WHITE PAPER

Wired, Wireless, and Contactless: comparing BMS design approaches

Contents

Abstract

Aggressive, world-wide net zero targets are driving up the manufacturing throughput of larger and more efficient energy storage systems (ESS) and a wider range of electric vehicles (EVs). Over 10 million EVs were sold globally in 2023, yet, there is simmering public concern over the safety of large high voltage (HV) battery packs powering these vehicles, and it is increasingly important for ESS and EV manufacturers to employ more cost-efficient battery management system (BMS) designs while also improving control over the safety, reliability, and efficiency of the battery pack. This paper discusses three different BMS hardware design approaches: fully wired, far field wireless, and near field 'contactless', and investigates and compares cost-efficiency, safety, and reliability aspects of each.

Introduction

It is a complex task to design an optimal, reliable, and safe high power battery pack. It must incorporate a high-voltage (HV) system of cells that store and deliver power; however, this requires galvanic isolation from a low-voltage (LV) system that exists in the same space within the battery pack. The BMS includes a method of measuring and communicating the cell or module parameters to a battery management system host (BMS host), which analyses those parameters, and subsequently controls the efficiency and safety of the pack.

The battery design must also be cost-effective while balancing the demands of its many requirements. It must have a minimized bill of material (BOM) cost, reduced manufacturing and assembly complexity, be compact to maximize the available energy density, able to dissipate heat efficiently, be electrically safe, mechanically robust, impact resistant, watertight, and robust to electromagnetic interference and cybersecurity attacks.

The data acquired from the battery pack must also be highly accurate to ensure efficient performance, correct state of health (SoH) and state of charge (SoC) estimates, and quick detection of and reaction to extreme events - for example cells exceeding safe temperatures.

Industry standards and regulations must also be adhered to. For sustainability reasons, the battery pack must be easy to service and software upgradable, and consideration must be given to repurposing of cells for second-life applications, and eventually, end-of-life recycling to enable a circular economy.

Battery pack and BMS designers must therefore employ the most cost efficient and effective hardware design approach to meet these demands. This paper describes three approaches, discussing some of the relative advantages and disadvantages of each.

BMS design approaches

Three different BMS hardware architectures are considered: wired, wireless, and contactless via Dukosi's chip-on-cell technology. Each of the three design approaches measure the battery cell's parameters and communicate them to the BMS host, which then monitors and controls the cells and application behavior based on an analysis of those parameters. The difference between the approaches lies fundamentally in the level at which data is gathered (cell, module, or pack-level), the method of data communication, and the need - for electrical isolation.

Wired BMS solution

A wired BMS is the traditional design approach. In this solution, multiple analog front end (AFE) chips are used as a BMS gateway to the cells, which are grouped together in modules, where each module typically contains between 6 and 24 cells in even numbers. AFEs are used to manage a series of cells up to a typical working voltage of 60-80V. With higher working voltages, creepage and clearance requirements must be taken into consideration during pack design, and special worker safety measures are required during assembly.

The module-level AFE is populated on a printed circuit board assembly (PCBA). The wire harness/leadframe/FPC connects the module's cell terminals to the PCBA, and a lead frame connects the wire harness to the module's cell terminals, as shown below. The PCBA is often housed in a plastic enclosure and secured with fasteners to mounting brackets. This combination of parts is repeated eight or more times to form the HV battery pack. Finally, another wire harness connects the PCBAs to the BMS via an isolated communications bus, such an isolated data chain.

