Original Article

Impact of Environmental Factors on Battery Degradation and Control Strategies in EVs

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Abstract

EVs have been a major way of decreasing pollution and finding energy that is not depleted. However, the performance of the batteries-especially those dependent on lithium-ion-which could degrade with time, has been a major factor affecting durability and reliability in EVs. Most discussion in this article has revolved around temperature, humidity, altitude, and atmospheric pressure as some of the prevailing conditions leading to the derailing of batteries. Advanced methods to control these factors in an effort to mitigate such negative effects with a view to ensuring batteries would last longer and always function well are discussed. For instance, with increased or decreased temperatures, chemical reactions of the battery change. In hot conditions, it dies faster, while at low temperatures, it cannot hold much charge. If the air happens to be humid, water can seep in pretty easily. This may lead to rust that can render insulation less effective. At higher altitudes, air pressure changes, which may further affect the balancing pressure of the battery cells and efficiency of the cooling system. These environmental stressors promote the growth of the SEI layer, the formation of lithium plates, and degradation of the electrolyte. All of these factors make a battery less powerful and reduce the electric current that can flow through it-possibly even dangerously so. Among the ways to deal with these problems are thermal management systems, a BMS, and adaptive charging algorithms. They include both active and passive cooling systems as a form of thermal management strategy. Both serve the dual function of preventing overheating or overcooling of the machine. Advanced BMS, through the use of sensors and real-time data, constantly monitors parameters such as the state-of-application of the battery and the immediate ambient surroundings, then makes the necessary operational adjustments to the battery in order to reduce the level of stress on it. Other adaptive charging techniques that further support longer life for batteries include temperature-compensated charging profiles and machine learning to predict the timing of maintenance events. The article proceeds to outline the effectiveness of these control strategies through industrial case studies, experimental data, and simulation models. One of the most important sections is the application of accelerated life testing to determine the speed at which batteries lose power under different circumstances. The findings indicated that the design of the EV should allow for the possibility of adjustment to changing situations, especially if their usage is to be widespread in different types of climates. This framework provides guidelines that car engineers, researchers, and policymakers can apply in developing greener electric cars.

1. Introduction

A. Background and Motivation

There is an increasing awareness of the threat of pollution, climate change, and dwindling resources. It is for this reason that the world is fast shifting toward energies that last for a very long period and can be reused repeatedly. In this regard, electric vehicles are gaining prominence in the transportation field. They are amongst the most vital factors in reducing demands for fossil fuels and carbon emissions, making them of prime importance to future transportation solutions. The battery, with a prevalent penchant toward lithium-ion, is a huge aspect of the functionality and appeal of electric cars. Lithium-ion batteries are preferred because they are lightweight, have long life spans, and boast immense energy storage capacity. However, with the large demand for electric cars worldwide, there is a need for batteries with long-lasting and improved real-world functionalities. The health and

strength of the battery directly affect an electric vehicle's functionality, range, and energy consumption. These factors contribute to and create difficult conditions that degrade the battery's charge-bearing capacity over time. You should be aware of such a breakdown since it affects the car's range, how long it takes to charge, and its safety features. Batteries degrade faster with variations in temperature, humidity, altitude, and air pressure. It is also crucial to discover the impacts that these batteries pose to the environment so that electric vehicles will function well and last for extended time. This paper reviews the impact of environmental factors on battery degradation mechanisms and also proposes mitigation strategies that can help nullify their effects in order to enable the wide acceptance of electric vehicles and their sustainable use in the long term.

