ISSN 2229-5518

Review on Battery Technology and its Challenges

Pruthvija B, Prof K P Lakshmi

Abstract— In the wake of 'SMART' everything, from gadgets to homes, power revolution is inevitable and around the corner. While chips and operating systems are becoming more efficient to save power it would still not be possible to meet the demand without advances in battery technology. Universities are looking at alternate materials, fabrication techniques and charging mechanisms to meet the power requirements. Several big technology and automobile companies have realized the limitations of Lithium ion batteries and are looking at new technologies. This paper, summarizes the challenges in two important aspects of battery technology namely types of batteries and battery health monitoring techniques.

Keywords— Battery Management System, Successive approximation Register, State of charge, State of Health, Monitor Control Unit, Engine Control Unit, Memory Sales effect.

1 INTRODUCTION

We are all witnessing a paradigm shift in the way we lead lives today. With automation overpowering all walks of life, we have an increased requirement for power generation and conservation. The functioning of smartphones, smart homes and smart gadgets are all limited by power. To meet the power demands, nano wire batteries that can withstand large number of charge recharge cycles, are seen as a replacement to solid state lithium ion batteries [1]. Nano wires possess high storage density of electrons, fast rate of diffusion and hence can also be used for operation involving high power sources like metros and other automotives [2]. Gold nano wires have been coated with manganese oxide and a gel type electrolyte to serve as safety protection layer. This electrolyte gel helps to bind the wires together and also helps to make the metal oxide smoother and breakage resistant resulting in large storage applications [3]. It is observed that silicon nano wire batteries find applications in wearable devices as they provide a flexible sources of energy. Apart from this it can used in bio medical applications, smart cards, and sensors in power remotes [4].

A company called Graphenano have come up with graphene batteries that can charge faster than Lithium ion batteries. Graphene batteries can sustain heat at high temperature and has higher efficiency of recharging. According to survey, from 2011 to 2015, the usage of portable devices has increased exponentially from 30% to 60% in US [5]. The electric vehicle manufacturing too is increasing as depicted in Fig. 1. During 2008, the Environment Protection Agency (EPA) of US launched a National Emission Standard to control the emission of poisonous gases during battery manufacturing process such as cadmium and lead [5]. The company says that these batteries can find applications in drones, cars and even at home [1]. Another group of researchers are looking at laser-made micro super capacitors which can charge 50 times faster and discharge ever slower than existing batteries. These super capacitors are a combination of battery and capacitor that can undergo multiple charge and discharge cycles without change in their characteristics. This has been possible due infusion of carbon materials during super capacitor electrode fabrication [6]. But these super capacitors weigh about 40% more than present day Li ion battery. To bring down the weight, researchers are looking at using carbon nano tubes and oxides of graphene as electrodes [7]. These techniques would also bring down the manufacturing costs and effort enormously [1].

- *Pruthvija B is currently a Research Scholar in Electronics and Communication engineering at BMS College of Engineering, India, PH-9483202713. E-mail: pruthvija94@gmail.com*
- *Prof. K P Lakshmi is currently Professor in Electronics and Communication engineering at BMS College of Engineering, India, PH-9740980902. E-mail: kpl.ece@bmsce.ac.in*

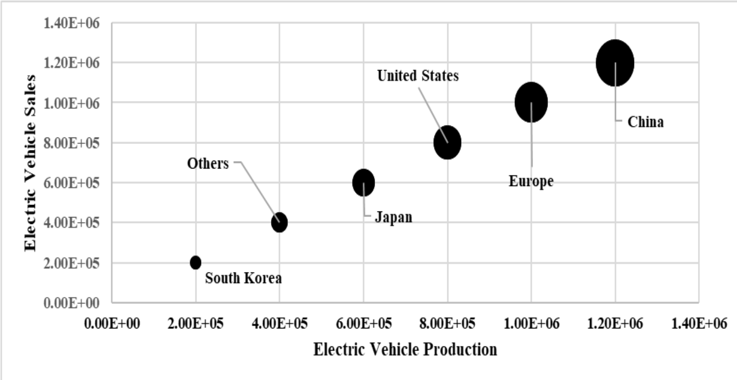

Fig. 1: Electric vehicles manufacturing in world from 2010

With the invention of electric vehicles, the demand for IC engine vehicles is decreasing slowly, and 2010 was called Year of Electric car [8]. According to International Energy Agency (IEA) studies, it is presumed that the number of electric vehicles on road will be reaching 2.5 million by 2020 [9]. Looking at the demands and improvement of electric vehicles, it is stated that the production of electric vehicles will increase rapidly and may reach out to about 100 million by 2050 [10]. Fig.2 depicts the increase in the number of manufacturing units over time from 2017 [12].

