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Battery Management System Standard

Sandia National Laboratories

IEEE P2686 Recommended Practice for Battery Management Systems in Energy Storage Applications

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Energy Storage Safety and Reliability Forum

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U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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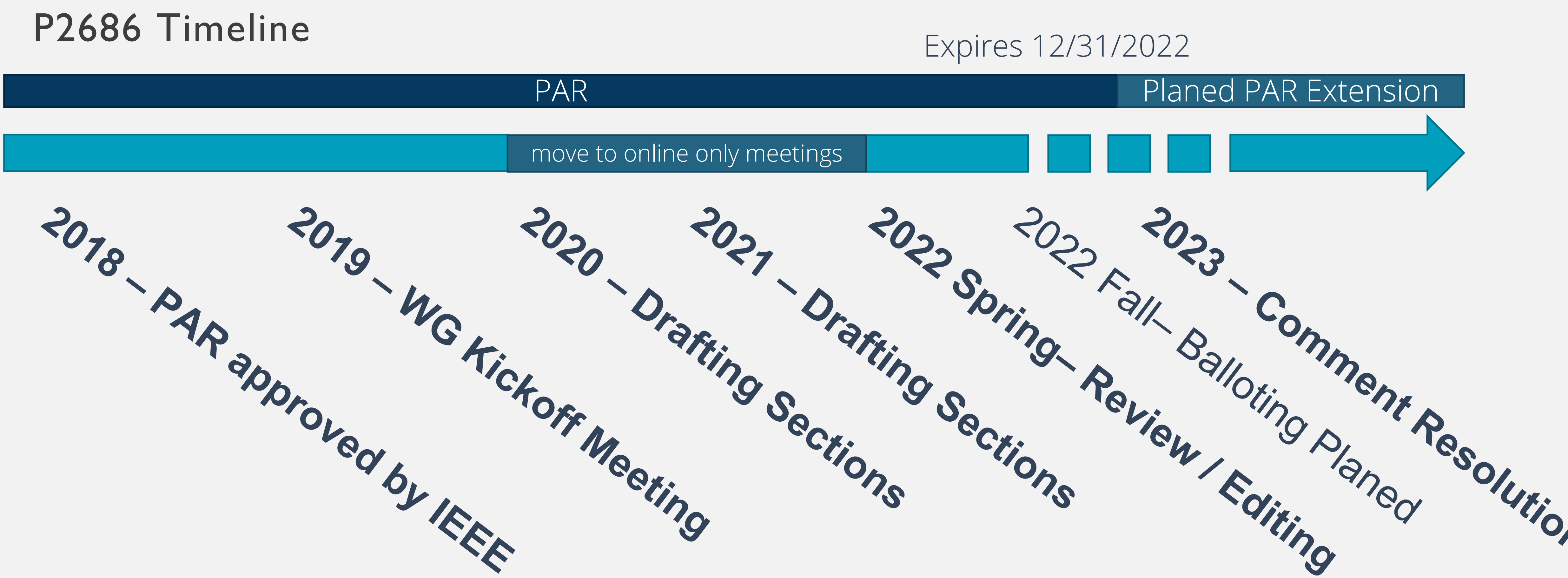
Purpose (UNDERGOING REVISION)

Well-designed battery management is critical for the safety and longevity of batteries in stationary applications.

- **(Battery Life)** New batteries have been developed recently that provide high performance at low cost but require precise management.
- **(Battery Safety)** Without established best practices in battery management design, industry confidence in its ability to prevent accidents could begin to erode.
- **(Interoperability)** Without basic standardization of interoperability, information exchange, information models, and protocols, system integration can be difficult and costly.

This [Recommended Practice] aims to address these gaps in the design, configuration, and integration of battery management systems.

Standard Development Timeline



Covid-19 resulted in a slower process (roughly a 6 month delay) but wider participation.

Document Structure and Progress

Battery Management Fundamentals

What is a battery management system? What is it designed to do? This section outlines how the BMS design and integration process should be conducted and guides the reader on how to navigate the rest of the document.

Hardware, Software, Devices and Functions

What are the physical and communication architectures of modern battery management systems? What are their functions? This section discusses a range of design options for the BMS.

Battery Management Configuration

If you have a X battery providing Y services, how should your BMS be configured? This section offers recommendations on the architectures and functions that should be used based on application and battery type.

