFePO4 battery, duration time is always larger than two hours under low temperature condition). Further, the relation between

OCV and SOC also changes along with battery aging and temperature changes. The disadvantages of OCV method limit its wide applications in EVs.

This problem can be addressed if the OCV can be obtained real-time to allow estimation of SOC during driving. Thus, the model-based approach has been developed to calculate OCV to further achieve online estimation of battery SOC. In the model-based approaches, a suitable battery model needs to be carefully designed.Battery equivalent circuit models and electrochemical models in the forms of standard state space are usually selected to estimate battery SOC, while SOC is one of the state variables in these battery models.

Then various state observers are adopted for online SOC estimation, such as Kalman filter (KF), Extended Kalman filter (EKF), Adaptive Kalman filter (AKF), Unscented Kalman filter (UKF), slide mode observer and H1 filter.

The accuracy of these model-based approaches largely depends on the training of the battery models, the adopted state observers, and the parameter tuning such as the key parameters in model and the noise covariance matrix for KF observers.Besides, the performance of battery SOC estimation by these different observers is only validated under limited conditions of the test data, and a reliable confidence-zone is usually difficult to obtain.Therefore, the estimation performance under various practical conditions, which are different from the test conditions, cannot be guaranteed.

3.1.2 SOH [STATE OF HEALTH]:

SOH represents battery State of Health. There is no single definition for the battery SOH. A general description of battery SOH can depend on several factors such as current, temperature, SOC, others represent some other stress factors such as the mechanical vibrations and over-potential. For EV applications, battery aging will result in the degradation of battery capacity and the increase of battery internal resistance. Thus, the battery SOH can be estimated by the internal resistance or usable capacity as a kind of prediction regime changes in the computer science field. Numerous approaches have been proposed to estimate battery SOH, which are categorized into three groups, namely, model-free, model-based, and data mining.

One can apply the standard capacity test or pulse current test to measure the battery aged capacity and increased internal resistance. However, this direct method is inconvenient and not recommended because fully discharge using the controlled current and temperature will interrupt the normal EV operations.

Besides, as battery SOH changes at a much slower rate compared with the battery SOC, wider ranges of battery operation and more test data are required to train the battery cycle life model, this inevitably increases the difficulty of engineering implementation.

CONCLUSION:

In conclusion, the bus selector in MATLAB is a valuable tool for managing and manipulating bus systems in power distribution simulations. It allows you to selectively connect or disconnect buses, enabling precise control and analysis of power flow. With the bus selector, you can efficiently model and simulate complex power systems, making it an essential component for power engineers and researchers using MATLAB. It's a powerful feature that enhances the capabilities of MATLAB for power system analysis.

CHAPTER 4

SOFTWARE DESCRIPTION

4.1. INTRODUCTION TO MATLAB

MATLAB is a software that's widely used in engineering and scientific fields. It's super useful for things like data analysis, mathematical computations, and creating visualizations. It's like a powerful tool that helps you solve complex problems and make sense of data.

Matlab has a lot of benefits! It's great for numerical analysis, data visualization, and algorithm development. You can use it for things like signal processing, image and video processing, and even machine learning. It also has a large library of functions and toolboxes that make it easier to work with different applications. Plus, it has a user-friendly interface which makes it accessible for both beginners and experts.

MATLAB is a mathematical software package which can be used for analysing and solving mathematical and engineering problems such as numerical computations, graphs plotting, programming and more. MATLAB treat all the variables in form of scalar , vector or matrices form. For this book of MATLAB Programming, it is aimed to give a new MALAB users have an overview of how to use the basic and intermediate level of MATLAB and of course to keep this free for students who might be using this book for their course. To start off, MATLAB is a scripting language (Note that I didn't mentioned it is programming language) for data analysis, think of it as a super-powered programmable calculator with useful default functions that are built specifically for math applications.