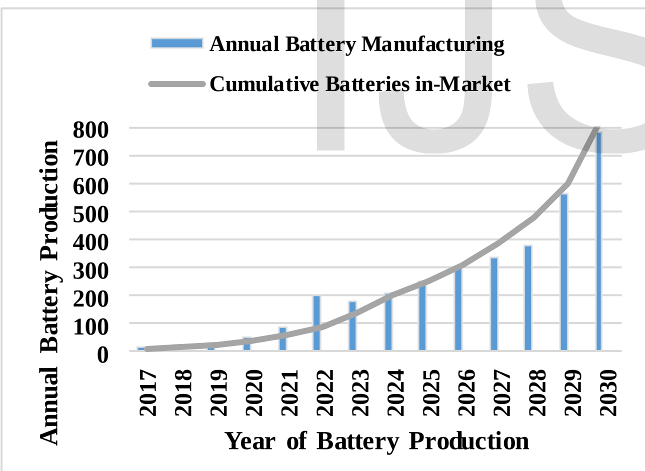

Fig. 2: Graph showing the increase in battery production

At present, the defined rechargeable batteries should be improvised for longer mobility and greater efficiency. Rechargeable battery technologies, like Pb-acid (lead acid), Ni-Cd and Ni-MH are used in various fields [13]. The usage is increasing over the last decade. In spite of their usefulness, the natural limitations of materials used to manufacture them, delay their application in extensive storage system. The main concern in using them is safety. However, low cost, long cycle life, high vitality efficiency and supportability are other concerns associated with their usage. When it comes to using batteries in automobiles, the other main issue is deployment of charging stations. Also, when a battery is no longer usable it should be recycled for preserving the ecosystem. Lead acid battery uses 85% of total lead available in world and its recycling is only about 60% of lead production [14].

Refurbishing and recycling of batteries may help in reduction of chemical waste and help us save the environment. For instance, the Pb acid and Ni-Cd batteries experience energy density restrictions when it comes to automotive applications. Ni-iron battery is challenged by poor cycling efficiency and self -discharge identified with erosion of iron anode.

Ni-MH batteries have higher density of energy while they exhibit poor temperature capacity. They can be safely operated around 200C only [15]. When these batteries are employed for applications that require more power, the functioning of the battery cannot be guaranteed as more power consumption results in an increase in power dissipation and hence in an increase in battery temperature. The increase in battery temperature might result in battery damage. Ni-MH battery are seen to be incapable of withstanding an increase in temperature even for short duration. Ni-MH batteries also exhibit poor coulombic efficiency which is the ratio of discharge rate to the charge rate of a battery for one full cycle [16]. Also the initial cost of Nickel –Metal Hydride battery are more compared to that of Ni-Cd batteries [17]. Apart from its disadvantages this battery seems to be ecofriendly since it does not contain any toxic elements and also Ni-MH is less cost compared to present Lithium-on batteries [18-19].

Lithium-ion battery (LIB) technology is relatively expensive because of material utilized, the cell outlining, producing procedure and assistant framework required for the task of making the battery. A major research area with respect to LIB is ability to draw more electrons i.e., more power (in case of electric vehicles) from the battery at its standard rate ability [20]. Batteries with different energy density is as shown in Table I.

While working with any rechargeable battery, necessary precautions should be taken to avoid short circuit during chemical reaction between natural electrolyte and electrodes inside the battery. Considering all these short comings of existing batteries, a novel battery has to be developed which can be operated safely, maintained easily and is eco-friendly.

In addition to research in the study of alternate materials/combination of materials, innovations in designing a device that monitors the health of the battery is also of importance. A Battery Management System (BMS) device is required to ensure the working of battery as per designed specifications. Going forward, these devices also need to keep track of the amount of battery degradation and to guarantee safety of the battery and its users. In Fig. 3 shows that the energy density of phone batteries is increased by 7 times when compared over 7 years [21, 22].