Communications and Interoperability

What data should be BMS make available to the ESMS? How long should the BMS sore data internally? This section provides recommendations on design choices around communications and interoperability.

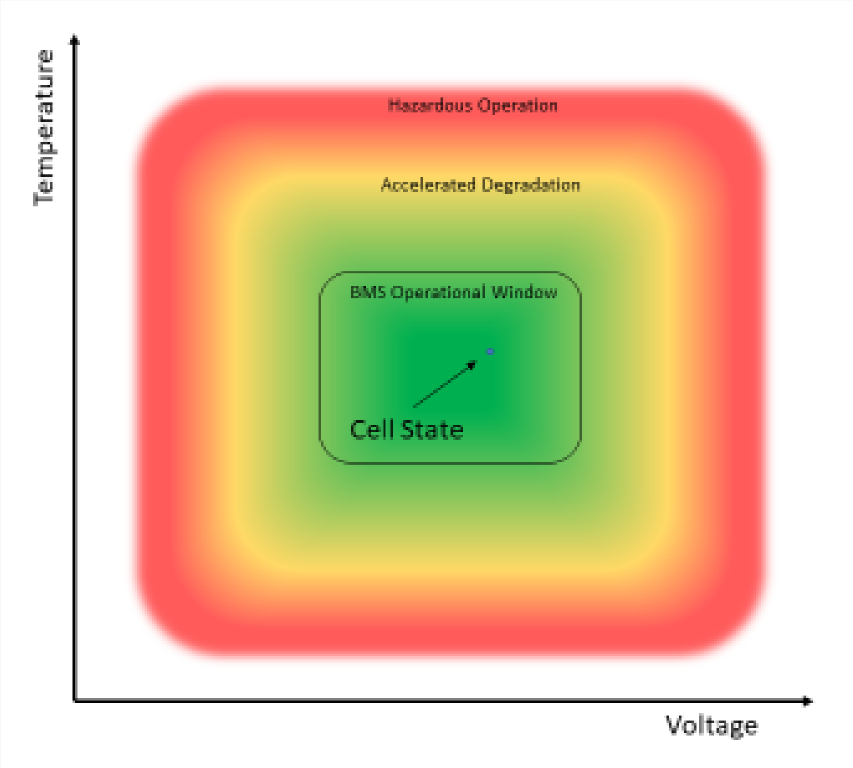
- 16 online working group meetings were held in FY21, averaging 16 participants per meeting (max 25, min 11) with 49 of 120 working group members having attended at least one meeting.
- Working group members represent critical stockholders form suppliers (e.g. SAFT, Deka Batteries, Zinc 8 Energy Solutions) to testing labs (e.g. CSA Group, Exponent, UL) and utilities (e.g. Southern Company, National Grid). Membership spans Asia, North America, and Europe.
- We have progressed through two major revisions from version 2 to version 4.
- We have restructured the introduction, revised the technology description clause, and flushed out both the configuration and communications clauses.
- We have built consensus on controversial topics such as reporting state-of-charge and how to designate the responsibilities of the BMS holistically with other safety devices.

What does a BMS do?

The IEEE Standard Glossary of Stationary Battery Terminology defines BMS as:

A system that includes active functions necessary to control activities such as charging, discharging, thermal management, and safety.

The main purpose of a BMS is to protect the battery, preserving operational safety and longevity.

