Temperature Control of Electric Vehicle Battery using Fuzzy Logic

By

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Supervisor

Dr. Lubna Moin

A dissertation submitted to
Pakistan Navy Engineering College (PNEC)
National University of Sciences and Technology (NUST),Islamabad
A thesis submitted in partial fulfillment of requirements for
Master of Science (MS) in Electrical (Controls) Engineering
July,2023

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July, 2023

Declaration

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This thesis is dedicated to *my Parents, my Wife and my Daughter*

ABSTRACT

The widespread adoption of electric vehicles (EVs) has brought significant advancements in transportation technology by reducing dependence on fossil fuels and addressing the importance of Renewable Energy storage systems. Battery Systems play a key role in EVs Battery Management Systems (BMS) in supplying power. This thesis presents a study on the application of fuzzy logic for electric vehicle battery temperature control. Fuzzy logic provides a flexible and robust framework for modeling and controlling complex systems with uncertain and imprecise information. By employing fuzzy logic-based algorithms, the temperature of the EV battery can be effectively regulated, ensuring optimal performance and longevity.

One of the critical aspects in the development of EVs is the efficient management of the battery system, particularly in terms of temperature control. The temperature of the battery cells plays a crucial role in determining their performance, lifespan, and overall safety. Battery operations outside temperature range leads to inefficiency in BMS. Literature review suggests many approaches in handling controlling of temperature through hybrid cooling, PSO based Fuzzy control to effectively regulate temperature.

The proposed approach involves developing a Fuzzy Logic Controller (FLC) that considers various input parameters such as ambient temperature and battery temperature error. These inputs are fuzzified and processed using a set of linguistic rules, enabling the controller to make intelligent decisions based on the current state of the battery temperature and generates appropriate control signals to adjust cooling or heating mechanisms to maintain the battery temperature within the desired range. To validate the effectiveness of the proposed approach, simulations are conducted using a representative EV battery system. The results demonstrate that the fuzzy logic-based temperature control system effectively maintains the battery temperature within the desired range, thereby improving battery performance, efficiency, and longevity. Moreover, during simulations, there was a decrease in overshoots of coolant pump power and refrigerant power by 60% and 80% respectively. The research contributes to the advancement of EV technology by providing an efficient and intelligent solution for battery temperature control and laying the groundwork for future developments in intelligent energy management systems for EVs.

Acknowledgements

First and foremost, all praises and thanks belong to Allah Almighty for His showers of blessings and mercy on me throughout my research work to complete it successfully.

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CHAPTER 1

INTRODUCTION

The pollution and energy scarcity concerns caused by conventional diesel locomotives are becoming increasingly urgent as the number of cars on the road increases. This is why every nation is pouring resources into building out and improving infrastructure for electric vehicles. Due to their use of cleaner fossil fuels, electric vehicles are far less polluting than conventional diesel vehicles. There is a decline in battery performance and possible safety risks over time due to factors such as variations in mass production, environmental deterioration, and the natural ageing process. For this reason, a BMS was developed to serve as communication hub between the power battery and the EV. Because of the significant amount of heat they produce when in use, batteries can suffer from the effects of overheating and inefficient heat dissipation. Because of this, it is crucial to have a system that can automatically regulate the battery's temperature. These constituent parts of the larger "battery management system" (BMS) are collectively referred to as the "battery thermal management system" (BTMS).

The increased popularity of electric vehicles can be attributed to the growing awareness of their environmental advantages over conventional gas-powered vehicles. Nevertheless, electric vehicles still face challenges, such as a limited cruising range and the need for battery optimisation. Temperature has a significant effect on battery performance and lifespan. Therefore, keeping EV batteries at a constant temperature is essential for optimal performance, safety, and longevity. The electric vehicle's thermal management system is responsible for maintaining a stable temperature in the battery pack. The heat generated by the battery pack during charging and discharging must be dispersed by the thermal management system for optimal battery performance. The radiator is a vital component of the HVAC system. The radiator actively removes heat from the battery pack in order to maintain a safe operating temperature. The radiator pumps a coolant through a system of tubes, which in turn cools the battery pack. The coolant removes the heat from the battery pack. The next step is for the coolant to travel through the radiator, where it will be cooled by air rushing past the fins. The rate at which the radiator cools is controlled by the combination of the fan and the coolant pump. By forcing air through the radiator's fins, the fan reduces the temperature of the coolant. The speed of the radiator fan is often adjusted by a fan controller based on the temperature of the coolant. However, it is the coolant pump's job to push the fluid back into the system once it has been used. The speed of the pump is often controlled by a pump controller that also keeps an eye on the coolant temperature and flow rate. In this thesis, we propose a novel approach to using fuzzy logic to control the temperature of batteries in electric vehicles. To regulate the radiator's cooling rate, we implement a fuzzy logic controller as part of our thermal management system. We are certain that, even in the most challenging driving and climatic conditions, our technology will result in more accurate and consistent temperature regulation of the battery pack. We will demonstrate the superior performance of our proposed system over that of standard PID controllers through simulations and experimental proof. Finally, we'll show how our approach can significantly lengthen battery life by reducing heat-induced damage.

1.1. Overview

In today's rapidly evolving world, technological advancements occur at a breakneck pace. Factors such as population growth, rising living standards, pollution levels, and diminishing supplies of natural resources all play a larger role now than they did in the past. Some changes, like advances in technology, can be seen as positive for humanity. Increases in consumerism, pollution, demands on natural resources, etc., have forced us to take measures to mitigate the negative outcomes of these trends. Due to energy scarcity, declining global fossil fuel, and non-renewable natural resource availability, electrical energy and fossil fuel consumption have consistently increased over the previous two or three decades. Because of this, renewable and alternative energy sources including wind, photovoltaics, fuel cells, bio-fuels, and hybrid green energy schemes are being looked at with fresh eyes as potential replacements for fossil fuels in areas like transportation and propulsion.

1.2. Battery Electric Vehicles

Battery electric vehicles (BEVs) are an example of a vehicle type that uses alternative energy and produces no emissions at the point of usage. Electric vehicles (EVs) propelled by electric motors have a number of advantages over their internal combustion engine counterparts, including their low environmental impact, high level of safety, superior energy efficiency, flexibility in energy source, ability to balance power grids, absence of local exhaust emissions, and quiet, nearly vibration-free operation [1, 2].

However, EVs have a few drawbacks, including slow charging times and a lack of energy density. Optimal energy management, motor design, drive technique selection, and control strategy are all factors that can boost EV performance [3]. Differential operation [4], many motor types [5], and a wide range of options [6] for electric vehicle (EV) motors all contribute to the complex decision-making process involved in designing an EV.

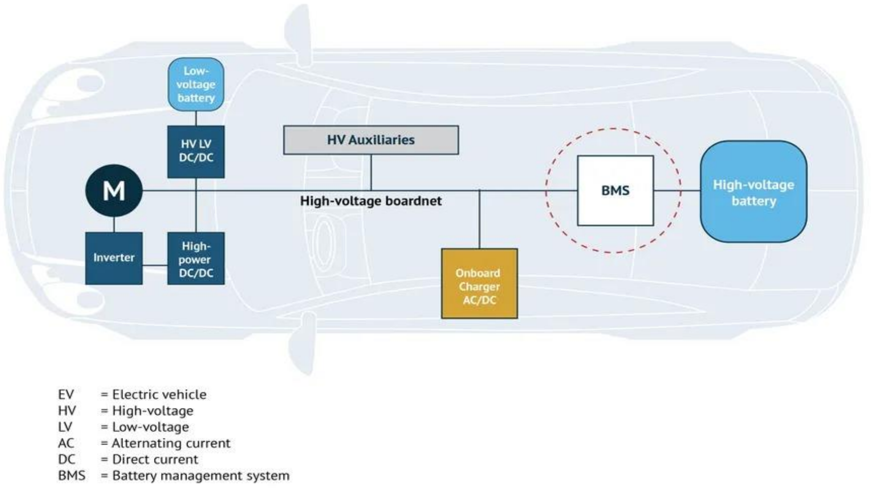


Figure 1 Battery Electric Vehicle Architecture

Electric vehicle specs and configurations vary by use case, with variations in gross vehicle weight, operating voltage, top speed, rated torque, and power sources. DC motors have been widely used in EVs due to their simple speed controls and the fact that their torque-speed characteristics are well suited to traction requirements [7]. Utkin [8, 9] invented Sliding Mode Control (SMC), a form of control based on variable structure theory. It's only been in the last several decades that strong controls like sliding mode control (SMC) have gained popularity. Switched feedback control is the mainstay of SMC. Once the nonlinear system's state trajectory has been pushed onto the sliding surface in state space, it will remain there indefinitely [8]. The ability to align the system's dynamic characteristic with the switching function, immunity to structural uncertainties, unmodeled dynamics, and disturbances [10, 11] are only a few of the many benefits of this control approach. SMC methods have wide-ranging utility and can be used to tackle a wide range of issues. Linear, nonlinear, MIMO, stochastic, and discrete-time systems all have their own theory- and application-based SMCs [12, 14].

1.3. Fuzzy Logic Controllers

Fuzzy logic (FL) controllers employ linguistic variables called fuzzy rules to approximate human knowledge and ability. A mathematical model of the system is unnecessary for the implementation of action-based linguistic fuzzy rules. This is because, while viewing the screen, an experienced human operator may make adjustments to the system's parameters to get the desired result without having to grasp the finer points of the system's dynamics or the inherent parameter fluctuations that contribute to the results. Complex, complex, and nonlinear systems can have their control needs fulfilled by a nonlinear and adaptive fuzzy logic controller (FLC) without having to rely on mathematical models and parameter estimation [15]. Robotics, traffic management, aircraft control, medicine, databases, pattern recognition, power systems, communication, management, medical fields, and psychology are just some of the numerous fields that have found use for FL [10, 16]. There are perks and cons to both FLC and SMC. Different approaches have been taken to combine FLC and SMC in order to mitigate their weaknesses and maximise their strengths. In combination with SMC, FLC lessens the hitting control term [17], delivers the necessary steady-state error dynamics [18, 19], lessens chattering [20], and increases system robustness [21]. While some research has looked into fuzzy rules for use in sliding mode controllers, other research has explored their use in the design of the sliding surface [22].

1.4. Background Studies

Recently, electric vehicles (EVs) have surpassed other eco-friendly vehicles in terms of popularity. Electric vehicles (EVs) provide a number of benefits over their gasoline-powered counterparts, including less pollution, lower operating costs, and improved passenger convenience. Undoubtedly, EVs have progressed to the point where many large automakers now develop them. The widespread adoption of batteries in electric vehicles (EVs), either as the primary energy source or as a backup source in hybrid EVs, is widely credited with the sector's meteoric rise [1]. Battery performance can be impacted by [2,3] parameters such as temperature, chemical composition, age, and charge/discharge cycles. Electric car battery monitoring is crucial but challenging due to the battery's specific characteristics. The SoC quantifies how much of a battery's total capacity is still available for use [4]. Accurate calculation of SoC helps safeguard the battery, avoid over discharge, and extend battery life, as well as enabling rational control schemes that conserve energy [5]. SoC is an important quantity that measures performance. Estimating a battery's SOC is challenging since batteries contain chemical energy that cannot be readily accessed [6]. Due to its inherent limitations and parametric uncertainties, battery models make accurate prediction of the SoC a challenging and time-consuming task [7]. In practise, SoC estimation is often inaccurate and unreliable [8].

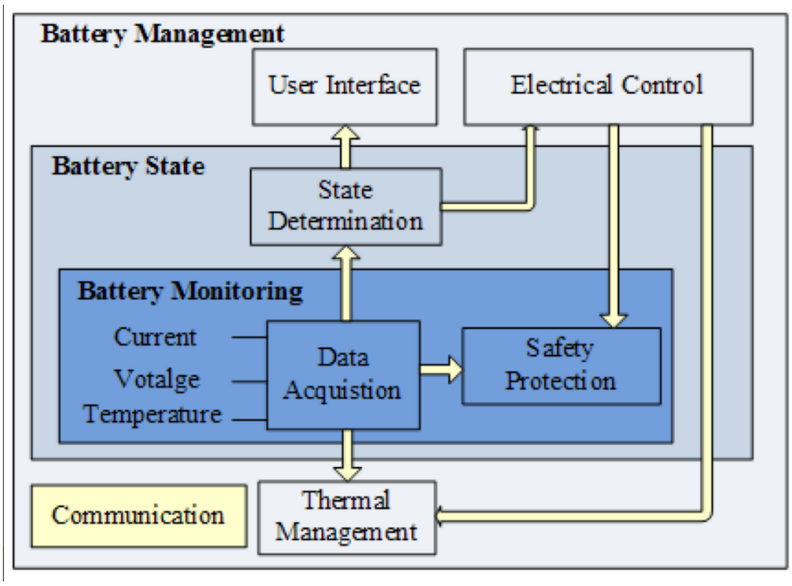


Figure 2 BMS Architecture

1.5. Electric Vehicles

The open circuit voltage of a battery cell can be determined using equation (1) below, which can be used for charge or state-of-charge measurement:

$$SOC(\%) = 100 \times \frac{Vm - Vmin}{Vmax - Vmin}$$

SoC measurements based on voltage "just work," but they are frequently off because of the effect of temperature on the battery [4]. Measurements of voltage and temperature under algorithmic control can liberate SoC evaluations from battery conditions. Hicham Chaoui and colleagues at the University of Ottawa [12] found that applying a predicted temperature value during the discharging process improved the precision of voltage-based SoC measurements. Similar to evolutionary algorithms, fuzzy logic is a popular AI method for dealing with problems that require a wide variety of inputs [10]. Fuzzy logic simulation is used to improve the controller's flexibility and ease of use [11]. Fuzzy logic's ability to function with imperfect data aids in enhancing measurement accuracy. The purpose of this work is to include fuzzy logic into a system for tracking electric vehicle batteries' voltage and temperatures.

1.6. Battery and Temperature

Numerous applications require a means of storing energy, and batteries that use electrochemistry to do so are used in fields as diverse as transportation and renewable energy.

Rechargeable batteries come in a wide variety of styles and capacities [23]. The following system criteria should be thought about during the battery design for the renewable energy system [24, 25]. NiMH batteries are employed in EVs in this experiment. NiMH batteries and its uses in EVs such the Honda EV Plus, Toyota RAV4L, and Mazda Demio are widely available from a variety of manufacturers [2].

In today's rapidly evolving world, technological advancements occur at a breakneck pace. Technological development, population growth, consumer growth, pollution ratio, and the loss of natural resources are all growing problems that threaten our planet. Some changes, like advances in technology, can be seen as positive for humanity. However, as these things have increased, so have our responsibilities to mitigate their negative consequences on the environment and society at large. With energy deficit, depleting world fossil fuel, and nonrenewable natural resources, the demand for electrical energy and fossil fuel has steadily increased over the previous two or three decades. Because of this, renewable and alternative energy sources including wind, photovoltaics, fuel cells, bio-fuels, and hybrid green energy schemes are being looked at with fresh eyes as potential replacements for fossil fuels in areas like transportation and propulsion.

Battery electric vehicles (BEVs) are a great example of a vehicle type that may be used to effectively implement alternative energy sources because they produce no emissions when parked.

An electric vehicle's many benefits include its lack of pollution and high level of safety, its ability to provide high levels of energy efficiency, its capacity to diversify energy sources, its capacity to equalise power systems, its demonstration of zero local exhaust emissions, and its status as a relatively silent, vibration-free, and comfortable mode of transportation. While EVs have many advantages, they also have a few drawbacks, including slow charging times and a poor energy density. Energy management, motor design, driving technique selection, and an appropriate control strategy are only few of the factors that should be considered to boost EV performance [3].

Differential operation [4] and other motor types are being studied for use in EVs. Electric vehicles (EVs) can be equipped with a variety of electric motors [6]. Electric vehicle configurations and requirements vary by use case, including maximum gross vehicle weight, operating voltage, top speed, rated torque, and power sources.

DC motors have been widely used in EVs due to their simple speed controls and the fact that their torque-speed characteristics are well suited to traction requirements [7].

1.7. Problem Statement

Traditional diesel locomotives are a source of pollution and energy deficit, and this is a growing public issue as the number of cars on the road increases. Because of this, there has been a surge in activity worldwide [1-3] to mass-produce electric vehicles. Conventional diesel automobiles produce more pollution than electric vehicles because they utilise more fossil fuels. Factors that cannot be addressed, such as differences that occur during mass production of batteries, the deterioration of the surrounding environment, the natural ageing process of batteries, etc., may cause the performance of batteries to gradually decline and may even pose safety hazards.

That's why it's imperative to install a battery management system (BMS) between the power battery and the electric vehicle [2-5] to ensure the power battery's security. A battery's internal temperature rises and the heat is distributed unevenly when in use since the battery produces a lot of heat. The battery's performance and lifespan will suffer as a result of these two issues. Therefore, it is essential to design a system that can maintain a constant temperature within the battery. These systems are essential components of battery management systems (BMS) and are collectively referred to as battery thermal management systems (BTMS) [6-8]. The goal of this study is to use MATLAB/SIMULINK to create and simulate a battery thermal management system that will sound an alarm if the battery temperature rises above a predetermined safe level.

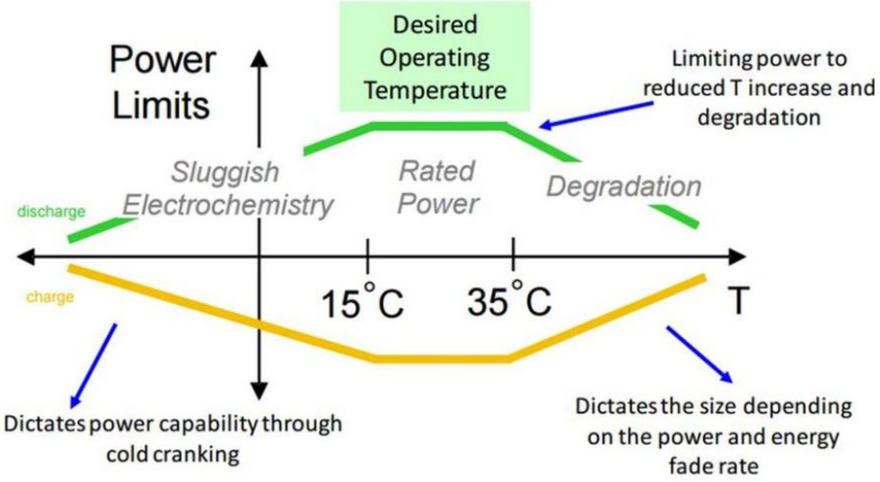


Figure 3 Li Ion Battery Temperature Operations

1.8. Research Objectives

The primary objective of this thesis is to propose a novel approach to electric vehicle battery temperature control using fuzzy logic and a radiator. Specifically, the objectives are:

- To design a thermal management system for an electric vehicle battery pack that incorporates a radiator for active cooling.
- To develop a fuzzy logic controller that regulates the radiator's cooling rate based on the current battery temperature and other relevant variables, such as the outside temperature, driving conditions, and battery usage.
- To compare the effectiveness of our proposed fuzzy logic approach to traditional PID controllers and demonstrate that our approach provides more accurate and stable temperature control, especially under varying driving conditions and ambient temperatures.
- To conduct simulations and experiments to validate the effectiveness of our proposed system.

- To demonstrate that our approach can significantly extend the battery's lifetime by reducing the temperature-dependent degradation of the battery.

By achieving these objectives, we aim to make a significant contribution to the field of electric vehicle technology by providing a more effective and efficient approach to battery temperature control. This will help to ensure optimal performance, safety, and durability of electric vehicle batteries, which are critical factors in the widespread adoption of electric vehicles as a more sustainable mode of transportation.

1.9. Research Significance

As the number of people who own and use automobiles continues to expand, there is a rising cause for concern over the environmental pollution and energy shortage difficulties that are generated by conventional diesel locomotives. These issues are caused by conventional diesel locomotives. As a result of this, each and every nation on the face of the earth is working hard and moving at a breakneck speed in order to develop electric vehicles. Conventional diesel vehicles are more dependent on fossil fuels than electric cars are, and as a result, conventional diesel vehicles are accountable for a greater amount of environmental damage than electric cars are. As a result of a number of factors that cannot be changed, the performance of batteries will gradually deteriorate, and this may even lead to safety issues. These factors include the variations that occur during mass production of batteries, the deterioration of the environment around them, the natural ageing process of batteries, and other factors that cannot be changed. Therefore, the link that connects the power battery and the electric vehicle is conceived of as a battery management system (BMS), with the purpose of ensuring the safety of the power battery. This is done in order to maximise efficiency.

1.10. Research Organization

Chapter 1 sows the problem statement and research objectives

Chapter 2 shows the relate studies

Chapter 3 shows the methodology of current research

Chapter 4 shows the results of current study

Chapter 5 dhows the conclusions and future work.

CHAPTER 2

LITERATURE REVIEW

2.1. Related Work

Batteries played a very significant part in the operation of a variety of different systems. It is utilised in the storage of energy, such as in solar energy systems, as well as in the provision of backup sources in the event that the primary source of energy is unavailable. Batteries need regular maintenance and inspections to ensure that they are in good health. It is possible to use it for a considerable amount of time if the batteries are cared for properly.

Studies show that people are interested in battery management systems because they can prevent the battery from being overcharged, overdischarged, and loaded above its capacity. Multiple aspects of a battery’s care, including its SOC, load, cell balance, and lifespan, can be handled by a management system. The percentage of remaining power in a battery is represented by its "state of charge," or SOC. Maintaining a constant SOC percentage helps the battery last longer [1].