B. Importance of Studying Environmental Impact

They can be driven in a great many diverse locations ranging from hot deserts, cold mountains, and cities along the sea that are humid. The weather can thus significantly affect the working life and performance of EV batteries. This is because of changes within the weather such as temperature, humidity, and air pressure. Their influence on EV batteries should be known so that they perform well without breakdowns at all types of weather. One critical factor that may alter battery performance is its temperature. With the rise in temperature, the electrochemical reactions within the battery accelerate. This in return accelerates the death rate of the battery coupled with reduced performance. During low-temperature conditions, the internal resistance of the battery may increase impeding the charging. Humidity can bring about many issues such as water infiltration within the battery, rusting of parts, and short-circuiting. Variations in height can also produce variations in the way through which the batteries work. This is because at very high altitudes, since the air pressure is low, the battery system may not offer good performance. For this reason, the temperature of the battery pack may become uneven. It is for this reason that an appreciation of these environmental factors affecting the battery life is particularly essential in view of the rising purchase of electric cars by people. These effects can allow one to learn different methods for prolonging battery life, improving the performance of electric automobiles, and making the electric car both safe and durable under all weather conditions.

C. Objective of the Study

This paper serves to give an in-depth review of the impact of environmental factors on the degradation of lithium-ion batteries used in electric vehicles. In other more specific terms, it describes how each of these environmental stresses-including extreme heat or cold temperatures, changes in humidity, and changes in altitude-speeds up the deterioration in performance of the batteries. Appropriately, a critical perception of the capacity loss mechanisms, higher internal resistance, and the associated safety concerns do call for how such degrading processes work. This could potentially shorten the life of an EV battery in almost every particular way. The paper looks at why bad results occur and proposes and considers a number of strategies to mitigate the negative impacts, some of which are an improved BMS, more advanced thermal management systems, and adaptive charging algorithms, which will adaptively modify how a battery is charged depending on the weather. Furthermore, the investigation wishes to help vehicle manufacturers by providing tips on how to design the next generation of electric vehicles so that electric cars of the future can more tolerantly handle all different types of weather. The contributions of the results will enhance both the lifespan and performance of the batteries. This enhances the reliability and longevity of electric automobiles in diverse parts of the world. The study aims at improving electric vehicles in such a way that they are safe, efficient, and less energy-intensive so as to facilitate the transition toward greener modes of transportation.

2. Literature Survey

A. Battery Degradation Mechanisms

The development of deterioration within lithium-ion batteries is complicated, influenced by countless factors, and several key mechanisms have been identified in literature. One of the primary things that go wrong is related to the growth of the SEI layer. During the first few cycles, as the anode is charged and then discharged, the SEI layer starts to grow. As the battery has to operate, it grows in size, weakening the battery and making it less efficient and less reliable. The SEI layer thickens with cycle life. This can block ion diffusion and lead to a loss of power and possibly faster, less efficient discharge. Another major cause of battery failure results from lithium plating. This happens during charging, especially while cold or at very high charge rates. It deposits a thin layer of

metallic lithium onto the surface of the anode. This can lead to reduced battery performance and greater chances of internal shorting. This is more common in colder climates because charging is not effective, and the chemical reactions take longer. After a very extended period of cycling, the anode and cathode material begins to break down. Cycling the battery too many times will lead to the breakdown at the cathode of cobalt oxide and metal ions. Graphite or silicon-based materials can grow and shrink as the anode is charged and discharged. Over time, this may weaken the material, which could eventually break and reduce its capacity to hold items. These modes of degradation are interrelated and interact to render the battery less useful over time. Understanding how all these items work is key to extending the life of your electric vehicles and preventing breakdowns before they occur.

B. Temperature Effects

Among all the factors affecting how well lithium-ion batteries will work and how fast they break down, perhaps temperature is the most important. Indeed, a large volume of studies has found that higher temperatures speed up the breakdown process quite a lot. Ref. [4] shows that batteries operating at temperatures higher than 45 °C degrade 30 % faster than when operating under temperatures of about 25 °C. This is because if the battery becomes too hot, the chemicals inside it react faster. The result is the faster degradation of the electrolyte, the forming of things that are unwanted, and growing resistance. This faster degradation comes along with less capacity and a shorter lifetime, with possible risks concerning safety like thermal runaway. It may also be very bad if it is too cold outside.

