High capacity battery packs

BRENT PERRY – Energy storage and battery technologies are developing rapidly. There is a clear trend of integrating batteries in marine electric systems due to the additional benefits of energy storage for electric propulsion.

Energy storage will typically provide a supplementary source of energy in the electric plant that can enhance energy efficiency when used together with diesel engine sets and offer backup power supply for increased safety, although designs are also being developed that use batteries as the main or sole energy source. It is expected that greater attention to fuel efficiency and fault tolerance in design and operation will create an increasing demand for battery use in marine electric propulsion systems in the years to come.

Generations invited Corvus Energy, a company specializing in designing and manufacturing high capacity battery packs, to show their recent developments in battery technologies and battery management and to share their experiences on marine applications.

Introduction

Battery technology is taking a new place in industrial applications, with the focus on increased performance, cost, safety and quality. What was once a promising technology has become a working product that can both optimize and in some cases replace fuel-driven engines, while expanding operational flexibility for operators. Today, it is possible to build successful battery systems that scale from 2.5 kWh to multi MWh.

Applications include hybrid and electric drive lines, dynamic positioning systems, large-scale uninterruptable power supply (UPS), emergency generators and multisized house systems; all engineered to meet the physical needs of some of the most rugged applications in the most challenging environments. This article is intended to follow the path, which led Corvus Energy to choose nickel manganese cobalt (NMC) chemistry as ideal for use in marine applications.

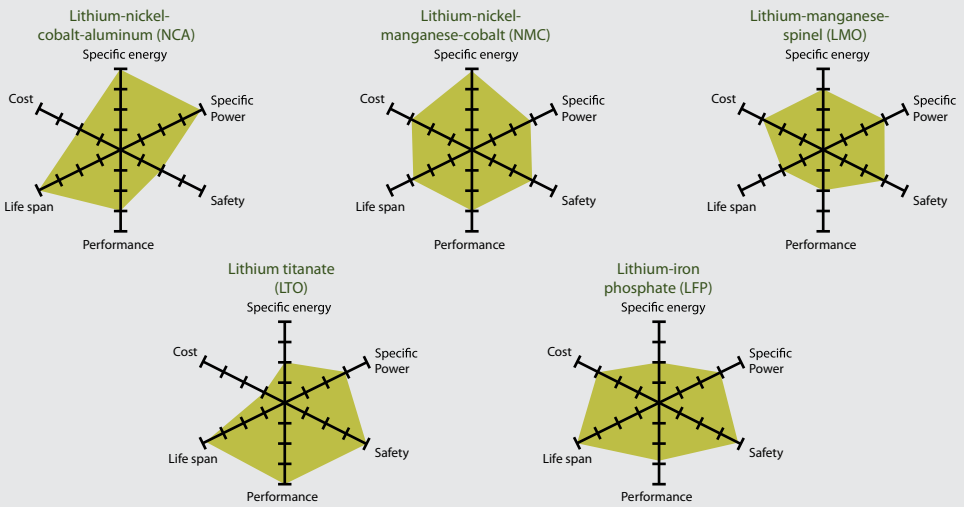
Corvus Energy's story is different from most battery companies today with background from boat building and marine engineering. The company's goal is to integrate actual energy-based products into systems and to deliver turnkey, "killer performance" solutions that exceed customer expectations and offer payback within one to five years, with up to 20 years of operational savings available to the clients.

Product overview

The marine industry is unique in its demands when it comes to an efficient battery system. The battery system has to:

- Be independent of any supporting systems, such as active cooling or heating, ventilation and air conditioning (HVAC)
- Deliver high output power and energy without developing high temperatures
- Offer very long life
- Offset the cost of the system in no longer than five years through reduction of fuel cost, maintenance, and service savings, compared with existing choices
- Maintenance free, IP67 rated enclosure
- Meet the demands of rugged environments, specifically those involving exposure to salt, temperature and humidity

1 There are trade-offs among the five principal lithium-ion battery technologies



Source: BCG research.
Note: The farther the colored shape extends along a given axis, the better the performance along that dimension.