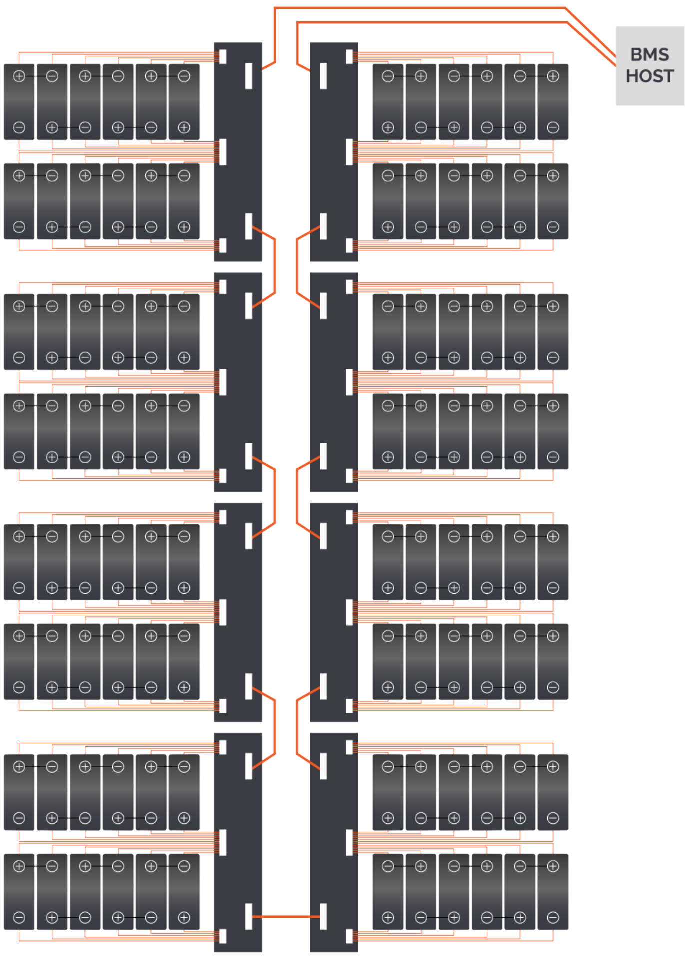

Figure 1: A traditional wired battery design with modularized cell grouping connected to PCBAs, which are respectively wired to the BMS host.

Typical BOM of a 12-cell modular wired BMS design with 8 modules:

- 8 x AFEs
- 8 x PCBAs
- 8+ x sense lead wire harness/FPC bundles
- 8+ x module sense lead frames
- 8+ x PCBA housings
- 16+ x housing retention fasteners
- Wire harness/FPC connecting PCBAs to BMS
- 1 x isoSPI transceiver chipset
- 1 x BMS isolation circuit
- 6 x PCBA isolation circuits

Advantages and limitations of the wired approach

Wired BMS' have been used for many years and are a proven, commercialized technology. Using wires to transmit data means they are potentially less susceptible to interference, signal loss, or cybersecurity threats than wireless systems. With some disassembly, the modules can be lifted out and replaced.

Comparing the voltage readings across cells in a module to the PCBA, versus a monitoring IC being placed on each cell directly, the former will require varying wire lengths to reach each cell, which can result in voltage drops that introduce inaccuracies into the measurements sent to the BMS host. The various sense lead wire lengths act like antennas, causing each to be sensitive to electromagnetic interference at their own tuning frequency. When sense leads cross bus bars, current through the bus bar can induce current in the sense lead, resulting in a voltage offset. These types of topics subsequently affect many functions such as SoH calculation, range calculation, and/or the ability of the BMS to quickly react and take control of any identified event or anomaly. Additionally, the modular approach is designed for optimum scalability in 12s, 6s, or 4s module increments, which constrains the pack's cost efficiency. When large looms of wiring are present, they add weight, and whether wires or FPC's are used, the many connectors are all potential points of failure, which could result in an interruption in function. These potential failure modes may result in the BMS design receiving a high-severity design failure mode and effects analysis (DFMEA) rating, which will require additional, costly, preventative measures. Isolation circuits will be necessary between the PCBAs to prevent electrical breakdown. All the wiring and components add considerably to the BOM cost and weight of the battery pack, and the time and effort needed (manual assembly process) to assemble them during manufacture is significant.

Far field wireless BMS designs

Wireless BMS options have become available in recent years. Like the wired solution, a far field wireless solution still uses AFEs and wires to measure and transmit the parameters from each cell in the module to its PCBA; however, data is then transmitted wirelessly from each PCBA to the BMS host. Far field wireless transmission with direct line-of-sight communication between antennas at the BMS host and each PCBA unit is accomplished by adding a waveguide space between or above modules to achieve line-of-sight communication. The typical working voltage for wireless BMS cell monitoring becomes localized at 60-80V. The wired isolated bus is replaced with a wireless network usually based on a consumer or industrial wireless protocol, and the wireless chipset is paired with an RF antenna designed for use in the enclosed pack environment. If direct line-of-sight cannot be achieved due to pack layout, or signal blockages, a mesh network protocol must be deployed for data-hopping. This in turn can introduce latencies in data transfer to the BMS Host, which can introduce safety challenges to deal with unexpected events quickly.