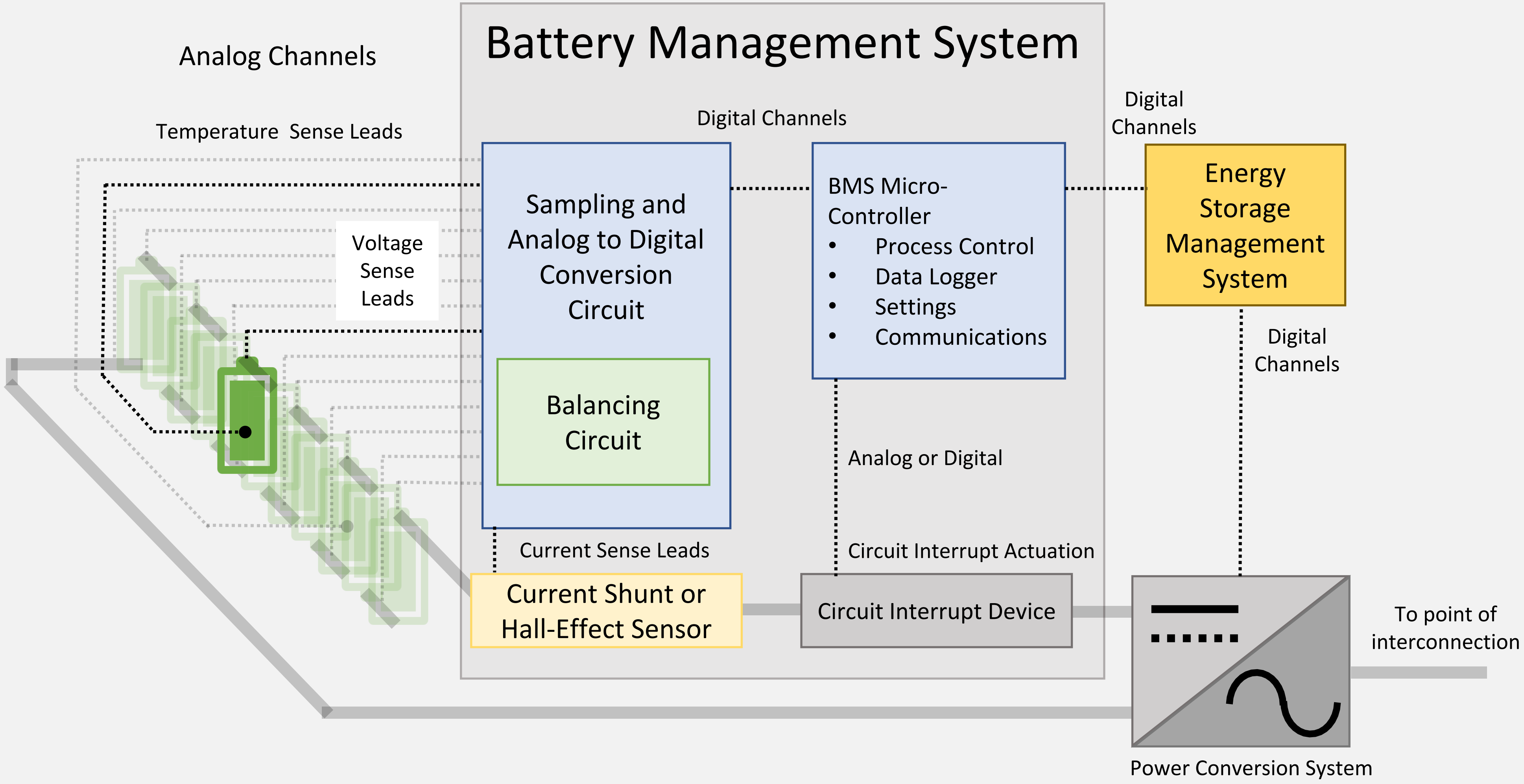


Example safe operational area (SOA) enforced by a BMS

Battery Management System Hardware, Software, Devices and Functions

Peripheral devices and subsystems

- Inverter / charger
- Sensors
- Circuit interrupt device
- Balancing circuit
- Many more …….



Battery Management Configuration

Different battery systems have different battery management needs. Some battery types are more sensitive to abnormal operating conditions than others. Because of this, battery management systems need to be configured by both anticipated use (application), and battery chemistry/formfactor (type).

Configuration by Application

The primary distinctions in the configuration of a BMS between applications is the prioritization between power and energy requirements, the number of cycles to be supplied, and the design life.

