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Design and Development of Lithium Ferro Phosphate Battery Pack with Smart BMS

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ABSTRACT: The purpose of this project is to Design and Developing Prototype of Lithium ion ferro-phosphate battery pack (LiFePO_4) with smart BMS. In that LiFePO_4 as a cathode material and a graphitic carbon electrode with metallic backing as the anode. The Technology of this battery is based on Lithium-Ion. As per comparison of lithium-ion based batteries, lithium ferro-phosphate battery is more efficient, environmental friendly to nature and also cost efficient. The paper includes detailed study of the lithium ferro-phosphate (LFP) battery cell and battery pack and their composition, working (charging and discharging), physical and chemical characteristics and applications.

KEYWORDS: Battery, Lithium ferro-phosphate, Cycle Life, charging-discharging time, BMS (battery management system)

I. INTRODUCTION

The lithium iron ferro-phosphate battery electrode was first described by "JOHN GOODENOUGH'S" research group at the "UNIVERSITY OF TEXAS" in 1996 as the cathode material for rechargeable lithium batteries. LiFePO_4 products are now in mass production and used in industrial product by major corporations including Cessna, BAE Systems etc.

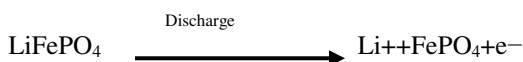
The lithium iron ferro-phosphate battery [LiFePO_4] is a natural mineral of the "OLIVINE FAMILY". It is the common minerals in the earth's surface that is "magnesium iron silicate" [MgFe] SiO_4 . The lithium iron phosphate battery is also called as "Lithium Ferro-Phosphate" battery i.e. LFP and uses LiFePO_4 as a cathode material. Phosphate based technology possesses superior thermal and chemical stability which provides better safety characteristics than those of Lithium-ion technology made with other cathode materials. Lithium phosphate cells are incombustible in the event of mishandling during charge or discharge, they are more stable under overcharge or short circuit conditions and they can withstand high temperatures without decomposing because of its low cost, non-toxicity, high abundance of iron, excellent thermal stability, electrochemical performance and specific capacity, it has gained some market acceptance and it is expected to widely expand the applications in the field of lithium batteries and take it to the new fields such as electric bicycles, gas-electric hybrid vehicles and automation vehicles. However, a trade-off is made for reduction of 14% in energy density.

II. METHODOLOGY

1. Lithium Ferro-phosphate (LiFePO_4) Battery Chemical Reaction:

Discharge Cycle:

Anode: Carbon-type material



In this chemical reaction, lithium ions (Li^+) move from anode to cathode electrode.

Cathode: Lithium ion Ferro-phosphate (LiFePO_4)



In this reaction, Lithium ions (Li^+) and electrons absorbed by the cathode electrode and the formation of lithium ion Ferro-phosphate (LiFePO_4).

Charge Cycle: During charging process, overall reactions are reversed.

Lithium ions (Li^+) move from cathode to anode electrode and electrons absorbed the anode (negative electrode)



This charging and discharging cycle can be repeated multiple times, allowing the battery to store and release electrical energy.

2. Battery Manufacturing Process

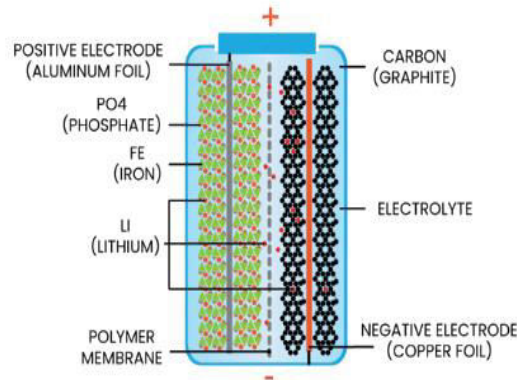


Fig.1. Basic Diagram of LiFePO_4 cell

Aim of this project is to developed a lithium-ion ferro-phosphate (LiFePO_4) battery, test them and record the charge / discharge cycle, performances and other parameters etc. Manufacturing the lithium-ion Ferro-phosphate (LiFePO_4) battery involves several steps. 1st design the specification and required material for manufacturing LiFePO_4 battery, including voltage, battery size, row material & applications.

