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Full Electric vs Hybrid – Refit and Newbuild Design Considerations

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SYNOPSIS

Hybrid solutions have now been accepted as mainstream propulsion technology in a variety of vessel types, due to their increased efficiency and lower operating costs. However, most systems today are being sold with a 10-year or more lifespan. Designing a battery to meet a 10-year mission is difficult due to the variety of different discharge rates and other variable criteria that must be accounted for. This leads to a tendency for the system designer to oversize the system capacity and ensure the batteries stay within 'gentle use' parameters. This paper will address the technical considerations for reducing battery size and battery re-coring. Operational profiles which are best suited for the use of this technology and safety considerations will also be discussed.

INTRODUCTION

Tugboats are optimised to pull hard, with large engines providing the bollard pull to direct and secure the largest of ocean-going vessels. Most of the time, tugboats are not engaged in their heaviest work, instead spending large amounts of time in transit, holding position or at the dock, with low load conditions making their large engines inefficient and increasing the amount of pollution produced. This inefficiency is easily corrected by battery hybrid propulsion. As such, this is an appealing choice for vessel owners – typical hybrid tugboats have been shown to reduce fuel consumption by over 20 per cent, with pollution savings in the same range or greater. A battery hybrid solution also provides redundancy of drive power, thus enhancing safety for the entire vessel.

However, many of these systems have been sold with a 10-year or more lifespan warranty. Designing a battery to meet a 10-year mission is difficult due to the variety of different discharge rates and other variable criteria that must be accounted for. This leads to a tendency for the system designer to oversize the system capacity to act as buffer of sorts and ensure the batteries stay within 'gentle use' parameters to optimise lifespan and protect from warranty claims.

As a result, there is a trend to reduce system design life warranty to five years, with the following effect: batteries that work harder, have a smaller size, a lower weight, and reduced capital cost for both hardware and installation. This creates a faster path to financial payback, on a system that fits into the vessel better, while still providing all the financial and safety benefits.

THE HYBRID TUGBOAT

Tugboats have extraordinary requirements for immediate power, endurance, robustness and safety in order to maintain their operational duties in all weathers. A tugboat requires powerful bollard pull capabilities, and in general excellent sea keeping abilities to withstand wind, waves and currents. However, studies have shown that during harbour towage, 100 per cent of full load (maximum bollard pull) on the main engines is used for only 2 per cent of a tug's operating life[1], leading to very poor fuel consumption and excessive exhaust emissions. These inefficiencies have opened the door to battery hybrid system integration.

HYBRID TUGBOATS – ENERGY STORAGE SOLUTIONS

Hybrid systems offer more flexibility for dynamic operational profiles. Modern lithium-ion energy storage solutions are capable of providing high power for extreme conditions and demanding situations. The energy storage solution can respond much faster than diesel mechanical solutions to changing weather or conditions. The response time is in milliseconds, and allows the system to shave peaks as they happen, decreasing wear and tear on the engines and reducing fuel consumption. Batteries provide a 'bridge', optimising generators and reducing low load operation. This offers instant spinning reserve and clean, quiet low speed propulsion and horsepower. The result is decreased fuel consumption, air pollution, noise and maintenance costs. Today's energy storage solutions are particularly suited to meet the demanding operating conditions and power requirements of hard working service vessels.

When used on a tugboat, the energy storage solution is charged using shore power overnight. The vessel will transit through the harbour on battery power, operating in zero emissions mode. When high-speed transit is needed, the diesel engine/generator takes over. Many vessels have hours of waiting and loitering on standby, and this low speed loitering, in a typical system, is done using an inefficient load cycle for diesel engines. Inefficient loading leads to increased maintenance and reduced engine life. In a hybrid, this part of the operational profile is powered by the energy storage system. An added benefit is a quiet, vibration- and emission-free environment for the deck crew.

SAFETY

Marine propulsion batteries are commonly hundreds of times as large as automotive electric vehicle batteries. The large size, high energy density, rapid charging requirements and extreme operational patterns represent new challenges in relation to safety. In order to prevent fire or thermal runaway, several measures are implemented. The first line of defence is thermal management. Controlling temperature with a liquid cooling system in the core of the battery is integral to ensuring not only the safety of the system but also the longevity. The cells contained in the battery last far longer when kept at an optimal temperature, and a robust cooling system can actually prevent thermal runaway rather than reacting to it after it has already occurred. Cooling, fire suppression and battery management systems are key to providing safety and protection from the cell level up to the system level.

While the industry standard for many years was passive air cooling, it is increasingly apparent that the smaller systems demanded by industry are required to operate at, or beyond, the limits of passive cooling. Virtually all of today's energy storage systems employ some form of liquid cooling, either as an optional addition to the standard system or as an integral component. Advanced, state-of-the-art batteries use integral cell level cooling systems. In these systems the coolant circulates within the very core of the battery module at low pressure, thus enabling greater charge and discharge currents, increased lifespans and reduced system sizes. Typically the energy storage solution will connect to a standard chiller using an inexpensive circulation pump, and is able to meet the very high power and load demands with a far smaller system size and resulting cost savings.

