COMPARISON ON STUDY OF LITHIUM ION & LEAD ACID CHARGING & DISCHARGING CHARACTERISTICS

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ABSTRACT:-

A lithium-ion or Li-ion battery is a type of rechargeable battery which uses the reversible reduction of lithium ions to store energy. It is the predominant battery type used in portable consumer electronics and electric vehicles.

Energy density: 250–693 Wh/L (0.90–2.49 MJ/L)
Specific energy: 100–265 Wh/kg (0.360–0.954 MJ/kg)
Charge/discharge efficiency: 80–90%
Cycle durability: 400–1,200 cycles
Self-discharge rate: 0.35% to 2.5% per month depending on state of charge
Specific power: c. 250–340 W/kg

Lithium batteries, as opposed to alkaline, are capable of giving off a strong energy surge after a long period of low discharge. This makes them ideal for fire alarms. Alkaline batteries provide good, long-term power, but they lose strength over time.

On the other side , the Lead acid battery are **inexpensive compared to newer technologies**, lead–acid batteries are widely used even when surge current is not important and other designs could provide higher energy densities.

Energy density: 80–90 Wh/L
Nominal cell voltage: 2.1 V
Self-discharge rate: 3%–20%/month
Specific energy: 35–40 Wh/kg
Charge temperature interval: Min. −35°C, max. 45°C
Charge/discharge efficiency: 50%–95%
Cycle durability: <350 cycle

In order to observe the characteristic nature of Lead acid & Lithium ion battery , a review is made on the subject using Matlab Simulink and Simscape.

1. INTRODUCTION:-

1.1 DETAILS OF LITHIUM ION BATTERY:-

Li Ion Battery Reaction:-

In the Li-Ion battery, both the electrodes can accept and release lithium ions. During the Intercalation process, the lithium ions move into the electrode. During the reverse process called de intercalation, the lithium ions move back. During discharging, the positive lithium ions will be extracted from the negative electrodes and inserted into the positive electrode. During the charging process, the reverse movement of lithium ions takes place.

Lithium cells are classified into two categories:

a) Lithium cells with solid cathodes
b) Lithium cells with liquid cathodes

a) Lithium cells with solid cathode:
Anode: Lithium metal
Cathode: MnO2 as an active material
Electrolyte: LiBF4 salt in a solution of propylene carbonate and dimethoxy ethane.
Net reaction: Li + MnO2 → Li MnO2
Reactions:
At Anode : Li → Li+ +e-
At Cathode : e-+ MnO2 → MnO2

Net reaction: Li + MnO2 → Li MnO2

(b) Lithium cells with Liquid cathode:
Cell reaction: 2Li + 2SO2 → LiS2O4

1.2 DETAILS OF LEAD ACID BATTERY CHEMICAL REACTION:- The chemical reaction in the battery occurs primarily during the discharging and recharging processes, and it is described as follows: When the battery is fully charged, the anode and cathode are PbO2 and Pb, respectively. As these are associated with resistance, the battery is discharged, and the electrons are charged in the opposite direction. The H2 ions pass into the anode and fuse together to form an atom. It reacts with PbO2 to produce PbSO4, which is white in color. Similar to the sulfate ion, the sulfate ion moves into the cathode, where it is converted into SO4. It becomes lead sulfate as it reacts with the lead cathode.

PbSO4 + 2H = PbO + H2O
PbO + H2SO4 = PbSO4 + 2H2O
PbO2 + H2SO4 + 2H = PbSO4 + 2H2O

The cathode and anodes are connected to the negative and positive edges of the DC supply during the recharging process. The positive H2 ions pass into the cathode, gaining two electrons and becoming an H2 atom. It forms lead and sulphuric acid after a chemical reaction with lead sulfate.

1.3 BATTERY LIFE:- LITHIUM ION BATTERY LIFE:- Lithium ion batteries can handle hundreds of charge/discharge cycles or between two and three years.

LEAD ACID BATTERY LIFE :- The optimum operating temperature for a lead acid battery is 250 degrees Celsius, or 770 degrees Fahrenheit. Longevity is shortened as the temperature spectrum widens. According to the law, any 80°C rise in temperature decreases the battery's half-life. A performance-operated battery with a 250C operating temperature has a lead acid battery life of ten years. And it only has a 5-year life span when maintained at 330 degrees Celsius.