– Interact with ship systems as today a smart battery must communicate and function in a fully integrated way to achieve best value performance.

The battery

There are four basic principles involved in delivering a successful battery, with each element needing to focus on safety, reliability, and quality.

1. Cell chemistry and construction
2. Battery management system
3. Battery engineering
4. Service and support

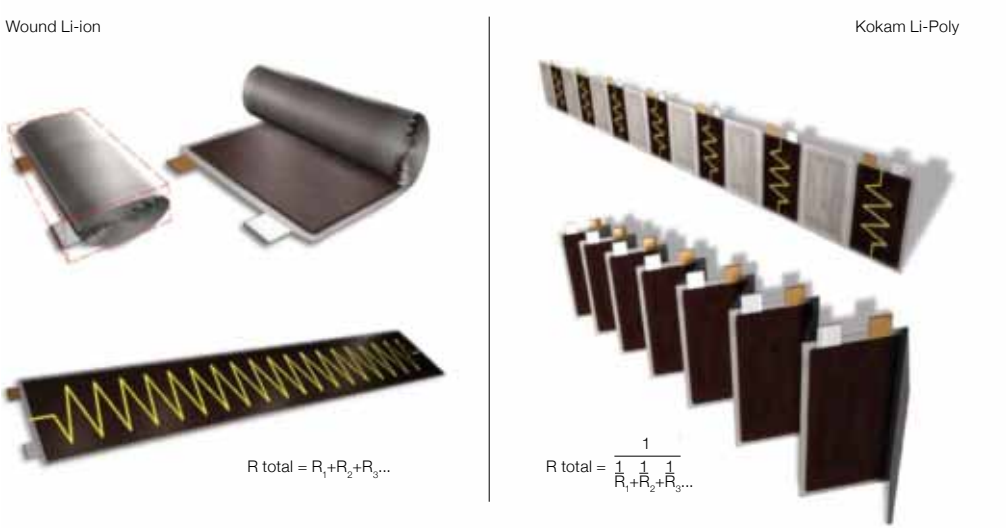
Cell chemistries

Chemistry is the bedrock of the new battery age. After years of testing, Corvus Energy focused on the impact that lithium brings to the market. The company chose lithium NMC as the underlying chemistry due to its superior performance and life, where it has proven to be the best overall choice for large-scale marine applications.

There are several lithium chemistries that are usable in commercial industrial applications, and each has specific benefits and uses, different life characteristics and safety features. In the journey to select the best lithium for the marine industry, Corvus Energy chose from those in Figure 1.

It is expected that greater attention to fuel efficiency and fault tolerance in design and operation will create an increasing demand for battery use in marine electric propulsion systems.

2 Wound (rolled), prismatic and Z-fold Li battery cells



The NMC cells produced by Dow Kokam demonstrated the best of all characteristics.

Of the choices available, NCA was deemed unstable or not safe enough. LMO did not offer enough life span. LTO did not meet Corvus Energy's energy/power density criteria, and LFP involved too much manufacturing risk to be incorporated into big pack technologies, which have scalable risk factors.

NMC met the energy/density requirements (the highest energy/power density commercially available), safety requirements and manufacturing risk requirements. The NMC cells produced by Dow Kokam demonstrated the best of all characteristics: a reliable cell-to-cell manufacturing process that demonstrated consistent performance matching technical data sheets, the fewest connections required, the highest charge/discharge efficiency in existence today, excellent energy density, very safe chemistry (that is, if the chemistry fails it will be a benign failure) and very repeatable manufactured quality.

Cell types

There are three principal types of cells: wound, prismatic (formed wound into rectangular shapes) and Z fold (layered by use of aligning film).