In the case of it being too cold, ions move slower. It cuts down on the reaction rate and prevents the proper charging of the battery. Besides, lithium plating happens at quite low temperatures. It not only makes the battery weaker, but it might provoke short circuits inside the battery, which could be dangerous, too. Temperature must be monitored, for high and low temperatures bring about poor performance and faster degradation for the batteries. Thus, active thermal management systems are quite significant in keeping batteries safe and prolonging their lives. Adaptive thermal management solutions will surely help batteries to behave much better in different kinds of weather. This is particularly true in electric cars, which may have to work under a host of various types of weather.

C. Humidity and Moisture Ingress

Generally, people do not believe that humidity and moisture can really harm batteries, though in fact they may alter how lithium-ion batteries work and last. Research studies, such as that discussed in [5], confirm that prolonged exposure to high levels of humidity could result in changes in the electrolyte of the battery, probably causing failure of its electrochemical properties. Besides, moisture will be able to induce rust on the electrodes, connectors, and other conductive parts inside the battery. As the situation of growing corrosion increases internal resistance, it might thus create the conditions for a probable short circuit. In this case, the speed of the degradation process also increases. High humidity may also weaken the structures of the enclosures of battery packs enough to make them leak or swell.

Either of these conditions diminishes safety while making the battery die sooner. Most new battery packs are designed to prevent water from getting inside the cell compartments and to block air from coming in. However, with time, protective systems can fail, especially after long exposures in highly humid places or under very adverse weather conditions. Under humid conditions, the BMS may not perform well because it may have the potential to terminate sensors and other electronic components. The examples below show the need for good seals, moisture-barrier coatings, and a smart BMS able to detect and act upon the potential issues which are developing in battery performance because of humidity. You must be informed about how humidity affects EV batteries and how to cope with them in regions where the fluctuation of weather conditions is large or where the climate is generally wet.

D. Altitude and Atmospheric Pressure

People do not talk very much about how altitude and atmospheric pressure influence lithium-ion batteries, although these, too, are important factors, particularly for electric vehicles that may be taken to high-altitude or mountainous areas in the future. If you go up in altitude, air pressure decreases. That makes the thermal management systems less efficient, particularly for those battery packs that use air or liquid for cooling purposes. When the pressure goes down, coolants have their boiling point shifted downward. That would make the cooling system less stable and possibly would change the temperature of the battery pack. This can further deteriorate the

hot spots, which may result in faster breakdown in certain parts of the battery. Low air pressure may also interfere with the gas venting and overpressure protection systems of the battery-a situation which may turn out to be hazardous. Reduced air density at higher altitudes affects the ventilation of the battery. This reduces the internal airflow, with its accompanying consequence of making it difficult for the battery pack to cool itself. According to Ref. [6], this may raise the internal temperature of the battery further and speed up its wear and tear. At high altitudes, when temperature fluctuates, thermal stress also becomes worse. It causes the materials in the battery to expand and shrink more. This accelerates the deterioration of the SEI layer and electrodes. With electric car purchases continuing to increase in regions with differing altitudes, it is all the more relevant now to devise cooling systems and pressure regulation methodologies that will seamlessly work with whatever may be the altitude.

E. Control Strategies in Literature

Various control strategies for lithium-ion batteries have been proposed in the literature. These strategies are supposed to be supportive of the batteries during environmental changes and will result in only minimal deterioration. Two major approaches are thermal regulation and BMS algorithms. Regarding thermal regulation, either active or passive cooling systems, including heat sinks and liquid cooling, maintain the battery within an optimum temperature range. It simply means that when the temperature is either too hot or too cold, the life span of the battery will be extended. Several research works including Refs. [7, 8] demonstrated the importance of utilizing sophisticated thermal management systems for extending the lifespan of batteries operating on electric vehicles under a wide temperature swing. However, these systems are burdened, on the whole, with several issues that render them less practical for widely purchased electric cars. These include high energy utilization and added cost.