The name MATLAB itself is an abbreviation for "MATRIX LABORATORY". Originally, it was a simple interactive matrix calculator in early 1980's. Gradually, it evolves into programming language developed by MathWorks. It started out as a matrix programming language where linear algebra programming was simple. It can be run both under interactive sessions and as a batch job. While other programming languages mostly work with numbers one at a time, MATLAB is designed to operate primarily on whole matrices and arrays. All MATLAB variables are multidimensional arrays, no matter what type of data. A matrix is a two-dimensional array often used for linear algebra.

MATLAB are also designed to be equipped with toolboxes. A toolbox is a package of custom functions and/or classes which are generally for a specific topic (such as control system, signal processing or even deep learning).The toolboxes are either provided officially by Mathworks and require a expensive license, others can be downloaded for free from the File Exchange. MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, C#, Java, Fortran and Python.

Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine, allowing access to symbolic computing abilities. An additional package, Simulink, adds graphical multi-domain simulation and model-based design for dynamic and embedded systems as of 2018, MATLAB has more than 3 million users worldwide. MATLAB users come from various backgrounds of engineering, science, and economics.

HISTORY:

Cleve Moler, the chairman of the computer science department at the University of New Mexico, started developing MATLAB in the late 1970s.He designed it to give his students access to LINPACK and EISPACK without them having to learn Fortran. It soon spread to other universities and found a strong audience within the applied mathematics community. Jack Little, an engineer, was exposed to it during a visit Moler made to Stanford University in 1983. Recognizing its commercial potential, he joined with Moler and Steve Bangert. They rewrote MATLAB in C and founded MathWorks in 1984 to continue its development. These rewritten libraries were known as JACKPAC.In 2000, MATLAB was rewritten to use a newer set of libraries for matrix manipulation, LAPACK.

MATLAB was first adopted by researchers and practitioners in control engineering, Little's specialty, but quickly spread to many other domains. It is now also used in education, in particular the teaching of linear algebra and numerical analysis, and is popular amongst scientists involved in image processing.

SYNTAX:

The MATLAB application is built around the MATLAB scripting language. Common usage of the MATLAB application involves using the Command Window as an interactive mathematical shell or executing text files containing MATLAB code.

Variables:

Variables are defined using the assignment operator, =. MATLAB is a weakly typed programming language because types are implicitly converted.It is an inferred typed language because variables can be assigned without declaring their type, except if they are to be treated as symbolic objects,and that their type can change. Values can come from constants, from computation involving values of other variables, or from the output of a function. In MATLAB, variables are used to store data for processing. Here are some key points about variables and syntax in MATLAB:

1. Variable naming: In MATLAB, variables are case-sensitive and can consist of letters, digits, and underscores. Variable names must start with a letter, and they cannot contain spaces or special characters, except for the underscore.

2. Variable assignment: You can assign a value to a variable using the assignment operator "=". For example, to assign the value 5 to a variable x, you would write: x = 5

3. Data types: MATLAB supports various data types, including numeric types (such as double, single, int8, int16, int32, int64, uint8, uint16, uint32, uint64), logical type (logical), and char arrays for storing text data.

4. Clearing variables: You can clear a variable from the MATLAB workspace using the "clear" command. For example, to clear the variable x, you would write: clear x.

5. Concatenating variables: You can concatenate variables using square brackets . For example, if you have variables A and B, you can concatenate them vertically by writing: C = [A; B], or horizontally by writing: C = [A, B].

4.2.CURRENT MEASUREMENT

In Simulink, you can model and simulate a current measurement system using blocks that represent sensors, signal processing, and visualization. Here's a basic example using a sinusoidal current source and a measurement block:

1. Open Simulink: Open Simulink in MATLAB.

2. Create a new model: Create a new Simulink model.

3. Add a Current Source: Use the "Signal Source" block to create a sinusoidal current source.

4. Add a Measurement Block: Add a measurement block like the "To Workspace" block to log the current data.

5. Configure Parameters: Set the parameters for the current source and measurement block according to your requirements.

6. Run the Simulation: Run the simulation to generate data.

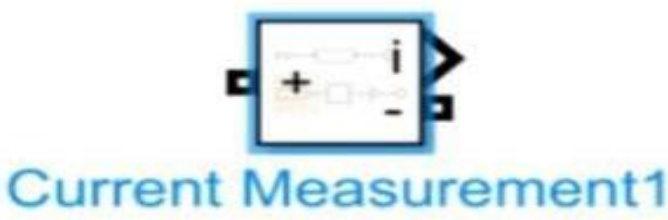


FIG:4.1 current measurement

4.3.VOLTAGE MEASUREMENT

To measure voltage in Simulink, you can use the "Voltage Measurement" block from the Simscape > Foundation > Electrical > Specialized Power Systems > Sensors & Measurements library. Connect this block to the line where you want to measure voltage.