Obtain a row material, including lithium carbonate, iron phosphate, conductive materials, electrolytes, separator materials & other Components.

Formation of electrode is the mixture of cathode and anode material according desired formulation. Apply the cathode and anode material onto metallic foils using a coating process. Integrate the separator material between the anode and cathode layer to create a layered structure. It prevent direct contact between the anode electrode & cathode electrode and also prevent short circuit between them.

Assemble cell by stacking anode, cathode & separator layers and then added electrolyte Solution to ion transport between the electrodes. Seal the cell in a pouch or cylindrical on appropriate enclosure to prevent leakage and Protect internal components. The overall design and structure of battery is formed, including such factors such as cell architecture, thickness of electrodes, power density, energy density etc.

After that battery process going to very important steps is Quality Control. In this battery performs the different tests for checking the Stability and optimal performances, likes charging/discharging cycle, SOC management, temperature management, capacity testing etc.

Analyze all the test results and documentation the entire manufacturing process, material used, process parameters and testing results for future reference and potential improvement.

3. Battery Pack Assembly Process

LiFePO_4 cells with matching capacities, voltages, and internal resistances. Make sure they are from a reputable manufacturer and have built-in safety features. Acquire battery cells, nickel strips, insulating materials, a spot welder (or soldering equipment if preferred), a battery management system (BMS), and a suitable enclosure. Inspect each cell of battery pack for any damage or defects. Spot weld or solder nickel strips onto the terminals of each cell, ensuring proper polarity and avoiding short circuits. Use insulating materials to cover exposed areas of the cells and prevent

accidental contact. Arrange the cells in series (positive terminal of one cell connected to the negative terminal of the next) and parallel (connecting all positive terminals together and all negative terminals together for a 1P configuration). Use a spot welder or soldering iron to connect the nickel strips between cells securely. Be careful not to overheat the cells during soldering to avoid damaging them. Connect the BMS to the battery pack according to their connection as per instructions.

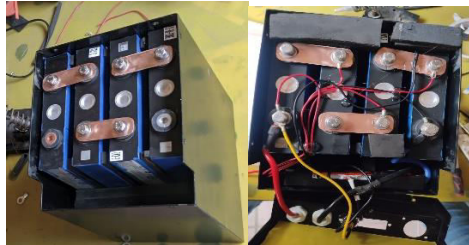


Fig no. 3 Battery pack assembly

The BMS will manage charging, discharging, and balancing of the cells, as well as prevent overcharge, over-discharge, and short-circuit protection. Before enclosing the pack, perform a thorough test of the assembled battery pack. Check voltages across each cell, ensure proper BMS functionality, and test the overall voltage and check the capacity of the pack. Once testing is successful, enclose the battery pack in a suitable and secure housing. Ensure proper ventilation and insulation to prevent overheating or damage to the cells. After the pack is enclosed, perform a final test to confirm proper operation. Install the battery pack in its intended application, following any specific mounting or connection instructions.

CALCULATIONS AND TESTING

1. Energy capacity (Wh) = Nominal Voltage (V) × Capacity (Ah)

Nominal Voltage (V) : 12.8V

Power (W) : 1000W

2. Capacity in ampere-hours (Ah) :

$$\text{Capacity (Ah)} = \frac{1000\text{W}}{12.8\text{V}} = 78.125\text{Ah}$$

$$\text{Energy Capacity (Wh)} = 12.8\text{V} \times 78.125\text{Ah} = 1000\text{Wh}$$

The cells are connected in series, the voltage adds up. The total voltage of the 4S configuration is the sum of the individual cell voltages.

The capacity of the entire battery pack (in Ah) is calculated as follows:

Total Capacity = C × Number of cells in parallel

Various tests are performed on Lithium Iron Phosphate (LiFePO₄) batteries to ensure their safety, performance, stability and reliability.