Cell equalisation is another function served by the battery management system. While it is essential that all of the system's batteries be fully charged, not all batteries perform the same. The battery cell balancer is set in such a way so that all of the batteries have the same value. This is done so that the other batteries will not be able to charge the battery to a different value. The allocation of more of the system's available power to a load that is given more priority than other loads that are a part of the system is what load management refers to. When the requirements of the battery are taken into account, the amount of time a battery will last is determined by the results of calculations involving state of charge, cell balance, and load management [1].

The load should receive an adequate amount of energy from the battery system if it has been well planned. On the other hand, if there is a problem with the battery system, it is possible that one or more of the batteries themselves are faulty. If even one of the batteries in the system is defective, the whole thing could end up functioning incorrectly [2].

In the warmer months, when the photovoltaic (PV) array, also known as the solar panel array, produces the most energy, the system relies on that energy extensively. All of the power supplied by a PV array would be transferred directly to the load or the batteries if not for the BCC. Current will continue to flow into the battery after it has achieved full capacity if the energy supply is higher than the load's need for energy. Each time a battery is charged and discharged, it loses some of its capacity and performance [3]. It is envisaged that the charging current will be automatically shut off after the battery is fully charged. Overcharging occurs when the voltage of a battery rises above its safe operating range, as is the case when a battery is constantly being charged. Internal heating, grid corrosion, extreme gassing, and electrolyte loss are just some of the problems that can occur when batteries are charged for long periods of time above their capacity. The battery's performance, lifespan, and vulnerability to permanent damage will all suffer unless this is resolved [4].

It is possible for the battery to be over-discharged if the electrical load is high but only a little amount of energy is being produced by the solar array. Battery life and performance will both suffer significantly if this situation occurs [4].

In order to keep the battery from being overcharged, a charge controller is often placed between the PV and the battery in a renewable energy system. The battery drain is constantly tracked by this controller. However, a charge controller's major concerns are often the battery's voltage and current, and not its temperature. Most charge controllers do not monitor the battery's interior temperature. Maintaining a cool battery requires constant monitoring of its temperature to avoid overheating. The battery's lifespan will be increased as a result.

2.2. Lead-Acid Battery

Lead-acid batteries are popular because of their inexpensive price and high efficiency compared to other energy storage options. It is also useful as a renewable energy backup system. Its high percentage of recyclable materials is a big reason why it has such a low production cost. Charging a lead-acid battery causes heat because of the chemical and electrochemical reaction taking place inside the battery. Internally heating batteries enhances their performance, durability, and utility. Lead-acid batteries have an increased capacity at higher temperatures. But as the temperature rose, so did the drainage rate of the lead-acid solution [7].

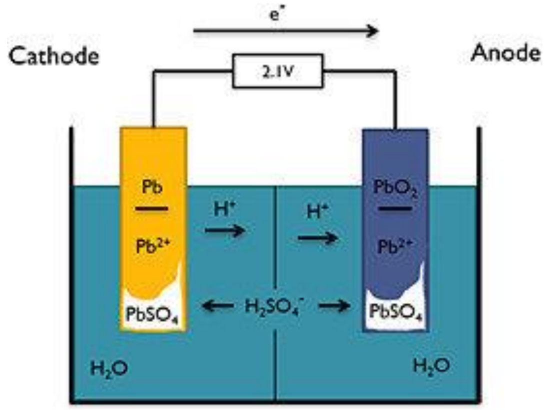


Figure 4 Lead Acid Battery

A battery's temperature rises as its charging time increases. Lead-acid battery discharge rates vary with temperature. A hot battery will take significantly longer to drain than a cool one due to the exponential relationship between temperature and discharge time. The battery discharges on its own when its internal chemistry is at odds with the ambient temperature. When a battery loses all of its charge owing to harmful chemical reactions, we call it "dead." If the temperature within a battery gets too high, it might discharge by itself [8].

As the temperature dropped, the lead-acid battery's performance deteriorated. The battery loses capacity as its temperature rises. High operating temperatures significantly reduced the battery's lifespan [9].

The charge and discharge characteristics of lead-acid batteries are affected by ambient temperature [10]. The battery should be kept away from severe temperatures. It has been shown that batteries work best and last longest when kept at temperatures between 20 and 30 degrees Celsius [5, 6], [8], [11]. Temperatures lower than 10 degrees Celsius or higher than 40 degrees Celsius might damage batteries. Battery life can be prolonged by keeping them at normal temperature [12].

2.3. Lithium-Ion Battery

Temperature can influence the active operation of batteries [5]. The charging and discharging times of a lithium-ion battery are affected by the ambient temperature. Battery heating occurs most frequently during the charging and discharging processes. If the battery temperature stays above 80 degrees Celsius for a long time, thermal runaway could occur. The battery could potentially start burning, catch fire, or even explode [6].

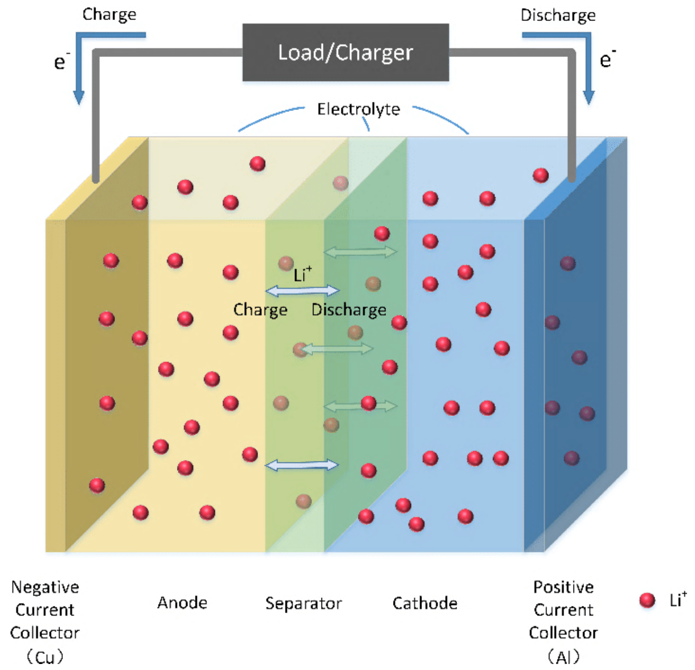


Figure 5 Lithium Ion Battery

A simulation showing how the temperature outside affects the temperature within a LiFePO4 battery cell is shown in Figure 1. The rate at which a cell's temperature rises is accelerated by a large temperature gradient between the cell and its surroundings.

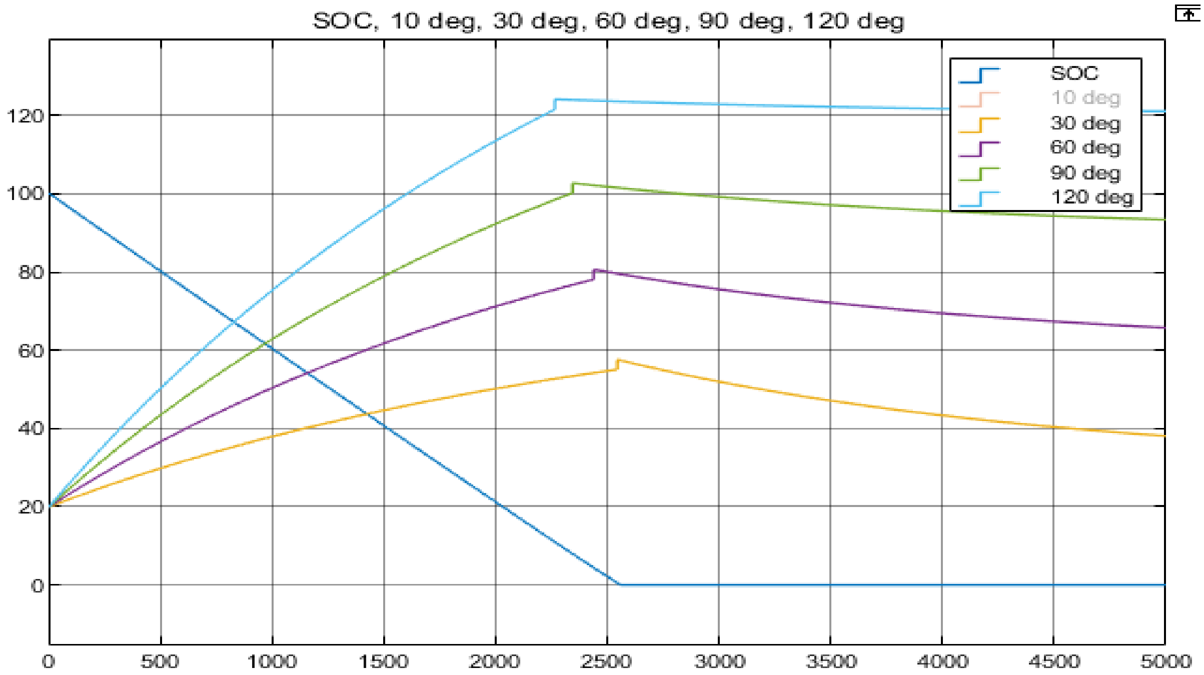


Figure 6 The average temperature of a battery cell as it goes through multiple discharge cycles in a controlled environment.

As can be seen in Figure 6, the same things take place when the battery is being charged; specifically, there is a change in the temperature of the cell.

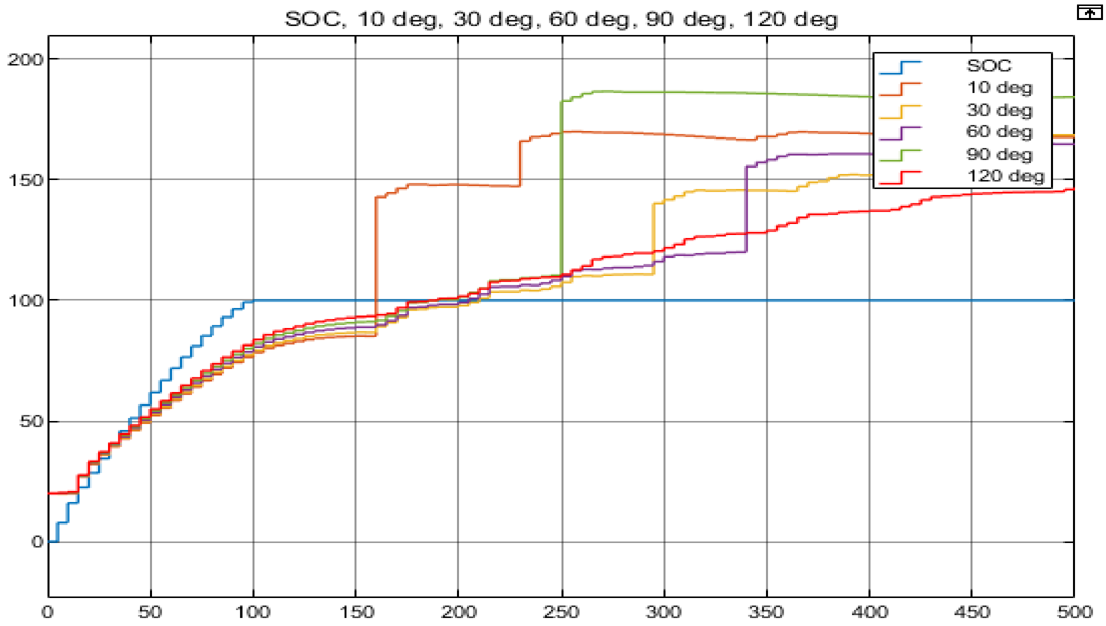


Figure 7 Calculated charging temperature of a battery at a constant ambient temperature.

Safe operating temperatures for lead-acid and lithium-ion batteries are lower than those for standard batteries. It is critical to keep an eye on the temperature of the system and prevent the battery from being overcharged or undercharged.

The goal of temperature regulation is to raise and maintain the temperature of a system at an optimal level without causing any harm. The finest tool for this purpose is the Fuzzy Logic Controller (FLC) because to its ability to combine fuzzy logic with classical logic. The promise of fuzzy logic in the regulation of non-linear dynamical systems has attracted a lot of study during the past two decades. In [1] he explains in detail how he created a thermostat that uses fuzzy logic. Traditional controllers are built with techniques borrowed from control theory. A feedback controller is used to ensure the output pattern is maintained.

Lithium-ion batteries (LIBs) are the focus of intense study because of their crucial significance as an EV energy source. Despite the meteoric rise in LIB sales around the world, the thermal safety issues remain the most agonising pain point and the primary target of inquiry for technological breakthroughs. The need to develop safety management systems for battery packs, as well as the requirement to model and evaluate battery cell thermal behaviour and thermal runaway, are only two examples of the many obstacles to thermal safety in LIBs that are discussed in this work. The mechanisms of heat generation and the thermal properties of LIBs are extensively explored, and the processes of heat formation, dissipation, and accumulation within the cell are outlined in great depth. The origins of the idea of thermal runaway are also discussed. Finally, strategies for identifying and stopping thermal runaways in individual cells and larger groups are presented. Several engineering approaches exist for preventing thermal runaway, such as better materials, more widespread use of additive manufacturing, and enhanced thermal, electrical, and mechanical design.

Controlling the temperature of high-voltage batteries is the most recent and crucial development in the history of cutting-edge electric and hybrid cars. At the moment, everyone is focused on this task. Temperature regulation systems can come in a wide variety of sizes, shapes, and configurations. To efficiently cool and heat the batteries over a broad temperature range, [3] suggests considering a temperature management system based on a liquid cooling system. The premise of this method is that maintaining a comfortable indoor temperature should be based on sound scientific principles. The high-voltage battery temperature management system took a lot of time and effort to create. Calculations, 3D modelling, and testing of the design were all part of this process.

An up-to-date method, fuzzy logic can be used to develop a control scheme for a model with several parameters or a nonlinear structure. Because of this, it provides answers to questions considerably more quickly than more traditional methods of control design. According to [4], a microcontroller, temperature sensor, operational amplifier, analog-to-digital converter, display interface circuit, and output interface circuit are the fundamental parts of a temperature management system based on fuzzy logic. Fuzzy logic was used in the development process to ensure that the appliance's temperature output could be precisely controlled.

Using numerical simulations, the authors of paper [5] describe how they created a VTMS for HEVs. HEV performance can be enhanced by de-designing the VTMS architecture according to well-established criteria and methods. The temperature response of the VTMS in HEVs during transient operations can be predicted using numerical simulations based on a comprehensive model of the system. The VTMS accurately represents the HVAC system in the vehicle. The components of the VTMS and the powertrain interact with one another, hence a VTMS and powertrain model are both necessary for HEVs. Together, the VTMS model and the vehicle power train model allow for an estimate of the VTMS thermal response and fuel economy. The VTMS architecture of a heavy duty series HEV is studied with the help of the detailed VTMS for HEVs model. To complete the integrated simulation, three distinct VTMS architectural designs are used. We examine the architectural designs of VTMS in three different settings and analyse their relative efficacy and efficiency. Each of the three VTMS designs is subject to rapid temperature changes and varied degrees of parasitic power consumption from the electric components. Due to the additional heat source components, the complexity of component operations, and the dependence of parasitic power consumption on drive modes, simulation findings reveal that greater care should be used while configuring the VTMS design for the SHEV.

Battery temperature must be monitored while charging to ensure the continued safety and efficiency of electric vehicle (EV) systems. It is not possible, with present thermal sensor technology, to measure the temperature of each individual battery cell in an electric vehicle. Information on a wireless temperature monitoring device for tracking the status of the batteries in electric vehicles is provided in [6]. The battery cell temperature sensor device created is passive, compact, and reasonably priced. The instrument has a range of over 5 yards and an accuracy of 1.5 °C (3) from -20 to 80 degrees Celsius. Accuracy is measured by charging and then measuring the temperature of a Li-ion battery cell with a rating of 18650-36V-4.4A.

Rapid technological advancements, less environmental impact, and enhanced efficiency have all contributed to the rise in popularity of electric cars (EVs). However, proper battery storage is crucial due to the association between temperature and battery performance and lifespan. You can't put a price on a reliable battery thermal management system (BTMS), which is crucial to the performance of EVs. This [7]study is designed to examine how accurately an induction heater can predict the thermal efficiency of a battery in a parallel system. The author uses GT-Suite for his testing and analysis. Working fluid is a water and ethylene glycol (EG) mixture that is controlled by a system of pumps and valves. By varying the fluid flow rate (from 2 to 27 l/min) and the induction heater power (from 2 to 6 kilowatts), the battery heating times were calculated. The simulations show that as fluid flow increases, so does the pace at which the battery heats up. According to the research, the optimal rate of heating for the batteries was found to be 27 LPM, and the overall system rate of heating, which is restricted by the capacity of the induction heater, increases linearly with flow rate.

Hybrid electric vehicles have seen a boom in popularity due to the environmental benefits they provide and their ability to cut greenhouse gas emissions. Furthermore, a fleet of hybrid vehicles powered by batteries would outperform a fleet of vehicles powered by petrol and oil. However, the product's major flaws are its exorbitant pricing and extremely short battery life. This feature allows its usage in the manufacturing of electronic components like super capacitors. The energy storage components of hybrid electric vehicles, including the battery and super capacitor, have been the subject of extensive research [8]. Has been utilized in this model. Then, Matlab/Simulink is used to model the energy management system that controls the flow of electricity between the battery and the super capacitor.

Accurate real-time estimates of battery pack temperatures were developed by using fast-computing simulation software [9]. In contrast to traditional methods, this simulation tool's accurate and comprehensive electrochemical-thermal model of a Lithium ion battery pack allows for precise forecasting of the temperature distribution across cells during current cycling activities. A predictive battery temperature model was developed, tested, and calibrated by expanding an existing electrochemical-thermal model made for individual cells to include the thermal losses and heat transport parameters of full battery packs. By manipulating the chemistry, spatial cell layout, and electrical structure of the battery pack, the model allows for design experiments to be undertaken. This model can be used in state-of-the-art temperature management systems to analyse and control the dynamic behaviour of any vehicle's battery pack.

Rechargeable batteries for EVs are widely available worldwide. These days, lithium-ion (Li-ion) cells are the most cutting-edge and trustworthy option for battery technology. Lithium battery technology has recently received renewed attention because of its positive effects on the environment and its potential for recycling. Typically, development aims to reduce costs, improve operational safety, and have a smaller ecological footprint. The author of [10] examines the structure, design, and operation of lithium-ion batteries at length. A mechanism for managing the charging and draining of Li-ion batteries found in EVs has been shown by researchers. Battery health is tracked, charging and discharging are managed, battery health is estimated, battery imbalance is avoided, overheating is limited, and any flaws are identified by this system. Lithium-ion batteries are widely used in automobiles due to their low cost, mobility, and tremendous power density. Charging and discharging times, carbon dioxide and greenhouse gas emissions, health consequences, recycling and refurbishment are all areas that could be improved upon. We take a look at the challenges and opportunities involved in producing batteries for EVs of the future. Increases in efficiency, lifespan, specific power, energy density, safety, and overall performance of Li-ion batteries in automobiles are all possible as a result of the research presented here.

Within the context of renewable energy systems, the author of paper [11] discusses the design and implementation of the Fuzzy Logic Controller (FLC) to better control battery capacity. The study's focus is on optimising the operation of energy storage devices (battery banks, pumped hydropower plants, etc.). This article recommends MATLAB/Simulink for modelling, analysing, and controlling energy generation and storage systems. FLC gives users greater management over charging and discharging cycles, extending the life of batteries in consumer devices.

The performance of lithium-ion batteries is especially vulnerable to overheating. There are many methods for reducing the amount of heat generated by a battery. When designing a cooling system for an electric vehicle (EV), it is important to keep the Li-ion battery module at an optimal temperature of 5 to 45 degrees Celsius. For reasons including safety, reduced maintenance costs, and a longer battery life, maintaining a constant temperature in the battery pack is essential. When settling on a cooling method, it's important to strike a balance between aspects including required space, cooling efficiency, temperature stability, and cost. Thermoelectric cooling, dielectric oil cooling, liquid cooling, and phase-changing material cooling are the four methods of cooling investigated in this study [12]. The advantages, disadvantages, and potential applications of these four different refrigerant systems are also thoroughly analysed in the research.

This article [13] aims to examine the use of fuzzy logic in a thermostat and discuss its benefits. This heating and cooling system is necessary for long-term regulation of the room temperature. We will analyse the system's probable problems and fix options within a fuzzy logic framework. This temperature regulation can be used in a wide variety of settings, including air conditioners, greenhouses, and aquariums, thanks to its versatility. All of these programmes use fuzzy logic to regulate energy use, limiting waste while yet satisfying requirements. Fuzzy logic and truth tables of varying degrees may be used in temperature control systems. However, improved management theory and practise is the ultimate aim of the system. It's able to make the necessary adjustments to the temperature utilising internal processes that might potentially correct errors and predict trends based on things like the date and time of year, the time of day, air flow, and so on.

This transition from ICE to EVs presents considerable technological obstacles. Different battery types call for unique approaches. Batteries generate heat, which must be dissipated using innovative methods. This literature analysis examines the pros and cons of five distinct AC systems. The use of liquid cooling, air cooling, phase change materials, and heat pipes are alternatives to vapour compression. In [14], the requirements and advantages of the cooling system were examined. Subsequently, research on refrigerants based on liquids began. The analysis of liquid cooling took into account the channel design/path, the channel shape (square or circular cross section), and the positioning of the cold plates. It is better to have a battery cooling system than to not have one at all. Since the phase change material absorbed heat, it was not as effective as other coolants such as air, liquid, a heat pipe, or vapour compression in removing body heat. In a vapour compression system, liquids are preferred over gases because of their higher heat capacity and heat transfer rate. Liquid cooling and vapour compression, in contrast to heat pipes, can remove moisture from the air. Vapour compression is a complex and time-consuming process that can be used to chill a room. Liquid cooling systems, despite their greater complexity, are widely employed in EVs.

