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Role of AI in improving rechargeable batteries for Electrical Vehicles

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Abstract: The demand for rechargeable batteries has seen exponential growth, especially during the last decade due to the increased popularity and usage of Electrical Vehicles (EVs). These batteries have become a critical part of the overall energy infrastructure and as such, there is a significant focus and interest around enhancing their capabilities. While EVs are considered one of the most promising ways to cut down the carbon footprint, battery waste poses another threat to our planet. One way to reduce this impact is to prolong the life of batteries so the net wastage over the life of any EV is reduced. In this paper, we will briefly list different types of batteries and analyse their usage and power supply. We will then cover the commonly adopted techniques and processes for increasing the efficiency and performance of batteries. Further, we will analyse and suggest some Artificial Intelligence (AI) driven concepts which could be useful in prolonging the usable life of these batteries.

Keywords: Lithium Ion, Electric Vehicle, Artificial Intelligence

1 Introduction

The history of batteries dates to 1800, discovered by Alessandro Volta, which had stacks of copper and zinc discs separated by saltwater-soaked linen (Britannica, T. Editors of Encyclopaedia, 2022). The next version also the forerunner of the dry cell battery, was invented by Frenchman Georges Leclanché, who created the Leclanché cell (Wikipedia - Georges Leclanché, 2022). The Leclanché cell was a wet cell and became the standard for doorbells at that time (Wikipedia - Georges Leclanché, 2022). In 1888, Carl Gassner invented a dry cell by significantly improving Leclanché's invention (UPSBatterycenter.com, 2014). However, the origins of today's batteries can be dated back to 1899 when Waldemar Jungner created the nickel-cadmium battery as one of his three battery inventions (Wikipedia - Waldemar Jungner, 2022). The invention of the modern battery of that time was concluded in 1900 when Thomas Edison won the patent dispute for a nickel-iron storage battery but even that wasn't very successful (Future Planet, 2021). The concept of the current rechargeable lithium-ion battery was envisioned by M. Stanley Whittingham in the 1970s, but it wasn't until 1990 that today's batteries were conceptualized (Wikipedia, 2022). This year can be truly regarded as the time when the batteries used in today's electric cars were invented.

There has been a significant development in the field of batteries. As such there are several [i]battery types in existence. These can be classified into two categories based on their life and purpose - Primary also known as single-use and secondary also known as rechargeable (Sinha, 2022)

1) Alkaline batteries - Alkaline batteries are amongst one of the most popular types due to their high energy density and long shelf life. These are single use batteries.
2) Nickel-Cadmium Batteries - They have a very long life and are very reliable and sturdy. They are secondary batteries and commonly used in portable computers and small battery-operated devices.
3) Nickel-Metal Hydride Batteries – A type of secondary batteries, these have a lifespan of two to five years. These batteries are expensive and produce a significant amount of heat while working.
4) Lithium-Ion batteries - These are secondary/rechargeable batteries with a long-life cycle of over five years. They charge faster and have a high energy density

2 Examples of Batteries in EVs

Lithium-ion batteries are currently used in most portable consumer electronics such as cell phones and laptops because of their high energy per unit mass relative to other electrical energy storage systems. They also have a high power-to-weight ratio, high energy efficiency, good high-temperature performance, and low self-discharge. Most components of lithium-ion batteries can be recycled, but the cost of material recovery remains a challenge for the industry. Most of today's EVs use lithium-ion batteries, though the exact chemistry often varies from that of consumer electronics batteries. Research is still ongoing to reduce their relatively high cost, extend their useful life, and address safety concerns about overheating (Batteries for Electric Vehicles, 2022)

Nickel-metal hydride batteries, used routinely in computer and medical equipment, offer reasonable energy and power capabilities. Nickel-metal hydride batteries have a much longer life cycle than lead-acid batteries and are safe and abuse tolerant. These batteries have been widely used in hybrid EVs. The main challenges with nickel-metal hydride batteries are their high cost, high self-discharge, heat generation at high temperatures, and the need to control hydrogen loss (Batteries for Electric Vehicles, 2022)