Wound cells (the most common cells, principally LFP or iron phosphate) are typical cylindrical cells that come in the shape similar to an "AA" battery (18650) or a "D" cell (26650). The cylinder "can" is made up of nickel-plated steel with positive and negative

electrode connections at either end. These cells are interconnected within a pack by welding nickel-plated tabs to either the positive or negative electrode connections of the cell. For higher current applications, the nickel electrode connections and tabs show much larger impedance than aluminum or copper.

These cells are excellent for use in small scale applications, where they are manufactured in a cost-effective way to a high level of quality, such as laptops, typically with lower continuous discharge/charge rates.

The weakness of this fundamental design is the drop in charge/discharge efficiency (increased impedance) as pack size grows, tied to thermal management risks/added costs where high power and fast charge are critical. They will be dependent on active cooling and heating systems and require environmental controls when in use in the marine industry, raising service issues and associated capital/maintenance costs.

These cells are best used in applications characterized by low energy need (best under 3 kWh capacity) and where small overall capacity is required.

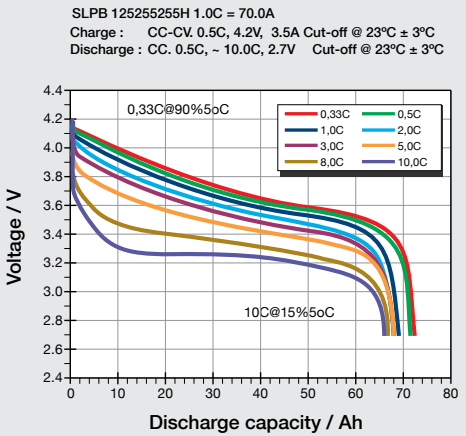
Prismatic cells are wound cells that are formed into rectangular or square cells, such as cell phone batteries. These cells have the same effective performance characteristics as wound cells, with the added issue that the forming process produces a strain on the anode and cathode at the rolled ends, which leads to uneven cooling/aging of the battery itself.

The thickness of the cells also means that they will store heat more effectively and take longer to cool/reduce the heat generated when configured in a pack. Corvus Energy determined that limitations on discharge and charge, and heat management, coupled with the risk of having so many cells in use, meant there were too many factors ranged against achieving successful integration into large-scale packs.

When it comes to Z fold cells, NMC cells are assembled using “Z fold” technology, where the cells are layered until the energy capacity has been met. The cells are then bonded to the master anode and cathode, which means that there are only single anode and cathode connectors at the summary point of the cell.

The advantage of this, beyond reducing connections (two versus as many as 80 using small independent cells), is that Corvus Energy has also developed a

3 Discharge characteristics for NMC cells



Chemistry	Lead acid (AGM)	Sodium nickel chloride	Lithium iron phosphate	Corvus lithium NMC
Nominal voltage	2.0V	2.58V	3.20V	3.70V
Maximum voltage	2.60V	2.9V	3.60V	4.20V
Minimum voltage	1.50V	2.0V	2.30V	2.75V
Energy vensity	20 Wh/kg	100 Wh/kg	129 Wh/kg	163 Wh/kg
Power density	75 Wh/l	150 Wh/l	255 Wh/l	320 Wh/l
Cycle life (80% DOD)	200	1000	>1500	>4000
Internal impedance	>20 ohms	150 milliohms	3 milliohms	0.5 milliohms
Initial cost1	$200/kWh	$800/kWh	$1,000/kWh	$1,100/kWh
5 Yr cost2	$1,750/kWh	$1,400/kWh	$1,166/kWh	$1,100/kWh
10 Yr cost2	$3,500/kWh	$2,800/kWh	$2,333/kWh	$1,100/kWh

thermal fuse at the anode, a safety feature not available when using wound or prismatic cells. From the thermal point of view, the Z fold is superior to all other forms of manufacture because instead of increasing resistance and impedance through an increase in capacity, it is actually reducing it, leading to a critical efficiency gain in terms of charge and discharge and consequent heat reductions. Because it is possible to clamp these tabs, there is also no risk of weld shear at the point of contact. Overall, Z fold cells are the best product available worldwide for use in large-scale packs and are ideal for our architecture.