Heat is detrimental to the performance and lifespan of the batteries used in electric vehicles. Maintaining battery safety without compromising efficiency is a challenging control task. In order to lessen battery overheating and unnecessary petrol usage, this research analyses energy management for a 48V mild-hybrid electric vehicle. The lack of active cooling in this family of hybrid systems makes them difficult to implement. In order to better understand the relationship between fuel economy and battery temperature, the author of study [15] constructed a 48V p0 parallel-hybrid and monitored it using dynamic programming. As a first step, the author optimised a powertrain control strategy limited by battery current. To calculate optimal fuel economy, the author adopted a temperature-constrained forecasting strategy that takes into account drivers' prior exposure to weather and travel patterns. The battery can be kept at a safe temperature using either method, but predictive temperature-constrained control offers additional benefits. This study presents a 48-volt mild hybrid with predictive battery heat regulation.

There is an urgent need for more research on electric vehicle command and control systems as the automotive industry shifts away from internal combustion engines and towards electric powertrains. Maintaining the battery at its optimum operating temperature ensures the reliable operation of an electric vehicle. In-depth analysis of how BTMSs cool Li-ion batteries is presented here. To determine whether or not these setups are compatible with Li-ion batteries, [16] breaks down each component and proposes BTM alternatives. This evaluation provides valuable insight that may be used to enhance battery temperature control systems and direct research efforts where they will have the biggest impact (such as improving the efficiency of electric cars on a worldwide scale).

Ultimately, [17]'s experimental investigation into a new battery heat management solution will aid in the advancement of electric vehicle technology. The designed battery thermal management system is highly efficient since it combines thermoelectric cooling with forced air cooling and liquid cooling. The battery is heated unnecessarily since the liquid coolant is in indirect contact with it. The thermoelectric liquid is cooled by forcing air into the container from the condenser side. A replica of an electric vehicle's battery pack is put through rigorous testing. Experiments show a promising cooling effect, and the power dissipation appears to be about right. The surface temperature of a single cell in a copper holder reduced from 55 degrees Celsius to 12 degrees Celsius during testing using a 40 V heater and a 12 V TEC module.

The range and top speed of an electric vehicle are capped by its battery. It is possible for the battery in an electric vehicle to overheat during the charging process. Because of this, batteries can be cooled with a heat pipe and PCM. To get rid of the battery's hotness, a heat pipe is used. PCM acts as a heat sink for the battery, allowing it to work for significantly longer and at higher capacity. The effectiveness of heat pipes and PCM in maintaining a constant 50 C in electric car batteries was investigated in [18]. Beeswax PCM was used for cooling, along with an L-shaped heat pipe. The battery simulator was heated to temperatures between twenty and fifty watts. The researchers used a heat pipe and a phase change material (PCM) to keep the battery's surface temperature below 50 degrees Celsius while under a heat load of 20 to 50 watts. Battery cooling technologies like as heat pipes and phase change materials (PCMs) are now under investigation.

A hybrid electric vehicle's electric motor is charged by a battery pack. The fuel economy of HEVs is excellent. Boosting a motor's torque can reduce fuel consumption. The project intends to incorporate climate and power management systems into a MATLAB/Simulink HEV. Fuzzy logic control for parallel HEV takes into account the driver's command, the SOC of the battery, the speed of the vehicle, the throttle percentage, and the efficiency of the engine to determine the optimal power distribution between the engine and the in-wheel motor (IWM). In [19], the author provides step-by-step directions for modelling a vehicle in MATLAB/Simulink. Before the HEV came released, the regular model had already reached a high level of efficiency. Transforming a regular model into a HEV is as easy as downloading some software, attaching some sensors to the back wheels, and putting a controller in the trunk. The suggested method of energy management is implemented using parallel HEV models. Rules-based torque distribution improves the HEV's fuel efficiency. Simulated data shows that the HEV model improves fuel efficiency by 23% while maintaining battery SOC.

HEVs' improved fuel efficiency is the result of electric motors and lithium-ion batteries. Thermal engineering for HEVs is challenging. Heat is produced by the batteries, generators, and motors of HEVs. Thermostatic control valves, water pumps, and fans are all regular components of cooling systems. Open-loop cooling systems are more prone to RPM overcooling. Electric motors now drive everything from pumps and fans to thermostats and compressors. Electric actuators are more efficient at keeping a steady temperature and have lower parasitic losses. Studies of HEV actuators are being conducted [20]. Heat from the HEV's powertrain, in theoretical terms. We cooled down the motors, engines, and battery packs. Ideal control theory can be used to foresee overheating in electric motors and batteries. MPCs regulate and keep tabs on the compressor. Nonlinear Lyapunov controllers allow us to adjust the rotational velocity of pumps and fans. Airflow management can save as much as 50 percent on energy costs. The cooling system in the average HEV is incorrect by 0.13 C. The use of thermal control reduces cooling energy needs by 81% when temperatures are stable. The most efficient nonlinear controller cuts cooling needs by 13% while lowering temperatures by 0.35 C. Keeping the temperature steady reduces the strain on the air conditioner. The battery pack, electric motors, and engine cooling actuators are all managed using model-based nonlinear controllers. Realistic HEV models were used to recreate real-world driving scenarios.

Lithium ion batteries are essential for EVs because of their high energy density. Overheating caused by frequent rapid charging and discharging can permanently reduce a battery's capacity and performance. This paper [21] discusses the temperature management system built into lithium ion battery packs. The Particle Swarm Optimisation (PSO)-based fuzzy logic controller is used in the battery management system. Overshoot, undershoot, and settling time are used to assess the system's performance. The recommended PSO-based fuzzy system has the fastest settling time for both the heating and cooling subroutines (32 min 13 s and 28 min 46 s, respectively, a difference of 0.497% and 0.975%). The battery module's temperature can also be adjusted. These findings corroborate the usefulness of the PSO-based fuzzy system in improving lithium ion battery temperature regulation.

This article [22] is geared towards electric vehicles in metropolitan areas, and it proposes a hybrid energy source that is both efficient and powerful. Fuzzy logic is used to manage ultracapacitor (UC) batteries. As part of this mission, a hybrid energy system will be developed for on-board use. The suggested energy storage system consists of two DC/DC interleaved converters, two UCs, and batteries. Design and analysis of a hybrid power system using a fuzzy-logic controller (FLC). An experimental rig confirmed the reliability of the control structure. Hybrid energy storage systems are utilised to ensure consistent output at high levels. Because of the FLC's durability and versatility, developing a power management algorithm that factors in road or vehicle data is a breeze. This study tested the hypothesis that adding road topographical data to the hybrid storage system's control architecture will improve the system's performance. Soon, a prototype car will put the control algorithm to the test. Numerous studies have examined the benefits of hybridization with energy storage for EVs. Theoretical and experimental evidence suggests that lithium batteries paired with UCs produce a more potent energy source. The power management algorithm takes the slope into consideration to prevent unexpected battery drain.

Converting power trains to electric propulsion is one way to reduce transportation's carbon footprint. Lithium battery performance and longevity are extremely sensitive to temperature changes. These batteries are useful for both HEVs and EVs. Insufficient knowledge of battery thermal dynamics may be to blame for BTM's undervaluation. As long as it stays within the safe working range, a cell's efficiency increases when the temperature outside of the cell rises. In [23], the author discusses thermal models of batteries and thermal management. The author performs thermal runaway and responsiveness experiments on lithium-ion batteries in cold temperatures and explains heat generation approaches for precise battery thermal analysis. To better understand the challenges and gaps between theory and implementation, we will also analyse the current BTM strategies employed by automotive suppliers. Increase temperature uniformity, battery lifespan, and big pack safety by optimising existing BTMs and developing novel techniques to mitigating battery thermal consequences.

Lithium-ion batteries, which are used in EVs, have a very high cycle life. BTMS is crucial since heat can hasten the breakdown of LIBs and endanger their security. In [24], researchers monitored battery temperatures and cycle counts to decide whether active air or passive PCM cooling was better for BTMS. One-dimensional electrochemical and two-dimensional thermal models are combined to predict the temperatures of sixteen 26650 cylindrical graphite-LiFePO4 lithium-ion cells. how well a model can explain observed phenomena. To generate a plausible current profile for a HEV battery, it is necessary to mimic the surrounding temperature, cooling inlet velocity, and PCM phase transition temperature. Predictions of battery cycle life and distribution can be made using temperature data with battery degradation models. AAC is more comfortable than PCM when the temperature is high outside.

Temperature heterogeneity is produced by active cooling at low air velocities. The air-cooled module's life nonuniformity is higher, but it has a longer cycle life. You can do two things with cyclical cost. Think about the battery's capacity loss because of parasitic loads. The cost of flying is less than that of using PCM. To decrease cycle expenses, increase the air cooling system's inlet velocity. This study recommends BTMS to increase LIB cycle time and cut costs.

Batteries can be used for a wide variety of purposes. Extra energy generated by solar panels can be stored in batteries and used later, such as when the sun isn't shining or at night. Batteries should be tested and maintained on a regular basis for best performance. However, keep in mind that not all battery management systems offer temperature monitoring capabilities if you intend to use one for this purpose. During the [25]experiment, a fuzzy logic-based system will oversee the battery's activities. The fundamental objective of this arrangement is to prevent the temperature of the battery from ever exceeding the limits of what is considered to be a safe working range for it.

In [26], the author provides experimental results for maintaining an adequate temperature in a Li-ion battery system, which will likely be used in future hybrid and electric vehicles. The results of these tests are presented in this study. Additional References Needed The cooling effectiveness of the modern thermal management system has been greatly improved by the use of loop thermosyphon technology. This is one of the main reasons why the system works so well. The results of these trials demonstrate that the current loop thermosyphon system is capable of transporting all of the heat generated by the battery cells while maintaining temperatures below 50 degrees Celsius. These findings are presented here. This is because all of the heat produced by the system is effectively removed.

The shift to renewable energy sources is a pressing issue today. Consequently, eco-friendly commuter and family travel options have shifted to include electric vehicles. Lithium-ion batteries are commonly used in EVs due to their high energy and current density. Use of lithium-ion batteries outside of their SOA (Safe Operating Area) can be dangerous. Therefore, all lithium-ion batteries, and particularly those found in EVs, must have a BMS. There are [27] books that provide in-depth examinations of the causes, traits, and topologies of BMS. In addition, a literature review is conducted to track the development of battery models and BMS hardware/system design. A new battery model is then presented, and its accuracy is demonstrated by simulation. In conclusion, we go over the planning and trial outcomes of a brand new BMS hardware system. The final section, "Conclusions and Future Work," is dedicated to the author's thoughts on how battery models and BMS hardware should be enhanced.

Advances in cellular hardware allow for novel intelligent battery solutions. The increased thermal interactions are a tradeoff for the greater temperature monitoring and control made possible by the circuitry of individual cells. The electro-thermal framework developed by the authors of [28] is used to model smart battery cells. The architecture is made up of a network of neurons and a simplified thermal model. This is the first time that data-driven and physics-based models of thermal batteries have been compared. Both models successfully represent the temperature response of smart battery cells. The precision and speed of NARX-based data-driven neural networks are marginally enhanced. Finally, several new applications show that the models are effective in predicting temperatures inside electric vehicles. Predicting the temperature in addition to the power state is a helpful addition. The novel management of cooling systems uses preconditioning based on temperature forecasts to improve energy efficiency and enable quick charging.

Most engineering programmes worldwide include control engineering in both their undergraduate and graduate curriculums. Control engineers study both classical, feedback-based control theory and the more recent, state-space-based theory. Intelligent control algorithms originate from soft computing paradigms like fuzzy control theory and neural networks, which in turn feed modern control theory. Many control engineering courses include laboratory work as a mandatory component. In order to assist students effectively apply the complex theories they have covered in class and get a good grasp of their ramifications, modern control theory laboratories must provide students with access to simple experiments. In this study [29], we present the architecture and implementation of a microcontroller- and commodity-based fuzzy temperature control system. The final product is meant to serve as a low-cost learning tool for students majoring in control engineering.

Both undergraduate and graduate students in engineering programmes around the world spend a large amount of time learning about control engineering. State space theory and classical feedback-based control theory are both covered in a control engineer's required education. Fuzzy control theory and neural networks are just two examples of the kinds of soft computing technologies that form the basis of the intelligent control algorithms at the heart of today's control theory. A comprehensive education in control engineering requires extensive hands-on experience in the lab. Providing students with meaningful opportunity to apply the complex concepts they've learned in class is a major challenge for today's control theory laboratories. This publication [30] describes the authors' efforts to build a microcontroller-based fuzzy temperature control system using commercially available components for about $100. The final product should be useable as a low-cost fuzzy control laboratory experiment by students of control engineering.

If the battery's temperature is maintained in the ideal range, charging and discharging can be performed quickly, safely, and effectively. Isn't this what battery temperature management (BTM) is supposed to do? However, keeping batteries at a comfortable temperature in both hot and cold climates is a hurdle that is difficult to overcome using the present BTM methods. The smart battery thermal management (SBTM) technology [31] discussed here uses sorption energy harvesting from air to offer practically zero-energy heating and cooling. The temperature shift generated by water vapour absorption and release from a metal-organic framework can be used to either cool or heat a battery, depending on its current temperature. The authors show that MIL-101(Cr)@carbon foam in a self-adaptive SBTM device can keep the battery temperature below 45 °C even at high charge/discharge rates, and that the battery capacity can be increased by 9.2% when used in colder conditions due to self-preheating. Our method shows potential as a means for thermo-related devices to reduce their power consumption, implement smart thermal management that can adapt to their environment, have a small footprint, have a high energy/power density, and not use any liquids.

Li-ion batteries play a crucial role in today's electric automobiles. However, concerns regarding battery longevity are slowing the mainstream adoption of EVs. Maintaining a steady temperature inside the battery pack is essential for maximising its service life. A cooling system's primary role is to maintain manageable temperatures within a battery. This research [32] analyses in depth the techniques that are currently employed for thermal management of cells, modules, and packs. In this article, the author analyses the benefits and drawbacks of today's cutting-edge (conventional) thermal cooling systems. Cell, module, and pack levels were considered as the authors of this study investigated cooling systems. The methodologies for thermal modelling batteries and the difficulties involved in creating batteries with an integrated cooling system are discussed. Possible future implementation to support vehicles with a higher quick-charging capacity is also considered, as are the advantages of these systems over the typical cooling system. In addition, this essay proposes a future strategy for dealing with EV difficulties that is both effective and economical.

To keep the heat exchanger at just the right temperature, the authors of this study advise using a fuzzy logic controller. One type of controller that makes use of artificial intelligence is the fuzzy logic controller. Fuzzy logic controllers are becoming increasingly popular for use in a wide variety of industrial control applications. The heat exchanger is an example of an instrument used in industry that must be precisely controlled. When combining liquids of various temperatures, a heat exchanger is often utilised. Maintaining a constant temperature is crucial in this situation. The heat exchanger is controlled by fuzzy logic to keep the combined fluid at a consistent temperature. In this research, [33] fuzzy logic control is combined with neural network methods in the models. Matlab is used to simulate models of fuzzy logic controllers. The results showed that the heat exchanger's temperature was successfully maintained by the fuzzy logic controller.

Electric vehicles are rapidly overtaking traditional gas-powered vehicles as the preferred mode of transportation. The concept of electric vehicles is intrinsically linked to the idea of global sustainability. Plug-in hybrids, battery electric cars, fuel cell vehicles, and conventional hybrids make up the four most common varieties of EVs. All EV performance is heavily impacted by the decision of energy source and storage. Due to their high energy density and long life cycle, lithium-ion batteries (high-voltage batteries) are widely utilised as a form of energy storage. Lithium-ion batteries have a shorter lifespan when subjected to high temperatures caused by frequent charging and discharging. For EVs to perform at their best, a battery thermal management system (BTMS) must be installed. In his study, [34] explains the background of BTMS used in EV development and how machine learning may be applied to predict and optimise BTMS performance in light of fast-charging procedures. BTMS was discussed as well, with an accent on its prevalence in tropical places like Thailand.

The methods of temperature regulation are discussed in paper [35]. Compared to vehicles powered by conventional fuels, electric vehicles are both more affordable and less harmful to the environment. The performance of EVs is proportional to the calibre of their batteries. Battery performance, and by extension the usability and safety of electric cars, is greatly impacted by temperature. Thermal management for power batteries is discussed, along with the conditions under which it must function. There is an examination of the different cooling systems and a need for greater research into this area, as well as discussion of the best operating temperature range of the battery, thermal field, the architecture of the temperature sensors, the choice of fan power, and the design of the battery pack.

Since lithium-ion batteries can store a lot of energy, they are frequently used as a power source in electric vehicles. However, batteries are severely damaged by high temperatures during manufacture. As a result, the battery won't last as long and the gadget won't function as well. Because of how the temperature of the power battery is controlled, this has major consequences for the reliability of electric vehicles. First, the method is described in [36], then a mechanism for controlling battery temperature is proposed using SIMULINK, and finally, the method is modelled. It's possible that the plan's viability may be demonstrated by simulation, letting all parties concerned witness the results for themselves.

The creator of a long-range battery-electric vehicle addresses heat management and battery charging concerns in his paper [37]. Waste heat recovery and charging point architecture are discussed as factors to consider when incorporating heat pumps into thermal management systems. The optimum control problem has a goal function that considers both the energy output of the chargers and the overall time spent charging, including journey time. To reduce the computational complexity of the problem, the author first converts it into a hybrid dynamical system by simulating the charging dynamics in normalised charging time. Since the vehicle's speed is fixed and it only pauses at charging stations, the driving dynamics can be represented in either the trip time or travel distance domains. In the hybrid dynamical system, each charging station is represented by a binary variable. Numerical approaches are used to generate potential solutions, and simulations are then used to assess how well they function. Charging times are cut by 30.6% and energy usage is cut by 19.4%, according to simulations of the proposed method.

The energy required to power the electric vehicles is stored in a battery pack. There is an urgent need for advancements in battery technology to meet the growing global demand for electric vehicles. This study [38] provides a literature review focused on the qualitative characteristics of BTMSs for electric vehicle batteries. The author conducted a thorough literature study to determine the various BTMS kinds that warrant further investigation and to outline their essential characteristics. This index was made so that you may learn more about the distinctions between the various BTMS. Researchers might benefit from this concise analysis of the present state of the art in battery heat management systems.

Electric vehicles (EVs) are becoming increasingly popular due to their low environmental impact. Weak battery performance, high costs, short lifespans, and safety worries all slow the development of electric vehicles. In order to maintain top performance under a variety of conditions, battery management is essential. Safe battery temperatures are maintained using battery temperature monitoring systems (BTMS). The building thermal management system (BTMS) incorporates thermoelectric, thermo-electric, air, and direct refrigerant technologies. How fast, small, light, cheap, dependable, secure, and energy efficient something is are all factors we consider. The combined liquid system (CLS) and a variation system with power factor correction (PCM) are recommended as the best thermal management techniques for high-performance batteries in the aforementioned publication [39]. To create and test CLS and PCM models, MATLAB/Simulink was used. Simulations allow one to foresee the battery's temperature changes and the energy consumption of the BTMS. Using a system model, we were able to replicate PCM's impact on a battery's temperature and provide a ballpark estimate of the battery's mass. Based on simulations, the battery is maintained at a consistent temperature. Combining simulation, battery thermal electric, and CFD models could be useful in the future.

Battery pack overheating is a serious issue that can significantly reduce the performance and longevity of electric and hybrid electric vehicles (EVs and HEVs). The overall performance of a battery pack can be negatively impacted if there are large temperature differences between its components. As part of the United States Department of Energy's Hybrid Propulsion Systems Programme. When it comes to improving the thermal monitoring and management of valve-regulated lead-acid battery packs for HEVs, the Energy Department's NREL collaborates with automakers and battery businesses. Calculate the temperature distribution among cells, modules, and packs with the help of finite element analysis. The author obtains thermal images of the surface of battery modules after being subjected to HEV charge/discharge profiles using infrared photography and liquid crystal thermography. This study [40] includes the author's personal non-confidential research results on battery temperature management alongside a review of the existing literature on the topic.

Experiments on a state-of-the-art heat management system for electric car battery packs are now underway. Combining thermoelectric cooling with forced air cooling and liquid cooling, as proposed in [41], makes for a highly efficient battery thermal management system. The liquid coolant absorbs the battery's waste heat as it comes into indirect contact with the battery. For the purpose of cooling the thermoelectric liquid, air is blasted into the container from the condenser side. The battery system model of an electric car is put through its paces in a battery of tests. The cooling effect appears to be promising, and the power dissipation is generally adequate, according to the experimental results. The surface temperature was reduced by around 43 degrees Celsius (from 55 degrees Celsius to 12 degrees Celsius) using a single cell in a copper holder, a 40 V heater, and a 12 V TEC module.

In studies [42], the charging and discharging cycles of the batteries were controlled and monitored by an electronic regulator known as a battery management system (BMS). The term "monitoring" refers to the act of keeping track of the battery's status while it is charged and discharged. The battery is constantly monitored while it is being charged and when it is being discharged. The voltage and current output of the battery, as well as its interior and external temperatures, are measured. The safety mechanisms (through alarms or battery shutdown) should be notified by the monitoring circuits if any of the monitored parameters deviates from the allowed range for that parameter. The parameter under study is therefore rendered harmless. This would guarantee that the system is risk-free to use.