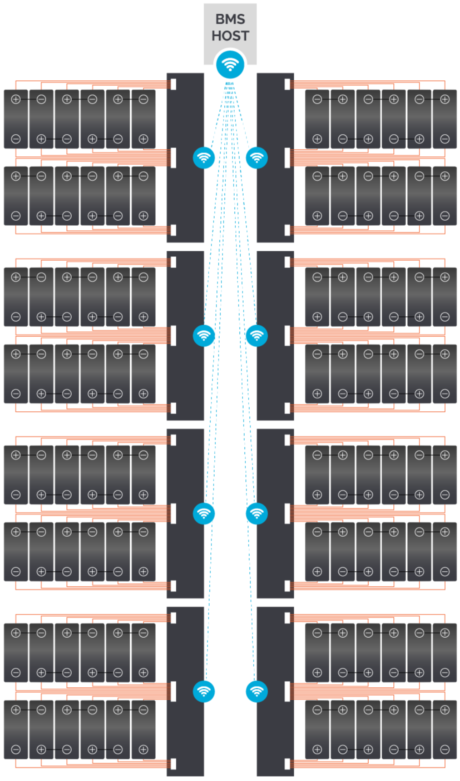

Figure 2: Far field wireless battery design with unblocked waveguide space providing signal Line of Sight (LoS)

Figure 3: Far field wireless battery design with blocked waveguide space requiring mesh network

Typical BOM of a 12-cell modular wireless BMS design with 8 modules:

- 8 x AFEs
- 8 x PCBAs
- 8 x sense lead wire harness bundles
- 8 x module sense lead frames
- 8 x PCBA housings
- 16+ x housing retention fasteners
- 8 x wireless devices on PCBAs
- 1 x wireless device on BMS

Advantages and limitations of the far field wireless approach

The use of wireless communications allows some of the wiring to be removed, reducing cost, bulk, and weight and manual installation steps on the assembly line. The requirement for the isolated daisy-chain communication bus is also removed, which eliminates the need for electrical connectors used for communication, and the ≧ 400V communication isolation circuits. The lower working voltage reduces potential points of failure.

However, due to a likely complex and unpredictable RF environment inside a metal box filled with metal components, pack designers must optimize their designs to reduce signal reflections and mitigate blockages that would cause signal degradation, blind spots or failure. This adds complexity and validation time, which costs time and resources, and any layout changes require new RF engineering efforts and validation. Far field wireless also poses more cybersecurity risks as communication signals can potentially be externally accessible.

Both the direct line-of-sight and mesh network approaches still maintain a typical modular approach of cell configuration, with the same sense lead wire harnesses and lead frames, connecting them from their PCBA to the battery cells, as found in wired solutions. Therefore, despite being referred to as wireless designs, much of the wiring remains, presenting the same issues seen in the wired solution such as measurement inaccuracies, additional weight, cost, and manufacturing complexity at the module level. In addition, if a mesh network is employed it can introduce increased latency to nodes further away from the BMS host making it more difficult to synchronize measurements from all modules.

Near field contactless BMS design

An innovative, alternative architecture using near field contactless communication has been developed by Dukosi. This novel chip-on-cell technology uses dedicated ICs, aka Cell Monitors, mounted directly on each cell to uniquely measure both voltage and temperature parameters at the cell-level.

To communicate the measurement data from the Cell Monitors to the BMS host, Dukosi's solution implements a near field contactless communication system using a single, lightweight and cost-effective RF bus antenna for closely-coupled contactless near field communication with each Cell Monitor. The data is transmitted using Dukosi's proprietary communication protocol, called C-SynQ®, which is designed specifically for large battery packs that require a many-node network in a safety-critical environment. It provides robust communications with essential data synchronization and fixed latency, yet also with the capacity for the battery to be configured with a variable number of cells without additional design overhead.

The bus antenna is located in close proximity (typically a few mm) to each Cell Monitor and can be routed around physical barriers and over the cells in almost any configuration, thus enabling cell-to-pack and cell-to-chassis designs more effectively. It terminates at a dedicated System Hub IC, which is typically integrated on to the BMS host PCB and communicates with the BMS host microcontroller via a serial peripheral interface (SPI).