A Corvus Energy's module has a capacity of 6.5 kWh and uses 24 cells. Using wound cells, more than 750 cells would be needed to develop the same capacity. Taking into account all chemical, software and manufacturing considerations, NMC cells have proved to be the safest and most reliable ones and are ideal for use in the marine industry. The fact that they are designed to incorporate up to 10C discharges (that is, 10 times the battery capacity) and can charge at 2C (30 minutes maximum to full charge) means that it is possible to deliver power that is equal to fuel driven motors and starts any machinery.

Key fundamental considerations after determining chemistry and manufacturing method are:
Voltage – The lower the operating voltage of the cell, the more cells are required to attain the necessary pack voltage. For example, a 320 volt pack will require 160 lead acid cells in series or 124 sodium cells in series or 100 iron phosphate cells in series. Corvus Energy's NMC cells will require only 86. The lower number of cells means lower interconnections between cells and less potential for failures.

Energy density – a higher energy density cell will yield longer running times than a lower energy density cell or the same running time with a smaller pack (this has an impact on the size, weight and cost of the pack).

Power density – a higher power density will mean that it is acceptable to receive and deliver higher current surges. This has an impact on size, weight and the cost of the pack.

Cycle life – There is a direct relationship to the overall cost, including cell costs and battery replacement costs.

Internal impedance – Directly related to cell chemistry and to the quality of manufacture. Lower cell impedance permits the cell to be safely operated at higher charge/discharge rates.

Lower Cost –The technologies with the lowest initial costs do not necessarily offer the best through-life economy.

The battery management system (BMS)

The battery management system is the "brains" when it comes to the performance and the life span of any technology based battery.

Typically, a BMS is developed to meet a single need, such as a laptop or a phone. In the marine industry, a multiple platform solution that is flexible but delivers industrial level consistency and performance was needed. This has been delivered by developing best in industry measurement and control tools that are specifically focused on safety, quality, reliability and lifetime performance. Using active monitoring, the battery management system reports both performance and out of parameter performance. Data is immediately directed “up the line” in the communications chain to all in the system.

Safety

Safety is the most important requirement in a battery pack. The BMS is responsible for ensuring that all operating functions of the pack are maintained within a safe window. This is demonstrated by the amount of redundancy that is available to the operator within the system. Each segment is isolated from one function to the other, with redundant processors in place to prevent an immediate failure taking the BMS down.

Even in the case of a dead short the BMS is robust enough to maintain shutdown functionality and communications to the ship.

Another safety feature of the Corvus Energy’s system is its redundancy. Because uptime is critical, the design works in the following way:

– Voltage is determined in series, up to 1058 VDC (string)
– Energy is determined by how many strings are in parallel

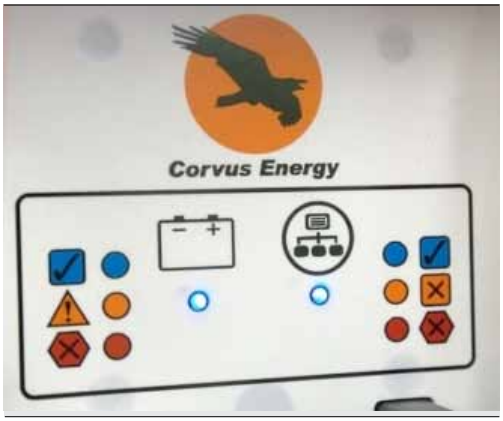
The architecture ensures a high level of redundancy, while allowing the shutdown of a single pack (in the case of module failure) without removing the balance of the system from the DC bus so that the system stays live and functional while the malfunctioning pack is “hot-swapped” out of the application.

Service and support

Uptime in any Industrial application is critical, and Corvus Energy ensures through training, monitoring and on-site support that the customer is working at peak efficiency.