The usage of lithium-ion batteries in grid infrastructure is on the rise. Since battery performance, deterioration, and safety can all be negatively impacted by improper operating temperatures, realising a battery thermal management system that can provide the optimal ambient temperature environment for working batteries is essential. The study [43] reviews the literature and provides a summary of the electrical and thermal characteristics of batteries and how they are affected by the operating temperature. It also compares and contrasts the relative merits and specific purposes of various cooling or heating methods. The author also examines control approaches that can contribute to thermal management, which is important because any battery thermal management system would benefit from having low power consumption, a high temperature regulating capability, and perfect temperature uniformity. There is a severe lack of standards for assessing battery temperature management systems. The author then presents a high-level summary of the most critical elements to think about when comparing different battery temperature management system designs. The authors conclude with some forecasts for the development of lithium-ion battery temperature management systems.

In this research, we use a technique based on the mamdani methodology of the fuzzy logic system to lengthen the life of rechargeable batteries. This paper [44] details the authors' efforts to create a fuzzy-control-based energy management system that makes use of MATLAB. Fuzzy control can help extend battery life, but the more space- and time-efficient sugeno method has numerous advantages over the more standard mamdani method. Furthermore, the membership function can be customised each dataset to produce optimal modelling results, all thanks to the flexible methods provided by fuzzy systems. MATLAB's mam2sug command line script can be used to convert output in mamdani notation to sugeno constant form. The improved production attributable to optimisation and adaptive methods and the mathematically calculated continuity of the output surface are the key benefits of the sugeno type.

The high cost and short lifespan of a single power system make energy management of hybrid power systems a significant topic in the field of electric vehicles. In order to determine the SOC of power batteries, the author of this paper [45] suggests a fuzzy energy management technique. The state-of-charge (SOC) of a power source is approximated using a particle filter (PF), and then the estimated value is used as an input variable in a fuzzy energy management controller. The SOC estimation result of the PF algorithm is more in line with the true value of the power battery SOC, as shown by the simulation results. When the PF SOC estimation result was put into the fuzzy controller for joint simulation, it was observed that the charge and discharge current and SOC consumption of the power battery were lowered, demonstrating the efficacy of the approach. It's a great resource for learning about the inner workings of hybrid electric car power management systems.

CHAPTER 3

METHODOLOGY

3.1. System Explanation with Fuzzy Logic and Radiator Cooling

We introduce a novel method for keeping the battery pack of an electric vehicle at a consistent temperature, which combines fuzzy logic with a radiator. Our proposed architecture consists of a fuzzy logic controller, sensors to track data such as battery temperature and environmental variables, and an active cooling radiator. The radiator pumps coolant through a network of tubes that make contact with the battery pack, actively cooling the system. The cooling rate of the radiator is regulated by a fan and a pump, the speeds of which are modulated by a fuzzy logic controller. The fuzzy logic controller calculates the optimum rate of cooling based on the current battery temperature and other variables. Fuzzy logic controller input variables include current values for battery temperature (BT), ambient temperature (OT), and remaining battery capacity (BU). The radiator cooling ratio (RCR) is a metric for evaluating radiator performance. Fuzzy sets are used to specify the input and output variables. To define fuzzy sets, we use thermodynamic concepts like "cold," "warm," and "hot." A membership level is assigned to each value of the input or output variable based on the correspondence between the fuzzy sets and the membership function. At 10 degrees Celsius, a battery's membership function might contribute 0.2% of its total membership to the "cold" fuzzy set. The fuzzy logic controller takes the input variables and applies a set of rules to determine the ideal cooling rate. Examples of these conditions are phrases like "if BT is cold and BU is high, then RCR is high." Each rule's membership degree in an output variable is computed using a fuzzy inference method. A defuzzification technique, such as centroid or mean of maximum, is applied to the output variable in order to obtain a precise reading of the cooling rate of the radiator. The mathematical model also includes the temperature behaviour of the battery pack. Heat conduction and convection within the battery are modelled using the heat transfer equation in the thermal model. The equation takes into consideration all three pathways for heat transmission. We discretize the thermal model using finite difference methods in order to solve it numerically. By fusing the thermal model with the fuzzy logic controller, we can achieve closed-loop regulation of the battery temperature. The radiator's fan and pump speeds are controlled by a fuzzy logic controller that takes into account the current temperature of the battery and other variables. To better control the battery's temperature, we propose using fuzzy logic in tandem with a radiator. The system employs a thermal model and a fuzzy logic controller to ensure the battery's highest potential performance, safety, and longevity.

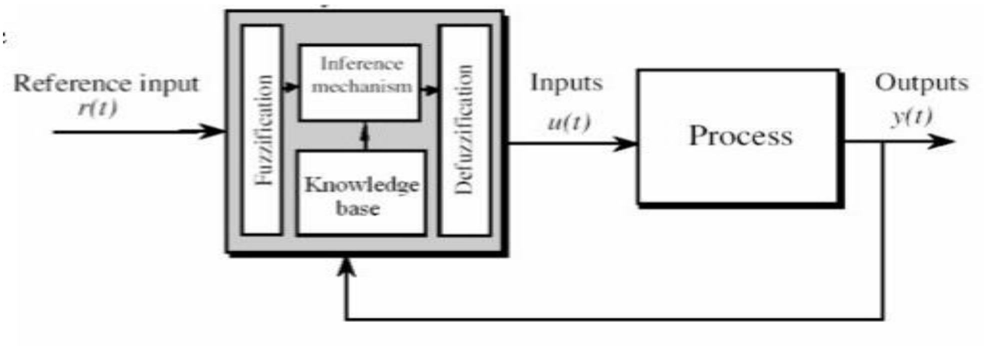


Figure 8 Fuzzy Logic Controller Setup

The following set of equations describes our proposed setup:

3.1.1. Heat Transfer Equation:

The heat transfer equation is used to describe the flow of heat through the battery pack. It is given by:

$$Q = \rho c p V \left(\frac{\partial T}{\partial t}\right) + \nabla.(k \nabla T) + \sigma \varepsilon (T^4 - T_{amb}^4)$$

The heat transfer rate, Q, is represented by the density, cp by the specific heat capacity, V by the volume, T by the temperature, t by the time, k by the thermal conductivity of the battery, s by the Stefan-Boltzmann constant, e by the emissivity of the battery, T_{amb} by the temperature of the surrounding environment, and d by the del operator.

3.1.2. Fuzzy Logic Controller:

Based on the current battery temperature and other factors, the fuzzy logic controller determines the optimal cooling rate. The input variables for the fuzzy logic controller are the current values of the battery temperature (BT), the outside temperature (OT), and the remaining battery capacity (BU). The RCR is a measure of the radiator's cooling efficiency.

Common terms for different types of rules include "cold," "warm," and "hot." This is one possible definition of the rule:

Low BT, high OT, and high BU are essential for a high RCR.

Using a fuzzy inference system, the degree of membership of an output variable is calculated for each rule. To get an accurate reading of the radiator's cooling rate, a defuzzification technique like centroid or mean of maximum is used to the output variable. A fuzzy logic controller can be built using the following formulas:

a. Fuzzy sets:

Each value of the input or output variable is given a membership degree based on the membership functions that define fuzzy sets. A battery stored at 10 degrees Celsius may be assigned a membership degree of 0.2 in the "cold" fuzzy set according to the membership function.

b. Fuzzy rule evaluation:

Fuzzy rule evaluation determines the degree of membership for each rule's output variable. Find the lowest common denominator among the input variables using the minimum operator, which is utilised in membership calculations. Fuzzy rules are evaluated using the following formula:

$$\mu(R_i) = min\big(\mu(A_1), \mu(A_2), \ldots, \mu(A_n)\big)$$

Where μ(R_i) is the degree of membership of the ith rule, μ(A_1), μ(A_2), ..., μ(A_n) are the degrees of membership of the antecedent variables.

c. Defuzzification:

The defuzzification process takes an approximate answer and makes it more precise. When it comes to defuzzification, the centroid and mean of maximum methods are by far the most common. Calculations for the centroid and mean of maximal defuzzification methods are as follows:

$$Centroid: RCR = \frac{\sum(\mu(R_i) \times R_i)}{\sum \mu(R_i)}$$

Mean of Maximum: RCR = R_i where μ(R_i) = max(μ(R_1), μ(R_2), ..., μ(R_n))

The ith output variable, denoted by R_i, is a fraction whose numerator is the precise radiator cooling rate (RCR).

Based on the temperature of the battery and other factors, the fuzzy logic controller determines the optimal cooling rate. Using terms like "cold," "warm," and "hot," we provide a set of natural language rules, and then we use membership functions to map those rules onto a collection of fuzzy sets. For instance, the following rule applies while heavily draining a cold battery:

Battery temperature (0.2) and battery utilisation (0.8) provide the level of membership for each fuzzy set; the numbers in parentheses indicate the cooling rate provided by the radiator.

The fuzzy inference system uses a method such as the minimum or product of the degrees of membership to determine the membership degree of the output variable (radiator cooling rate) for each rule. Defuzzing the output variable with the centroid or mean of maximum could help us determine the radiator's cooling efficiency more precisely. The centroid defuzzification method may precisely yield a result of 0.8 in the case of the radiator's cooling rate if the degree of membership for the "high" fuzzy set is 0.9.

3.2. Thermal Model:

The heat transfer equation for the battery pack can be expressed as:

$$\frac{\rho c p \partial T}{\partial t} = \nabla . k \nabla T + q_{dot} - \varepsilon \sigma (T^4 - T_{amb}^4)$$

the Stefan-Boltzmann constant, the specific heat capacity, the temperature, the duration, the thermal conductivity, the rate of heat generation, the emissivity, and the ambient temperature T_{amb}.

3.3. Finite Difference Method:

Finite difference methods, notably the explicit or implicit Euler technique, are frequently used to discretize the heat transport equation. In the finite difference method, the battery pack is gridd out so that forward and backward differences can be estimated as partial derivatives. The heat transport equation can be stated using the explicit Euler method as:

$$\begin{aligned} T_i, j+1 = T_i, j &+ \frac{\Delta t}{(\rho c p)\left(k_i + \frac{1}{2}, j(T_i + 1, j - T_i, j) - k_i - \frac{1}{2}, j(T_i, j - T_i - 1, j)\right)} \\ &+ \frac{\Delta t}{(\rho c p) V_i}, j q_{dot_i}, j - \frac{\Delta t}{(\rho c p) \varepsilon \sigma (T_i, j^4 - T_{amb}^4)} \end{aligned}$$

The heat transfer equation is typically discretized using finite difference methods, most notably the explicit or implicit Euler technique. To estimate forward and backward differences as partial derivatives, the battery pack is gridd out in the finite difference approach. Using the explicit Euler technique, the heat transport equation may be written as.

3.4. Radiator Cooling Rate:

By adjusting the speed of the fan in relation to the output of the coolant pump, the radiator's cooling capacity can be adjusted. Radiator cooling rate is dependent on coolant flow rate and fan speed, and may be modelled with a simple equation:

$$Q_{dot} = C_{p \rho V \Delta T}$$

where Q_{dot} is cooling power, C_p is coolant's specific heat capacity, is coolant density, V is coolant flow rate, and T is coolant's inlet-to-outlet temperature differential.

The cooling power can be related to the radiator cooling rate using the following equation:

$$R_{cooling} = \frac{Q_{dot}}{(\rho_c * V_{air})}$$

where R_cooling is the rate at which the radiator cools the air, _c is the air density, and V_air is the air volume flow rate.

Pulse-width modulation (PWM) is a method of controlling fan speed in radiators by varying the fan's duty cycle. A linear function, such as, can be used to approximatively describe the connection between fan speed and duty cycle.

Power consumption of the fan,

$$V_{fan} = \ k(duty) \ * (duty - cycle)$$

fan speed (V_fan), a constant (k_duty) that connects duty cycle to fan speed (V_fan), and PWM signal duty cycle ($duty_{cycle}$).

A similar PWM signal that modulates the pump's duty cycle can be used to regulate the coolant pump's output. A similar linear function can be used to approximatively describe the connection between flow rate and duty cycle:

Calculating Pump Voltage:

$$V_{pump} = K * Duty\ Cycle$$

The duty_cycle parameter controls the proportion of time the PWM signal is active, the V_pump parameter specifies the flow rate of the coolant pump, and the constant k_duty links the duty cycle to the flow rate.

Modulating the PWM signal frequency to the fan and pump regulates the radiator's cooling rate. The fuzzy logic controller considers several factors, including the current battery temperature, while setting the appropriate duty cycle. A linear function such as can be used to approximate the relationship between the duty cycle of the radiators and the rate at which the air is cooled:

$$R_{cooling} = k_{duty_{fan}} * duty_{cycle_{fan}} + k_{duty_{pump}} * duty_{cycle_{pump}}$$

where the constants k_duty_fan and k_duty_pump relate the fan and pump duty cycles to the radiator cooling rate, and the duty cycles of the fan and pump PWM signals are duty_cycle_fan and $duty_{cycle_{pump}}$.

3.5. Lithium Ion Battery

A lithium-ion battery consists of two electrodes (cathode and anode) separated by an electrolyte, as shown in the figure 3 below.

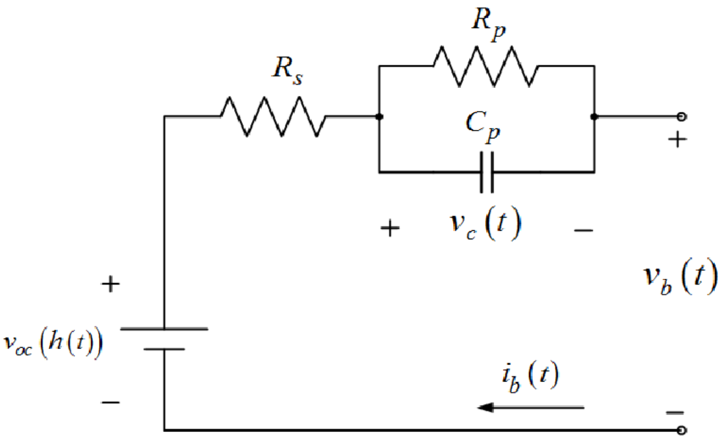


Figure 9 Lithium Ion Battery

The cathode and anode are typically made of transition metal oxides and graphite, respectively. The electrolyte is usually a lithium salt dissolved in an organic solvent.

The electrochemical reactions that occur in a lithium-ion battery can be represented by the following equations:

$$Cathode: LiCoO2\ --> \ Li1-xCoO2\ +\ xLi+\ +xe-$$

$$Anode: 6C\ +\ xLi+\ +xe-\ --> \ LiCx$$

$$Overall: LiCoO2\ +\ 6C\ --> \ Li1-xCoO2\ +\ LiCx$$

where x is the state of charge (SOC) of the battery, which represents the fraction of the lithium ions that have been extracted from the cathode and inserted into the anode. The SOC can range from 0 (completely discharged) to 1 (fully charged).

The voltage of a lithium-ion battery can be modeled using the following equation:

$$V\ =\ V_{oc}\ -\ IR\ -\ \frac{KQ}{Q}$$

where V is the terminal voltage, V_oc is the open-circuit voltage, I is the current, R is the internal resistance, KQ is the capacity fading coefficient, and Q is the remaining capacity. The capacity fading coefficient represents the rate at which the battery capacity decreases over time and is usually determined experimentally.

The capacity of a lithium-ion battery can be calculated using the following equation:

$$C\ =\ \frac{Q}{\Delta V}$$

where C is the capacity, Q is the charge transferred during discharge, and ΔV is the voltage drop during discharge.

The temperature of a lithium-ion battery can also have a significant impact on its performance and lifespan. The rate of the electrochemical reactions and the diffusion of lithium ions through the electrodes and electrolyte are strongly temperature-dependent.

To control the temperature of a lithium-ion battery, a temperature sensor can be placed inside the battery pack to measure the temperature. The fuzzy logic controller can use this temperature measurement and other relevant variables, such as the current and voltage, to adjust the duty cycles of the radiator fan and coolant pump PWM signals, as described in the previous sections.

3.6. Fuzzy Logic System

Fuzzy logic is a form of artificial intelligence that has proven effective in the management of complex systems that require human judgement or are subject to environmental uncertainty. There are four main parts to fuzzy logic: rules, rule evaluation, input variables, and output variables.

Decisions in fuzzy logic are based on the values of the input variables. The use of sensors and other inputs allows for the measurement or calculation of these parameters. Outcomes like decisions and actions taken are represented by the output variables in a fuzzy logic system. Actuators and other control systems frequently receive these signals.

In a fuzzy logic system, the connections between input and output variables are governed by rules. "if-then" statements are commonly used to indicate the rules that govern the relationship between input and output variables. If the indoor temperature and humidity levels reach a predetermined point, the air conditioner, for instance, might be configured to activate at full power.

In order to determine whether or not the rules in a fuzzy logic system are correct, it is necessary to take into account both the actual values of the input variables and the extent to which each rule is true or false. Fuzzy set theory is applicable here because it permits the use of fuzzy sets to describe imprecise or uncertain data. Fuzzy sets are characterised by their membership functions, which transform input values into membership probabilities.

The final decision or action of a fuzzy logic system is frequently represented by a single set of output values, which is calculated by adding the results of each rule's evaluation. The output set is then defuzzified to get back the original, crisp value.

The table below depicts one configuration of a fuzzy logic system for regulating motor speed in accordance with environmental variables like temperature and load:

Input Variables	Membership Functions
Temperature	Low, Medium, High

Load	Light, Medium, Heavy
Output Variable	Membership Functions
Speed	Slow, Medium, Fast
Rules	Output
IF Temperature is Low AND Load is Light	THEN Speed is Slow
IF Temperature is Low AND Load is Medium	THEN Speed is Slow
IF Temperature is Low AND Load is Heavy	THEN Speed is Medium
IF Temperature is Medium AND Load is Light	THEN Speed is Medium
IF Temperature is Medium AND Load is Medium	THEN Speed is Medium
IF Temperature is Medium AND Load is Heavy	THEN Speed is Fast
IF Temperature is High AND Load is Light	THEN Speed is Medium
IF Temperature is High AND Load is Medium	THEN Speed is Fast
IF Temperature is High AND Load is Heavy	THEN Speed is Fast

In this research, the fuzzy logic system uses the temperature and load of the motor as input variables and produces the speed of the motor as the output variable. The rules define how the output variable should change in response to changes in the input variables. The membership functions define the degree to which each input value belongs to each fuzzy set. The defuzzification process converts the fuzzy output set into a crisp output value, such as a PWM signal for controlling the motor speed.

3.7. Battery Thermal Management System

A battery thermal management system (BTMS) is a system that regulates the temperature of a battery to ensure safe and optimal performance. A BTMS typically consists of a combination of active and/or passive cooling systems that control the battery temperature.

The temperature of a battery can affect its performance and lifespan. Lithium-ion batteries, for example, operate best at temperatures between 20°C and 25°C. Temperatures outside of this range can reduce the battery's capacity, increase its internal resistance, and shorten its lifespan.

The thermal behavior of a battery can be described using the following equation:

$$C_p * \left(\frac{dT}{dt}\right) = Q - h * (T - T_{amb})$$

where: C_p is the specific heat of the battery dT/dt is the rate of change of the battery temperature Q is the rate of heat generation by the battery h is the heat transfer coefficient between the battery and the surrounding environment.

Battery thermal management systems (BTMS) are used to regulate the temperature of a battery to ensure optimal performance and prevent damage. A BTMS typically uses a combination of active and passive cooling methods to maintain a safe and consistent operating temperature range. The following equations describe the basic principles behind BTMS:

Heat generation: The amount of heat generated by a battery is proportional to the current flowing through it and the internal resistance of the battery. This can be expressed as:

$$Q_{gen} = I^2 x\, R_{int}$$

where Q_gen is the heat generated (in watts), I is the current flowing through the battery (in amperes), and R_int is the internal resistance of the battery (in ohms).

Heat transfer: The heat generated by the battery must be transferred to the surrounding environment to maintain a safe operating temperature range. Heat transfer can occur through conduction, convection, or radiation. The rate of heat transfer is proportional to the temperature difference between the battery and the environment, and the thermal conductivity of the materials involved. This can be expressed as:

$$Q_{trans} = h\ x\ A\ x\ (T_{bat} - T_{env})$$

where Q_trans is the rate of heat transfer (in watts), h is the thermal conductivity of the materials involved (in watts/meter-Kelvin), A is the surface area of the battery (in square meters), T_bat is the temperature of the battery (in Kelvin), and T_env is the temperature of the environment (in Kelvin).

Cooling power: The cooling power of a BTMS is the amount of heat that can be removed from the battery per unit time. This can be expressed as:

$$P_{cool} = m_{dot} x\ Cp\ x\ (T_{in} - T_{out})$$

where P_cool is the cooling power (in watts), m_dot is the mass flow rate of the cooling medium (in kilograms/second), Cp is the specific heat capacity of the cooling medium (in joules/kilogram-Kelvin), T_in is the inlet temperature of the cooling medium (in Kelvin), and T_out is the outlet temperature of the cooling medium (in Kelvin).

Fuzzy logic control: Fuzzy logic can be used to control the cooling power of a BTMS based on the temperature of the battery and other factors. The input variables can include the temperature of the battery, the current flowing through the battery, and the ambient temperature. The output variable is the cooling power of the BTMS. The rules and membership functions for the fuzzy logic control system will depend on the specific application and the desired temperature range.

Overall, a BTMS must balance the heat generation of the battery with the rate of heat transfer and cooling power to maintain a safe and consistent operating temperature range. The equations and principles described above can be used to design and optimize a BTMS for a specific battery and application.

Material	**Thermal conductivity (W/m-K)**	**Specific heat capacity (J/kg-K)**
Aluminum	205	900
Copper	400	385
Water	0.6	4186
Air	0.026	1005

Table 1 Typical thermal properties of materials used in battery thermal management systems.