Communication of data between the System Hub and the BMS Host application is enabled by the Dukosi DKCMS API.

Figure 4: Near field contactless BMS design using Dukosi DKCMS connected to a 3rd party BMS host

Typical BOM of a 96 cell Dukosi Chip-on-Cell design

- 96 x Cell Monitor ICs on mini-PCBAs
- 1 x System Hub IC
- 1 x bus antenna
- 2 x connector pins

Advantages and limitations of the near field contactless approach

Using a near field contactless design, battery pack designers can remove the ≧60V PCBAs with AFEs, the sense lead wire harness bundles and related connector pins, the module sense lead frame, and the isolated daisy-chain communication bus. High voltage creepage and clearance design concerns such as surface tracking and wire short circuits are also designed out. Electrical communication connectors and pins are not required. Even with the requirement for 96 Cell Monitors this can reduce component count by up to 10X, while also improving reliability up to 2X[1], and reducing the overall BOM, cost and weight as well.

Other benefits include intrinsic isolation and, since manufacturers only need to attach a Cell Monitor to a ~4V cell, a safer and simplified assembly process. Assembled cells can be fully tested in an automated way prior to pack assembly. Designers are also freed from the physical constraints of scalability imposed by modular multi-cell AFEs, while improving pack packaging efficiency by not requiring separately mounted cell monitoring controllers and eliminating the need for waveguide space when a far field wireless system is used, hence increasing the energy density per pack.

With a cell-level approach the communications network is a star configuration where latency is low, and constant. This improves data integrity by providing synchronized measurements of all cells in series. Considerably greater granularity in temperature measurements, with one integrated temperature sensor and up to two extra thermistor measurements for each series cell increment (each parallel cell group) is available, improving safety monitoring and allowing the BMS host to react more quickly to an individual cell overheating. The Dukosi System Hub commands every Cell Monitor to take a measurement simultaneously and receives back the full pack's synchronized voltage and temperature measurements. The use of a single bus antenna eliminates the latency and determinism problems seen with wireless mesh networks, which improves the performance, efficiency, and safety of the battery. The Cell Monitors can be used for cell-balancing with either an integrated FET or an external MOSFET (for higher balancing current needs).

Finally, each Cell Monitor includes built-in Flash storage, which can be configured to store each individual cell's lifetime performance data, event logging along with material and manufacturing provenance information. This can be used to identify the real status of each cell for shipping, storage, or analysis for a warranty claim, and later for cell grading in refurbishment and second life applications, and end-of-life recycling.

Comparison of Design Approaches

The following table summarizes the impact of key attributes for each BMS design[2]:

Attribute	Wired	Wireless Line-of-Sight	Wireless Mesh-Network	Contactless near field
Pack size	Baseline	Larger	Larger	**Smaller**
Scalability	Modular	Modular	Modular	**Individual Cells**
Cell Increments	12s-24s	12s-24s	12s-24s	**1s-216s**
HV Isolation	Requires mitigation	Isolated at the module level	Isolated at the module level	**Intrinsically isolated**
Security	**Baseline**	Potential for outside access	Potential for outside access	**Baseline**
Data Storage	At the BMS Host	At the BMS Host	At the BMS Host	**At each cell or parallel cell group and/or BMS Host**
Design & Development	Baseline	Complex (additional RF engineering)	Complex (additional RF engineering)	**Simpler**

Conclusion

Battery technology and their management systems need to keep pace with growing demand for EVs and BESS to enable the transition to a clean energy economy and achieve net zero emission goals. As shared in this paper, the design and configuration of today's EV and BESS battery packs are strongly influenced by the choice of battery management system. Most currently use modular cell designs, which necessitate complex wiring, increased weight, and reduced reliability compared to new, state-of-the-art alternatives. Dukosi chip-on-cell technology is a highly effective enhancement to a high voltage battery BMS. It can create a more reliable, secure, and safe battery pack, while also being simpler and lower cost to design. This is enabled by a flexible architecture that uses individual Cell Monitors and contactless near field communications, among other technical advantages. Unlike traditional design methods, which can limit future battery architectures, the simplicity and scalability of Dukosi's unique technology is a key enabler for next-gen battery pack designs.

[1] Dukosi internal testing

[2] Using a typical industry design

Distribution

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