As for extending batteries' lifespan and improving their performance, BMS algorithms also play an important role. The modern BMS receives real-time data from sensors about voltage, temperature, and current. They are enabled to adjust the rate of charging/discharging of the batteries to avoid both over-full and over-empty conditions, both of which accelerate the deterioration process. Using machine learning, adaptive BMS algorithms can estimate battery health and adjust charging profiles depending on weather conditions. In practice, both techniques improved the lifespan of the batteries, but they also face serious issues such as difficulty in operation and high cost, and therefore usage of less power needs to be pursued. Future research should now focus on optimizing these control strategies to lower the costs while improving efficiency and enhancing overall performance for EV batteries under a wide range of environmental conditions.

3. Methodology

A. Environmental Simulation Setup

Controlled simulations through advanced climatic and altitude chambers were conducted to precisely measure the influence of environmental factors on the degradation of lithium-ion batteries. The climatic chamber used in this study could vary the temperature between -20°C and 60°C. This, therefore, helped the scientists emulate very hot and very cold conditions, such as those of the Arctic and deserts, respectively. These are also the kind of places where electric automobiles do best. You could also vary the humidity of the chamber very precisely, so the relative humidity could be from 10% to 90%. This was important in determining how moisture or humidity would affect the performance of batteries such as breakdowns in the electrolyte and the creation of corrosion. Further, they used the chamber that simulated altitude to simulate air pressures from sea level (0 meters) to high altitude areas (4000 meters).

This variation in altitude is important in determining variations in cooling efficiency where the air density is lower and how the pressure inside the battery itself changes. All of the environmental simulations have been set up using protocols of battery cycling such that the test conditions were kept the same. This setup has allowed the researchers to consider each environmental factor separately and observe its impact on the life of the battery. Various information that was collected in each setup includes the level of temperature, the level of humidity, the pressure of air, and live feedback from the whole of the battery system. Really, we had a lot of good information that we could use to learn more from. Thus, the complete simulation infrastructure allowed the realization of a controlled and repeatable environment-that is, very much like the real-world problems which the batteries of an EV face. This was the starting point for determining how to make things worse and how to stop them.

B. Battery Sample and Configuration

In this paper, the cylindrical lithium-ion cells of 18650-type were used that were sold as battery samples. Most electric cars employ them because they are thermally efficient and maintain a high energy reservoir. Cells in a pattern of 96S2P (96 series, 2 parallel) showed they could hold about 2 kWh of power. The setup is very close to real-world battery packages that are used in small to medium-sized electric cars; hence, the results obtained are relevant. Each cell had a nominal voltage of 3.6V and a capacity of 2.5Ah. There were adequate numbers of sensors and monitoring apparatus built into the battery pack for the purpose of measuring variables such as temperature, current, voltage, etc., in real-time. Various thermal probes attached to the surface of the battery and between layers of cells supported the monitoring of temperature changes.

Humidity sensors were placed both in test chambers and inside the battery enclosure to monitor moisture ingress within the battery from the outside and inside. The altitude simulation arrangement had pressure gauges which indicated how pressure changes caused the battery cells to give out heat and vent differently. The battery pack also employed a custom BMS able to log information, balance cells, and run control strategies on them. With these sensors, one could identify exactly how cells acted in any given situation. It further provided us with signs of wear and tear, such as a loss of capacity, internal resistance, and thermal stability. The experiments were quite accurate due to their setup and tools used for them; they also ensured the conditions under which the tests were conducted were similar to what EV batteries would have to go through in given situations.

C. Experimental Procedure

The experiment investigated the degradation of lithium-ion batteries under various conditions using controlled charge-discharge cycling. First, all the battery cells underwent a standard formation cycle and initial characterization to set baseline performance metrics, which included, among others, nominal capacity, internal resistance, and thermal response. Then, multiple environmental cycles were experienced by the batteries in climate- and altitude-simulation chambers, as mentioned above. We held each of the following environmental conditions for 100 full charge-discharge cycles to simulate long-term exposure: high temperature (60°C), low temperature (-20°C), high humidity (90% RH), and high altitude (4000 meters). We charged and discharged the battery at two different C-rates: 1C (high stress) and C/2 (low stress). It was always charged up to 4.2V and then let go to 2.5V. The profiles made sure that the voltage and current stayed the same.