Temperature error (e)	**Rate of temperature change (de/dt)**	**Cooling power (P_cool)**
Negative (cold)	Negative (cooling down)	Low
Negative (cold)	Zero (stable)	Medium
Negative (cold)	Positive (heating up)	High
Zero (ideal)	Negative (cooling down)	Low
Zero (ideal)	Zero (stable)	Low
Zero (ideal)	Positive (heating up)	High
Positive (hot)	Negative (cooling down)	Medium
Positive (hot)	Zero (stable)	High
Positive (hot)	Positive (heating up)	High

Table 2 Fuzzy logic control rules for a battery thermal management system

Parameter	**Value**
Maximum operating temperature	60°C
Minimum operating temperature	-10°C
Optimal operating temperature range	20-40°C
Heat generation rate	500 W
Heat transfer rate	200 W
Cooling power	300 W
Mass flow rate of cooling medium	0.1 kg/s
Inlet temperature of cooling medium	20°C
Outlet temperature of cooling medium	30°C

Table 3 battery thermal management system performance parameters

Figure 10 depicts the signal response of the battery, EV grid, and load connected on same line. In this configuration, a fuzzy logic controller is not present. The simulation found that when power was supplied to the system bus from solar cells, current flowed to both the load and the batteries. When the battery is fully charged and its state of charge (SOC) does not change, the cell temperature remains higher than 120 degrees Celsius during operation. This means the battery is not receiving any charge or discharge. The equation is obtained by using the curve-fitting feature of MATLAB.

$$V = 155\ e^{0.2x\ SOC} - 150.62e^{-15xSOC}$$

Where V_{OCV} is OCV of battery unit, e is Euler's constant. SoC of a battery can be estimated by simply employing coulomb counting method using following equation:

$$SOC_i^t = SOC_{i0} - \frac{1}{Cp}\int_0^i battery\, dt$$

Where SoCi (t) and SoCi o are the present value and initial value of SoC of ith battery, Cp is the capacity and i battery is the output current of the battery unit.

Signal Response during Simulation

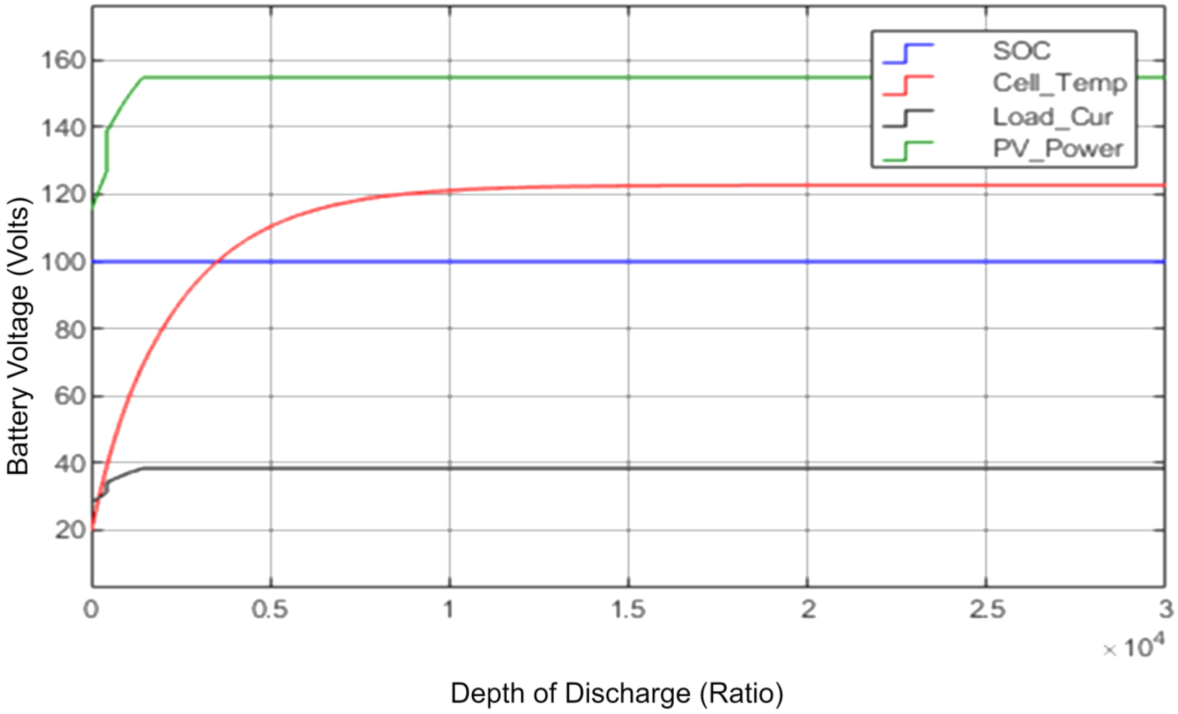


Figure 10 Simulation signal response with 100% SOC and 40°C battery ambient temperature.

Figure 11 depicts the signal response during a battery charge, which shows that the EV's power output increases from around 80 to around 160 watts. The battery was completely discharged before charging began, and it was charged from zero to one hundred percent. Because of this, the system's overall safety could be compromised, the battery's lifespan could be drastically reduced, and the battery could even explode.

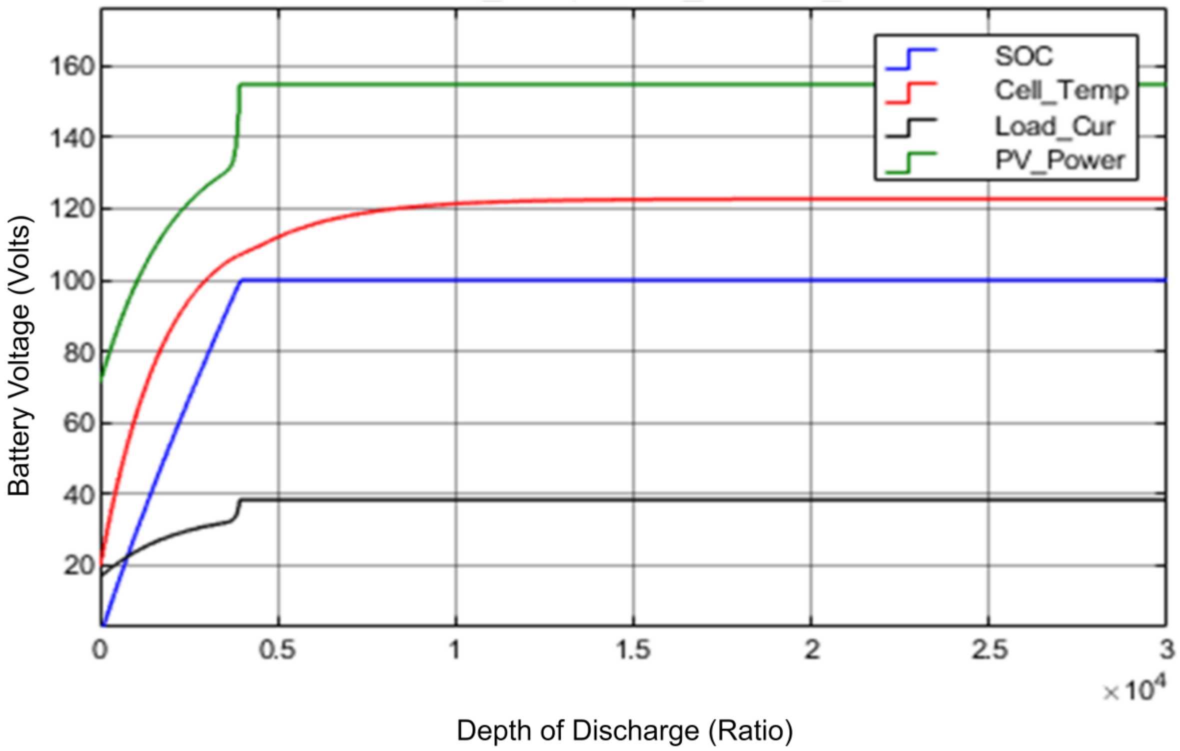
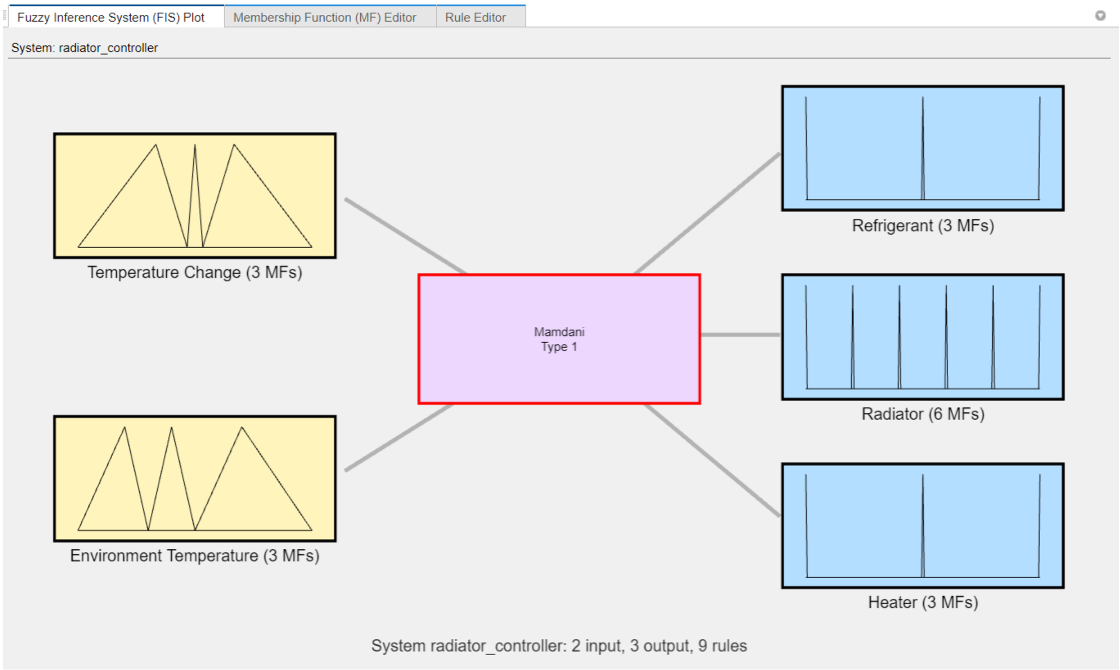


Figure 11 Signal response during simulation with 0% SOC and 40°C ambient temperature

3.8. Heating – Cooling Unit Fuzzy Controller

A fuzzy logic controller is built into the device to automatically control the battery's heating-cooling unit when its temperature reaches outside thresholds. This situation will last until the battery's temperature returns to its normal operating range. Temperature Error and Environment temperature (TEMP are the two input variables that make up the fuzzy logic-controlled system shown in Figure 12. In terms of outputs, we have the control signals for Refrigerant, Radiator and Heater



System radiator_controller: 2 input, 3 output, 9 rules

Figure 12 Variables for fuzzy logic-controlled battery management

3.9. Parameters of Fuzzy Controller Inputs

Table 3 details the inputs and their associated settings for fuzzy logic controllers.

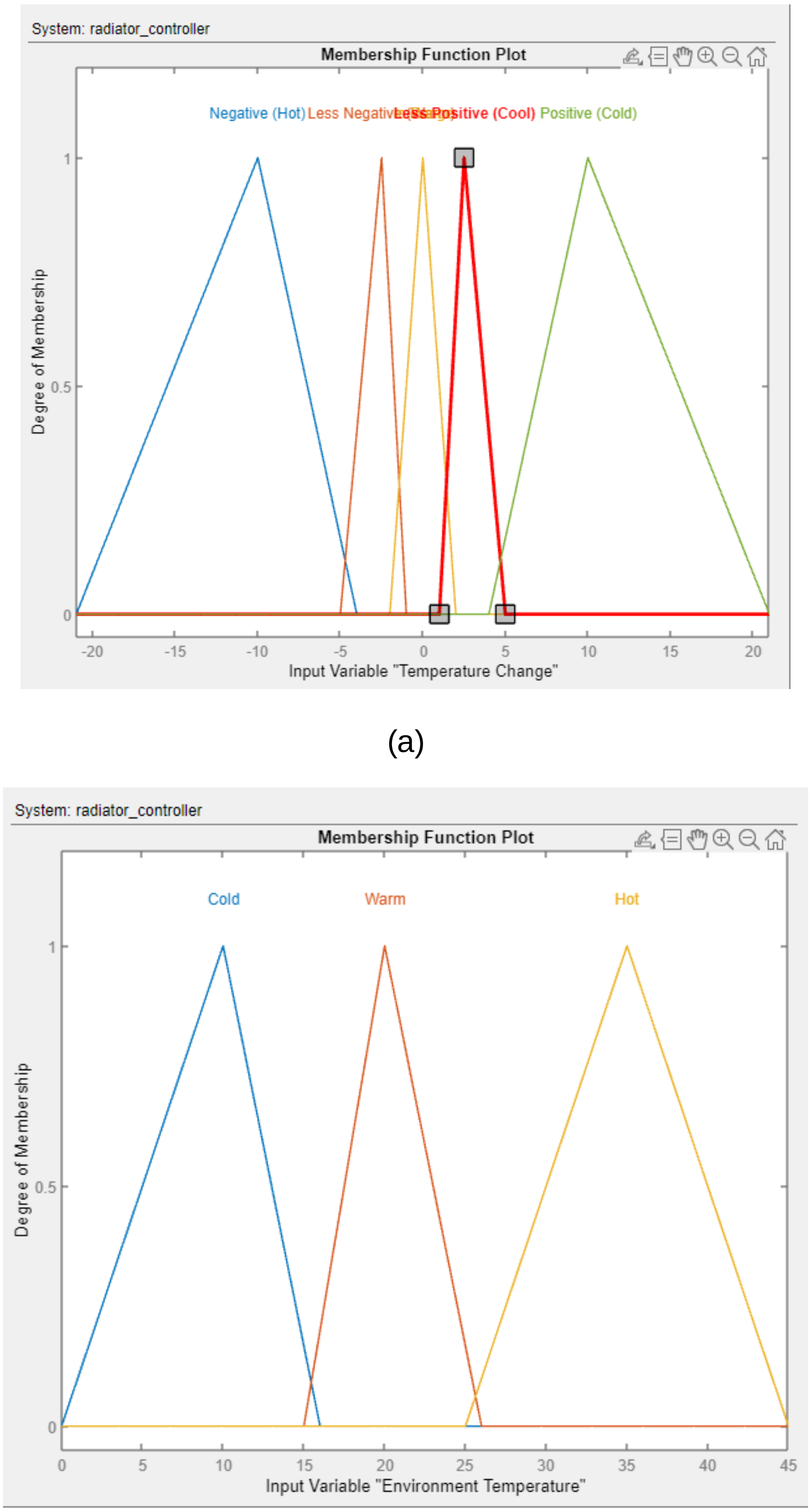
Inputs		**Outputs**		
Temperature Change(ΔC)	**Environment Temperature (C)**	**Refrigerant**	**Radiator**	**Heater**
Negative	Cold	Full Open	Full Close	Full Close
Negative	Warm	Full Open	Full Close	Full Close
Negative	Hot	Full Open	Full Close	Full Close
Less Negative	Cold	Half Open	Full Open	Full Close
Less Negative	Warm Hot	Half Open	Full Open	Full Close
Less Negative	Hot	Half Open	Full Open	Full Close

In Range	Cold	Full Close	Full Open	Full Close
In Range	Warm	Full Close	Full Open	Full Close
In Range	Hot	Full Close	Full Open	Full Close
Less Positive	Cold	Full Close	Full Open	Half Open
Less Positive	Warm	Full Close	Full Open	Half Open
Less Positive	Hot	Full Close	Full Open	Full Close
Positive	Cold	Full Close	Full Close	Full Open
Positive	Warm	Full Close	Full Close	Full Open
Positive	Hot	Full Close	Half Open	Half Open

Table 4 Rule Base for FLC Inputs & Outputs

The fuzzy input ΔT

The fuzzy input ΔT is divided into five membership functions, labelled NEG (-20 to -5), Less NEG (-5 to -2 percent), In Range (-2 to 2), Less POS (2 to 5) and POS (5 to 20). The temperature of the Environment is represented by the fuzzy input TEMP. The ranges for the three membership functions are as follows: (i) low, (0–15 degrees Celsius); (ii) medium, (15–25 degrees Celsius); and (iii) high, (25–40 degrees Celsius).. There were two fuzzy input variables, and their corresponding membership function charts are shown in Figure 13. The membership function's output plots, which show the possible values for each input parameter, were triangular in shape. Input variable membership function graphs (Figure 13) (3) (a) ΔT (b) Environment Temperature

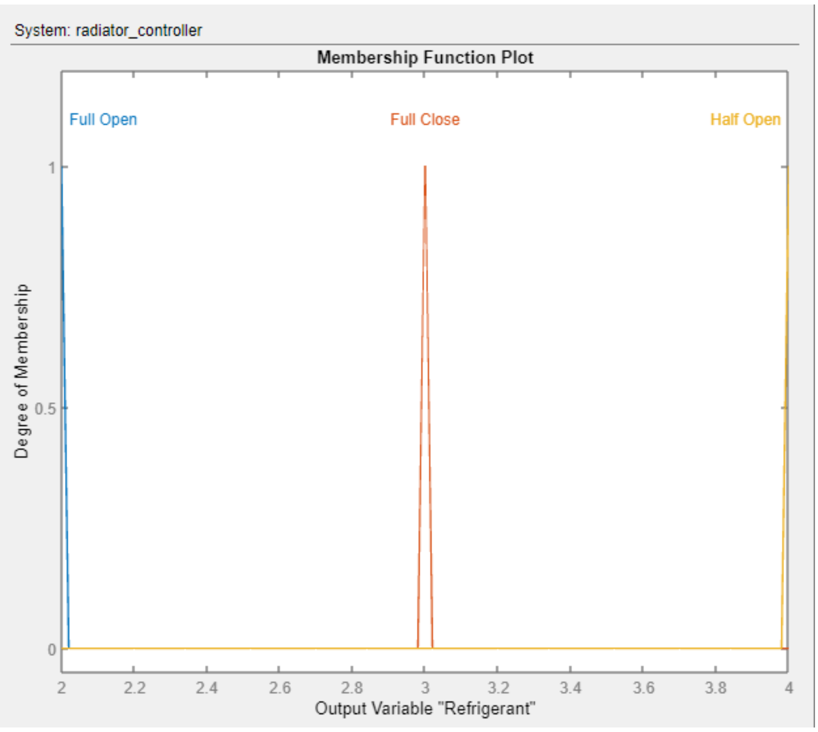


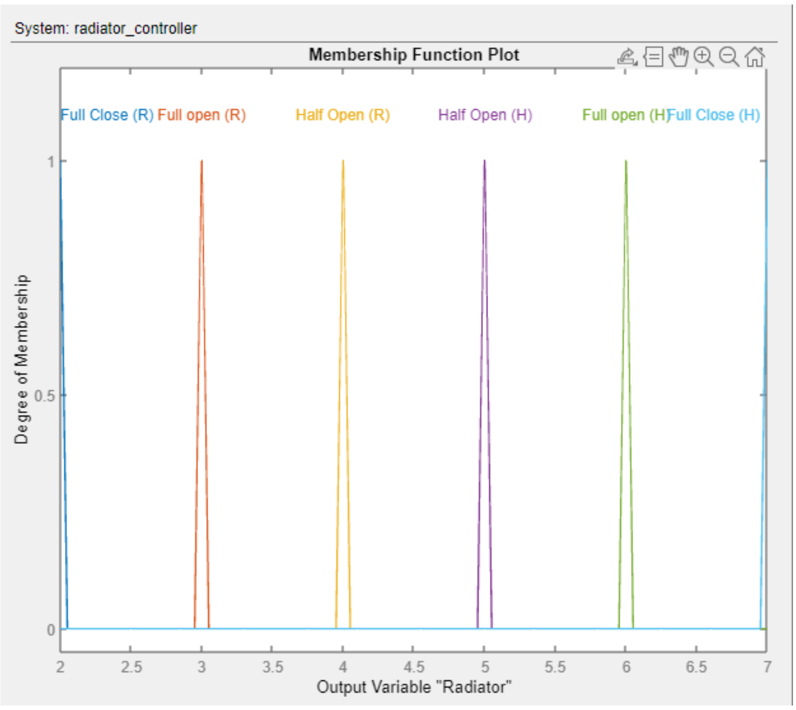
(a)

(b)

Figure 13 ΔTemperature and Environment temperature membership function plots

To prevent the battery from being destroyed, a separate control signal is used to disable the power source, allowing the battery to rest and allow the temperature of its cells to decrease. Only if the temperature is over the battery's predetermined working temperature will this signal activate.





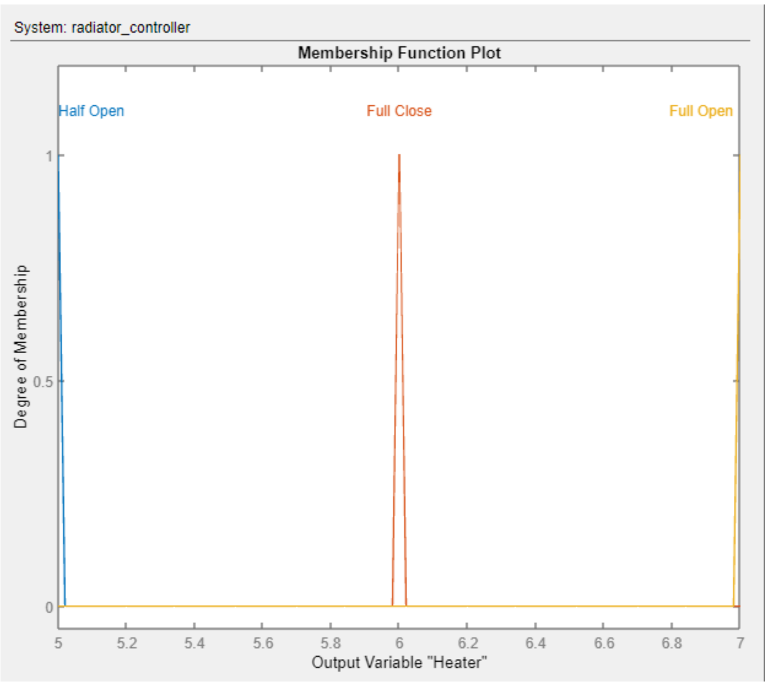


Figure 14 Membership feature depicts Refrigerant, Radiator, Heater to battery

Figure 15 depicts the surface-level reaction of each mode to changes in charge level and battery cell temperature. The system can be put into one of three states: discharging, charging, or isolation.