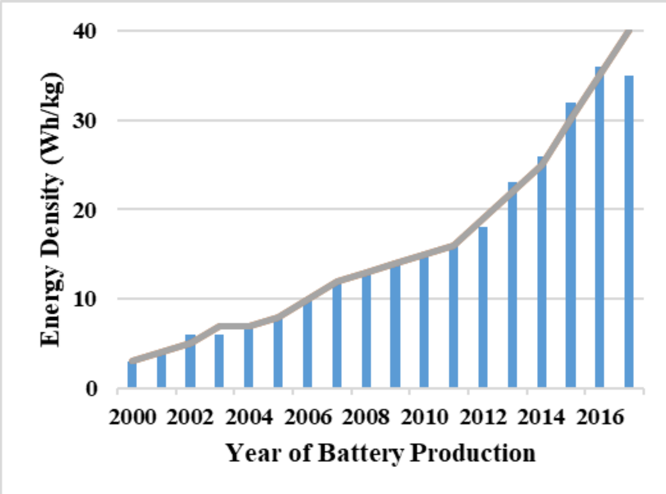

Fig. 3: Energy density of phone battery versus year

Table (a): Comparison of specifications of various batteries

Specifications / Batteries	Lead-acid	Ni-MH	Li-ion	Ultra-Capacitor
Energy density (Whr/kg)	40	70	110	5
Number of Charge and Discharge cycles	500	800	1000	500000
Working temperature (°C)	-300 to +500	-400 to +500	-400 to +600	-400 to +850

TYPES OF BATTERIES

2.1 LEAD ACID: The primary functional outline of lead acid battery was created by Gaston plante in 1860 and since then, improvements and developments have been happening to cater to the demands of time. Car batteries have incorporated significant innovations made in lead acid battery technology. The greater part of overall generation of lead goes into batteries. At present, lead acid battery has a positive cathode of lead peroxide (PbO2) and a negative terminal of lead (Pb). Electrolyte is sulphuric corrosive arrangement with particular gravity in range 2.12 to 1.30 (28% to 39% by weight) [23].

Limitations:

1. In lead-acid battery, the sulphuric acid (36%) and water (64%) are typically used as electrolyte. During battery recharge, hydrogen gases from these electrolyte vaporizes and causes highly flammable gases which are hazardous [24].
2. The electrode plates dipped inside the electrode increases the weight of battery which weighs for about 30 to 60 pounds on an average [24].

2.2 NICKEL CADMIUM: The main Ni– Cd battery was first made by Waldemar Jungner of Sweden in 1899.

Nickel-cadmium battery is typically composed of Nickel hydroxide as positive electrode and Cadmium hydroxide as negative electrode dipped in potassium hydroxide where alkaline electrolyte was first used [25].

Limitations:

1. Ni-Cd battery is hazardous since it contains toxic metal (Cadmium) which may cause problem during battery disposal. Because of this reason, these material combination is restricted in many countries.
2. For charging Ni-Cd battery it is imperative to use high voltage charger which in turn warrants high investments.
3. It is difficult to estimate the behavior of the battery.
4. These batteries exhibit memory effect especially while recharging the battery when the charge is still above the minimum. This leads to catastrophe with respect to battery capacity.

2.3 LITHIUM ION: Lithium batteries were proposed by M Stanley Whittingham, a British Scientist at Binghamton University, while working for Exxon in the 1970s [26]. He considered titanium sulphide and lithium metal for anodes. In the current day Li ion batteries, the positive electrode consists of metal oxide and the negative electrode is Carbon with lithium salt as the electrolyte [27].

Limitations:

1. Manufacturing cost is high and it compulsorily requires monitoring circuits to operate the battery in safety conditions.
2. Susceptible to high temperature when battery is overcharged and due to overheat.
3. The efficiency decreases after certain charge-discharge cycles. The battery loses its efficiency even while the battery is not in use.
4. Even though Lithium ion battery has less self-discharging rate, when it crosses its lower voltage limit, it causes deep discharge and renders the battery unusable.
5. Over-charging or over-heating may cause battery to explode because internal pressure due to electrolyte decomposition forms gases which lead to swelling and may even catch fire.