Lead-acid batteries can be designed to be high power and are inexpensive, safe, and reliable. However, low specific energy, poor cold-temperature performance, and short calendar and lifecycle impede their use. Advanced high-power lead-acid batteries are being developed, but these batteries are only used in commercially available electric-drive vehicles for ancillary loads (Batteries for Electric Vehicles, 2022)

Ultracapacitors store energy in a polarised liquid between an electrode and an electrolyte. Energy storage capacity increases as the liquid's surface area increases. Ultracapacitors can provide vehicles additional power during acceleration and hill climbing and help recover braking energy. They may also be useful as secondary energy-storage devices in electric-drive vehicles because they help electrochemical batteries level load power (Batteries for Electric Vehicles, 2022)

3 Monitoring Battery's Health

Batteries also have an embedded Battery Management System (BMS) which has the primary function of monitoring the battery's voltage, state of charge, health, temperature and controls the charging and discharging of a battery. It also protects cells of the battery from any violations of current, voltage, or temperature, increases the life cycle of a battery, and keeps the battery in a state that fulfils the administrators' requirements (Thomas, 2021)

4 Commonly used techniques in enhancing Life and Battery Performance

There are several commonly used techniques to improve a battery's life and performance. Some of these include the following -

1. **Temperature monitoring and management** - Lithium-ion batteries are susceptible to component deterioration and pose serious safety issues like the possibility of fire or explosion when exposed to extreme temperatures. A common approach is to monitor their usage in high and low-temperature extremes to prevent such scenarios.

2. **Charging patterns and timing** can have a huge impact on the life of batteries. As an example, batteries are strained in both highly high and low "states of charge", so it is recommended to reduce their usage at 100% and charge them as much as possible instead of using them when they are close to a 0% charge. Another common recommendation is to utilise a partial charge bringing the battery's state to 80% and not overcharging the device beyond 100%, although a lot of work has been done in this area to prevent overcharging by introducing auto-cut off mechanisms in some devices.

3. The **time** taken to charge a battery has a direct impact on its deterioration. Faster charging, although preferred with "rapid chargers", will significantly shorten the life of a lithium-ion battery as it generates a lot more heat than standard charging. Electric car companies like Tesla have added new features like Thermal Battery control with liquid cooling to minimise such deterioration but such enhancements are still expensive and have very limited proof of their overall effectiveness.

4. As discussed earlier, Lithium-ion batteries are prone to some issues such as slower charging, safety issues. To overcome these problems **nanotechnology** is used. This system makes use of nanotechnology that contains Nanoparticles, high valued capacitors that are useful to enhance overall efficiency. A large amount of power can be stored in lithium-Ion batteries. For this, coated anode-cathode, and Lithium Manganese Silicate (Li_2MnSiO_4) are used to improve the electro-chemical strength of the battery (Fulari, 2020)

5. For enhancing battery performance, a method that increases capacity and expands the life of the battery is often used. This will be achieved for an electric vehicle battery by realising the greatest charging profile and recognizing plugged-in time for enhanced durability & life. In this method, for a pre-set finite time the charger will charge and pause for the rest until fully charged.

6. Another common technique is to perform **battery charging with rest periods** and allow minor discharges but refrain from complete discharge. Lithium-ion batteries don't have a charge memory as Nickel Cadmium batteries. Deep-discharge cycles are thus not necessary. Using a partial discharge cycle is healthier for such batteries. However, battery experts advise letting lithium-ion batteries almost totally drain after 30 charges (BU-808: How to Prolong Lithium-based Batteries, 2021) The precision of the device's power gauge is lowered by a situation known as digital memory, which is brought on by constant partial discharges.

