Table of Contents

Introduction ................................................................. 3
Market Classification and Application Examples 3-4
Design Considerations .................................................... 5-7
Regulations ................................................................. 8
Material Handling Design .................................................. 9-10
About Inventus Power ....................................................... 10
Introduction

Rapid adoption of Lithium-ion (Li-ion) technology is expected for medium format batteries, solving some serious pain points for larger stationary and motive applications. The Li-ion battery pack market is about a $20B dollar market today and growing. Applications like forklifts and e-bikes have a collective 11% growth rate to $10B in 2020 and most of them require high power or are medium format.

Most medium format batteries are replacing gas or propane Internal Combustion Engines (ICE) or Sealed Lead Acid (SLA) batteries. Gas is great at storing energy; it’s cheap, proven and abundant. However, ICEs are loud and polluting. Their maintenance needs can be high and access to fueling stations can be challenging. These issues can all be worse for indoor use (i.e. in a warehouse) Finally, there are regulatory requirements that make ICE less appealing, especially in the EU and Asia. Until recently, most larger applications switching from ICE to battery power would use SLA. SLA is simple, dependable, robust and inexpensive and can be used in a wide range of temperature environments, but there are many disadvantages to this technology. The batteries must be stored full state-of-charge and do not lend itself to fast charging. SLA batteries are very heavy; the gravimetric energy density is very low. The cycle life is usually 200 to 300 cycles, but even a “deep cycle” SLA is damaged by repeated full discharges causing cycle life to be as low as 50 cycles. Again, there are the regulatory requirements pushing for more environmentally-friendly solutions.

Li-ion batteries offer many advantages, such as superb cycle life and high energy density, so it has become the standard in most industries...

Market Classification and Application Examples

There is no standard industry definition for a medium format battery. Shipping guidelines do set forth an equivalent lithium content for what is considered medium in that context, but that definition is not helpful, because the limits are small in any other design criteria.
A medium format battery is 500Wh–10 kWh and 24V –96V and requires modular solutions designed for scalability and ease of replacement for SLA and ICE.

For consumer or portable products, with low voltage and capacity, there are well-defined design guidelines such as IEEE 1625 and 1725 for cell phones and laptops. There are also widely available off-the-shelf solutions for protection, communication, etc. On the other extreme, large batteries with very high capacity and/or voltage have extremely complex design challenges and take years of development for custom solutions.

A medium format battery is 500Wh – 10 kWh and 24V – 96V and requires modular solutions designed for scalability and ease of replacement for SLA and ICE.

**Medium Format Batteries:**
- 500Wh – 10 kWh, 24V – 96V
- Replacement of SLA and ICE
- Lower TCO with Li-ion in high use
- Cell balancing and matching solutions developed for high series designs
- CAN Bus communication for noisy environments
- Mechanically robust for size and use rigorous use models
- Modular designs for scalability, shorter design cycles

Here are some examples of applications that are adopting our medium format batteries:

- Material handling equipment
- Battery backup units
- Lawn and garden equipment
- Industrial cleaners
- Aerial scissor lifts
- Drones
- Golf carts
- Light electric vehicles
Design Considerations:

Architecture:
The first thing to consider when designing a medium format battery is to determine what type of architecture to use. The architecture layout will dictate how all the cells are connected and how they are connected to the Battery Management System (BMS).

With larger batteries, there are several different options that are typically designed:

- **Centralized architecture**: Like small battery design, cells are connected to one BMS board which performs all the main functions such as cell monitoring, protection, cell balancing, and communication. Because the board is typically designed for one type of configuration, it minimizes the number of components and board size, making it a cost-effective solution. However, this type of design offers very little scalability.

- **Distributed architecture**: This architecture is comprised of several smaller groups of cells that are tied to a slave monitoring board. The monitoring board will monitor and balance those groups of cells. The slave monitor is then daisy chained to another slave monitor group and so forth. This solution offers the most flexible and scalable option as it can add and/or remove group of cells very easily.

- **Hybrid architecture**: This approach combines the features of the centralized and distributed. There is a slave module which talks directly to the BMS board, but it is not as scalable as the distributed version since BMS is limited to talk to a specific number of channels. It is more cost effective than the distributed option.