Table (b) and Table (c) depict a comparison of various car manufacturing company using Li-ion and other batteries with their capacity and power generated [28,29]. From the comparison it is clear that Li ion has better performance attributes.

Table (b): Comparison of capacity and power of Lithium-Ion battery used in various cars

Car Models	Capacity (kWh)	Power (kW/CP)
Renault Twizzy	6.1	4/5
Hyundai Ioniq	28	88/118
Nissan Leaf	30	80/107
Volkswagen E-Golf	24.2	100/136
Tesla Model S	100	193/259

Table (c): Types of Batteries in electric vehicles

Battery	Nominal Voltage (V)	Rated Capacity (Ah)
Lead acid	6	235
Ni-Cd	6	180
NiMH	201.6	6.5
Li-ion	360	33.1

3 BATTERY MANAGEMENT SYSTEM

Battery Management System is any electronic frame that deals with shielding of battery from working outside its safe operating area, monitoring its state by processing received data from the sensors, control its condition, verifying it and/or adjusting it [30].

To guarantee the safety of battery operated devices, BMS is as important as the selection of materials for manufacturing batteries. In areas like automotive industry, they ensure that the components are protected, dependable and efficient. BMS not just controls the operating conditions such as current, voltage and power of the battery to enhance its life but also precisely estimates the State of Charge (SOC) and State of Health (SOH) for smart application [31].

In case of Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV), the unpredictable behavior of battery would lead to catastrophe if a monitoring system is not included. From the safety point of view, at all unusual conditions the BMS should alert the user and perform necessary corrective action.

Adding to this function, the BMS should also monitor the temperature of the coolant surrounding the battery pack in case of an automotive system. This helps in efficient distribution of power to all individual components.

Some of the functions that BMS should include are:

1. Data procurement from various sensors regarding voltage, current and temperature.
2. Ensure safe working conditions of the battery
3. Estimate the status of battery
4. Capacity to control the charge of battery
5. Perform cell balancing
6. Perform thermal management
7. Communicate between various battery components
8. Convey battery status to appropriate controllers

In order to perform the above functions, some of the important parameters to monitor are:

3.1 State of Charge (SOC): State of charge refers to the amount charge in a battery. The estimations of SOC can add to the performance of BMS and its dependability. Battery charge and discharge cycles involve release of complex substances like arsine in case of lead-acid batteries, Cadmium in case of Nickel-Cadmium batteries, Fluoride gas in case of Lithium-ion batteries, and their estimation is difficult to make. It is therefore difficult to appraise the SOC precisely under different operational conditions [32]. There are a few sorts of LIBs in the market, for example, those containing $LiFeO_4$, lithium polymers and $LiCoO_2$ that involve high emission of power from the battery and possess complex topology of battery cells where SOC calculations requires time.

There have been numerous advancement and research works of late to enhance SOC estimation exactness. Some of the standard estimation approaches are

1. Coulomb-counting or ampere-hour (Ah) technique
2. Open-circuit voltage (OCV) method and
3. Impedance estimation strategy

All the above gives a more natural and dependable estimation. The efficiency of all these techniques are limited by the correctness of sensors used to estimate the amount of current flow per unit time.

In techniques that utilize machine learning-based estimation (additionally called data driven methodologies, for example, the artificial neural network– fuzzy logic (FL)) [33] and support vector machine strategies, a high computational effort is required. This is because they require extensive datasets to be built to model the nonlinear behavior of a battery. Moreover, most machine learning-based SOC estimation models is not being considered due to high initial cost. Apart from the above mentioned techniques, the state-space display based estimation strategies, (for example, utilizing the Extended Kalman Filter channel (EKF)) are being considered which decrease the computational time and increase the accuracy in the estimation of SOC [34].

3.2 State of Health (SOH): State of Health refers to overall status of a battery. Important factor that limits the SOH of a battery are aging and charging cycles. Considering an example, the SOH of a normal Li-ion battery is reduced to

80% after 1000 charge cycles [35]. The general equation for SoH is given as

$$SOH = \frac{Nominal\ Capacity - Capacity\ Loss}{Nominal\ Capacity}$$

Estimation of SOH using alternating current method generally requires hardware component which is expensive. Another method for SOH estimation with no hardware requirements may consumes time to monitor complete charge and discharge of a battery [36].