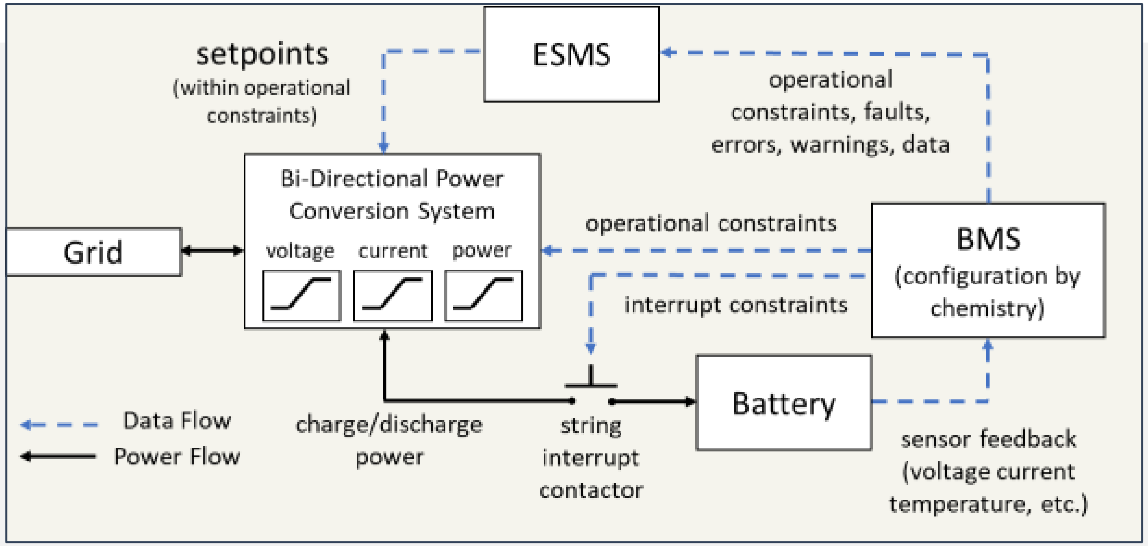
Configuration by Battery Type

The environmental and operational limits for batteries can generally be found on the manufacture's specification sheet. Generally, these limits are based on the material properties of battery and on testing to determine the rate of degradation under different operational conditions.

Configuration by Application

Grid supporting

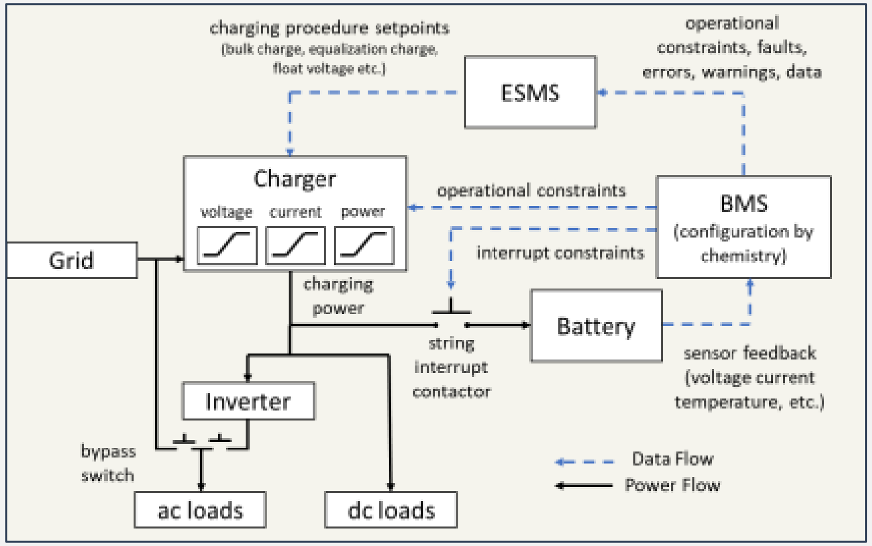
A commonality of almost every grid supporting application is that **the value derived from any one cycle is much less than the capital cost of the energy storage asset.** Because of this, the BMS in such applications is designed to preserve the battery's life above achieving a specific power setpoint.