Alternatively, you can use the "PS-Simulink Converter" block from the Simscape > Utilities > Simulink Extras library to convert physical signals to Simulink signals. Connect it to a Simscape > Foundation > Electrical > Specialized Power Systems > Blocks > Electrical reference block, and set it to measure voltage.

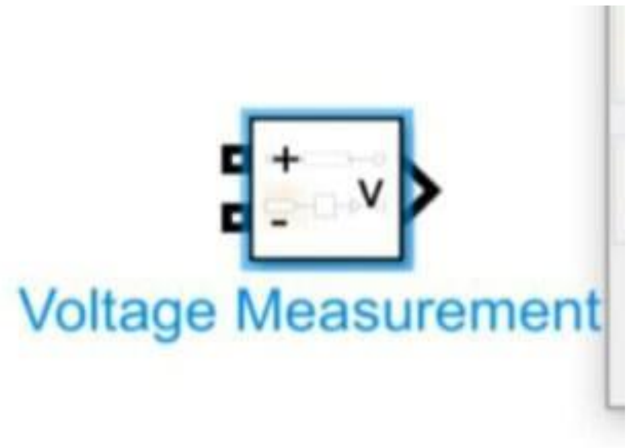


FIG 4.2 voltage measurement

CONCLUSION

In conclusion, Matlab and its Simulink library offer powerful tools for technical computing, data analysis, modeling, and simulation. With a wide range of built-in functions, toolboxes, and visualization capabilities, Matlab is a versatile software package suitable for various applications in engineering, science, and research. Additionally, the integration of Matlab with other programming languages and its multi-platform support make it a flexible and accessible tool for users across different domains. Whether you're a student, an academic, a researcher, or a professional in industry, Matlab provides the resources and support needed to undertake and complete diverse projects with efficiency and precision.

CHAPTER 5

BATTERY PACK

5.1 INTRODUCTION OF BATTERY PACK

A battery pack is a collection of individual batteries that are connected together to provide a larger energy storage capacity. It's commonly used in devices like smartphones, laptops, electric vehicles, and even renewable energy systems. The battery pack allows for portable power and can be recharged when it runs out of energy. It's like having multiple batteries combined into one unit for convenience and efficiency. Battery pack need to meet vehicle's electrical power and energy demand. Assembly of cells into module and ultimately makes the battery pack. Battery packs need to manage the electronic control interface with remaining vehicle control modules and to maintain their cells within predetermined operating parameters for life and safety of battery. Individual cell voltage is insufficient to provide required power since practical considerations with electrical motor, cabling and power electronics limit the current flow to < 50 V and weight < 22 kg for ease of handling and safety. Battery modules are electrically combined to provide full power and energy need for electric vehicles. Depending upon the vehicle type and design, electrochemical cells may account for about 50-75 % of pack cost, weight and volume. Specific performance of battery pack system is always less than that of modules and the modules less than that of cells.

Battery pack must be placed in vehicle by ensuring the safety during normal condition, crash events and vibration. So, placing a battery pack outside the passenger zone of the car is possible, but it will require structural reinforcement to be added to ensure crash integrity. It will also increase the cost, weight and volume International Research Journal of Modernization in