1.4.ADVANTAGES OF BATTERY:-

Advantages of Lithium – Ion Battery:-

1. Light weight compared to other batteries of similar size
2. Available in different shape including Flat shape
3. High open circuit voltage that increases the power transfer at low current
4. Very low self-discharge rate of 5-10% per month. Self-discharge is around 30% in NiCd and NiMh batteries.
5. Eco-friendly battery without any free lithium metal .

Advantages of lead acid battery:-
Advantages
1. Inexpensive and simple to manufacture.
2. Mature, reliable and well-understood technology - when used correctly, lead-acid is durable and provides dependable service.
3. The self-discharge is among the lowest of rechargeable battery systems.
4. Capable of high discharge rates.

1.5 DISADVANTAGES
Disadvantages of Li-Ion Battery:

1. The deposits inside the electrolyte over time will inhibit the flow of charge. This increases the internal resistance of the battery and the cell's capacity to deliver current gradually decreases.
2. High charging and high temperature may leads to capacity loss .When overheated, Li-Ion battery may suffer thermal run away and cell rupture.

Disadvantages of Lead acid battery

Use of Conc.H2SO4 is dangerous and use of lead battery is fragile.

1.6 APPLICATIONS :-LITHIUM ION BATTERY
Lithium Ion batteries find a massive range of applications right from smart watches to renewable energy storage systems to electric vehicles. The upcoming innovations in Lithium Ion batteries include factors which can help the battery tolerate fast charging, offer higher capacity and increased safety.

LEAD ACID BATTERY:- These batteries are widely used in portable consumer electronics, automotive batteries, uninterruptible power supplies, electric vehicles and grid energy storage.

1.7 MATLAB:

Matlab is a high-level language with interactive environment which enables to performing computationally intensive tasks faster than with traditional programming languages such as C , C++ and FORTRAIN. It has various components to support simulation of various complex electrical and power electronics systems.

Simulink: Simulink is a platform for multidomain simulation and Model-Based Design for dynamic systems . It provides an interactive graphical environment and a customizable set of block libraries and can be extended for specialized applications. Simulink library Information inserts a table that lists library links in the current model, system, or block.

Simscape:

Simulink is a graphical programming environment for modelling, simulating and analysis of dynamic systems where as Simscape is a Physical modelling part in simulink environment. It extends Simulink with tools for modelling and simulating basic electrical circuits and detailed electrical power systems. These tools facilitate modelling of the generation, Transmission, distribution, and consumption of electrical power, as well as its conversion into mechanical power. Sim Power System is well suited for the development of complex, self-contained power systems and power utility applications.

1.8 Battery Performance Parameters:-

The Performance Parameters of Battery are SOC(State of Charge),Depth of Discharge and Charging and Discharging rates .

1.8.1 SOC: - It gives the ratio of the amount of energy presently stored in the battery to the

Nominal rated capacity. It is the fraction of the battery capacity that has been used over the total available from the battery.

1.8.2 Depth of Discharge: - The Depth of Discharge of a battery determines the fraction of power that can be withdrawn from the battery.