A battery pack can be supported over its lifetime (up to about 20 years) to ensure that it matches the requirements for the original application and any changes to use of the vessel.

4 Battery On Board physical status panel

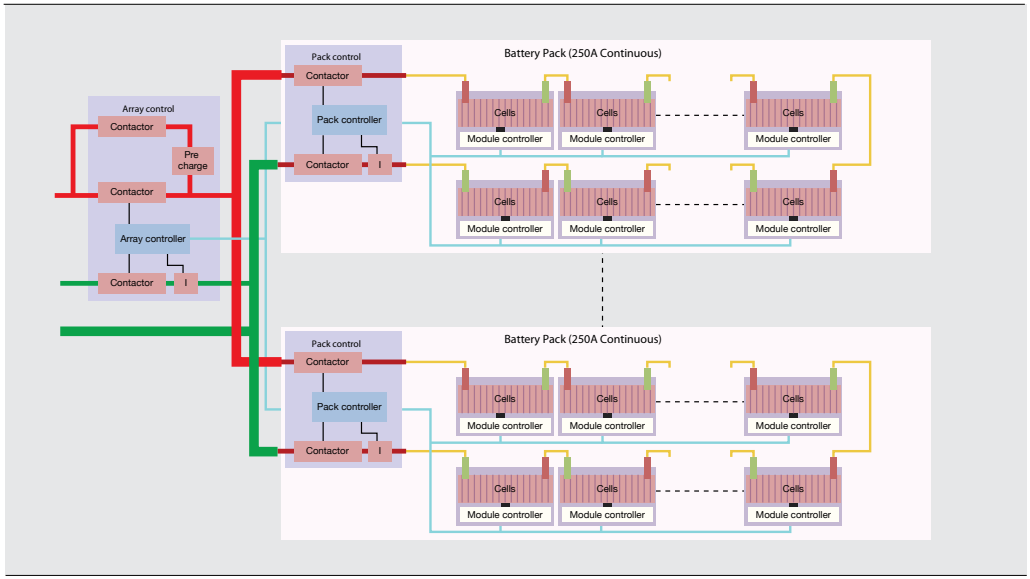


BMS

The term BMS encompasses both hardware and software and effectively manages the following features:

– Operating and storage temperature
– Operating cell and pack voltage
– Charge and discharge
– Depth of discharge
– Accurate energy gauging
– Effective communication of data inside or outside the pack
– Safety parameters and alarms
– Duty Cycle Programming
– Scalability in voltages from 12 to 1058 VDC
– Scalability of energy, from 2.5 kWh to multi-MWh
– Remote monitoring and programming
– Prevention of over and under voltage of every cell
– Prevention of overcurrent in the pack
– Prevention of over and under temperature of every cell

5 Redundant architecture



Recyclability

Today, being accountable for one's lifestyle is becoming more and more important. Customers can count on the fact that Corvus Energy's batteries are 99 percent recyclable; the company will take the batteries back on completion of life to perform this service.

Conclusion

In a high capacity battery pack (≥ 1 kWh), the pack is only as good as its weakest part. A weak cell, a malfunctioning BMS or a poor interconnection will cause a premature fault within the pack. In the case of a cell phone or a laptop computer, a premature fault will cause, at the most, brief inconvenience and a small replacement cost. In the case of a battery pack ≥1 kWh, the replacement cost will be quite high and the downtime of the battery-powered equipment can be significant.

Cell, BMS and manufacturing quality, as well as a commitment of service, are essential for high capacity battery packs. All of these components must work together so that the engineering solution specific to the marine industry delivers a long-term, reliable contribution to the success of Corvus Energy's customers. Externally, this demands that outside bodies such as Lloyd's Register, CE, Det Norske Veritas, ABS, GL, RINA, UNT, ATEX, etc.. give formal approval of the technology in order to validate the product, the process and the performance.

Brent Perry
Corvus Energy