Engineering Technology and Science. Mechanical Packaging influences the robustness against water and dust intrusion. Figure 5: Electric Vehicle Battery Pack. Low voltage (< 50 V) battery pack are typically grounded to vehicle chassis, whereas high voltage (> 50 V) systems are required to be electrically isolated. Voltage and current of pack, battery and module are measured and controlled by Battery Management System (BMS). Electric vehicle battery packs commonly employ thermal management system to maintain cell temperature within normal operating range. Most lithium-ion batteries are capable of achieving desired balance of available energy and power in the range of 10-40°C. Cooling system can vary in design and complexity but typically fall into three categories: passive air, active air, or liquid temperature control. A passive air approach receives air from passenger cabin and relies on vehicle operator

To determine conditioning strategy. This arrangement was used in Toyota Prius. In active air approach, conditioned air from vehicle air conditioning system to battery pack. Such arrangement was used in First-Generation Ford Escape Hybrid, US Model. Due to additional air channel involved, weight and cost associated will be more. So, use of active air approach is less common. Liquid cooling allows greater degree of thermal control as compare to air cooling. Liquid is cooling is volumetrically efficient due to high specific heat capacity. But it does increase the weight and cost. As a result, this type of cooling is for large EV and PHEV batteries like in Ford Focus and Chevrolet Volt.

5.2. Construction

Lithium-ion batteries mainly consists of anode, cathode, separator between two electrodes and electrolyte which fills the space of the battery. Since, lithium is unstable in element form, so the combination of lithium and oxygen called lithium oxide is used for cathode. Lithium oxide is used as an active material and is coated International Research Journal of Modernization in Engineering Technology and Science International Research Journal of

Modernization in Engineering, Technology and Science with conductive additive and binder coating. Aluminium substrate of thin aluminium film is used to hold the frame of cathode. Cathode determines characteristics of battery. Higher the amount of lithium, higher is the capacity of the battery with higher potential difference between anode and cathode. When battery is charged, lithium ions are stored in anode not inn cathode. Graphite is use for anode due to its structural stability, low electrochemical reactivity and low cost. Electrolyte is a medium for the movement of only lithium ions between cathode to anode. High ionic conductivity material is use for electrolyte. Electrolyte is composed of salts, solvents and additives. Separator ensures the safety of battery by acting as a physical barrier between cathode and anode Construction details of Lithium-ion battery.

5.3. Working of Lithium-ion batteries

Anode and cathode are capable to store the lithium-ions. Cathode is the source of lithium-ions and it determines the capacity and average voltage of the battery. Anode stores and release lithium-ion form cathode, allowing the pass of current through external circuit. Electrolyte carries positively charged lithium ions from the anode to the cathode and vice vera through separator. Movement of ions creates free electrons in anode, ultimately creating the charge at positive current collector. Separator blocks the flow of current inside the battery. While the battery is discharging and providing electric current, anode releases lithium ions to cathode, generating flow of electrons from one side to another. While charging the battery is charging lithium ions are released by cathode and receives by anode.

Energy density and Power density are two most important terms associated with batteries. Energy density is the amount of energy a battery can store relative to its mass and is expressed in Watt-hour/Kilogram. While, Power density is the amount of power a battery can store relative to its mass and is expressed in Watts per kilogram.

5.4. Types of lithium-ion batterys:

Based on constituents' lithium-ion batteries can be divided into following types

- Lithium Iron Phosphate (LFP)
- Lithium Nickel Manganese Cobalt Oxide (NMC)
- Lithium Manganese Oxide (LMO)
- Lithium Cobalt Oxide (LCO)
- Lithium Nickel Cobalt Aluminum oxide (NCA)
- Lithium Titanate (LTO)

5.5 BATTERY PARAMETER

Some important battery parameters are as follows

1. Rated Voltage – It is the nominal voltage value at which battery is supposed to operate.

2. Cut-off voltage – It is the voltage value below which, if voltage drops it will damage the battery.

3. Capacity – It is the amount of charge that battery can deliver at rated voltage. Battery capacity is measured in Ampere-hour or amp-hour. Capacity of battery is also expressed as energy capacity of battery which is the product of capacity of battery and rated voltage.

4. C-rate – C-rate is the discharging rate of battery relative to its capacity. C-rate is basically the discharging current, at which battery is being discharged, over nominal battery capacity. This discharging rate is sometimes referred as number

of hours it takes to fully discharge the battery. In general, C-rate depends on charging and discharging currents.