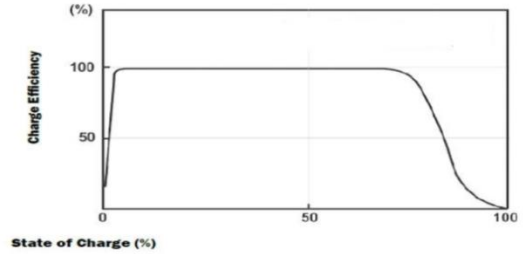


Figure 1.1 :- Graph between State of charge and charge Efficiency

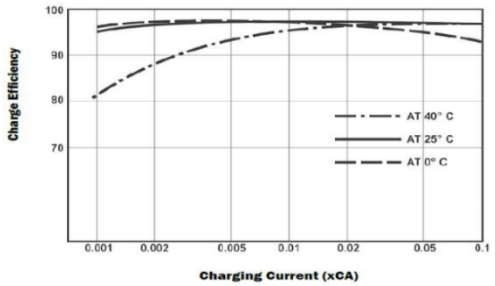


Figure 1.2:- Graph between Charging current & ChargeEfficiency

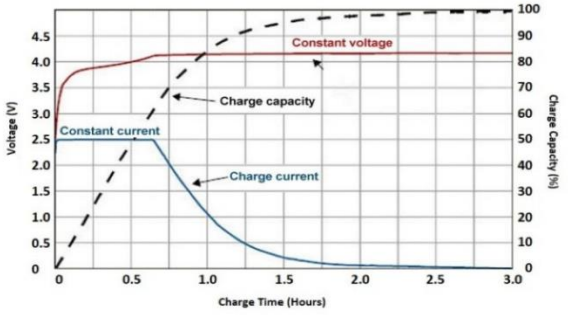


Figure 1.3:- Charge curve of Lithium –Ion Battery

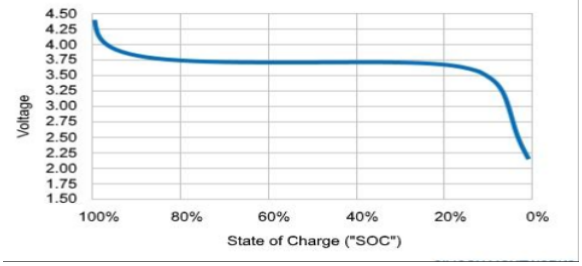


Figure 1.4:- Discharge curve of Lithium–Ion Battery

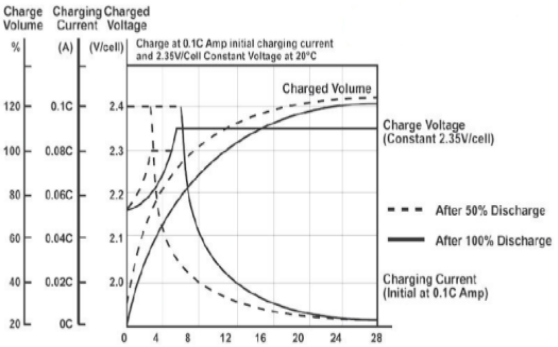


Figure 1.5:-Lead Acid battery charge characteristics taking case that charging is non continuous and peak voltage higher.

2. PROBLEM STATEMENT-

To observe the SOC and charging current of Lead acid & Lithium-ion battery with different loads using Matlab Simulink and Simscape.

OBJECTIVE–

1. Identifying time duration while charging different batteries separately and in different combination.
2. Identifying variation in charging current characteristics of different batteries.
3. Design and develop the circuit for display of SOC and charging current for different varying loads through simulation.
4. Experimentation and validation of results.
5. Analysis of results.

3. SEPARATE LITHIUM ION & LEAD BATTERY CHARGING:

Circuit diagram of Lead Acid & Lithium ion battery charging separate is shown in figure and design parameters are also shown below .Simulation results are shown both in display and waveform basis.

. DC Voltage Source = 12 Volt
. Battery nominal voltage:- 7.2 volt
. Rated capacity:- 55 Ah
. Initial state of charge:- 45%
. Battery response time:- 30 seconds

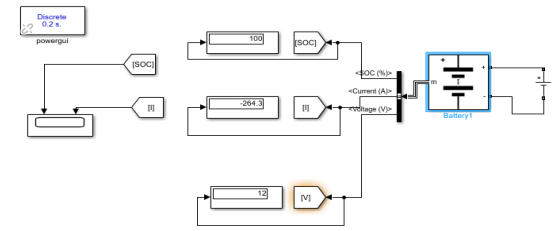


Figure 3.1 :- CIRCUIT DIAGRAM OF BATTERY CHARGING FOR 425 SECONDS

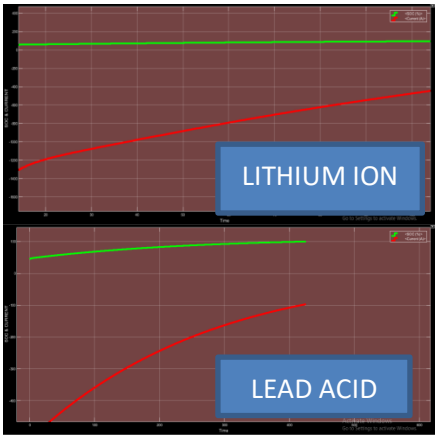


Figure 3.2:- SOC & CURRENT WAVEFORM OF BATTERY CHARGING FOR 425 SECONDS

ANALYSIS:-

ANALYSIS OF LEAD ACID BATTERY CHARGING :-

Initially the SOC & nominal voltage of Lead Acid battery taken as 45% and 7.2 volt . The SOC reaches to 100% and charging current becomes -96.81 mille Ampere within a period of 425 seconds .The charging current was more initially and reduced by time i.e with 24 volt DC source for charging lead acid battery of initial voltage of 7.2 volt , the charging current reduces exponentially .