1. Capacity test
2. Cycle life test
3. Self-discharge rate test
4. Short circuit test
5. Over charge and Over-discharge test

In a lithium ion ferro-phosphate battery (LiFePO₄), estimate the crucial factor is SOC. Different methods are used to estimate SOC.

The SOC indicate the current level of charge in the battery.

SOC % = Current Capacity / Nominal Capacity

For a LiFePO₄ Battery,

An SOC of 0% typically indicates that the battery is completely discharged.

An SOC of 100% typically indicates that the battery is completely charged.

SOC is estimated using voltage, current and temperature measurement along with BMS system to use monitor charge/discharge cycle accurately.

1. Open circuit voltage method
2. Kalman filter method
3. Coulomb counting method
4. BMS algorithm

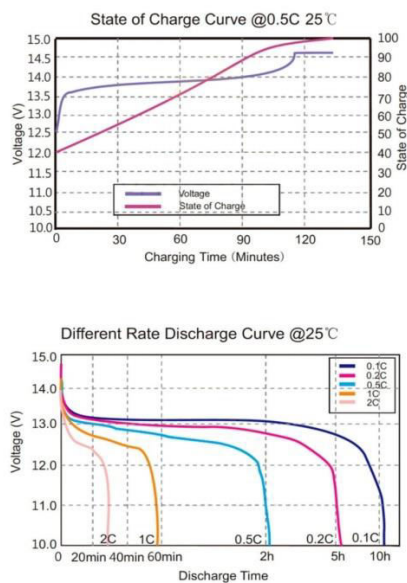


Fig no. 4 Charging-Discharging nature of battery performance

III. RESULT ANALYSIS

Analyzing result based on the SOC, SOH and DOD in lithium ion ferro-phosphate (LiFePO₄) battery pack.

1. State of Charge (SOC) :
To estimate SOC, observe the beginning and end of the charge/discharge cycle.
2. State of Health (SOH) :
SOH indicate the overall health or condition of the battery pack compared to initial state of new.
3. Depth of Discharge (DOD) :
DOD measure the percentage of the battery capacity that has been used during a discharge cycle.
Monitor DOD over cycles to understand deeply the battery is being discharged.

In a safety consideration, implement safety protocols based SOC and SOH to prevent overcharging and deep discharging or other unsafe conditions. [3]

Implement Bluetooth communication capabilities in the BMS to enable wireless data transmission. Design a user-friendly interface for displaying the BMS results via Bluetooth. This could be a mobile application for smartphones or a desktop application for computers. Consider factors such as readability, graphical representation of data, and ease of navigation. [6]

Software for the BMS to log the monitored data periodically or in real-time. Implement algorithms for analyzing the data, such as predicting battery health, estimating remaining capacity, and detecting abnormalities or faults.

Sr. No.	Voltage (volt)	Current (Amp)	Power (KW)
1.	13.1	0.0	0.0
2.	13.1	6.7	0.087
3.	13.0	10.0	0.130
4.	13.0	13.1	0.170

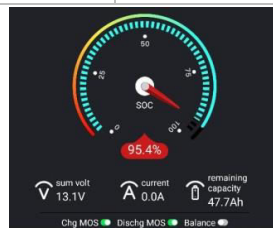


Fig no. 5. Result of Resistive Load

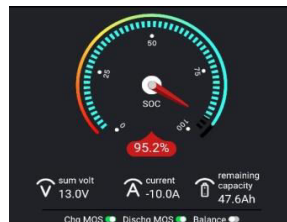


Fig no. 6 BMS Result via Bluetooth

IV. CONCLUSION

The comprehensive exploration of modelling and simulation techniques for lithium iron ferro-phosphate (LFP) battery pack has provided valuable insights into the dynamic behavior of these energy storage systems. The overall process for designing a prototype of battery pack is covered considering the various design considerations that can affect the overall performance parameters of batteries like charging, discharging, and lifecycles.

The various parameters are display through the smart BMS application which is give the different values of each cell like voltage, current, temperature etc. The integration of BMS, case study analysis, and project planning provides a holistic approach to advancing of understanding and application of LFP batteries.

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