5. Battery Efficiency – It is the ratio of total storage system input to total storage system output.

CONCLUSION:

In conclusion, the battery pack project represents a significant step towards achieving our goal of creating a reliable and efficient energy storage solution. Through meticulous planning, rigorous testing, and innovative design, we have developed a battery pack that meets the highest standards of performance, safety, and durability.

CHAPTER 6

6.1 BATTERY PACK MODELLING USING SIMULINK

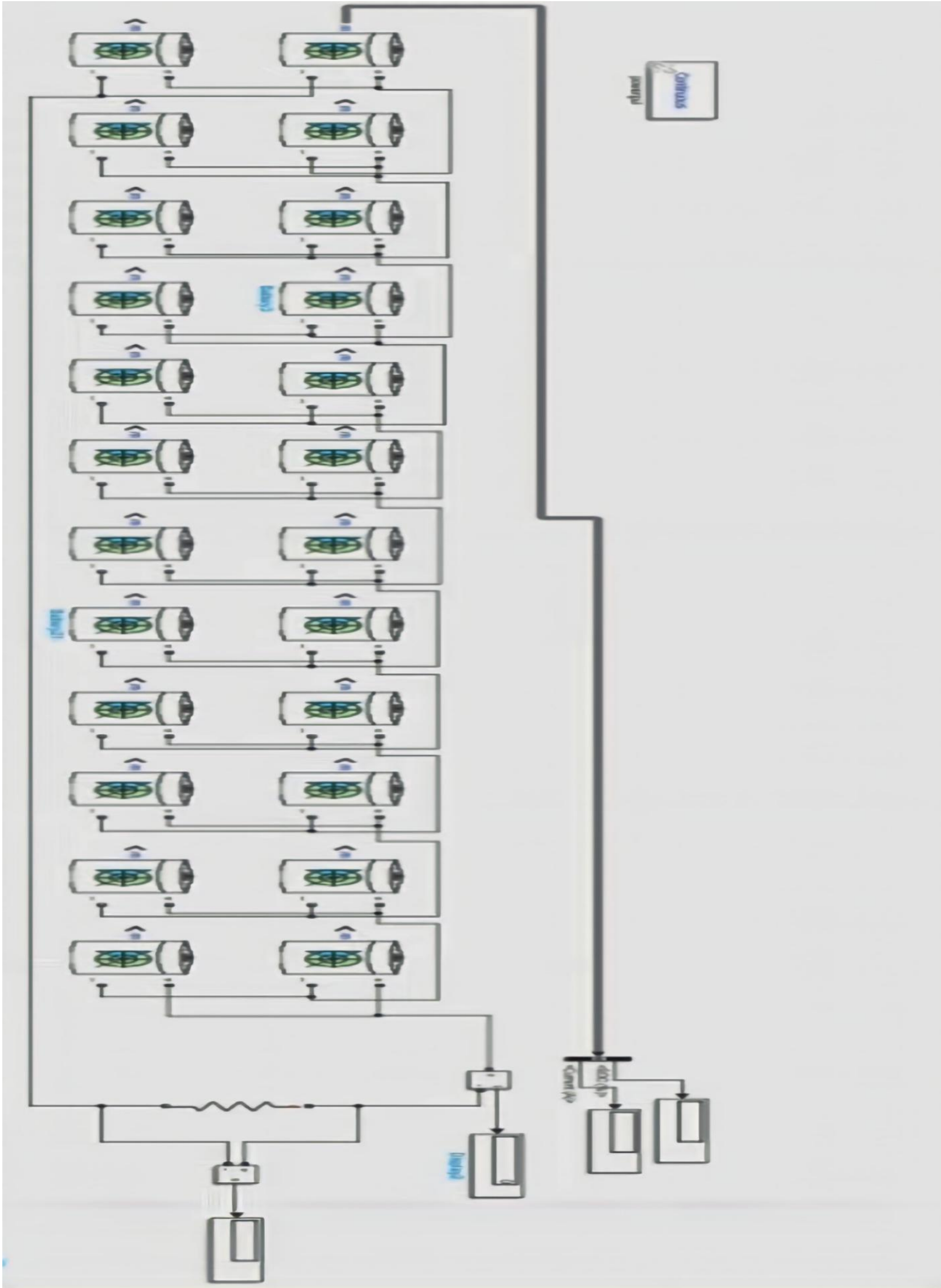
Battery with required value of parameters can be modelled in Simulink for design of the battery pack. Voltage and current requirement of vehicle determines the number of cells need to be connect in series or parallel in order to achieve required power and energy demands. Combination of series and parallel connection of batteries. Volume required for battery pack can also be estimated by considering the volume occupied by individual cell. Range of the electric vehicle can be estimated by considering battery pack capacity and energy consumption of battery per unit distance. Building a Simulink model starts with taking into account individual cell parameters like cut-off voltage, nominal voltage, maximum cell voltage, ampere-hour rating, size of cell. Then, the energy and power requirements of the vehicle is considered which the battery pack need to fulfill. Simulink model allows graphical visualization of battery pack and give idea for type of Lithium-ion battery need to be use to meet target demands in given space constraints, or gives idea regarding the size of battery pack and how much space designed battery pack will occupy.