Genetic algorithm technique is one of the cost effective method to estimate both SOC and SOH with less number of sensors within a short duration. The Genetic algorithm technique considers the terminal voltage of the battery and current of the battery for the process. And this SOH estimation can be done while battery is in use [37].

3.3 Voltage Measurement: Estimation of on-cells voltage (when battery is in use) is an imperative and troublesome part in any battery especially in Li-ion batteries. Observing every cells' voltage that is testing of every cells' voltage with respect to a common reference using a voltmeter for a battery that is deployed in an equipment or an automobile is tedious and extremely difficult. Hence the above conventional method is no longer preferred. Each Li-ion battery is made up of as many as one hundred cells with each Li-ion cells' safe operating voltage is 2.7V~4.2V and the aggregate voltage of a unit battery can be up to 420V.It is therefore difficult to estimate on-cells voltage directly by typical estimation strategies (Voltmeter testing).

Two varieties of ICs are manufactured for voltage measurement: one for high voltages (4.2V) that finds application in automobiles, etc. and one for low voltage measurement (2.4V) [38] that can be used in hand held gadgets like mobile phones, etc. An Integrated Chip (IC) manufacturer should guarantee that the high voltage gadget will be shielded from temporary effects such as memory effect, voltage surges. Ensuring this raises the cost of the gadget. While other IC manufacturers focus on low voltage devices so that it should not cross the lower voltage limit rate. This technique includes hardware such as capacitors, resistors and diodes to lower the incoming voltage before reaching the components. A high voltage monitoring IC ensures better safety whereas lower voltage monitoring IC may require more improvement to guarantee proper working even under unsafe condition. Estimating of cell voltage depends on the amount of voltage being conducted and also the number of cells to examine. Usually a Successive Approximation Register (SAR) type Analog to Digital convertor (ADC) is frequently used to monitor the battery voltage in a specific time [39]. A SAR ADC exhibits more controlling efficiency over higher voltage flow and has less calculations involved

3.4 Temperature monitoring: Thermistors are normally used to monitor battery's temperature. The temperature information from thermistor is often read out of an ADC. Temperature sensors screen every cell of any energy storage system (ESS) like power banks or a gathering of cells in case of small batteries used in versatile applications.

Since the chemical composition used to develop a battery is unpredictable, also a battery with repeated current spike can result in the battery touch off.

Temperature estimations are not only restricted to monitor the temperature but also to decide whether it is safe to charge or to discharge [40]. A coolant is circulated around the battery pack to maintain the temperature of the cells within safe limits.

3.5 Current measurement: Current is the rate of flow of charged particles called electrons and a current measurement system monitors the charge entering and leaving the battery pack. There are various techniques that are adopted for current measurement. The prominent ones are:

1. A typical setup to measure current consists of a current sense amplifier connected to a Monitor Control Unit (MCU) with an integrated low resolution ADC. But the current sense amplifier IC for current measurement is expensive.

2. A high resolution ADC is also used for current estimation. If battery is associated with a heavy load, for example, an electric vehicle, the moderate ADC sometime neglect the concurrent current spikes that are conveyed to IC during voltage/current fluctuations from the main source. For avoiding this, a SAR ADC with a current sense amplifier front end is used [41]. If load connected to a battery changes, it causes a general mistake while measuring battery charge. Estimating these errors after some time will cause battery pack charge status error. With most current estimation blocks, there are analog comparators such as Field Effect transistors (FET) is used to cut off the current above conditions which leads to battery or equipment damage. These FET drivers isolate the battery from the charger or load during any fault. An average a few microseconds is required for current measuring device, and in many applications it helps to detach the battery or the charger [42].

3.6 Cell balancing: A battery pack consists of many cells in it and all these cells are not alike. The differences in battery could arise during manufacturing process or during working conditions. Slight differences in capacities or self-discharge rates or internal resistances could also lead to variation of cell performance in operation. Uneven temperature distribution in battery bank could also lead to variations in performance [43]. Cell balancing is therefore necessary to extend the life of battery pack and to ensure safe operation. Cell balancing is a technology that distributes large amounts of energy between cells, for the efficient use of available energy in a battery. Cell Balancing can be:

- Dissipative or passive or active: Removing of voltage from most charged cell.
- Non dissipative: Distribution of energy between cells and thus there will be no wastage of energy.