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Centralized
- Optimized for one type of battery configuration
- Lowest cost
- Little Scalability
- Hard to repair
- High voltages

Distributed
- Very flexible
- Highest cost
- Scalable
- Easy to repair
- Isolated voltages

Hybrid
- Combination of centralized and distributed
Balancing and Communication:

The BMS monitors the current going in and out of the battery; it also monitors the voltage of each cell string and temperature at various places within the battery. The BMS is also used to communicate information over to its load and/or charger. It reports out the state of charge of the battery, state of health (which shows how the battery has degraded over its virgin state), and reports any faults that battery has seen. It can also be used to do active thermal management (turn on/off fans), reducing charging current if it gets too hot or turning on a heater if it is too cold for charging.

Cell imbalance can occur due to uneven current draws on the cell, uneven heating on the cells, and unmatched cells being used at assembly.

One of the problems that larger batteries encounter is cell imbalance. Cell imbalance is uneven charge on the cells in series. Cell imbalance can occur due to uneven current draws on the cell, uneven heating on the cells, and unmatched cells being used at assembly. Cell imbalance can cause premature end of discharge, can overcharge cells or undercharge cell. All of this can reduce battery life. Almost all medium and larger format batteries require cell balancing circuitry. Due to the number of cells that these packs have, it is very hard for all the cells to stay in balance for duration of their life without any cell balancing circuitry. Cell balancing circuits tries to equalize the cell charge to keep all the cells connected in series at the same level.

Cell balancing can be accomplished in two ways:

- **Passive balancing** which dissipates charge from the most charged cell. Charge is burned off as heat. This typically done via a bleeding resistor.
- **Active balancing** which moves charge around from one cell to another. This is a “greener” approach since energy is not wasted. Active balancing requires more complex algorithms and components so it is higher cost.

Communication of load and internal modules about their status and any faults they have experienced/are experiencing is key in larger battery pack design.

There are several communication buses these could utilize:

- **2C** is common bus in the small battery world. It can be good for when travelling short distances. It is usually not used for external communication especially in a noisy environment like automotive and or industrial. This can be a suitable bus for internal communication between modules.
- **RS-232** is a point to point bus. It is not suitable for a permanent installation due to low speed, poor reliability, and poor noise rejection. It is commonly used a diagnostic bus.
- **CAN bus** is the standard for automotive and industrial applications. It has great noise rejection and can travel very long distances.
Most electronics circuits cannot handle high voltage and most digital electronics are based on 5 volts, so there is a need to isolate high voltage potential from the sensitive 5V electronics such as microcontrollers.

**Contactors:**

Medium format batteries need to be able turn on and off the battery output. Most medium and larger batteries use contactors to accomplish this task.

Contactors are used to switch a high current load in the hundreds of amps range. Small batteries typically use Mosfets to switch on the loads. The problem with mosfets is that they are not bi-directional, the control is not completely independent of the output, and the selection is limited when dealing with high voltage and high current. The contactors are controlled via the BMS circuit. If the BMS detects there is a fault due overcurrent, overvoltage, and overtemperature, it can open the contactors to turn off the battery output to the load and or charger.

Many battery packs typically have a 2 contactors (one of the ground side and another on the positive side). This offers redundancy if one goes bad and offers complete isolation from the load and from any potential ground faults. Some battery packs will utilize a pre-recharge contactor with a current limiting resistor to soft start a load. This will limit the inrush the current when applying battery voltage to a completely discharged load. Fault detection circuitry is recommended on the contactors themselves. Since they are your safety components, it is wise to ensure that you can tell if the contactor becomes shorted, won’t close, or becomes high resistance. If any of those faults occur, you can communicate that to the application.

**High Voltage:**

Most electronics circuits cannot handle high voltage and most digital electronics are based on 5 volts, so there is a need to isolate high voltage potential from the sensitive 5V electronics such as microcontrollers.

There are several isolation methods that engineers have used in battery packs:

- **Optocoupler:** High voltage signal on one end of the optocoupler is transferred over via light to the low voltage side. These are a cost-effective way of isolating a circuit but can degrade over time, usually have high power consumption, and have limited bandwidth.