5 Use of AI to Enhance Battery's Life

The adoption of EVs relies massively on the performance and efficiency of their underlying batteries. Frequent charging of batteries can hamper the espousal of electric vehicles. Imagine spending hours charging your EV batteries when you are on a road trip with your family, it's quite a spoilsport. Hence, we need efficient ways to understand battery health, and performance as well as measure their degradation over time.

5.1 Measuring the decay in battery performance

There has been immense research being carried out to predict battery health. With major advancements in ML algorithms and modern AI techniques, we can with 10x higher accuracy understand battery health. Especially with the use of Ensemble ML algorithms, we can precisely measure the decay in battery performance over time.

Researchers from Cambridge have discovered a very informative method to understand the lifespan of a battery (Zhang, et al., 2020). The present industry standard to understand battery life depends on monitoring current and voltage graphs when the battery is charging and discharging. What the researchers have proposed as an alternative is to send electric pulses to batteries and then observe their responses. The responses recorded are then picked up and processed by an ML algorithm. A major advantage of this proposed methodology is that while measuring the responses they have been able to separate relevant data from the noise that the model could pick up. This process is a stand-alone technique that works in isolation and can simply be added to a battery system. This measurement is then performed over thousands of scenarios to train the model and capture every aspect. This is then tested on real time data to measure the performance of the model. The response of electric signals from the model has shown to have a strong correlation with the aging of the batteries which has then led to subsequent research in understanding why and how the batteries degrade (Zhang, et al., 2020).

5.2 Estimating battery life

AI is also used to train models to assess the battery's life cycle and forecast how long it will last, the battery's life determines how long it will last on a single charge by analysing the charge particles flow and pattern. During charging and discharging of a battery, lithium ions travel between the cathode and anode, which are composed of nano-sized grains and particles. The behaviour of cathode particles composed of nickel, manganese, and cobalt (NMC) has been researched in depth. NMC is by far the most prevalent battery option for electric vehicles. When the battery is discharged, the particles absorb the lithium ions and release them when the battery is charged. Using X-rays from the Stanford Synchrotron Radiation Lightsource at SLAC, the researchers analysed the particles in the battery during rapid charging. Then, scanning X-ray transmission microscopy was utilised to examine every single particle of the same type. Experiment results, data from mathematical models of rapid charging, and equations from physics and chemistry were all utilised by the scientific machine learning method. This is another prevalent use of AI to predict battery health, charge level, and remaining life span (Goled, 2021)

5.4 Efficient testing of AI battery enhancements

AI is also used to speed up the testing cycle during the experimentation of battery enhancements. Panasonic, which makes batteries for Tesla and Ford, has managed to reduce testing times for charge cycles to around six months in some cases. Without AI, the batteries would have been charged and discharged over a period of three years.

Stanford University, MIT, and the Toyota Research Institute have a joint project to work on how to charge EV batteries in 10 minutes while preserving the life expectancy of the cells. In a report published in Nature, they explained how they had reduced testing time from 500 days to just 16. The study's co-author William Chueh said, "The AI aspect of our work is all about speeding up the research-and-development cycle so that we can iterate faster and faster." (Smith, 2020)

6 AI Opportunities for the Battery Industry

Whilst there has been a lot of progress in the use of Artificial Intelligence (AI) and machine learning (ML) to help speed up the improvement in batteries and reduce costs, the battery industry still has a ton of opportunities yet to be exploited to improve the overall process of research, design, manufacturing, monitoring and improvement of these batteries. The existing research and techniques have been immensely useful in improving batteries by changing their architecture and structure to make them operate faster, last longer and be safer. However, the overall process of improving batteries remains hampered by slow experiments, long turnaround times and a difficult discovery process. The following are some of the areas in which AI's potential seems promising in bringing change.

6.1 AI's chemical recipes

AI can pick through scientific papers online and material databases and run modelling for different combinations of chemical components in cells to ascertain optimum performance for fast charging, long life and obsolescence.