The disadvantages of dissipative balancing are:

1. Energy is wasted from most charged cells.
2. The cells may get affected due to removal of extra energy from a most charged cell that is generated during balancing of high current.

The disadvantages of non-dissipative balancing are:

1. Expensive due to its dynamic operation and also less reliable.
2. During stand-by condition of current, Power might be wasted to a greater extent when compared to dissipative balancing technique.

Irrespective of the balancing technique (active or passive), the balancing process is based on one of the following algorithms:

- Voltage based cell balancing
- Final voltage based cell balancing
- Cell balancing based on SOC history

Cell balancing based on Voltage method is a very simple technique in which balancing of cells is done during charging of a battery to equalizes the cell voltage, while SOC is not considered.

But when load is connected, the internal resistance of the cell varies from one cell to another, where the voltage based cell balancing might be difficult.

In Final Voltage Based method or one end cell balancing, the principle operation involves balancing of cells either when during charge of a cell is full or empty. This technique effectively helps in the estimation of SOC.

Sometimes, when the battery in nearer to full charge (for ex 98 or 99%), the source may be disconnected, at that instant, the time required for cell balancing will be less, and final voltage based cell balancing might become problematic [44]. In SOC based cell balancing method, the prime operation involves balancing of the cell at any point of time. This helps SOC measurement considering history of each and every cell voltage. This technique can be used irrespective of the amount of charge in cells (high or low). However, the disadvantage of this method is the requirement of previous history of the cells for estimating SOC which requires a lot of memory operations.

3.7 Thermal management: The thermal management involves monitoring and controlling of battery temperature to ensure that the battery is not damaged by high or low temperature. Unlike SOC and SOH that depend on more than one parameter for their estimation, temperature estimation solely depends on measurement of individual cell temperature [45].

Thermal management is done by controlling a fan or an electric warmer, as required, which helps to keep the temperature of the battery under ideal conditions. A thermal management equipment estimates the battery temperature by thermal sensor/s and performs cooling or warming task, and sends a crisis flag to Control Unit about its variation.

Ongoing Research on Batteries and Battery management System:

1. In one research, a unique BMS is being designed that gets the data from various sensors about battery health, processes it and stores the information about every cell. This real time data of cell performance is periodically transmitted through wireless mechanisms [46].
2. In yet another research [47] battery charging process is also monitored in addition to battery health status while storing data regarding charge, analyzing it and reporting with a software controlling for present individual cell connections is also performed.
3. To enhance the battery safety of lithium ion, a new combination of solid metal batteries with LLZO (Garnet type) electrolyte is being considered. This also offers fast charging of battery and better efficiency [48].

Researchers are also looking at an intelligent battery management which consists of multiple charger for charging individual columns of a battery for better efficiency.

Conclusion

New material combination for realizing batteries with good characteristics coupled with advanced BMS will help the user to operate their device safely. Batteries have to be dependable and reliable at any environmental or all working condition. A novel battery with less harmful substances possessing good energy density, low memory effect and less susceptible to pressure or temperature variations has to be developed. An attempt is made in this review to survey the current popular battery technologies and to highlight their limitations. This could serve as a precursor to further research.

Also, an efficient, reliable BMS that includes all the necessary blocks to protect the battery and its associated system/s by continuously monitoring the system current, voltage, temperature etc. is to be developed. Fault diagnosis and display systems with some amount of automatic fault correction mechanism is also the need of the hour. An optimum BMS would shield both user and equipment any harmful effects. In the latter part of the paper we have tried to list the various techniques used in a battery management system to monitor various battery parameters and also compiled the disadvantages of the techniques. We conclude by stating that realization of a smart world is dependent and limited to advances in battery technology.

REFERENCES

[1] Max Langridge and Luke Edwards, "Future batteries, coming soon: Charge in seconds, last months and power over the air", July 2018.

[2] Nic Lutsey, Mikhail Grant, Sandra Wappelhorst, Huan Zhou, "Power Play: How Governments are Spurring the Electric Vehicle Industry," International Council on Clean Transportation, White paper, 2018.

[3] Candace K. Chan, Stephen T. Connor, Yuan Yang, Ching-Mei Hsu, Robert A. Huggins, and Yi Cui, "Nanowire Batteries for Next Generation Electronics," 2008.