- **Magnetic isolation:** Use a changing magnetic field between 2 coils to pass information over.

- **Capacitive isolator:** Changing electric field between capacitors plates to pass information over.

There can be dielectric breakdown between 2 conductive points in presence of high voltage. High voltage potential difference can create “dendrites” that can bridge across insulation surfaces. The dendrites can create shorts and also cause opens. The best way to mitigate this is to ensure proper creepage and clearance distances between conductors.
Regulations:

Just like in the small battery world, there are regulations for medium and larger batteries to ensure safety. UL is one agency that certifies medium and larger format batteries and enforces the following standards:

- **UL1973** for stationary batteries. These are typically energy storage batteries that store energy from solar panels or they store energy from the grid and turn on during peak times or during power loss.
- **UL2271** for light electric vehicle such as e-scooters, wheelchairs, material handling equipment.
- **UL2580** for EV batteries.

<table>
<thead>
<tr>
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<th>UL1973</th>
<th>UL2271</th>
<th>UL2580</th>
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<tbody>
<tr>
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<td>Isolation Resistance</td>
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<td>Vibration Endurance</td>
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<tr>
<td>Temp Cycling</td>
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Material Handling Design:

Market Requirements:

Material handling equipment is adopting Li-ion battery technology because of noise, pollution, regulatory requirements and the cost savings and improved productivity to be gained with longer runtime.

The following requirements were developed for this market:

- Nominal Voltage: 36V-48V, Scalable
- Capacity: 140Ahr to 180Ahr Scalable
- Communication: CAN BUS
- Current: 100A Nominal
- Active Balancing
- Cycle Life: 1000+ Cycles
- Automotive Vibration and Shock
- Regulations: UL 2271

Design:

Inventus Power started with the basic building block which was an 18650 cell. This was a mid-rate cell with a 2.5 Ahr capacity. This basic building block is used for many battery packs. Tesla has around 8,000 of these type of cells in their battery packs. The 18650 was used to make a two series and twenty parallel module. The modules then could be put together in series or in parallel to provide the voltage and/or capacity that was needed. This allows the system to be very modular.

Each module has 2 thermistors to monitor the temperature of the cell block. The pack also employs a plastic holder to hold the cells to allow adequate separation between the cells. Each module has voltage sense on the 2 strings to monitor the cell voltages.

This figure shows how the modules can be assembled the needed voltage and capacity.
Warehouses, factories and other industrial environments must have equipment that run non-stop, moving and storing goods for maximum efficiency. These batteries enable greater efficiency and less equipment down-time.

As seen in the final table, the biggest savings we get converting over to lithium from lead acid is the gain in energy density due to the lower weight of Lithium-ion by almost half.

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<th>Lithium Ion</th>
<th>Pb-Acid</th>
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<tbody>
<tr>
<td>Volume</td>
<td>.075 m³</td>
<td>.080 m³</td>
<td>Similar Size</td>
</tr>
<tr>
<td>Weight</td>
<td>92 Kg</td>
<td>183 Kg</td>
<td>Huge Weight Savings</td>
</tr>
<tr>
<td>Gravimetric</td>
<td>89 Wh/Kg</td>
<td>46 Wh/Kg</td>
<td>~2x Energy Density</td>
</tr>
<tr>
<td>Energy Density</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Warehouses, factories and other industrial environments must have equipment that run non-stop, moving and storing goods for maximum efficiency. These batteries enable greater efficiency and less equipment down-time.

**About Inventus Power**

Inventus Power, founded in 1960, is the world’s largest power systems manufacturer that integrates and delivers battery packs, chargers & docking stations and power supplies across the consumer, commercial/industrial, medical and military & government markets and is located in ten countries across four continents.

With headquarters in Woodridge, Ill. and manufacturing facilities in the United States, Mexico, Brazil, China and Malaysia, we are globally positioned to be a catalyst for our customers’ success. Inventus Power utilizes decades of design, engineering and market expertise to apply innovative technology to our OEM customers’ devices, and ensures a reliable, high quality product through our vertically integrated processes and performance testing capabilities.

For more information, visit [inventuspower.com](http://inventuspower.com).