ANALYSIS OF LITHIUM ION BATTERY CHARGING :-

Initially the SOC & nominal voltage of Lithium Ion battery taken as 45% and 7.2 volt . The SOC reaches to 100% and charging current becomes -264.3 mille Ampere within a period of 425 seconds .The charging current was more initially and reduced by time i.e. with 24 volt DC source for charging lead acid battery of initial voltage of 7.2 volt , the charging current reduces somewhat linearly.

4.SEPARATE SERIES CHARGING OF LITHIUM ION & LEAD ACID BATTERIES:-

Circuit diagram of Lithium ion series & Lead Acid battery series charging separate is shown in figure and design parameters are also shown below .Simulation results are shown both in display and waveform basis.

. DC Voltage Source = 30 Volt
. Battery nominal voltages:- 7.2 volt
. Rated capacity:- 55 Ah
. Initial state of charge:- 45%
. Battery response time:- 30 seconds

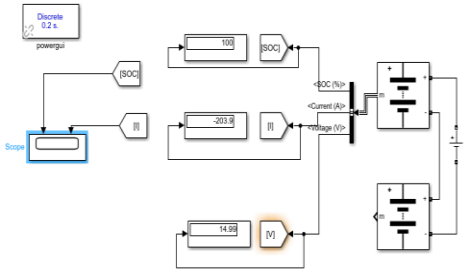


Figure 4.1:-CIRCUIT DIAGRAM OF BATTERY CONNECTED IN SERIES WITH LITHIUM ION BATTERY FOR 1 HOUR

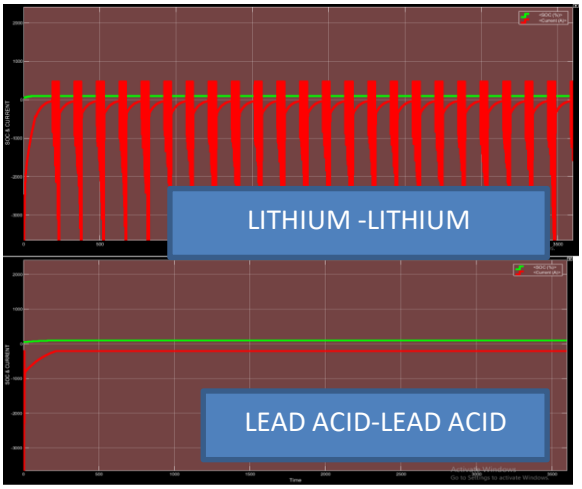


Figure 4.2:-SOC & CURRENT WAVEFORM OF LITHIUM ION SERIES & LEAD ACID SERIES BATTERIES FOR 1 HOUR

ANALYSIS:-

ANALYSIS OF LITHIUM ION –LITHIUM ION SERIES BATTERY CHARGING: - Initially the SOC & nominal voltage of both lithium ion batteries taken as 45% and 7.2 volt . The SOC reaches to 100% and charging current becomes -677.8 mille Ampere within a period of 1 hour as observed. The charging current was more initially and reduced to constant i.e with 30 volt DC source for charging lead acid battery of initial voltage of 7.2 volt , the charging current initially increases & in a short time reduces and then after a small interval of regular 200 seconds , it further increases and then reduces again and this continues .

ANALYSIS OF LEAD ACID –LEAD ACID SERIES BATTERY CHARGING: - Initially the SOC & nominal voltage of both Lead Acid batteries taken as 45% and 7.2 volt. The SOC reaches to 100% and charging current becomes -207.8 mille Ampere within a period of 1 hour as observed. .The charging current was more initially and reduced to constant i.e. with 30 volt DC source for charging lead acid battery of initial voltage of 7.2 volt , the charging current becomes constant.