[4] Dave Gershgorn, https://www.popsci.com/researchers-accidentally-make-batteries-last-400-times-longer, By April 22, 2016.

[5] Nanowire Battery Tutorial, https://www.mepits.com/tutorial/479/latest-technologies/nanowire-battery.

[6] URL: https://www.designingbuildings.co.uk/wiki/Graphene_batteries

[7] Namdar M, Asl S H, "Flexible Micro Supercapacitor Based on Laser Scribed Graphene (LSG)," Journal of Nanoscience and Nanotechnology Applications, ISSN 2577-7920, 7 March 2018.

[8] develop-micro-supercapacitors-for-miniature-digital-devices-4728611.html. 12 July 2018.

[9] Nic Lutsey, Mikhail Grant, Sandra Wappelhorst, Huan Zhou, "Power Play: How Governments are Spurring the Electric Vehicle Industry," International Council on Clean Transportation, White paper, 2018.

[10] URL: http://www.mandatory.com/fun/131790-top-5-disadvantages-of-electric-vehicles

[11] S. Schlegel and D. Westermann, "Energy storage capability of battery electric vehicles," IEEE Power & Energy Society General Meeting, Vancouver, BC, pp. 1-5. doi: 10.1109/PESMG.2013.6672507, 2013.

[12] Technology Roadmap – Electric Vehicles and plug-in hybrid electric vehicles. Report 2011.

[13] Kularatna, Nihal. "Rechargeable Batteries and Their Management. Instrumentation & Measurement Magazine", IEEE. 14. 20 - 33. 10.1109/MIM.2011.5735252, 2011.

[14] Geoffrey J. Maya, *, Alistair Davidsonb, Boris Monahovc, "Lead batteries for utility energy storage: A review", Journal of Energy Storage 15-145–157, 2018.

[15] www.epectec.com/batteries/cell-comparision.html. 2011

[16] Jilei Liu a, Chaohe Xu b, Zhen Chen a, Shibing Ni c, Ze Xiang Shen, "Progress in aqueous rechargeable batteries," Advanced Research evolving science, 2468-0257. October 2017.

[17] J. A. McDowall, "Substation battery options: present and future," in IEEE Power Engineering Review, vol. 20, no. 11, pp. 4-7,. doi: 10.1109/39.883279, Nov. 2000

[18] Syed Murtaza Ali Shah Bukhari, Junaid Maqsood, "Comparison of Characteristics - Lead Acid, Nickel Based, Lead Crystal and Lithium Based Batteries," 17th UKSIM-AMSS International Conference on Modelling and Simulation, DOI 10.1109/UKSim.2015.69, 2015.

[19] URL: https://smartgrid.ieee.org/images/files/pdf/battery_storage_whitepaper.pdf,

[20] X. Chen, W. Shen, T, Z. Cao and A. Kapoor, "An overview of lithium-ion batteries for electric vehicles," 10th International Power & Energy Conference (IPEC), Ho Chi Minh City, pp. 230-235. doi: 10.1109/ASSCC.2012.6523269, 2012.

[21] Kellen, Barry P, "Lead acid battery Manufacture," Encyclopedia of Occupational Health and Safety, March 2011. http://www.iloencyclopaedia.org/component/k2/item/661-lead-acid-battery-manufacture.

[22] URL: https://www.gsmarena.com/counterclockwise_phone_batteries-news-28202.php

[23] Cheng, K.W.E.. "Recent development on electric vehicles," 3rd International Conference on Power Electronics Systems and Applications, PESA. 1 – 5, 2009

[24] P. G. Horkos, E. Yammine and N. Karami, "Review on different charging techniques of lead-acid batteries," 2015 Third International Conference on Technological Advances in Electrical, Electronics and Computer Engineering (TAEECE), Beirut, pp. 27-32. doi: 10.1109/TAEECE.2015.7113595, 2015.

[25] M. Caruso, "Nanostructured lead acid battery for electric vehicles applications," 2017 International Conference of Electrical and Electronic Technologies for Automotive, Torino, pp. 1-5. doi: 10.23919/EETA.2017.7993216, 2017.

[26] David Sandoval, "Disadvantages of Lead acid battery", https://itstillruns.com/disadvantages-lead-acid-batteries-8158723.html.

[27] Pani, "Nickel Cadmium battery," https://electronicspani.com/nickel-cadmium-battery/ June 2014.