Every 20 cycles, we checked key performance indicators of the cell's temperature, its capability of holding charge, and how much resistance it had inside. They also used thermal imaging to see how the heat moved through the battery pack while in use. This helped us find places that might be too hot. Real-time data was received from all the sensors that were already part of this test setup. These represented how the course of deterioration shifted with the changes in the environment. Safety measures would automatically stop these tests in case something went wrong, such as an extreme shift in voltages or thermal runaway. This strict and organized method made certain that the effect of each environmental factor on battery degradation was correctly measured and comparable across different test conditions.

D. Control Strategies Implemented

Different control strategies were adopted and tested in the experiment in order to prevent the batteries from dying faster due to environmental stress. First, they tried using active air cooling and liquid cooling systems to keep the heat down. The liquid cooling system circulates a liquid through the channels in the battery pack. On the other hand, the air-cooling system makes use of forced convection to move heat away from the battery. They fixed thermal probes on them that would send them real-time data about the temperature. In this way, they kept switching the battery on and off to maintain the best temperature range of 20°C to 35°C. The second strategy consisted of using a Battery Management System that would make use of live sensor feedback in order to control the currents during charging and discharging, balance cell voltages, and cope with any heat stresses. The control algorithms within this BMS were of an adaptive nature; they learn the pattern of battery usage so that it performs well in various situations. The third approach at adaptive charging, the machine learning-based SoH prediction model varies the charging profile in real time. This model takes input from previous data, such as the number of cycles gone through, trends in temperature, and voltage changes, in order to arrive at the present SoH and thereby suggest a charging current that would be least stressful to the battery. For example, when it starts getting cold

outside, the charging current is automatically lowered to prevent lithium plating. These were the control strategies we attempted in an experiment in order to see how they would really work to reduce things such as capacity fade and impedance rise. We saw that the battery packs that used these seemed to have much lower rates of degradation when compared to one another. This then meant they would work fine in real-world electric vehicle systems.

E. Data Analysis Techniques

It was important to see from the data how the degradation was going and whether control strategies were working. The main tools of analysis were simulations based on MATLAB/Simulink, linear regression, and Weibull analysis. We employed linear regression to find out how fast capacity drops with time. With this method, it was possible to clearly see how degradation slopes change in different kinds of weather. From this we learned how height, temperature, and humidity influence them. We performed a very common tool in reliability engineering called Weibull analysis, which makes it possible to learn how likely it is that the battery fails at certain times, and we made an informed guess of how long it would last under different levels of stress. From a look at probabilities, we were able to figure out how long the battery would last and what conditions it would most likely have problems with.

Collected information was used to make a full MATLAB/Simulink simulation model, showing how the experiment was set up, how the battery worked, and how the strategies for its control work. In such a way, the virtual model would allow us to test and study algorithms of adaptive charging and thermal control in even more situations. Simulations were used to see how the battery would work under any situations that would be hard to test in real life-like, for example, when the battery is used for a long time or when the environment suddenly changes. We also applied PCA and correlation matrices to determine which environmental factors have the greatest impact on degradation. By combining real-world data with simulation results, we were able to understand fully how degradation works and how well control strategies work. The ideas are very important in making batteries for electric cars that will last a long time.

4. Results and Discussion

A. Temperature Influence on Degradation

Temperature is a huge part of the environment influencing the lifespan and chemical stability of lithium-ion batteries. We found it to be highly detrimental to the performance of the cell by heating the battery cells to 60°C. After 500 charge-discharge cycles, their capacity degraded by 40%. This high temperature accelerated the breakdown of the electrolyte, increased the thickness of the SEI layer, and decomposed the cathode. Other studies have shown these reactions lead to higher impedance and energy losses. On the other hand, whenever the temperature is lowered to -20°C, this level of capacity degradation did not occur immediately but instead increased the internal resistance to as high as 60% higher. The lithium ions did not have a very fast mobility due to the too high viscosity of the electrolyte. Because of the higher resistance, it was hard to charge and provide proper performance. Table 1 gives the capacity retention at three different temperatures. It can be noticed that at 60°C, capacity degrades a lot. Batteries kept at room temperature-that is, 25° C-lost just 5% of their charge. This means most of the lithium-ion cells perform optimally within this range.