5.BATTERIES PARALLEL CHARGING: Separate battery Parallel charging is shown in figure and design parameters are also shown below .Simulation results are shown both in display and waveform basis.

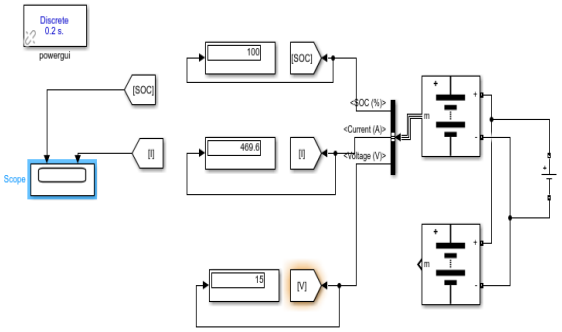


Figure 5.1:-CIRCUIT DIAGRAM OF BATTERY PARALLEL CHARGING FOR I HOUR

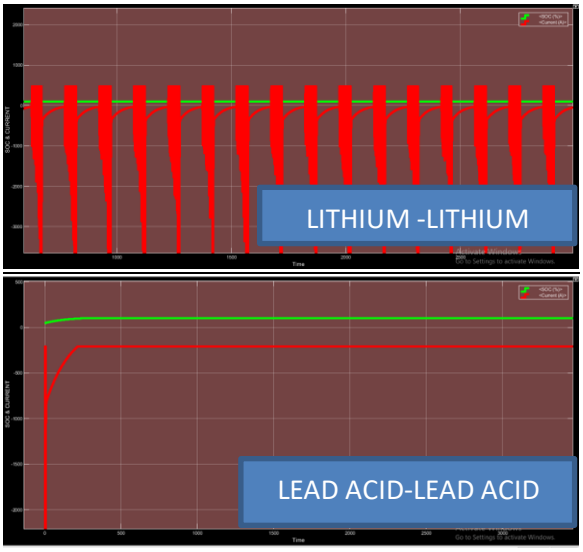


Figure5.2:- SOC & CURRENT WAVEFORM OF SEPARATE BATTERIES CONNECTED IN PARALLEL FOR CHARGING FOR 1 HOUR

ANALYSIS OF LITHIUM ION –LITHIUM ION PARALLEL BATTERY CHARGING:-Initially the SOC & nominal voltage of both lead acid & lead acid battery taken as 45% and 7.2 volt. The SOC reaches to 100% and charging current becomes 469.6 mille Ampere within a period of 1 hour as observed i.e with 15 volt DC source for charging lead acid battery of initial voltage of 7.2 volt, the charging current initially very low & then reduces and this reduced current maintains constant throughout .

ANALYSIS OF LEAD ACID –LEAD ACID PARALLEL BATTERY CHARGING:-Initially the SOC & nominal voltage of both lead acid & lead acid battery taken as 45% and 7.2 volt. The SOC reaches to 100% and charging current becomes -207.8 mille Ampere within a period of 1 hour as observed. The charging current was more initially and reduced to constant

i.e with 15 volt DC source for charging lead acid battery of initial voltage of 7.2 volt, the charging current initially increases & then reduces and this reduced current maintains constant throughout.

6. BATTERY DISCHARGE:

Both battery discharge is shown in figure and design parameters are also shown below .Simulation results are shown both in display and waveform basis .Initially the battery charging is taken as 100% and nominal voltage of battery is taken as 7.2 volt .

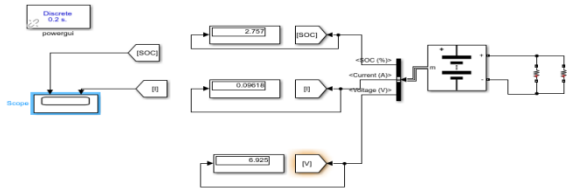
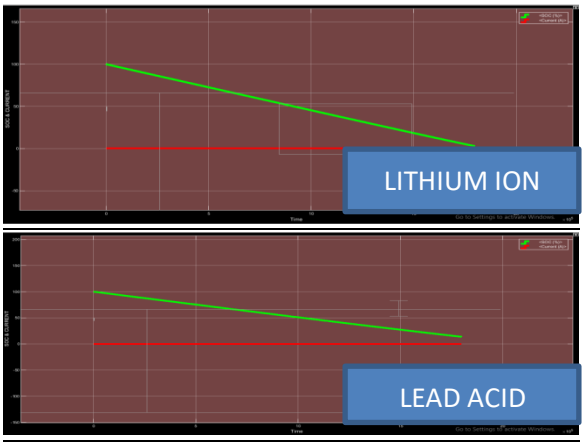