[28] Jiajun Chen, "Recent Progress in Advanced Materials for Lithium Ion Batteries," ISSN 1996-1944, January 2013.

[29] Da Deng, "Li-ion batteries: basics, progress, and challenges," Energy Science and Engineering 2015; 3(5):385–418, doi: 10.1002/ese3.95, August 2015.

[30] Tatsuo Horiba, "Lithium-Ion Battery Systems," Digital Object Identifier: 10.1109/JPROC.2014.2319832, 2014.

[31] Li Yamei, Zhen Liping, "Battery Management System," International Conference on Measuring Technology and Mechatronics Automation, 978-0-7695-3962-1/10, 2010 https://batteryuniversity.com/learn/article/how_to_monitor_a_battery.

[32] H. F. Gibbard, "Nickel metal hydride battery technology," Proceedings of WESCON '93, San Francisco, CA, USA, 1993, pp. 215-219. doi: 10.1109/WESCON, 488437, 1993.

[33] Mark Verbrugge, Edward Tate, "Adaptive state of charge algorithm for nickel metal hydride batteries including hysteresis phenomena," Journal of Power sources, Volume 126, Issues 1-2, pp 236-249, February 2004.

[34] Anirban Mukherjee, "Advances in Battery Management Using Neural Networks and Fuzzy Logic" School of Electrical and Computer Engineering, Cornell University, Ithaca, 2013.

[35] Sunghun Jung 1 and Heon Jeong , "Extended Kalman Filter-Based State of Charge and sate of Power Estimation Algorithm for Unmanned Aerial Vehicle Li-Po Battery Packs ," Energies 2017, 10, 1237; doi: 10.3390/en10081237 August 2017.

[36] Weng, Caihao & Feng, Xuning & Sun, Jing & Peng, Huei. "State-of-health monitoring of lithium-ion battery modules and packs via incremental capacity peak tracking," Applied Energy. 180. 360-368. 10.1016/j.ap energy...07.126, 2016.

[37] Zhenpo Wang, Jun Ma, And Lei Zhang, "State-of-Health Estimation for Lithium-Ion Batteries Based on the Multi-Island Genetic Algorithm and the Gaussian Process Regression," IEEE Access, Digital Object Identifier 10.1109/ACCESS.2017.2759094, 2017.

[38] Battery Management System Tutorial. 2013.

[39] Dante Gabriel Muratore, "A Study of Successive Approximation Register ADC Architectures," Ph.D. Thesis, 2017.

[40] Oleksandr Karpin,"Sensing-Thermistor-Based Temperature Measurement in Battery Packs," Cypress Perform, July 2013.

[41] Stefan Dietrich, Sebastian Strache, Jan Henning Mueller, Lukas Lohaus, Ralf Wunderlich, and Stefan Heinen, "A Low Power High-Side Current Sense SAR ADC for Automotive Applications," Integrated Analog Circuits & RF Systems Laboratory, 2010.

[42] Scott Hill, "Integrating the Current Sensing Resistor," July 2018.

[43] Jian Qi, "Review of Battery Cell Balancing Techniques," Australasian Universities Power Engineering Conference, AUPEC 2014, Curtin University, Perth, Australia, 28 September – 1 October 2014.

[44] http://liionbms.com/php/wp_passive_active_balancing.php white paper, 2013.

[45] Ahmad A. Pesaran, "Battery Thermal Management in EVs and HEVs: Issues and Solutions," Advanced Automotive Battery Conference, Las Vegas, Nevada, http://liionbms.com/php/wp_passive_active_balancing.php, February 6-8, 2001.

[46] URL: www.dukosi.com/news/dukosi-lands-2-million-for-next-generation-battery-management-technology/ August 2018.

[47] BCMS-PRO Scalable Battery Charger and Management System with Data Storage, Analysis and Reporting, https://www.batterypoweronline.com/view-press, August 2018.

[48] Shicheng Yu, Andreas Mertens, Hermann Tempel, Roland Schierholz, Hans Kungl, Rüdiger-A. Eichel. "Monolithic All-Phosphate Solid-State Lithium-Ion Battery with Improved Interfacial Compatibility." ACS Applied Materials & Interfaces, 10 (26): 22264 DOI: 10.1021/acsami.8b05902, 2018.