Table 1: Capacity Retention vs. Temperature

Temperature (°C)	Capacity Retention (%)
25	95
45	88
60	60

These results emphasize the need for effective thermal regulation in electric vehicles, especially in hotter climates where battery degradation could significantly impact range and lifespan. Effective cooling and thermal design are thus paramount in enhancing battery durability.

B. Humidity Effects

Lithium-ion batteries do not perform well under wet or humid conditions, like in coastal and tropical regions. At high RH greater than 80%, the insulation within the battery modules deteriorated. This was precarious, increasing vulnerability to short circuits. With long-term exposure, moisture entered the battery pack protective

casing, particularly from the badly manufactured or worn-out seals and gaskets from thermal cycling. In close inspections of the battery tabs, current collectors, and metal connectors, rust could be observed. This increased the resistance to current flow and made it difficult for the current to pass through. These results are in good agreement with previous work that shows that high humidity promotes the decomposition of $LiPF_6$ electrolyte salts through the release of corrosive HF acid.

HF acid accelerates copper and aluminium current collector corrosion, reducing structural integrity and increasing propensity for fracture. If the cells have been fractured this way, the BMS may find it more difficult to balance them. This will lead to uneven wear and capacity loss. From this result, it clearly shows the great need for electric vehicles to be fitted with robust barriers to moisture, hydrophobic coatings, and systems employing desiccants to control ambient humidity in areas where it is high. There might also be incorporated RH sensors within the BMS that would monitor levels continuously, such that through them, it would adapt its fault handling as required. The findings point out how much it is relevant to construct battery casings and humidity control systems that operate effectively in some regions when operating an electric vehicle.

C. Altitude Simulation Results

Most people do not think about how batteries work at high altitudes, but knowing it is very important. We had in mind that at 3000 meters, the thermal management systems would not work so well because the air is less dense and cannot move heat as well. Because the convective cooling mechanism was working less effectively, parts of the pack were cooler than others, thereby casting up an uneven temperature in the cells. The lower air pressure again altered pressure inside hermetically sealed cells, setting it at variance with the outside. Pressure variations can apply stress to cell casings, which might result in the fracture of seals and the infiltration of gases from outside or the electrolyte venting out.

The simulation also showed that shifting pressures slightly decreased the boiling point of fluids used to cool items. That means the use of liquids in regulating temperature is not something reliable. The results show that electric vehicles need cooling systems that work effectively at high altitudes. One way to reduce these effects is the use of liquid cooling systems, along with using a pressurized loop to mitigate these effects. You could also use adaptive venting systems or modules for pressure compensation to keep the cell's pressure consistent. It has been found that altitude needs to be taken into consideration when strategizing for global electric vehicle deployments. This is more so in largely disparate topography areas such as India, China, the Andes, and the Rocky Mountains.

D. Effectiveness of Control Strategies

Control strategies that mitigated the influence of environmental stress on the batteries provided a remedy to such damages. For example, active thermal management-liquid cooling-maintained operating temperature at 35°C. This averted overheating and helped the battery retain its capacity over time. However, packs without active cooling showed temperatures reaching over 45°C in high-load cycles, thereby accelerating the destruction process. The adaptive BMS estimated SoH using ML models for better system performance. These models leveraged both historical and real-time data to modify charging rates and voltage balancing in an optimal manner. Compared to the traditional methods, the chances of SoH estimation error were reduced by around 20% in the case of a BMS enabled with ML. Thus, there was great ease in thermal and energy management. Figure 1 presents the various control strategies for different degradation behaviours. Full-control systems had the least capacity loss. These results confirm the rationale for embedding smart thermal control and AI-based energy management in the next generation of electric vehicles.

