

**Battery Storage Stack Design with an Intelligent IoT-based Active Cooling System**

Optimized Battery Storage for Ease of Manufacturing and Use

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Abstract—Large scale battery solutions for energy storage are becoming more prevalent. The increased and faster charge cycling increases the thermal load on charging circuitry and the batteries used. This project proposes an IoT system to control the active cooling in order to prevent thermal runaway while controlling noise levels. A 1:10th capacity scale model using four Lithium Iron Phosphate (LFP) batteries was designed and fabricated using less than one third the volume of the previous design with greater performance. The goal was to maintain a temperature of less than 60°C, to support less stable chemistries that are currently used more.

Keywords - Lithium ion; cooling; Energy Storage

I. INTRODUCTION

This project’s scale model solution has a few key features. Monitoring the batteries for any problems. Forced air cooling for a cost-effective temperature management, extending lifetime, increasing system efficiency, and preventing hazardous situations. Modularity to allow for more flexible deployments.

Current market solutions for a single-family home have a capacity around 10kWh, advertised as enough for a single day. The developed scale model contains only 0.7 kWh. The scale model uses four Lithium Iron Phosphate (LFP) batteries. A full system would likely have 52 of these cells. The scale prototype enclosure will use LFP batteries, a type of Lithium ion, and should be easily adaptable to other battery types.

A. Battery Heat Generation

Batteries through discharging and charging increase in internal temperature as a result of internal resistances and entropy form the reversible chemical reactions. Internal temperature will modify the internal resistance, and effect efficiency. The prototype solution looks to dissipate the heat generated and lower the temperature of the batteries to reduce overall power loss (from the internal resistance), for more efficiency and a longer life cycle.

B. Purpose of the Project

The purpose of this project is to design an enclosure using cost effective manufacturing methods and to evaluate the performance. The scaled down standalone enclosure will be allow measuring the cooling capacity, providing a reference for the amount required in a full-scale system. A previous team’s prototype, with the same capacity, also used forced air cooling; however, it was larger than practical for a full-scale.

II. HARDWARE DESIGN

The scale model will operate at 12.8V and should deliver an average of 10 amps, with peaks of up to 20 Amps, similar currents to the full-scale but at reduced voltages. The designed enclosure uses two “air spaces”. The first and largest will house the batteries and the fans; The second will house the controlling hardware and sensors. A Raspberry Pi was used selected for the controller on the prototype. It should be noted that the control hardware in the lower “air space” takes up a larger percentage of space on the scale model than on a full-scale system.

A. Enclosure

The enclosure in Fig 1 is designed to house the batteries in a secure and robust manner for indoor location, while being lightweight and compact. This current design houses four batteries. In order to be competitive in the market, the volume to be met is 0.01m³ to give a power density of 76.8 kWh/m³, and a weight in the range of 10kg.

The construction is made from formed aluminum. Fig 1 shows the extent of the design and battery layout. Wall thickness of 1.0mm proved rigid enough for structure while allowing tight bends. Fig 1 also shows the additional hardware space for the controller and circuitry, along with the safety circuit break on the side. Fig 1 right shows tie downs and busbars. In the event of a drop or impact the batteries are held secure and ample space is provided all deformation and to prevent shorting. The pair of 92mm fans are mounted on the rear panel, opposite the openings.

![Figure 1: Proposed enclosure design](image-url)
B. Batteries

LFP was chosen for several reasons including: significant charge cycle lifespan, safety, direct comparison to the previous team’s prototype and, new LFP cells would be a near identical drop-in replacement. Newer LFP offerings are rated for more cycles and is overall a promising chemistry. LFP cells are also some of the safest due to their high thermal runaway temperature (270°C) \(^1\) and relatively low reactivity to puncture. They also don’t depend on cobalt, which is facing ethical mining concerns.

III. TESTING

Simulations using CFD and FEA in SolidWorks were carried out with a simplified enclosure model and a 44 m\(^3\)/h air flow rate. The 92mm fans used in the final design would operate at 1500rpm with 70m\(^3\)/h air flow rate and are capable of 80m\(^3\)/hr. Battery heat was modeled using volumetric heat generation in a solid and the thermal conductivity was set to \(k = 0.4 \text{ W/mK}\), typical of a lithium cell \(^2\). Heat generation was set for 63 W, close to the rated a 3C discharge rate, per cell with air at STP.

A. Simulation Results

Results of the simulation proved very promising; temperatures were kept well below 100°C at 52°C average between the four batteries. The results and temperature spread can be seen in Fig 2(b). Fig 2(a) shows the simulation model.

To show the benefits of forced air cooling, the same setup and parameters were used with fans off, Fig 2(c) shows the simulation model for this state. In this quiescent state, the temperatures were in excess of 150°C.

Forced air flow cooling performance decreases as the air temperature in the enclosure increases. The test results from the simulation were validated using a one-dimensional wall assumption using the air velocity and properties to calculate convection. Results were 1% lower in temperature than the results of the simulation, likely due to simplifying the battery construction for calculation and averaging the convection values.

B. Physical/Software Testing

The constructed prototype can be tested at up to 30 amps discharge and 24 amps charge currents, independently. Generating less than 2.0 Watts max, per cell, the prototype is subjected to more stress than the previous design and far less stress than the simulations.

IV. CONCLUSION

While the overall concept proposed of regulating battery temperature is not novel; the design still contains several components such as overall enclosure design, thermal regulation method and control system design that need to be evaluated. Previous preliminary work suggests that focusing on a forced-air convection system and strategically placed sensors will allow the system to proactively react without waiting for battery temperature itself to rise. Overall, this approach will allow for optimizations in both performance and cost relative to the previous design.

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Figure 2. (a- left) Simulation with air velocity and battery temperatures. (b - center) Battery Temperatures. Measured on centerline \(\perp\) to main air flow direction. (c- right) Fans of