IBM has also been exploring alternatives to nickel and cobalt in a bid to find more sustainable materials and reduce costs. The job of evaluating the 20,000 possible compounds to use as the electrolyte would have taken some five years without AI. IBM was able to employ machine learning to get the job done in nine days.
The company's lab director told the WSJ, "The AI is now becoming much more central as we tweak the solvents and electrolytes to get the battery even better in terms of capacity and life cycle because we have had more time to train it." (Smith, 2020)

6.2 Innovating next-generation fuel cells

Battery fuel cells use clean hydrogen fuel, which can be generated by wind and solar energy, to produce heat and electricity, and lithium-ion batteries, like those found in smartphones, laptops, and electric cars, are a popular type of energy storage. The performance of both is closely related to their microstructure: how the pores (holes) inside their electrodes are shaped and arranged can affect how much power fuel cells can generate, and how quickly batteries charge and discharge (Brogan, 2020)

However, because the micrometer-scale pores are so tiny, their specific shapes and sizes can be difficult to study at a high enough resolution to relate them to overall cell performance. Researchers at Imperial College have applied machine learning techniques to help them explore these pores virtually and run 3D simulations to predict cell performance based on their microstructure. The researchers used a novel machine learning technique called "deep convolutional generative adversarial networks" (DC-GANs). These algorithms can learn to generate 3D image data of the microstructure based on training data obtained from nano-scale imaging performed on synchrotrons. The work carried out in this research still requires further enhancements and applications to the current manufacturing possibilities to design electrodes for next-generation cells (Brogan, 2020)

6.3 Identification of new electrolyte materials

Like the other elements in a battery, electrolyte chemistries can be tweaked to boost desirable properties like energy density or reduce undesirable ones like its toxicity. Historically, identifying new electrolyte materials has been a very cumbersome and time-consuming non-systematic process. The molecules in most battery electrolytes may have upward of 20 heavy atoms, and there are a lot of ways those atoms can be combined. The Argonne team has been experimenting using their novice Electrolyte hunting algorithm on a database of organic molecules that have up to 17 heavy atoms consisting of 166 billion candidates (Oberhaus, 2020). That would be an unreasonably large space for an AI to seek out promising candidates without having a good idea of what it was looking for (Oberhaus, 2020)

7 Can AI make Battery Industry More Sustainable

The improvements in battery performance, lifecycle, density, footprint, choice of materials, and recycling all have huge potential to reduce the waste and carbon footprint on our planet. As the popularity of electric vehicles starts to grow explosively, so does the pile of spent lithium-ion batteries that once powered those cars. Industry analysts predict that by 2020, China alone will generate some 500,000 metric tons of used Li-ion batteries and that by 2030, the worldwide number will hit 2 million metric tons per year (Jacoby, 2019). It is therefore crucial to prioritise making the recycling process of Lithium-ion batteries efficient and worthwhile. One area in which further research needs to be done is making the recycling process more intelligent by using AI-enabled IoT devices (Jacoby, 2019).

One obvious point of intervention in the entire battery life cycle is to extend the life of batteries. There is already a lot of work in progress in this space, some of which have been discussed earlier in this paper. Prolonged life cycles will reduce our net battery waste requiring lesser energy spent on recycling the used batteries. Lithium mining itself has significant environmental challenges as producing one ton of lithium requires over 2.2 million litres of water (Campbell, 2022). This is undoubtedly a growing area of concern and another opportunity for innovation in this industry. AI has the potential to accelerate the discovery of alternate materials that can be used for making better batteries. The faster we identify the alternate materials the quicker would be the shift away from lithium.

The management of supply and demand is one of the biggest obstacles in the renewable energy adoption. When the sun shines or the wind blows there is often an oversupply of energy compared to the night or when the wind drops. The imbalances can only be smoothened by storing the energy efficiently and this is where better batteries hold the key to the decarbonized future. The faster adoption of AI in battery innovation will lead to an efficient storage ultimately making the usage of renewable energy more feasible.

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