Figure6.1:- CIRCUIT DIAGRAM OF DISCHARGE OF LITHIUM ION BATTERY WITH LOAD RESISTANCE 72 OHMS FOR 500 HOURS



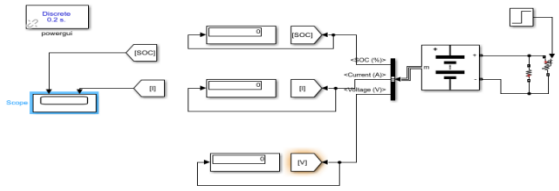


Figure 6.2:- CIRCUIT DIAGRAM OF DISCHARGE OF BATTERY WITH LOAD AS STEP SIGNAL FOR 25 HOURS

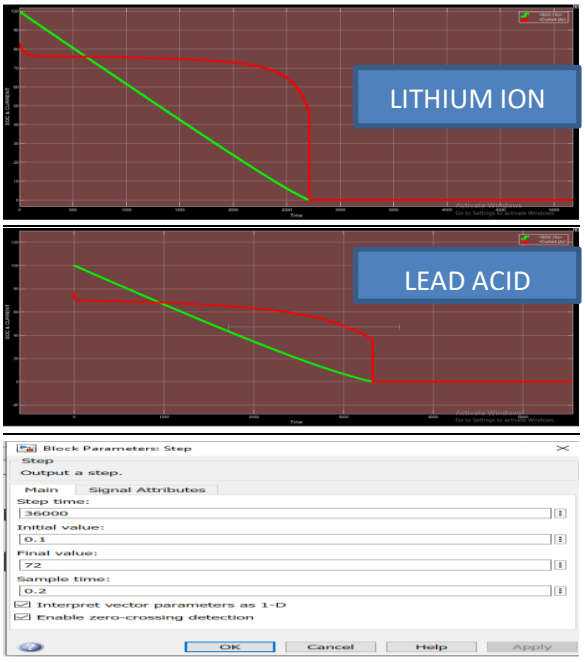


Figure6.3:- IMAGE SHOWING DETAILS OF STEP SIGNAL

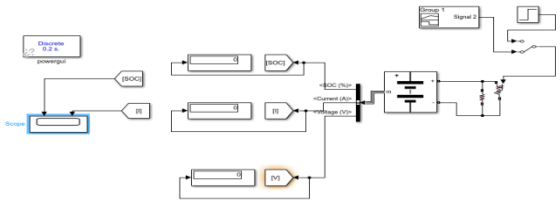


Figure 6.4:- CIRCUIT DIAGRAM OF DISCHARGE OF BATTERY WITH LOAD AS STEP SIGNAL WITH RAMP START FOR 20 HOURS

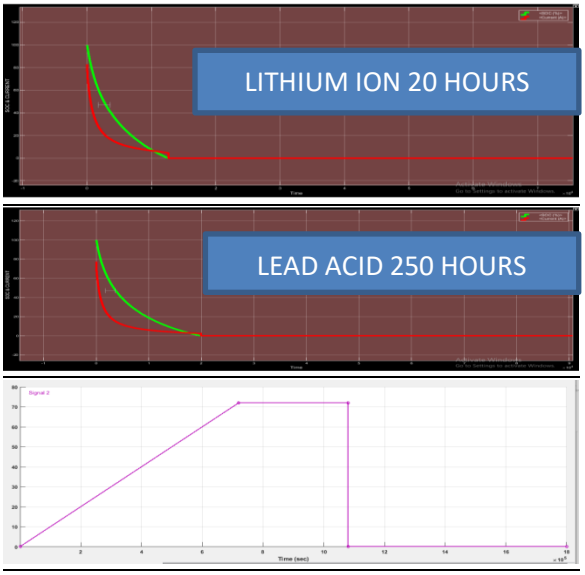


Figure 8.6:- IMAGE OF STEP SIGNAL WITH RAMP START DEVELOPED IN SIGNAL BUILDER

ANALYSIS

ANALYSIS OF LITHIUM ION DISCHARGE:-For a period of 500 hour, the lead acid discharges from 100% to 2.757% and low discharge current develops and voltage reduces to 6.925 volt when 72 ohms resistance is connected at load & with step load, the current reduces in step with little curvature and finally becomes constant and the for step signal with ramp start load, the current purely reduces exponentially and then becomes constant.