For the Simulink model, we have used the battery parameters of Tesla Model S electric vehicle for building the Simulink model of battery pack Tesla have used cylindrical type of cells in their battery pack. Tesla installed the battery pack on the floor of the vehicle, thus resulting in more space in passenger space. Batteries are connected in series and parallel to make battery modules and ultimately the battery pack for required energy and traction power.

Batteries achieve the desired operating voltage by connecting several cells in series;each cell adds its voltage potential to derive at the total terminal voltage. Parallel connection attains higher capacity by adding up the total ampere-hour (Ah).

Some packs may consist of a combination of series and parallel connections. Laptop batteries commonly have Li-ion cells in series to achieve a nominal voltage14.4V and two in parallel to boost the capacity from 2,400mAh to 4,800mAh. Such a configuration is called 4s2p, meaning four cells in series and two in parallel. Insulating foil between the cells prevents the conductive metallic skin from causing an electrical short.

Most battery chemistries lend themselves to series and parallel connection. It is important to use the same battery type with equal voltage and capacity (Ah) and neverto mix different makes and sizes. A weaker cell would cause an imbalance. This is especially critical in a series configuration because a battery is only as strong as the weakest link in the chain. An analogy is a chain in which the links represent the cells of a battery connected in series.



FIG,5.1: Simulink diagram of battery pack

ADVANTAGES

1. High Energy Density: Lithium-ion batteries have a high energy density, meaning they can store a lot of energy in a compact size. This makes them ideal for portable devices like smartphones and laptops.

2. Longer Lifespan: Compared to other rechargeable batteries, lithium-ion batteries have a longer lifespan. They can withstand hundreds of charge-discharge cycles before experiencing a significant decrease in capacity.

3. Low Self-Discharge: Lithium-ion batteries have a low self-discharge rate, which means they can hold their charge for longer periods when not in use. This makes them more convenient and reliable.

4. Fast Charging: Lithium-ion batteries can be charged at a faster rate compared to other battery technologies. This is especially beneficial for devices that require quick charging, like electric vehicles.

5. Lightweight: Lithium-ion batteries are lightweight, making them suitable for portable applications. This is particularly important for devices that need to be carried around or for electric vehicles where weight affects overall performance and range.

APPLICATIONS

1. Electric Vehicle (EV) Powertrain Modeling: Simulating the behavior of a battery pack within an electric vehicle's powertrain. Analyzing the impact of different driving cycles on battery performance.

2. Battery Management System (BMS) Development: Designing and testing control algorithms for a BMS to ensure optimal battery operation.

- Implementing state-of-charge (SOC) estimation and balancing algorithms

3. Renewable Energy Systems Integration: Modeling battery packs for energy storage in renewable energy systems (e.g., solar or wind).Analyzing the interaction between the battery pack and renewable energy sources.

4. Consumer Electronics: Simulating the behavior of batteries in consumer electronics like smartphones, laptops, or wearables.