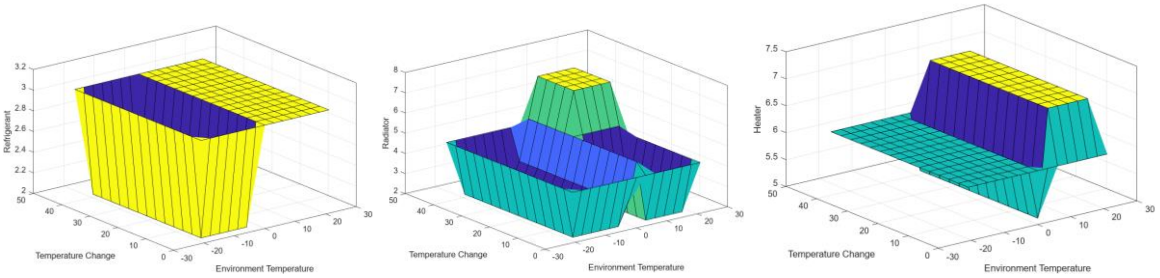


Figure 15 Fuzzy output variables Surface View

When the electric vehicle network is not in use, the battery can maintain the load running in drain mode. Electric vehicle charging stations have been improved. If the battery cells reach a particular temperature, the subsystem control block will cut power and isolate the battery.

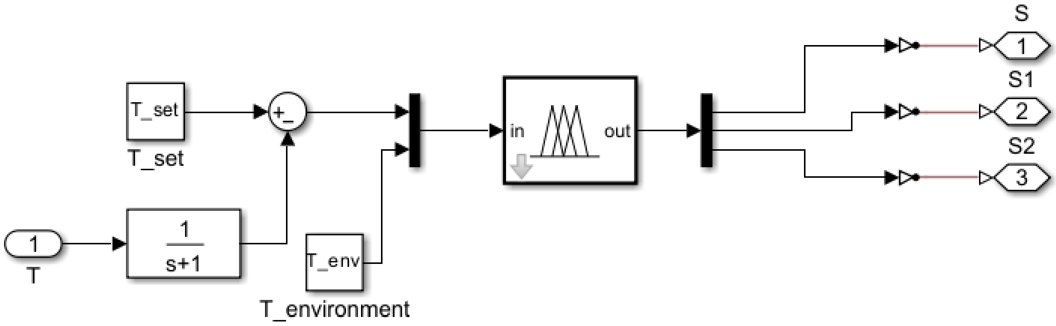


Figure 16 Method for simulating the output of a fuzzy controller.

Figure 16 shows the simulation framework that was used to verify the system's performance. Here, we study the impact of FLC on a power source using MATLAB's lithium-ion battery. If the battery's state of charge (SOC) falls below a specific point, the EV grid will begin charging it automatically. The simulated light bulb stands in for the true weight. The System controls both heating and cooling process by applying relevant membership functions to maintain temperature and to avoid any overshoots

Fuzzy logic is useful in many situations because it can make judgements with little or imprecise data. A wide variety of non-linear inputs can be used to generate an output with the help of fuzzy logic. Fuzzy logic included the processes of fuzzification, inference, and defuzzification. Fuzzification is the process of applying the membership function (MF) to transform discrete data into continuous data. The fuzzy logic controller receives the clean data as input. Inference [13] occurs when the fuzzy rules and the modified MF data are integrated.

In Figure 17, a battery and PV array that are not controlled by fuzzy logic are shown connected to a bus. The simplicity of the system's installation means that a BMS, which controls the battery's charging and discharging cycles, is not required. The PV array and battery are connected together, which is also connected to the load. Figure 17 is a capture from a simulation run in MATLAB Simulink.

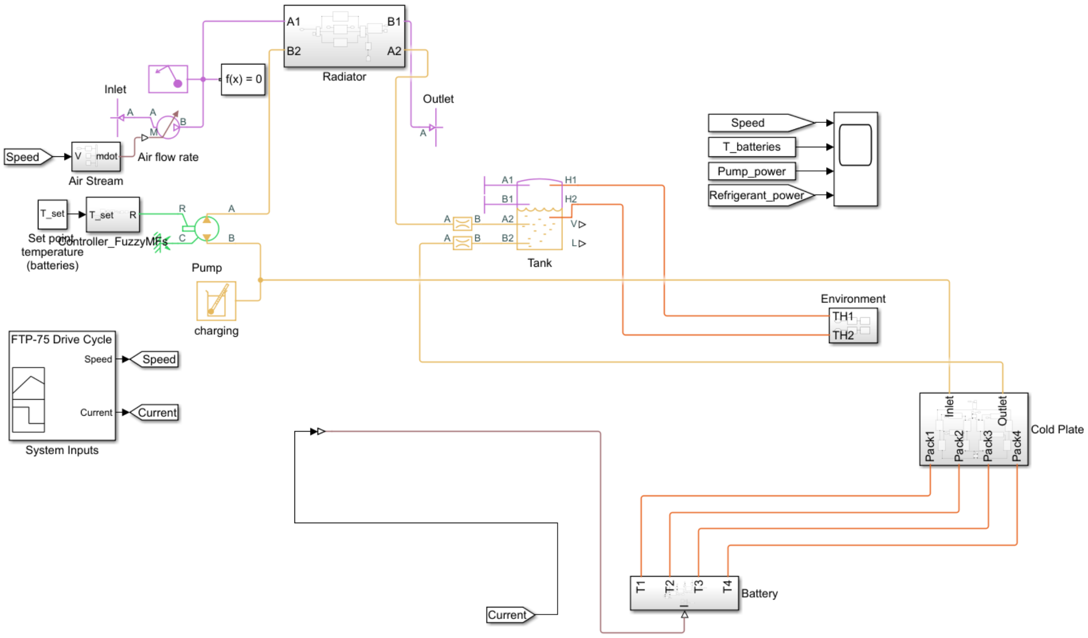


Figure 17 Model of the System with Coolant control unit

Figure 18 shows the combined response of the bus, which transfers power between the battery, the PV array, and the load. This arrangement does not include a fuzzy logic controller. A constant temperature of 40 degrees Celsius was maintained around the battery pack, and the SOC was initially set to 100%, indicating full charge. The load current is multiplied by a factor of 10 so that the scope may measure the state-of-charge, temperature, photovoltaic power, and cell voltage. It was found through simulation that current flowed to both the load and the batteries when the system bus was powered by solar cells. The battery's cell temperature remains above 120 degrees Celsius even when the battery's SOC remains constant during use. Therefore, the battery is neither being charged nor discharged.

3.10. Signal Response During Simulation

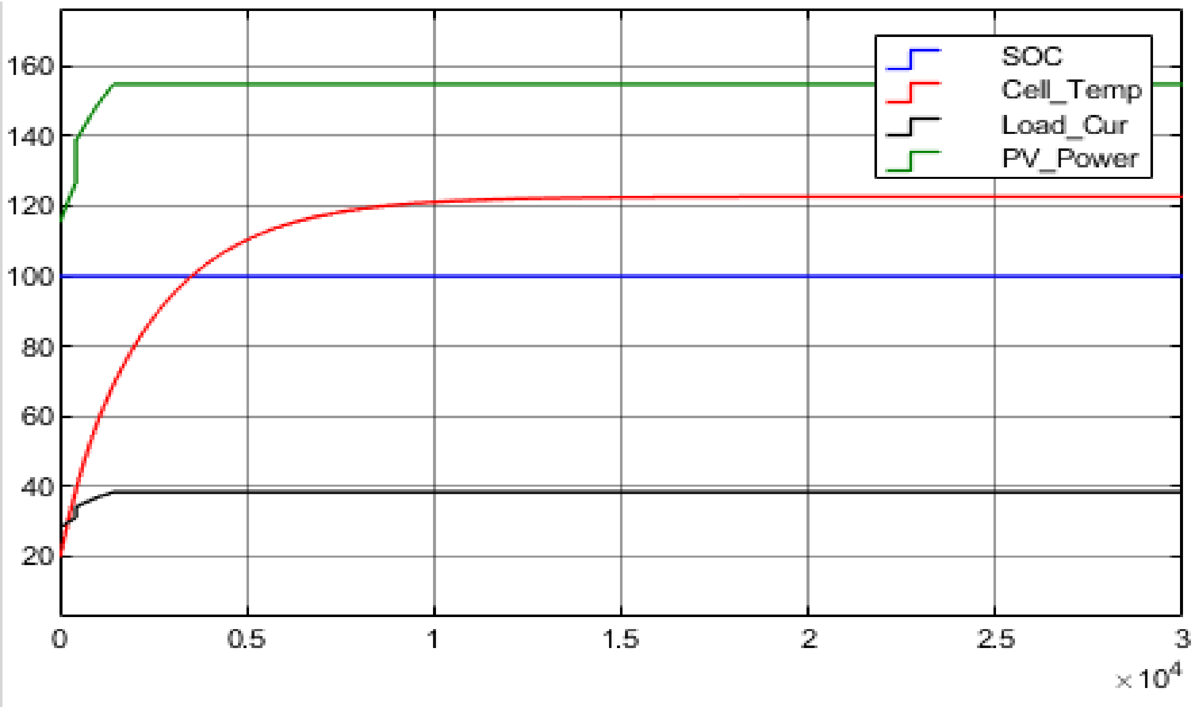


Figure 18 The simulated signal at full battery capacity and 40C.

The signal response during battery charging is depicted in Figure 19, showing that PV power produces roughly 80 watts initially and rises to around 160 watts by the time the battery is fully charged. The battery was drained to zero before being charged, and the process was repeated until it reached full capacity. During charging, the temperature of the battery cell can reach nearly 120 degrees Celsius. If this state is allowed to remain, the battery's safety may be compromised. The battery's life could be shortened, the system could be compromised, or the battery could even explode [6].

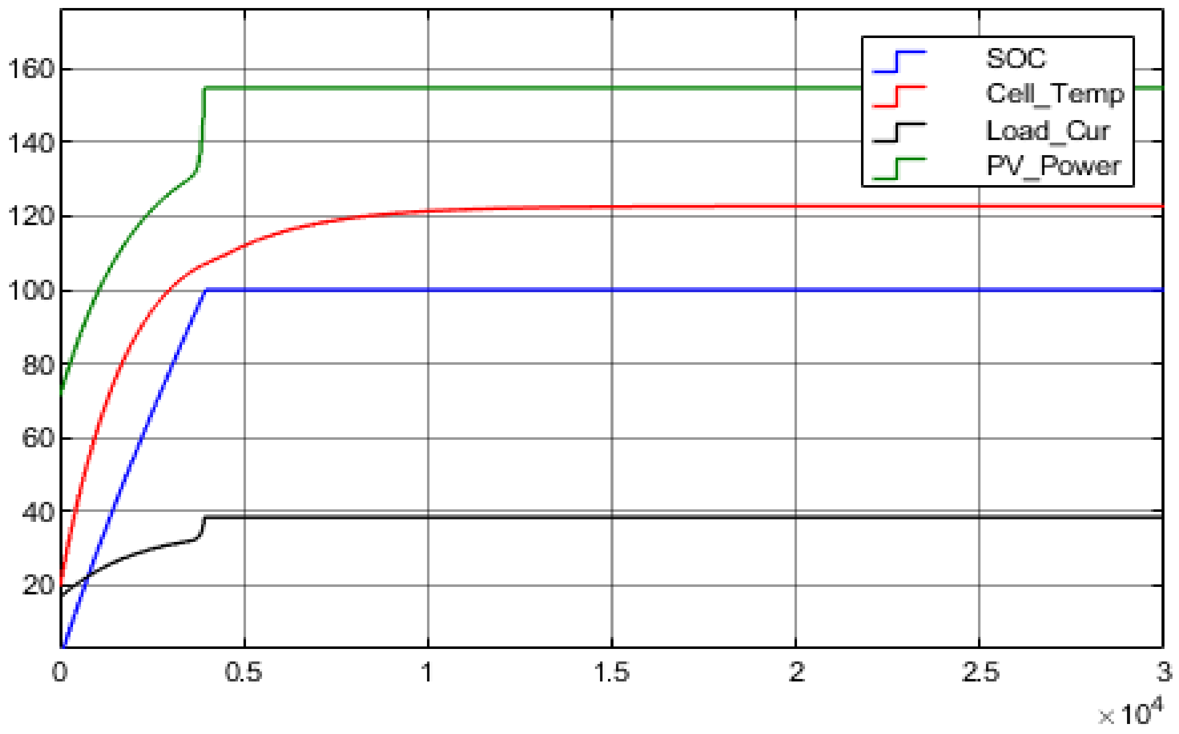


Figure 19 Simulated time-varying signal response with 0% percent battery charge and 40 degrees Celsius ambient temperature

3.11. Pump Controller

A fuzzy logic controller will cut power to the battery if its temperature increases above a predetermined level. This will keep happening until the battery cools down to a normal temperature. In the simulated scenario depicted in Figure 20, temperature Error(TEMP) serve as the input variable for a fuzzy logic-controlled system. For Output RPM of the Pump and Its Power is considered.

The battery's charge level determines how strong the SOC input signal is. Both the TEMP and solar power modes take the temperature of the battery cells as an input signal. Signal for the solar power input is produced by the PV array. The Batt2Load input allows the battery voltage to be changed relative to the load. Using a separate output signal, the batteries can be cut off from the rest of the system bus. In addition, the PV2Batt can control the amount of energy transmitted from the PV array to the battery by sending a signal to the system bus.

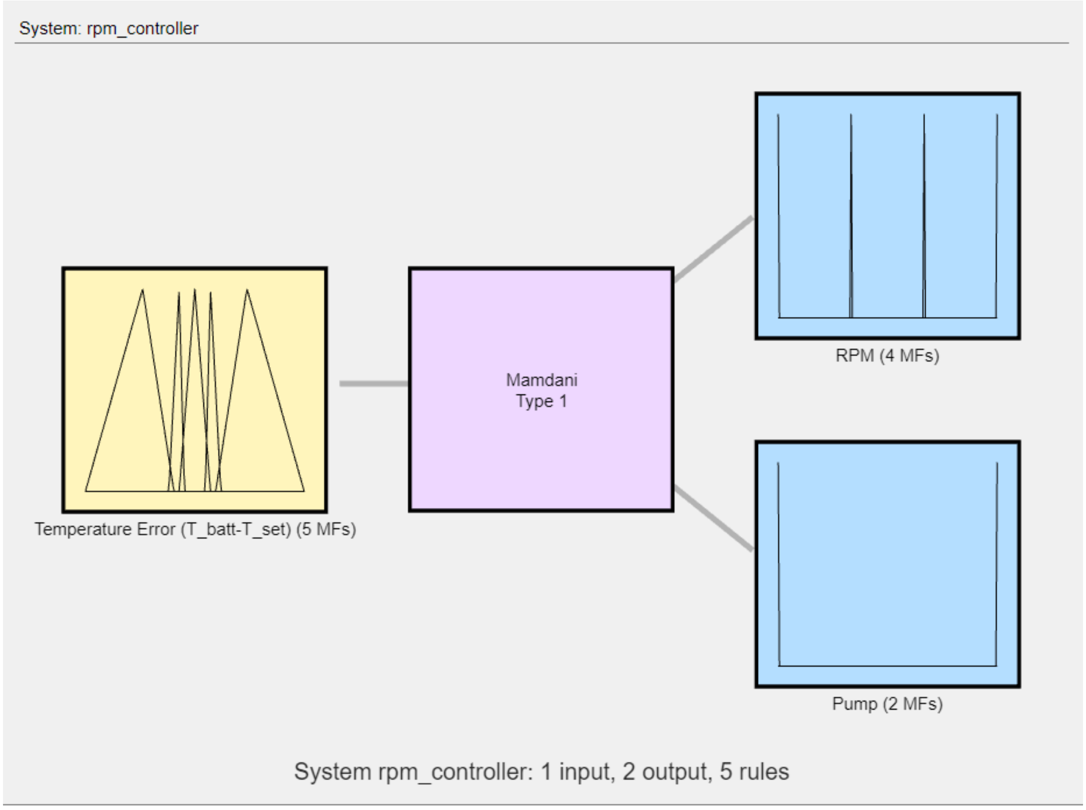


Figure 20 Parameters for the Pump Controller's input and output

3.12. Parameters of Fuzzy Controller Inputs

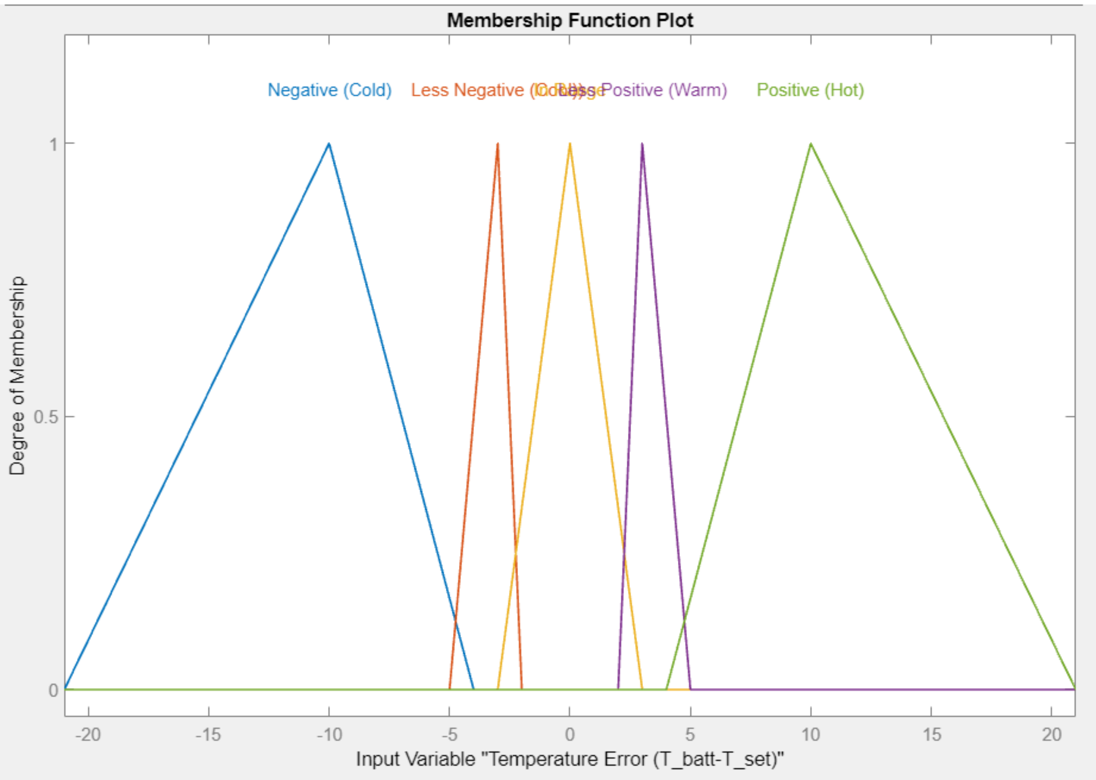
The inputs and output values used by fuzzy logic controllers are listed in Table 5. The Temperature Change of a battery is reported as Degree Celcius. The RPM variable represents the Pump revolutions. The Pump Sitch is turn Pump on or off.

Input Parameters	Membership Function	Range
ΔT (C)	Positive	2 to 20
	In Range	-2 to 2
	Negative	-2 to -20
Pump Speed (RPM)	LOW	1000
	MED	2000
	HIGH	4000
Pump Switch	ON/OFF	0/1

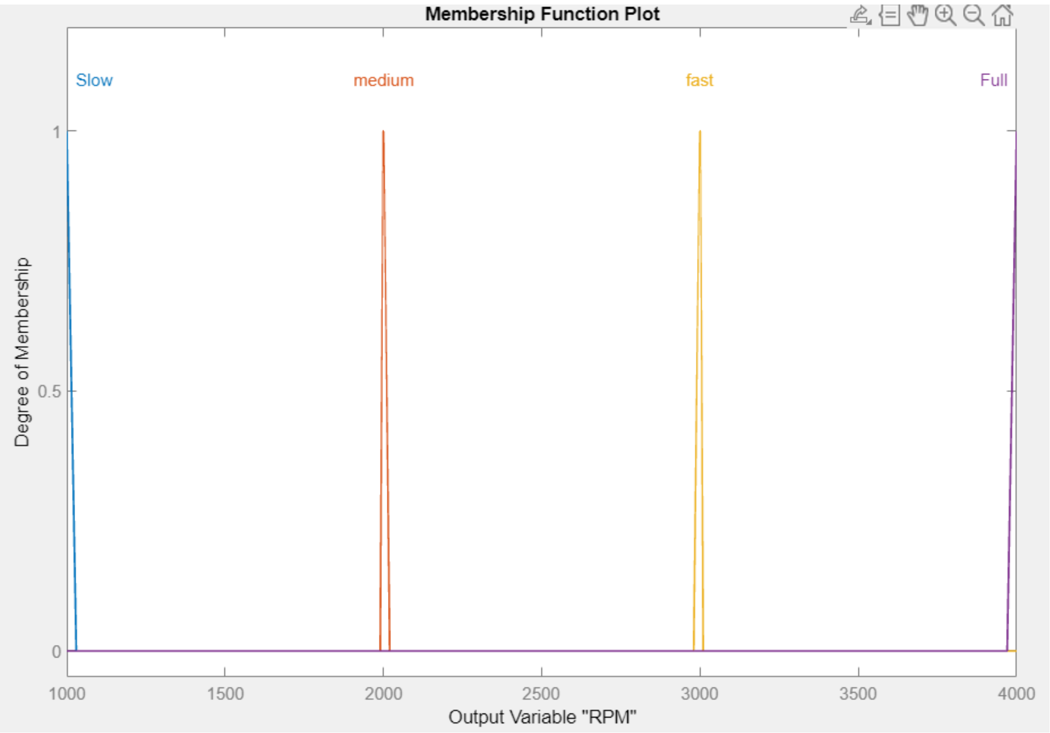
Table 5 Parameters of Fuzzy Pump Controller Inputs.