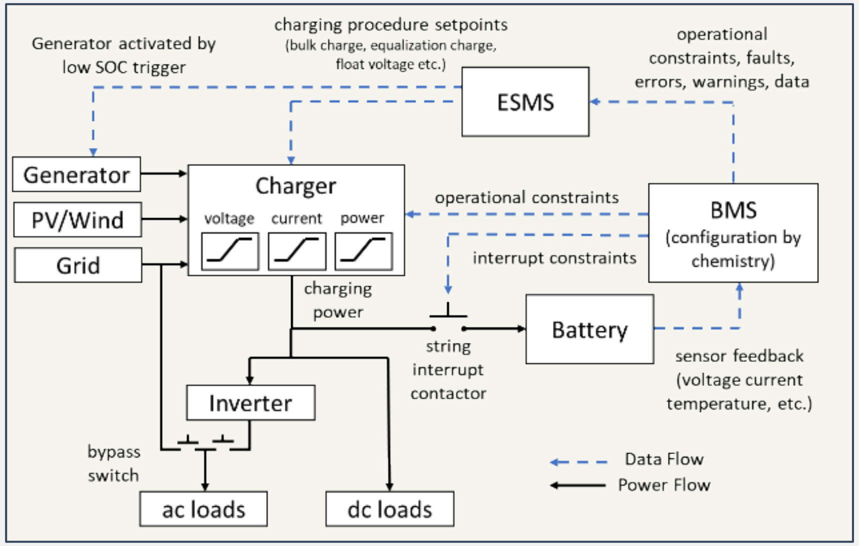
Grid supporting

Non-Grid Supporting

Non-grid-supporting applications generally fall into two categories: standby applications, where the battery system operates only when supply from the grid fails; and off-grid applications, in which the battery system is frequently operated in conjunction with a renewable-energy source, such as a photovoltaic system, and may be paired with a fossil-fueled generator.



standby applications



off-grid applications

Configuration by Battery Type

Lithium-ion battery systems should implement the following battery management functions:

Voltage management

- Functions: over voltage and under voltage
- Operational constraints: maximum cell voltage, minimum cell voltage,
- Interrupt constraints: trip max cell voltage, trip min cell voltage
- Notes: This is safety function. It should be implemented on each cell in the system.

Current management

- Functions: excessive discharge current and excessive charge current
- Operational constraints: max discharge current, max charge current
- Interrupt constraints: trip max discharge current, trip max charge current
- Notes: This is safety function. It should be implemented on each string system. Parameters can be adjusted based on temperature and SOC. This function is in addition to short-circuit overcurrent protection that should be implemented in each module with an appropriately sized circuit breaker or fuse.

Charge management

- Functions: Overcharge, Overdischarge, and unbalanced charge
- Operational constraints: max soc, min soc
- Interrupt constraints: trip max soc, trip min soc, max imbalance
- Notes: This is a safety and longevity function. The BMS supervises the ESMS to provide redundant overcharge protection. Cell charge balancing is an important BMS function for most lithium-based chemistries.

Temperature management

- Functions: Overtemperature and undertemperature
- Operational constraints: max temperature, min temperature
- Interrupt constraints: trip max temperature, trip min temperature
- Notes: This is a longevity function. The battery system should be designed to be robust to failures of the thermal control system, such that the thermal control system is not essential to the safety of the overall system.

Lithium ion battery systems may implement the following battery management function: thermal runaway vent-gas management

Communications and Interoperability

Measurement accuracy

This section describes the recommended minimum measurement and calculation accuracy recommended for battery management. These minimums apply to the data acquisition layer of the real-time control computation stack discussed in Section 5.2.4.1. Some BMS applications will require much higher accuracy or sample rates then those specified here.

Battery energy storage recommended minimum measurement and calculation accuracy recommendations for manufacturers

Parameter	Minimum measurement accuracy	Measurement window	Range
Cell voltages	± 10 mV (8 bits/cell)	200 ms	0–5 V
Module voltages	(± 1% V_{nom})	200 ms	(module voltage)
String voltages	(± 1% V_{nom})	200 ms	(string voltage)
Cell/module temperatures	± 0.2 °C	1 s	-40 – 80 °C
Current	(± 2% I_{rated})	200 ms	-
Power	(± 2% P_{rated})	200 ms	-

BMS Cybersecurity

The planned revisions to IEEE 1547.3 were reviewed and mapped onto what is needed in a BMS. The role of the BMS in cybersecurity is to have specific features that enable cybersecurity at the network and organizational levels.

Physical security: Physical security can be a critical element of cybersecurity.

Physical access to an installed BMS, as well as the network it is connected to, should be controlled by barriers, locks, or other access control measures

Access control: This section provides recommendations for access control for users.

Password requirements, assigned permissions, and roll based access control (RBAC) are covered.

Software update management: Software/firmware updates can enable additional features and algorithmic improvements in deployed systems. Updates can also enable the correction of software bugs and cyber-vulnerabilities. However, the software update process can also itself be a cyber-vulnerability and so care should be taken in how updates are performed.