ANALYSIS OF LITHIUM ION-LEAD ACID SERIES DISCHARGE:-The SOC reduces from 100% to 0% within a period of 300 hours & current remains constant throughput for 72 ohms resistance at load .For step , the SOC reduces to 0% in 250 hours & current constant throughput . For step, the SOC reduces to 0% in 250 hours and current constant throughput .For step with ramp start, the SOC reduces to 0 % in 1200 seconds & current reduces to nearly zero in a step format with a curvature in 1750 seconds .

7.SIMULATION RESULT OF BATTERY CHARGING

TABLE 7.1 SIMULATION RESULT OF BATTERY CHARGING & DISCHARGING

CHARGING OF BATTERIES WITH INITIAL STATE OF CHARGE = 45%		
SOC		**TIME**
LITHIUM ION BATTERY	**100 SECONDS**	**100%**
LEAD ACID BATTERY	**425 SECONDS**	**100%**
DISCHARGING OF BATTERIES WITH INITIAL STATE OF CHARGE = 100% WITH LOAD AS 72 OHM RESISTANCE		
SOC		**TIME**
LITHIUM ION BATTERY	**500 HOURS**	**2.757%**
LEAD ACID BATTERY	**500 HOURS**	**13.64%**

8.CONCLUSION:- The analysis and design of batteries charging and discharging have been carried out for various performances parameters of voltages and loads. For charging, the fixed voltage source of 12 volt for 7.2v battery is used. The loads vary from purely resistive load or step load to step load with ramp at start. Both Lead Acid & Lithium Ion have been designed to deliver output characteristics with fixed DC voltage source for charging and also outputs of Discharging of batteries studied with load variations seen through display and waveform characteristics .This work was carried out with the help of Matlab-Simulink. The result of simulation is presented for comparison. These design concepts are validated through simulation in the Matlab and the results are presented for analysis of various batteries.

The depth of discharge and battery capacity is strongly affected by the discharge rate of the battery. The battery capacity degrades due to sulfation and shedding of extra material .The degradation of battery capacity depends most strongly on the interrelationship between the following parameters:-

1. The charging/discharging regime which the Battery has experienced.
2. The exposure to prolonged periods of low discharge.
3. The average temperature of the battery over its lifetime.
4. The initial state of charge of both batteries set at 45% and it is found that Lead acid battery takes 425 seconds to full charge while Lithium Ion Battery takes 100 seconds to full charge. So charging of Lithium Ion battery is fastest. With initial state set to full charge, it was found that Lead Acid Battery discharge to 13.64% in 500 hours while Lithium Ion Battery in the same period discharge to 2.757% with load resistance set at 72 ohms in both cases. While lead acid charging through simulation, it is seen that initially the charging current is high and the charging current reduces exponentially with time onwards. Theoretically if lead acid battery is being discharged very quickly, then the discharge current is high but practically if discharged for long period of 500 hours with load resistance nearly 100 ohms , the discharge current is constant . while in Lithium Ion Charging, the charging current develops constant current algorithm and it is observed, unlike Lead Acid , where charging current decreases exponentially ,

here in Lithium Ion Battery, the current deduces to constant nature hood in a very short period of time duration .Even seen in Lithium Ion also like in Lead Acid that discharging for 500 hours results to constancy in current characteristics .

Refrence:-

[1]Tenno, R. Tenno and T. Suntio, "Battery impedance and its relationship to battery characteristics," 24th Annual International Telecommunications Energy Conference, 2002, pp. 176-183, doi: 10.1109/INTLEC.2002.1048653.

[2]Lakshmi Kp and Pruthvija .B," Review on Battery Technology and its Challenges", International Journal of Scientific and Engineering Research 11(9):1706 , September 2020

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

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

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

[6] 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.

[7] 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.

[8]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.

[9] 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

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

[11] 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.

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