3.13. The fuzzy input ΔT

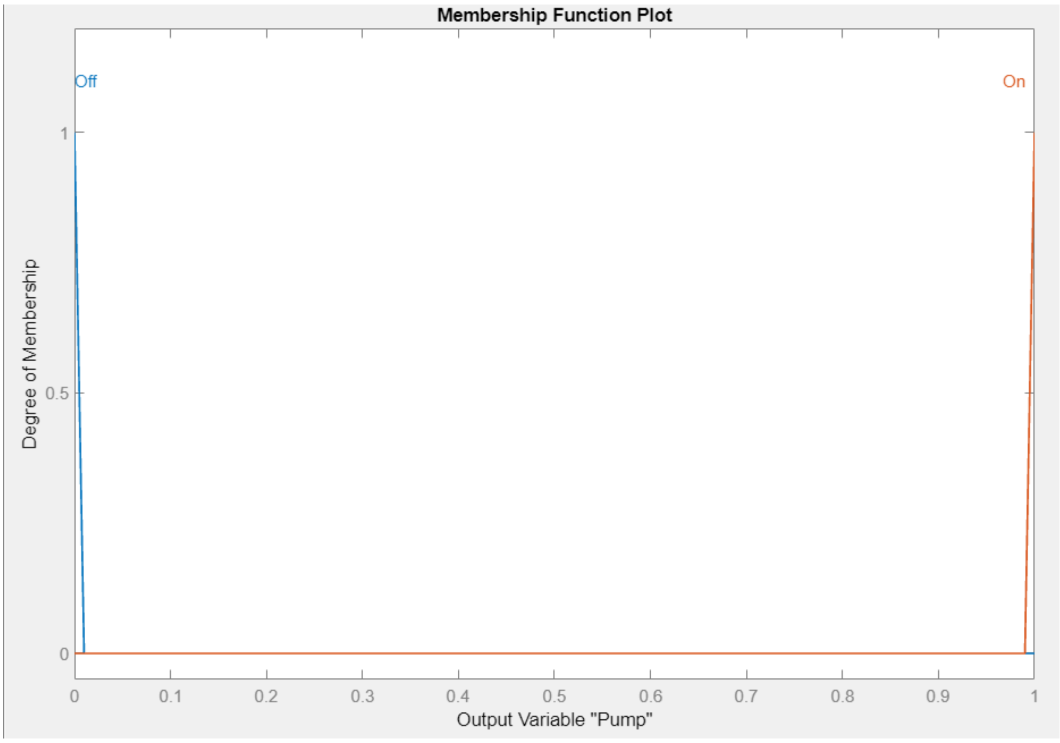
There are five distinct battery charge states represented by the membership functions of the fuzzy input ΔT: Negative(-20 to -4), Less Negative (-5 to -2), In Range (-2 to 2), Less Positive (2 to 5) and Positive (4 to 20). Fuzzy input TEMP is being used to measure the temperature of a battery cell. There are three temperature ranges represented by the membership functions: 0–50 degrees Celsius for the LOW range, 15–85 degrees Celsius for the MED range, and 50–100 degrees Celsius for the HIGH range. On the low level, the PV power fuzzy input can be adjusted from 0 to 10 watts, on the medium setting from 5 to 95 watts, and on the high setting from 90 to 100 watts. The three membership functions for the fuzzy inputs are shown graphically in Figure 21. The membership function has trapezoidal output graphs that show the range of values for each input parameter.



(a)



(b)



(c)

Figure 21 ΔT, RPM and Pump Switch in a, b, and c, respectively, displayed on the membership function.

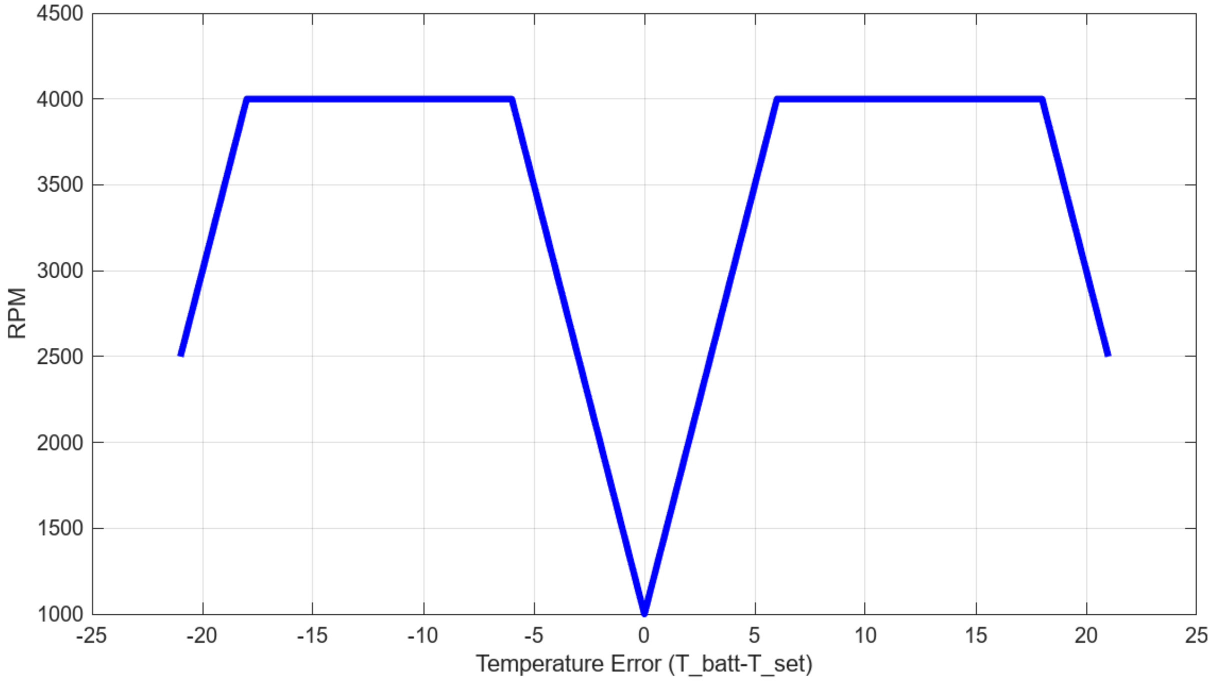
The membership function graphs of the battery-to-load, isolation, and photovoltaic-to-battery output variables of the fuzzy controllers are shown in Figure 8. Its ON and OFF states represent its two roles within the team. The two states control the switches in the system-bus-connected control block. Whenever the battery to load control signal from the fuzzy controller output is set to the ON state, the system will permit current to flow from the battery to the load. The battery will not drain into the load in the case of a blackout. When a separate control signal is received, the battery's power source is cut off to prevent overheating damage. If the temperature outside rises above the battery's safe operating range, the alarm will go off.

Table 6 displays the fuzzy inference rules. All possible combinations of input and output variables for a fuzzy logic controller are displayed here.

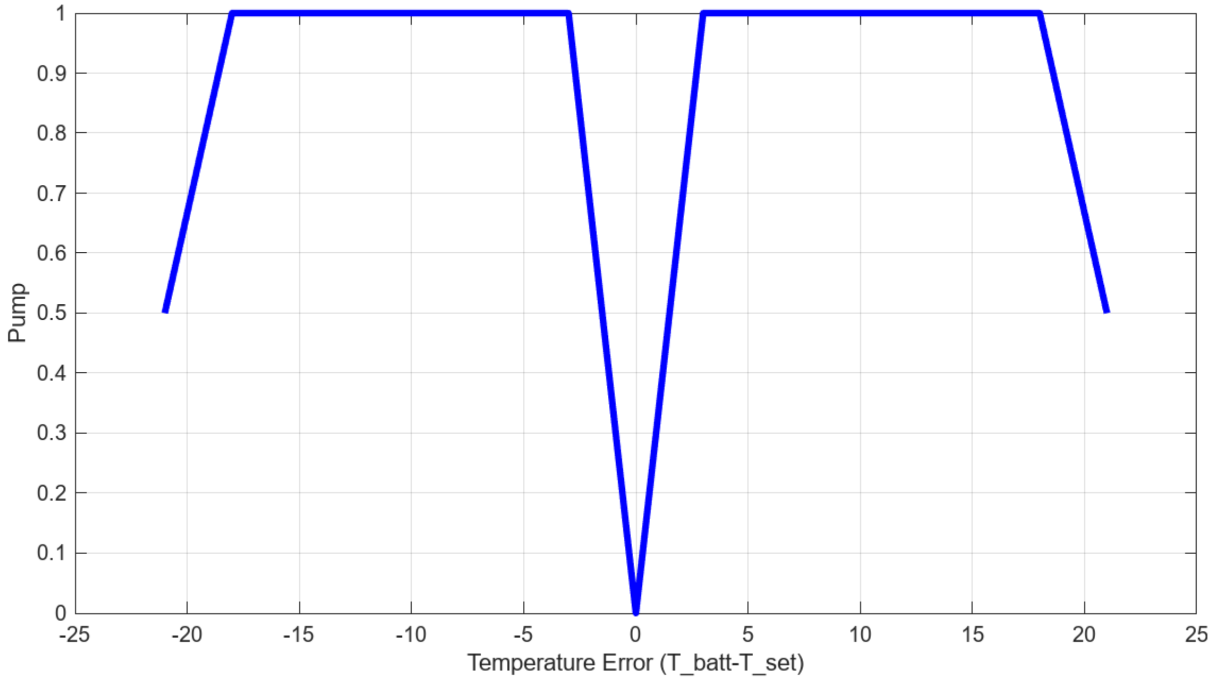
Temperature Error (ΔC)	**Pump**	**RPM**
Negative	On	Full
Less Negative	On	Medium
In Range	Off	Low
Less Positive	On	Medium
Positive	On	Full

Table 6 Rule Table For Fuzzy Pump Controller.

Surface-level responses to changes in battery charge and temperature are displayed for each mode in Fig. 22. The system is capable of operating in two distinct modes: discharge, charge, and isolation.



(a)



(b)

Figure 22 The obvious connection between ΔT and the two fuzzy output variables

The following is a simplification of the three fuzzy output variables' relationship with the two fuzzy inputs, percentage of charge (SOC) and battery cell temperature (TEMP): (a) Control signal from battery to load vs charge and temperature; (b) control signal from battery to isolation switch versus charge and temperature; and (c) control signal from photovoltaic module to battery versus charge and temperature.

In drain mode, the battery can supply energy to the load even if the PV array is not generating any. The battery will be charged by the photovoltaic cells during this time. If the temperature of a battery cell rises above the acceptable range, the system will switch to isolate mode and disconnect the battery from the rest of the system using the subsystem control block.

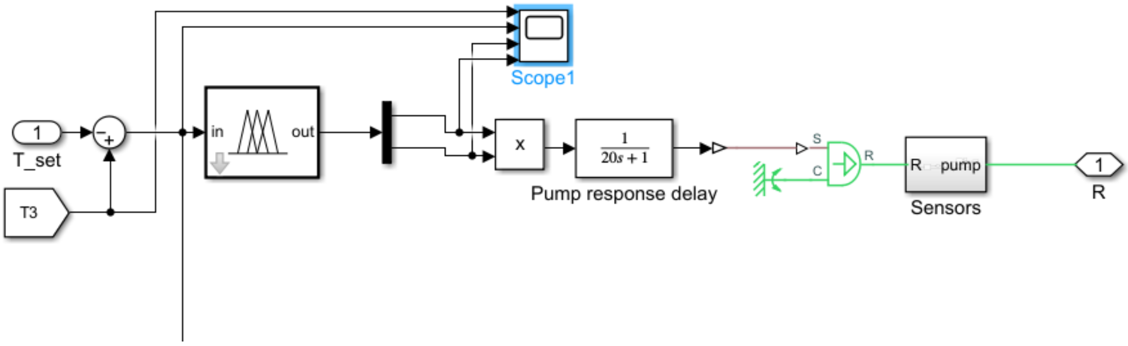


Figure 23 Simulation set-up for testing Fuzzy Controller Output Response.

In Figure 23, we see the simulation setup that was used to check the system's functionality. In this scenario, we used a MATLAB-Simulink lithium-ion battery to model how the battery will react to changes in temperature. The PV array is used to charge the battery when its state of charge (SOC) drops dangerously low. In this virtual world, the actual burden of carrying a lamp is represented by a lamp. The subsystem block controls the switch that connects the PV array terminals to the system bus. The subsystem block links the battery connections to the system bus.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1. Outputs of FLC

Fig. 24 depicts an example of the output produced by the battery management system after it has been processed by the fuzzy logic controller. This mode of operation for sampling is known as the isolation mode, and the temperature of the battery cell is currently at 80 degrees Celsius. The fuzzy controller will shut off the distribution of power to the load if the temperature of the battery cell goes beyond the limit. This will be accomplished by toggling the OFF-condition switch on the Batt2load subsystem block. Because of this condition, the PV array will not be able to charge the battery, and the fuzzy controller will send an isolated signal to the isolation control block on the battery.

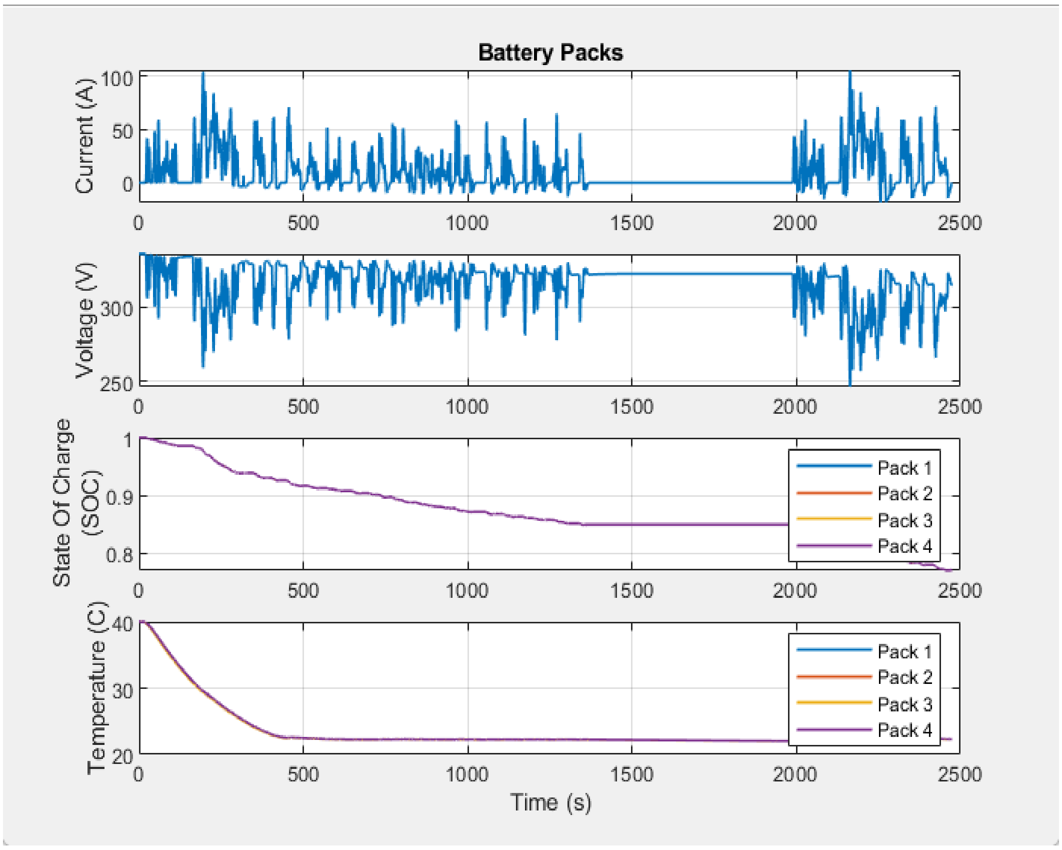


Figure 24 Temperature and its Effects on SOC observed

4.2. Monitoring of Temperature

The temperature of the battery cell will increase while it is being charged. Additionally, it is affected by the temperature of the surrounding air around the battery. In the beginning of the simulation, the temperature was programmed to be at a constant 70 degrees Celsius. To better observe the changes, the SOC of the battery was reduced to 20%, and the load current was magnified by a factor of ten in the scope. When the temperature of the cell reaches more than 80 degrees Celsius, the battery SOC charging current is cut off, even though the SOC is still set at 40%, according to the signal response displayed in Figure 24. The current being drawn from the load has decreased, which indicates that the battery has stopped supplying it with electricity. As long as the temperature of the battery cells is higher than what is considered normal for functioning, the system will continue in its current state.

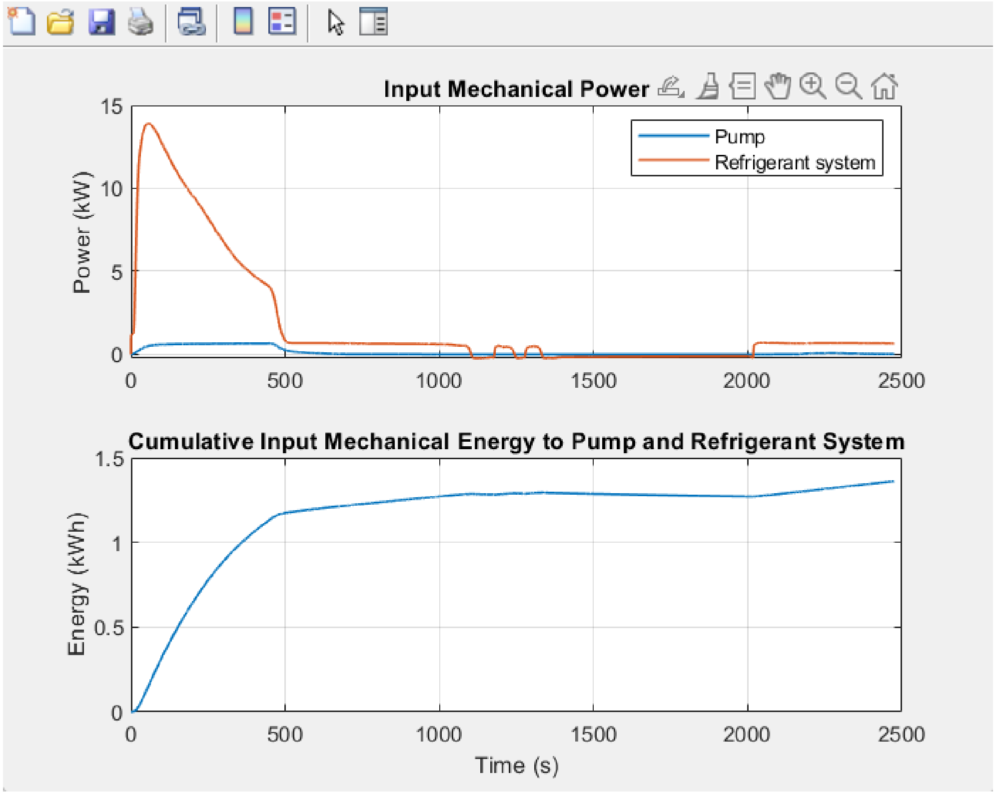


Figure 25 Signal response of Power and Energy consumed when FLC is applied to the system.