- Assessing the impact of different usage patterns on battery life.

5. Grid Energy Storage: Modeling battery packs for grid-scale energy storage applications. Studying the contribution of battery systems to grid stability and peak load shaving.

6. Uninterruptible Power Supply (UPS): Simulating the performance of battery packs in UPS systems. Analyzing how battery characteristics influence the UPS response to power outages.

Conclusion

In the process of designing a battery pack, it is imperative to carefully evaluate the specific requirements. If a high-capacity system is desired, prioritization should be given to a configuration where the number of cells in parallel is increased. On the other hand, if a higher voltage system is needed, emphasis should be placed on a configuration with an increased number of cells in series.

A circuit is designed for the SOC of Li-ion battery at different states of charging and is modelled and simulated on MATLAB/Simulink tool. The concept of State of charge is considered and pertained to determine the charging and discharging characteristics of a Liion Battery. In order to achieve high efficiency, the multi-state charging is enforced on the battery for filling the capacity of the battery and then it is further evaluated. Along with this, an 8-bit microcontroller is inserted and introduced having a constant voltage of 20V and a current varying from 5A to 60A which manipulates the configured three state current design. Simulating and modelling a circuit having fixed charge and discharge percentage helps in improving the battery life as well as degradation of the battery which is illustrated in the circuit having 85% charge and 15% discharge rate. The results of simulation tell us that, operating on Lithium-ion battery of 12V 6Ah, the time interval of filling is reduced to approximately 30% at a working temperature of 35˚C.

FUTURE SCOPE:

Currently, most battery models in Simulink are based on equivalent circuit models, which provide a good balance between accuracy and computational efficiency. However, there is a growing interest in developing more advanced electro chemical models that can capture the complex electro chemical processes within the battery. Future research may focus on implementing advanced electrochemical models, such as pseudo-2D models or multi-scale models, in Simulink to improve the accuracy of battery pack simulations.

1. **Thermal-Electrochemical Coupling** : Thermal management is critical for the performance and safety of battery packs. Future battery pack models in Simulink may incorporate thermal-electrochemical coupling to accurately capture the interactions between heat generation, thermal transport, and electrochemical processes within the battery cells. This can enable more accurate thermal modeling and design of thermal management systems for battery packs.

2. **Multi-Physics and Multi-Domain Modeling:** Battery pack behavior is influenced by multiple physical phenomena, including electrochemistry, thermal dynamics, mechanical stresses, and control algorithms. Future battery pack modeling in Simulink may involve integrating multi-physics and multi-domain models to capture the interactions between these different physical aspects. This can provide a more comprehensive understanding of battery pack behavior and enable holistic design and optimization.

3. **Ageing and Degradation Modeling**: Battery ageing and degradation are major challenges in the practical implementation of battery packs. Future battery pack models in Simulink may include sophisticated ageing and degradation models to predict the long-term performance and lifetime of battery packs. This can

facilitate the development of adaptive control strategies and predictive maintenance algorithms to enhance the durability and reliability of battery packs.

4.Hardware-in-the-Loop (HIL) Simulation: HIL simulation is a powerful tool for validating battery management systems (BMS) and control algorithms in real-time using physical battery hardware. Future battery pack models in Simulink may be designed to support HIL simulation, enabling real-time interaction with physical battery prototypes or test benches. This can accelerate the development and testing of BMS and control algorithms for battery packs.

5. Integration with Power Electronics and Grid Systems: As battery packs are increasingly used for grid-connected energy storage and vehicle-to-grid applications, future battery pack models in Simulink may be integrated with power electronics and grid systems models. This can enable comprehensive simulations of battery pack interactions with power converters, grid networks, and electrical loads, facilitating the integration of battery packs into diverse energy systems.

6. Machine Learning and Data-Driven Models : The growing availability of

battery data presents opportunities for developing data-driven battery models

using machine learning and artificial intelligence techniques. Future battery pack modeling in Simulink may involve the integration of data-driven models with physics-based models to leverage both empirical data and fundamental physical understanding for improved accuracy and adaptability.

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