Conclusions

- Well-designed battery management is critical for the safety and longevity of batteries in energy storage applications.
- Standardization will help engineers navigate design options and owner's know what to expect from the BMS.
- The P2686 working group is a global effort with membership from a large range of institutions.
- We are on track to publish a completely new BMS standard in 2023.

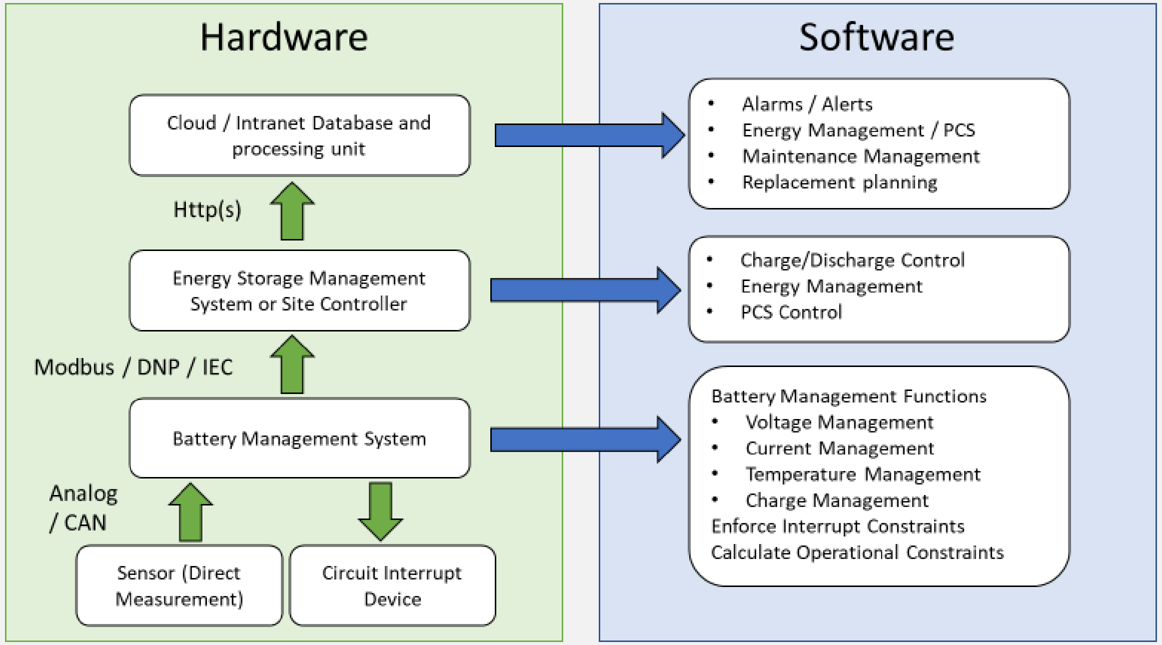
Funding for me to be able to serve as the working group chair was provided by the DOE OE Energy Storage Program. Thank you to Dr. Imre Gyuk for supporting the development of energy storage technology and safety standards.

If you have knowledge of BMS design and would like to participate in the P2686 WG, please email me at dmrose@sandia.gov, and join us for the next digital working group meeting.