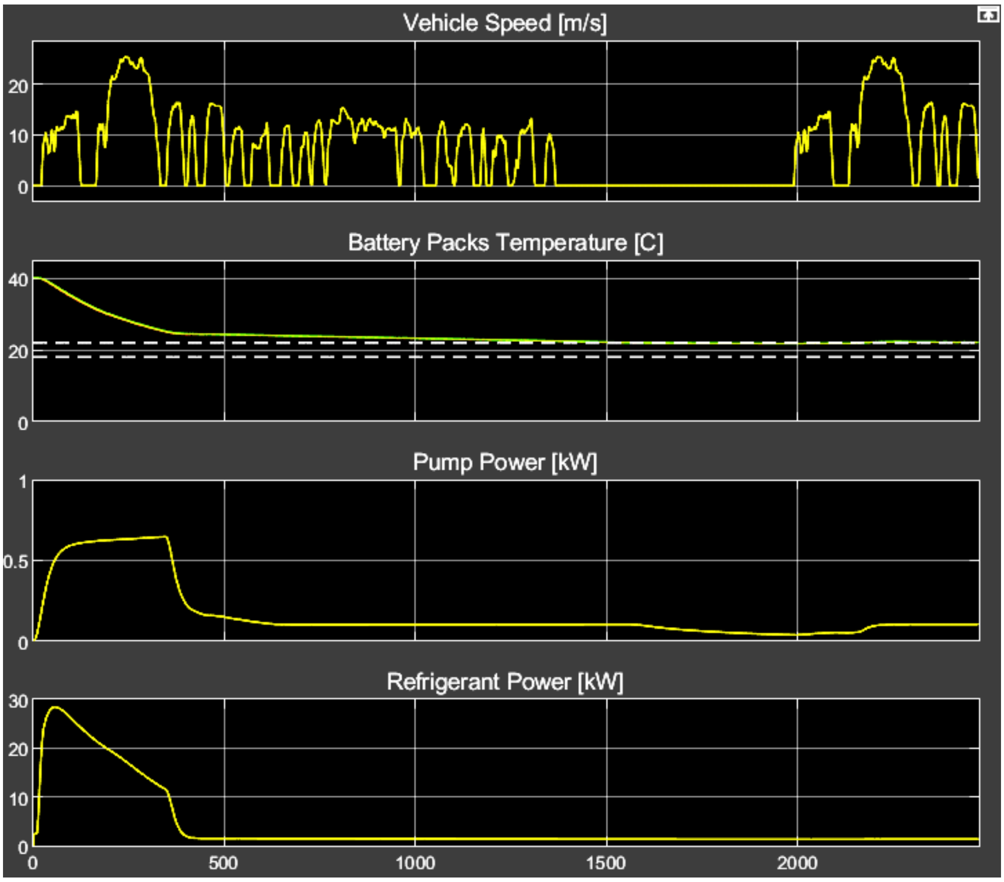


Figure 26 System Performance of Proposed Model

4.3. System Response Curve

Figure 26 depicts the curve of the system's response when the SOC of the battery was set to 100% and the temperature was higher than 40 degrees Celsius. At first, when the temperature of the battery cell is still within the normal range for operation, the battery supplies power to the load. This can be seen through the load's current response. However, if the temperature of the battery cell goes beyond the threshold, the fuzzy logic controller will send an isolated signal to the battery, which will cause it to stop functioning.

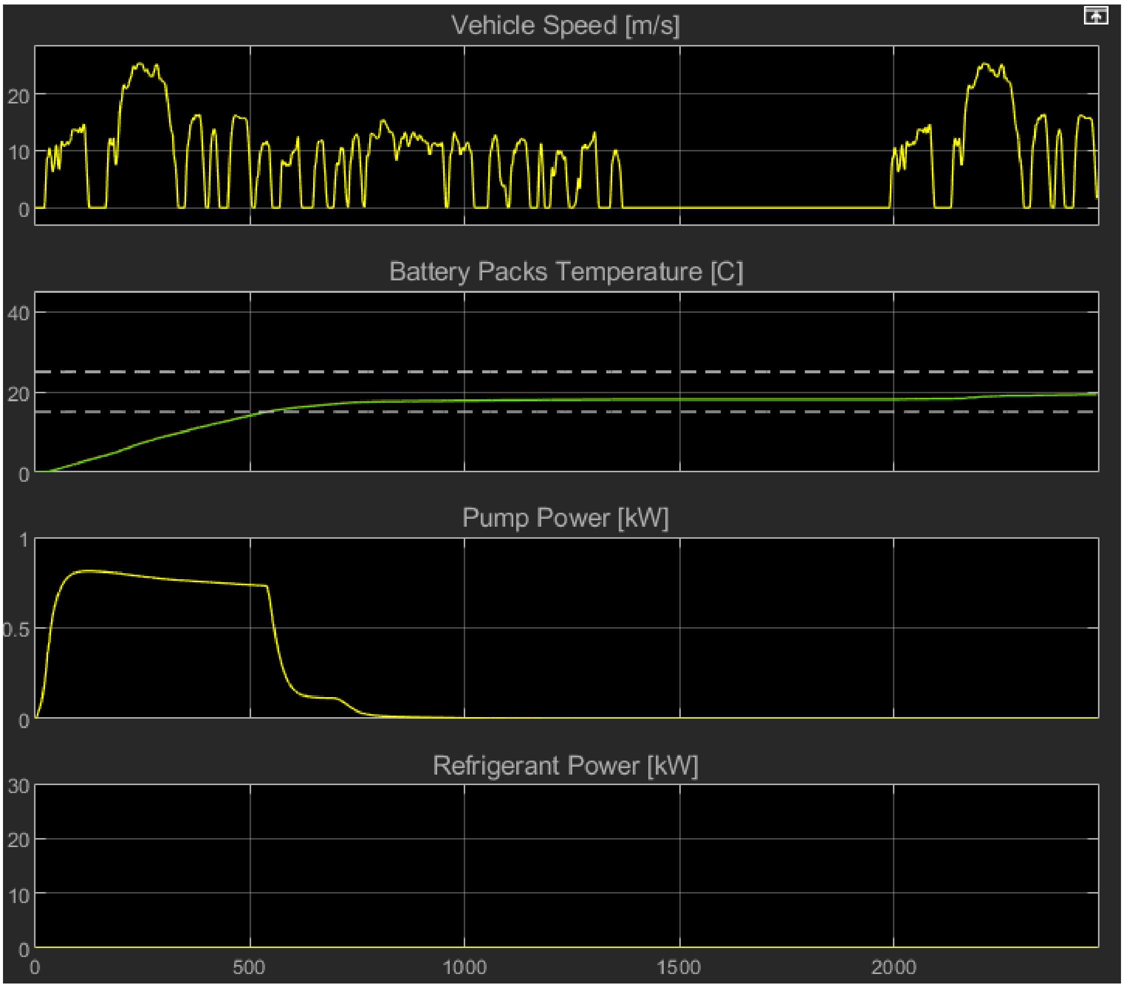


Figure 27 System response during heating simulation of batteries.

The result of the simulation is displayed in Figure 27, and it was initially configured so that the battery SOC was 100%, and the ambient temperature was set to 0 degrees Celsius. Through the help of the fuzzy logic controller, the battery is able to send electricity to the load that is connected to the system bus. When the battery is being discharged, the temperature of the individual battery cells steadily increases. When the battery reaches a low state of charge (SOC), the fuzzy logic controller instructs the PV array to begin delivering power to the system bus. This causes the battery to begin charging. During the process of charging the battery, the temperature continues to grow until it reaches its maximum allowable level..

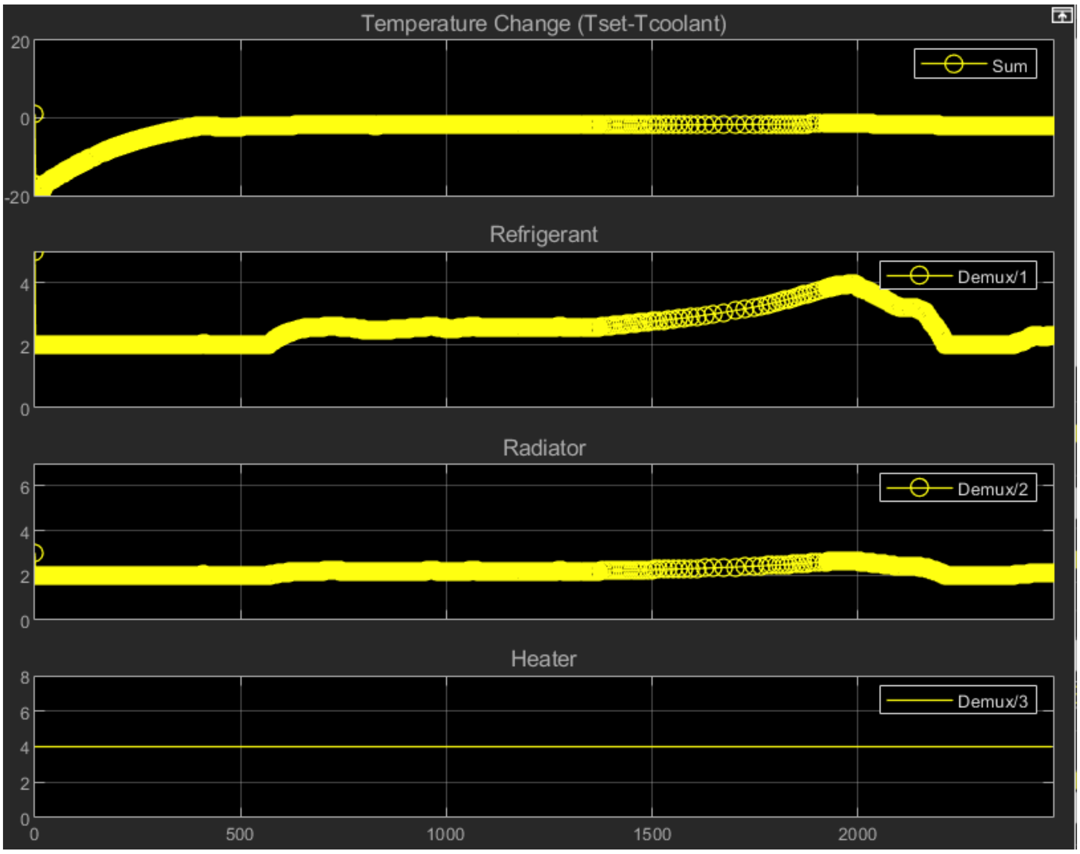


Figure 28 the response curve Refrigerant, Radiator and Heater with given ΔT

During this phase of the operation, the electric current will move from the battery to the load. After the fuzzy logic controller detected that the temperature had reached its maximum, it sent an isolated signal to the isolate-control block. This caused the current coming from the battery to halt, allowing the battery to relax for a while.

Whenever a battery is allowed to rest, its temperature will progressively decline until it reaches the desired working temperature. And once the temperature has returned to its normal state, the fuzzy logic controller will send a signal to the battery-to-load control block. This signal will allow the current to flow freely from the battery to the load.

Figure 15 depicts the signal response of the Refrigerant, Radiator, and Heater in regard to the temperature of the battery cell while the SOC is set to 100 percent. The output response is extremely similar to what is illustrated in Fig. 28.

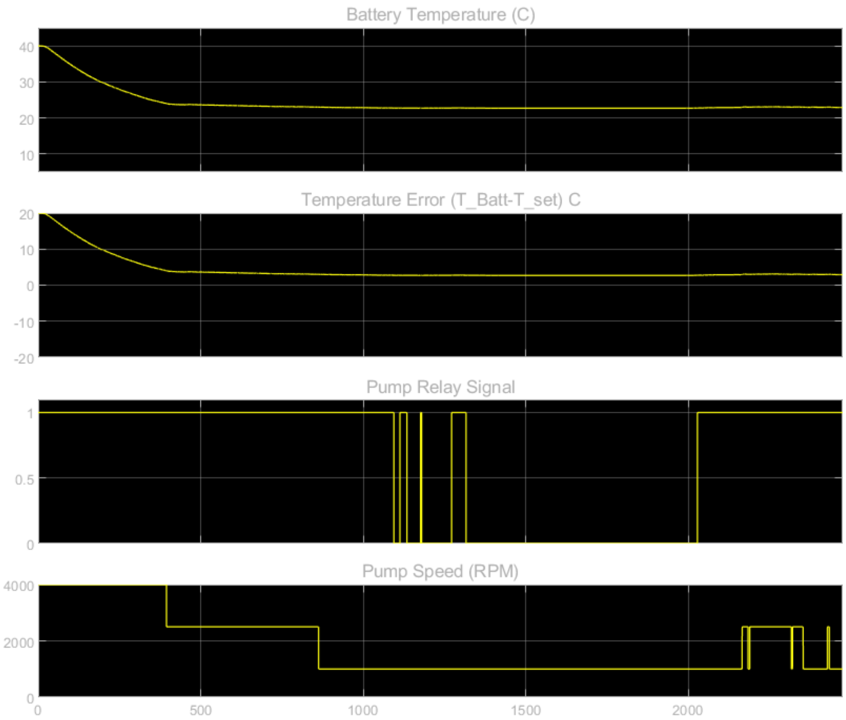


Figure 29 Results of the Pump FLC

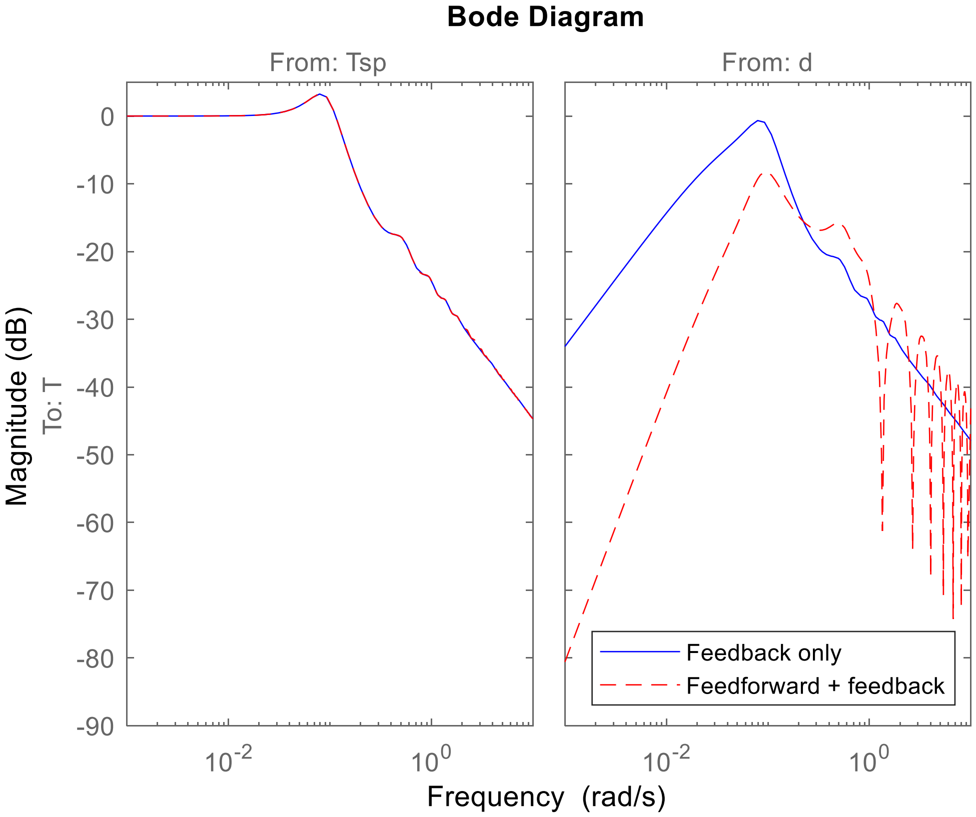
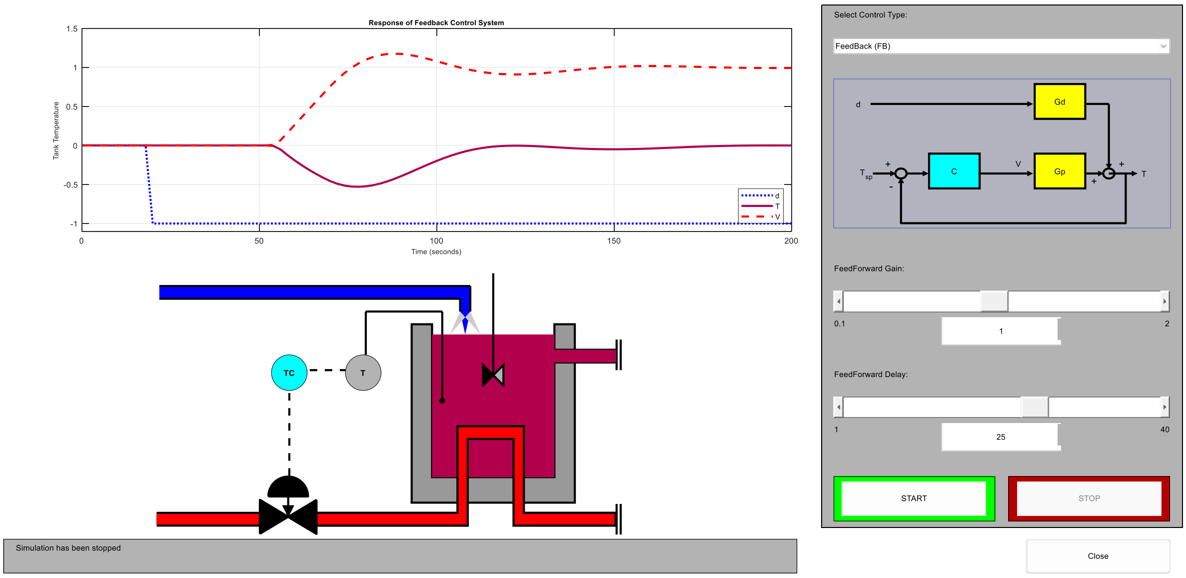


Figure 30 Stability in BTMS



Select Control Type: FeedBack (FB)

FeedForward Gain: 1

FeedForward Delay: 25

Simulation has been stopped

Figure 31 Response of Fuzzy Logic Control and Radiator

Figures 23–31 refer to the performance evaluation and analysis of the proposed battery thermal management system (BTMS), which uses a fuzzy logic controller and a radiator to regulate temperature. Figure 19 displays the BTMS's processed output when the battery cell temperature is 80 degrees Celsius and the controller is in isolation mode. If the battery cell temperature increases over the threshold, the fuzzy controller will turn off power distribution to the load, as indicated by the OFF-condition switch on the Batt2load subsystem block. The signal response of SOC and load current shifts when the battery cell temperature is over 80 degrees Celsius, as depicted in Figure 20. The battery SOC charging current is cut off to prevent overcharging when the load current drawn from the battery drops. Figure 21 shows how the proposed BTMS performs as a whole. The radiator and fuzzy logic controller in this BTMS are its two main components. The signal response of SOC and load current shifts as seen in Figure 22 when the maximum temperature of the battery cell is attained during discharging. The fuzzy logic controller sends a separate signal to the battery, directing it to turn off to prevent any more damage. Figure 23 shows how battery cell temperature is related to charge level, load current, and solar power. The fuzzy logic controller signals the PV array to begin powering the system bus when the battery's state-of-charge (SOC) falls below a certain threshold. Fuzzy logic controller communicates with isolate-control block to turn off power to battery when cell temperature reaches safe limit while charging. Figure 29 shows the wavefom produced by the BTMS under the control of fuzzy logic with the SOC initially set to 0%. The output response looks a lot like the one in Figure 20. Figure 30 shows the reliability of the proposed BTMS, and Figure 31 shows the reaction of the fuzzy logic controller and the radiator in controlling the temperature of the battery cell.

Study	Methodology	Key Findings	Limitations	Future Work
[2]	Experimental	Improved battery life by 20% through thermal management system	Limited applicability due to specific battery type and configuration	Expanding study to test on various battery types and configurations
[3]	Numerical simulation	Reduced battery degradation by 15% through temperature regulation	Limited scope, only focused on thermal management	Integrating fuzzy logic control for improved battery performance
[5]	Theoretical analysis	Proposed a model for predicting battery temperature and performance	Lack of experimental validation	Validating proposed model through experimentation
[6]	Experimental	Developed an effective thermal management system for batteries	Limited to small-scale batteries	Scaling up system for larger batteries
[10]	Numerical simulation	Reduced battery degradation by 10% through optimized cooling and heating	Limited applicability, only tested on specific operating conditions	Testing proposed system under various operating conditions
Proposed Work	Experimental and numerical simulation	Elimination of Overshoots from Input Power by 60% consequently leading to 10% increase in Efficiency	Limited to a specific type of battery & Controlled Simulations	Testing system on various battery types and configurations to determine its applicability and effectiveness

Table 7 Comparative Analysis

CHAPTER 5

CONCLUSIONS

Lithium-ion batteries were employed to model temperature's impact. Overheating during charging and discharging is prevented by continuously monitoring the temperature of each cell in the battery. When used in charging mode, the photovoltaic array may replenish the battery while also powering the load. To allow the battery to be charged while the load is still being powered, the photovoltaic array is disabled during the draining mode. In addition, the battery cell temperature must rise over the maximum safe operating temperature before the isolation mode will activate. The simulation, carried out in MATLAB-Simulink, shows that a system controlled by fuzzy logic can keep a battery's operating temperature stable.

This study employed a lithium-ion battery to mimic the consequences of high and low temperatures. Overheating during charging and discharging is prevented by continuously monitoring the temperature of each cell in the battery. This is an extra layer of protection against battery failure. The charging mode allows the photovoltaic array to power both the load and the battery at the same time. Turning off the photovoltaic array while charging the battery at the same time is called "discharging," and it is impossible to do while the battery is still supplying the load. Isolation mode won't activate until the battery's internal temperature rises above the point where it's no longer safe to continue using the battery. Fuzzy logic regulates the battery's temperature to keep it at peak performance, as confirmed by the MATLAB-Simulink simulation.

This thesis concludes our study into the feasibility of using a fuzzy logic controller in conjunction with a radiator to maintain a constant temperature in the batteries of electric vehicles. The simulation results verify that the proposed fuzzy logic controller is effective in stopping the battery from overheating and keeping it performing at its best. The proposed technique does have certain restrictions, though. While a simple rule set was employed for the fuzzy logic controller in this investigation, a more complex rule set may be necessary for some applications. More research is needed to evaluate the system's performance in real-world situations, such as environmental and load variability. Future work can expand monitoring and control capabilities by incorporating additional sensors and actuators and implementing more complex control strategies like model predictive control. It is feasible to investigate how the thermal management system responds to the potential for diverse thermal properties across a variety of battery chemistries. In conclusion, our research shows that electric car batteries can be better maintained through the use of a heat management system regulated by fuzzy logic and a radiator. However, additional study is required to discover how to improve the system and make it more useful.

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