THE ROLE OF ELECTRIC BATTERY MONITORING AND MANAGEMENT SYSTEMS IN THE REALIZATION OF RENEWABLE AND SUSTAINABLE ENERGY

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ABSTRACT

The fifth IPCC report outlines motivation to stop burning fossil fuels and find alternative sources of energy. Fossil fuels are mostly burnt on demand to produce work and heat, which are either used directly, or indirectly to produce electricity. However, most alternatives only produce electricity, and in such a way that supply and demand do not match. Therefore, electrical energy storage must be developed on large and small scales. One of the keys to small scale storage is batteries. An important part to developing batteries is battery monitoring and management systems that can squeeze out more performance per cell.

Keywords: battery management system, battery chemistry, battery safety

1. THE GROWING IMPORTANCE OF ELECTRICITY AND ITS STORAGE

The fifth IPCC summary for policy-makers states that fossil fuel burning must be reduced significantly over the next few decades to avoid risking serious damage to the climate. To achieve this, alternative sources of energy must be harnessed. [1]

A major consequence of this is the importance of electricity greatly increased, as many key alternative energy technologies exclusively produce electricity. For this paper, these include:

- photovoltaic cells
- solar thermal power stations
- hydroelectric dams
- wind turbines
- tidal power stations
- nuclear power stations

Furthermore, they produce electricity in such a way that rates of supply and demand do not match and cannot be controlled to the degree that fossil power stations can (i.e. nuclear stations produce constantly, the sun rising, wind blowing and tides swaying cannot be controlled). [2]

This is not an issue with fossil fuels, for they can be burnt as and when needed, and are easily stored when not. So to move from fossils to alternatives, the problem of supply and demand must be solved. There are a number of things that can be done to solve this:

- Manage demand where possible, e.g. factories that vary their production with electricity supply
- Increase transmission line capacities, and interconnected lines to form larger grids to help connect varying supply and demand across large areas that have different sources and different or time-shifted consumption patterns, such as the UK adding large interconnects to Ireland, Norway and France.
- Increase large scale storage capacities, such as pumped storage facilities and making use of hydroelectric dams as controllable supply, for nation-level fluctuations.
- Increase medium scale storage capacities, such as flywheels, for town, street, facility, and large building level fluctuations and replacements large emergency generators.
- Increase small scale storage capacities, such as batteries, capacitors and flywheels (again) for use in portable, backup, and smoothing storage applications.

Batteries are of particular interest to this paper due to their proven use in transport, particularly motor vehicles, and the potential shown by current research, particularly by motor sports such the FIA's WEC LPM1 class and Formula E, and the iMechE's Formula Student. [3] [4] [5]

2. THE NATURE OF BATTERY TECHNOLOGY

Batteries store chemical energy that they can convert directly into electrical energy to do work in an electric circuit. The structure of a battery is 1 or more electrochemical cells, each with an anode and cathode that perform redox reactions with an electrolyte with an ion barrier to separate the two half cells. The redox reaction produces a voltage across each half cell that opposes the continuation of the reaction. This forces work to be done in any connected circuit in direct proportion to the continuation of the reaction. [6]

Batteries have low energy densities (both Joules per Kilogram and Joules per Litre), as can be seen in fig. 1), and high materials and manufacturing costs compared to liquid hydrocarbon fuel technologies, which has made them preferable to batteries for many applications for the last hundred years.

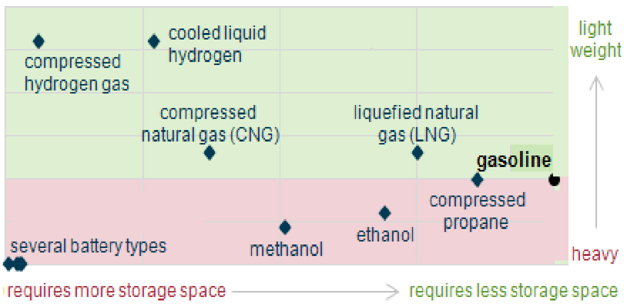

Fig. 1. Energy density comparison of several transportation fuels (indexed to gasoline) [7]

Despite this, the promise of breakthroughs in development from choice of the active chemicals (the battery chemistry) has meant options have continually already been explored for a long time, and research into more complex, exotic, and newly available chemicals and methods still continues. [8]

It must now be said that batteries are an old and mature technology; electric cars could be found by the end of the 19th century [9] and the chemistry behind them, electronegativity, was also researched and understood in the 19th century. [10] So there are many battery chemistries that have already been explored, and their advantages and disadvantages have been known for some time.

Fig. 2 compares the energy densities of a selection of battery chemistries (which is a zoom-in on the bottom-left of fig. 1). As can be seen, the choice of anode, cathode, and electrolyte heavily affects the performance of the battery. However, there is more to consider than just the performance.

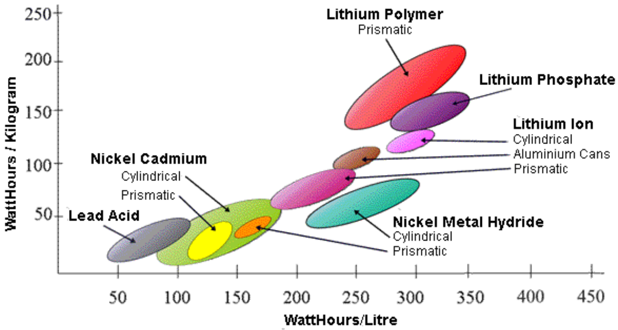

Fig. 2. Energy density comparison of a selection of battery chemistries [6]

For example, Gold (Au) has an electronegativity of of 2.4, and Caesium (Cs) of 0.7. This large difference would in theory produce a very energy dense battery. However, both chemicals are very expensive and rare, and Caesium is, to say the least, impractically deadly to handle in anything but a specialised facility. [11] [12]

3. UNLOCKING CHEMISTRIES WITH CELL PROTECTION TECHNOLOGY

So it is clear that some chemistries are unfavourable due to their cost and safety concerns. Consequently, battery chemistries like Lead-Acid, Alkaline (Zinc-Manganese-Dioxide) and Nickel-Cadmium have become the norm for most applications. However, some previously less popular chemistries have narrow operating regions in which they are safe and superior to these chemistries, but pose a hazard to people, equipment, and themselves outside of those regions.

For example, Lithium chemistries tend to catch fire when charged to discharged too much, an explode if used after short-circuiting (when the ion barrier wears away and the anode and cathode can close the circuit inside), whilst Nickel–metal hydride batteries produce pockets of hydrogen gas if overcharged or charged too quickly, which can explode. Meanwhile all batteries heat up when under heavy use, and these chemistries are capable of drawing enough current for enough time to get very hot and start a fire. [13] [14]

This has made them impractical in the past as the benefit of the added performance did not out-weight the hazards and replacement needs, or any attempt to add more cells than needed to mitigate any risk.

Circuitry and microcontroller technology has improved greatly over the last few decades, and this has allowed the for the taming of these battery chemistries, by designing physically small and lower power monitoring, management and protection systems. These monitor important parameters of the individual cells (such as voltage across the anode and cathode, and temperature) in real time and either use this information to manage the load on them, or to control a circuit breaker than disconnects any offending cells from the circuit and prevents them operating outside safe parameters.

This allows Nickel-Metal Hydride and the various Lithium chemistries to be used to their full capacities without risking going past their limits. The challenge then becomes a question of tuning the arrangement of the cells and the charge/discharge patterns of the application to squeeze as much performance as possible out of the system.

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