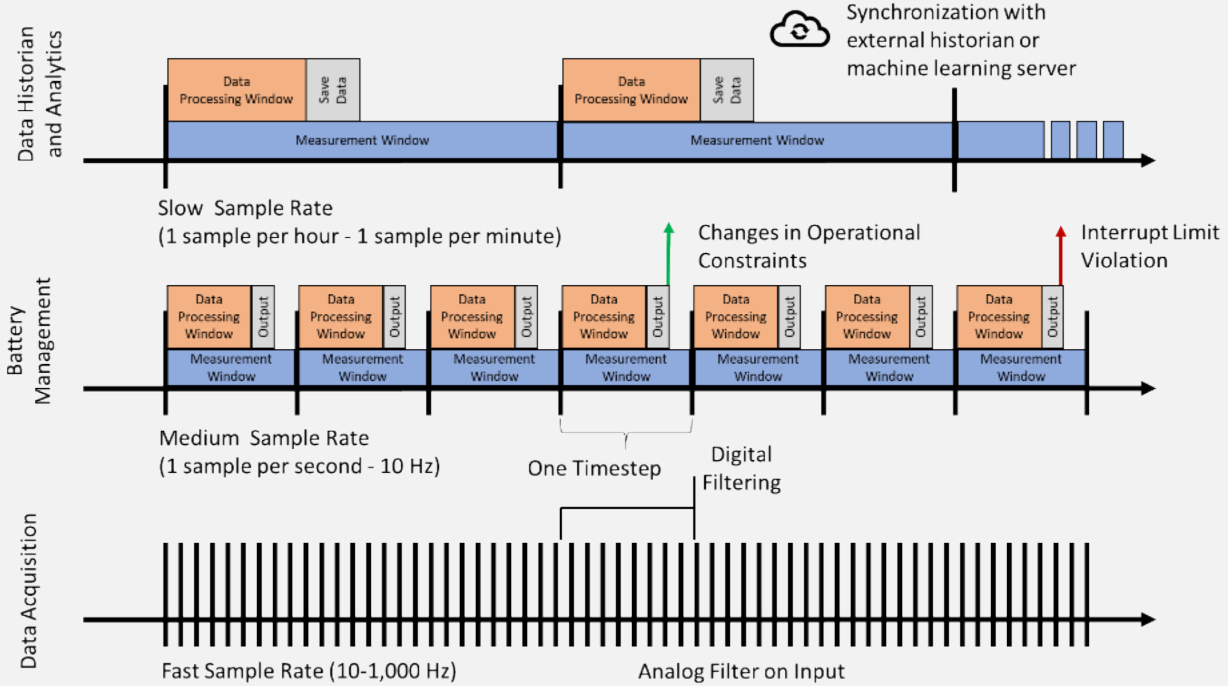
Backup Slides

Battery Management System Hardware, Software, Devices and Functions

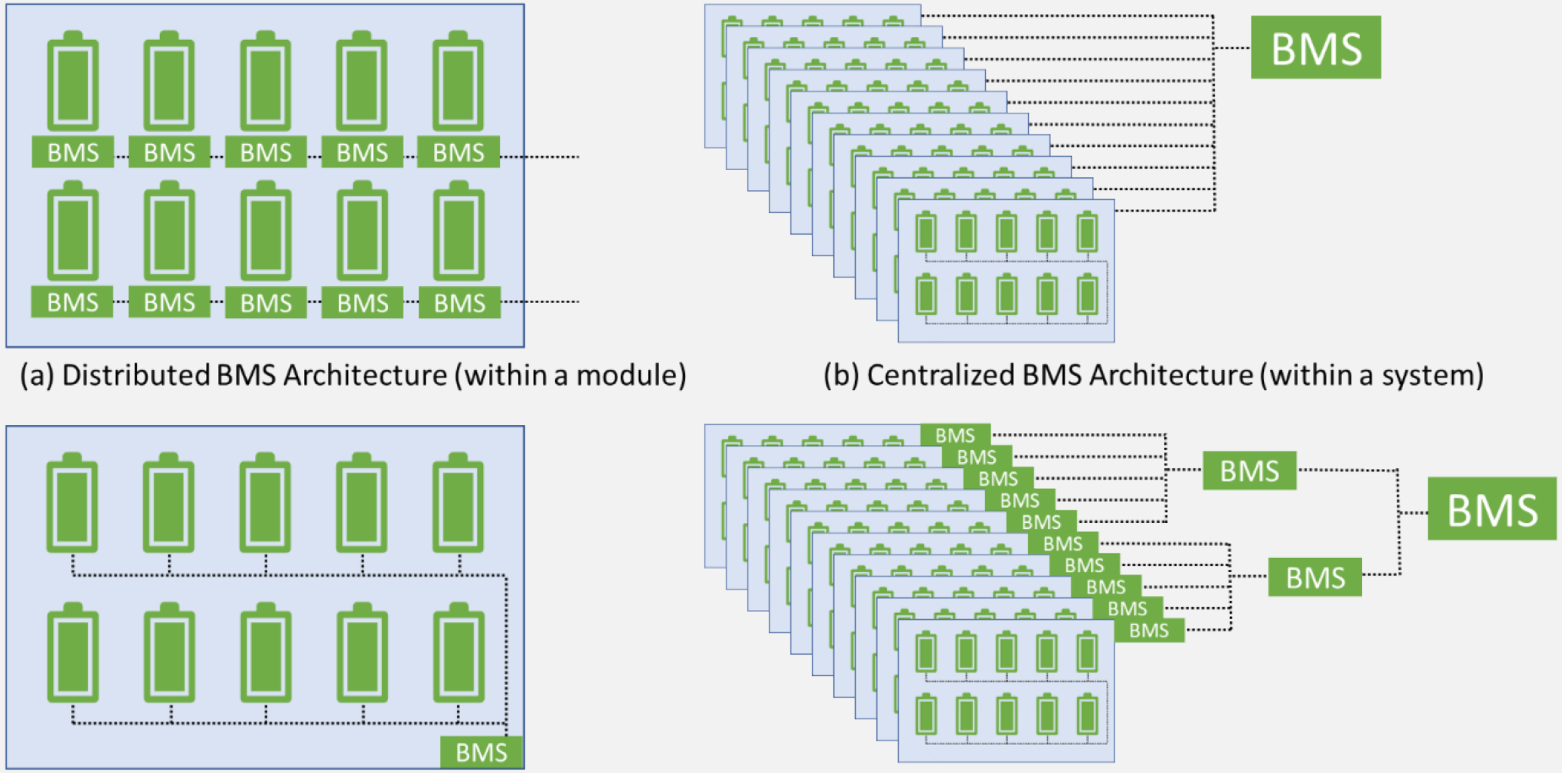
Software architecture layers for battery management