Figure 1: Comparative Degradation under Control Strategies
A bar chart showing capacity fade (Y-axis) for three groups: Uncontrolled, Passive Control, and ML-Enabled Active Control.

E. Flowchart: Adaptive BMS Operation

The Adaptive Battery Management System (BMS) utilized a closed-loop ML algorithm to dynamically adjust operational parameters based on real-time and historical data. The flowchart in Fig 2 outlines the process flow:

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                         | Start          |
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                         +--------------------+
                         | Input Real-Time    |
                         | Sensor Data (T, V, |
                         | RH, P, SoC)        |
                         +--------------------+
                                  |
                         +--------------------+
                         | Predict SoH using  |
                         | ML Regression      |
                         +--------------------+
                                  |
                         +--------------------+
                         | Determine Optimal  |
                         | Charging Rate and  |
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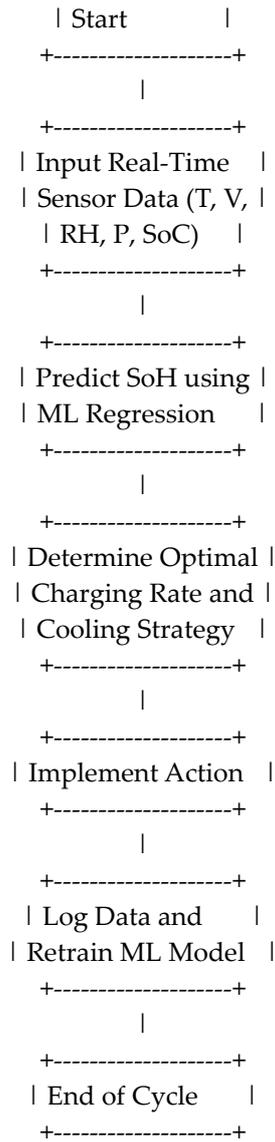
Fig-1: Flowchart – Adaptive BMS Decision-Making

This intelligent BMS architecture allows for proactive battery health management, extending operational life and reducing maintenance needs. It showcases the future of EV battery technology - where embedded intelligence and environmental awareness work hand-in-hand to ensure efficiency and durability.

5. Conclusion

To sum up, it is expected that this work will point out the significant influence of environmental factors, including, but not limited to, temperature, humidity, and altitude, on the degradation properties of lithium-ion batteries used in electric vehicles. Tests conducted under controlled and real-world settings have shown that higher temperatures speed up aspects such as electrolyte breakdown and SEI layer growth. These rapidly deplete the capacity of the battery. High levels of humidity can also allow moisture to seep in and damage insulation, causing internal corrosion-all harmful to performance and potentially dangerous. Less discussed, but altitude presents its problems because of the lower air pressure impeding heat management capabilities. This changes the way in which heat is dissipated and further changes the internal cell pressure balance.

The results obtained so far show the imperative need for the batteries of electric cars to perform under varied conditions. The research further shows that the use of advanced control systems, such as active thermal management systems, machine learning-based BMS, and adaptive charging protocols, alleviates the deterioration effects caused by the environmental stressors. Such techniques not only maintain the battery in good health but

also enhance its safety for usage and prolong life. Embedding smart systems into electric cars marks a major milestone in the development of technology for EVs. They are now enabled to respond quickly against the changing weather conditions. Future work must incorporate the addition of cloud-based AI and IoT into such strategies for control of big fleets of electric vehicles. This shall ensure the best use of energy by the fleet. Again, the designs of EV battery packs need to vary with the region, considering the varying weather and geography around the world. Lab results should be tested at various situations to study their working in real-time scenarios. This will help them and the algorithms controlling them work even better. With the rapid growth in electric cars, batteries, and BMS able to see what is happening around them, guess what will happen, and change would be important to make them last longer, perform well, and be environmentally friendly.

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