Real-Time Control Computation Stack



Battery Management System Hardware, Software, Devices and Functions



(a) Distributed BMS Architecture (within a module)

(b) Centralized BMS Architecture (within a system)

(c) Centralized BMS Architecture (within a module)

(d) Modular BMS Architecture (within a system)

Physical architecture

Battery management can be structured in a variety of ways. The figure shows a range of example physical architectures for battery management within modules and systems. Note that the terminology is context-dependent, so modules can have a "centralized" BMS within a "modular" system architecture.

"The physical architecture of the BMS should follow the physical architecture of the battery it serves."

Internal Data Historian Aggregation / Compression

One of the challenges for managing battery energy storage system data is that the number, frequency, and precision of all the potentially relevant data are such that data storage and processing are expensive and time consuming.

- An on-board record of errors, faults, and warnings should be retained for the life of the battery
- To save memory, the BMS historian may be configured to record only changes in values, or changes in the trends that values are taking, rather than recoding values on a specified schedule.
- There is sometimes a need for all data produced by the BMS to be recorded such as during certain performance tests. Generally, these data are recorded separately from the BMS historian in a discrete memory location or even in an external device such as the ESMS.

Recommended Steady State Data Retention Periods and Sample Rates

Data Name	Retention Period (recommended minimum)	Sample Period (recommended minimum)	Estimated On-Board Memory (based on double precision variables)
Cell/module voltages	30 days	1 sample / min	345.6 kbytes per cell (1,036.8 kbytes with short-board[b] method)
Module voltages	30 days	1 sample / min	345.6 kbytes
String voltages	30 days	1 sample / min	345.6 kbytes
Cell/module/ambient temperatures	30 days	1 sample / min	345.6 kbytes per sensor (1,036.8 kbytes with short-board[b] method)
Cell resistances [a]	For the life of the battery	1 sample / day (at the same SOC and T if possible)	29.2 kbytes per 10 years per cell (87.6 per 10 years with short-board[b] method)
Current	30 days	1 sample / min	345.6 kbytes
Power	30 days	1 sample / min	345.6 kbytes
Aggregate State-of-charge (SOC)	30 days	1 sample / min	345.6 kbytes
Aggregate State-of-health (SOH)	For the life of the battery	1 sample / day	29.2 kbytes per 10 years

[a] Lithium-ion battery systems may not record cell resistances
[b] For purposes of data retention efficiency, the "short-board" method can be used. This refers to recording only three values per string: max cell value, average cell value, and minimum cell value. If this method is used, then the number of series cells/string should be specified. Further, integer values corresponding to the cells that the maximum value and minimum values were recorded from should be recoded along with each measurement.