Given the possible issues associated with fire and explosion, classification societies and flag authorities have rightfully focused on how to prevent and manage fires and thermal runaway. No matter the amount of regulation applied to suppression technology, battery manufacturers retain responsibility for incorporating sophisticated prevention systems into the design of the batteries. With lithium energy storage systems exceeding several MWh of capacity now regularly being discussed, the risk of thermal runaway or fire cannot be taken lightly. Today's hybrid designs must take this into account and do everything possible to ensure that a fire cannot start in the first place, adding to the shift in thinking that has driven designs to incorporate high performance liquid cooling systems. These liquid cooling systems manage battery safety inside the core of the module through temperature control and management at the cell level. Separate fire suppression is critically important too, but must be viewed as a secondary system to manage the issue in extreme circumstances, after all else fails.

Fire suppression systems are therefore recommended to control external fires adjacent to the energy storage system to prevent them from causing a thermal event in the battery room. If desired, fire suppression in the battery room may also be employed to give further peace of mind as a backup system. Fog-type fire suppression systems provide adequate cooling to suppress virtually any fire (outside of a major catastrophe involving the vessel itself) that may pose a hazard to the energy storage system. In order to meet classification society standards, the energy storage system itself must be rated for IP67 water resistance and therefore able to safely withstand the activation and use of fire suppression.

BATTERY MANAGEMENT SYSTEM

The battery management system (BMS) is able to actively monitor the health of the system and raise temperature warnings. If a specific component in any one part of the entire system is out of spec, the system will warn the captain and monitoring team. The monitoring team will then proactively engage with the vessel and determine what, if any, course of action needs be taken. If the warnings continue without intervention from the team, or if the vessel crew ignores the warnings, the system will protect itself and the vessel by disengaging from the DC bus and isolating all the modules in the system via their internal contactors, effectively reducing system voltage from a maximum of 1,000V to ~100V (the voltage of a single module).

Controls are powered separately from the energy storage system, offering redundancy in the system to ensure continued operation. The system will always have an external power source, guaranteeing that the cooling system will remain operational and the management system stays in communication with the vessel and system administrator team at all times, regardless of system status.

CHARGING INFRASTRUCTURE

A hybrid tugboat can be connected to shore power overnight to fully charge. The vessel can then leave harbour on battery/electric power, which also means zero emissions. Later in the day, diesel power can be used for the high-speed transit, while the batteries are recharged from onboard generators.

A modern hybrid energy storage solution requires the ability to communicate with and control the charging infrastructure of the batteries. A lithium battery is very sensitive to voltage and current. Voltage must be kept at a constant setting specified by the manufacturer.

The BMS must be able to direct the charging system to increase current at specific set points to increase charging rates, ultimately decreasing charge times and optimising the usefulness of the system. Conversely, the BMS must also be able to reduce the current at other times to increase the longevity of the system and meet the vessel owner's objectives for lifespan of the system. The BMS will take account of all types of information from the modules and surrounding systems, such as temperature, state of charge and system age, to determine the best charging profile at any given time.

THE 5-YEAR VS 10-YEAR BATTERY

Vessel energy storage systems can now be designed based on a 5-year lifespan, compared with the traditional 10-year lifespan approach, which until now has been typical of the industry. Even though energy storage is proven to reduce fuel costs and have a short payback time, the initial investment can be substantial. With a smaller system, the investment is inherently reduced and vessel owners can enjoy an even faster payback time. Instead of investing for 10 years, vessel owners can invest for the next five, and at the end of that period the cells within the energy storage system are replaced and the modules are 're-cored' and upgraded.

A key condition for the 5-year battery is to have a highly effective cooling system to control temperature. With liquid cooling of each cell, it is possible to achieve maximum charge and discharge of the battery without compromising safety or accidentally depleting the battery.

The 5-year battery system is a new approach to marine energy system sizing. It significantly reduces operational and installation costs and avoids the loss of system life and capacity due to lithium cell chemistry aging, which on a 10-year system can amount to more than a 10 per cent loss. As soon as cells are manufactured, they start to age as a result of the chemical reactions they undergo. Depending on the cell chemistry and how the cell is stored, a system may lose 1-2 per cent capacity per year. The longer the system life, the more a system will lose over time. On a 10-year system, that 2 per cent can amount to over 20 per cent capacity loss. With a 5-year system, such cell capacity loss is greatly reduced.

The physical footprint of any energy solution is an important consideration for vessel designers and operators. When choosing the appropriate system type, a significant advantage of the 5-year battery is the greatly reduced physical size and weight. As of 2017, we have seen system size reductions in the order of 30 per cent. With a smaller energy storage solution, weight is reduced, and operators can benefit from a high-power system that improves working conditions, operations and costs.

RE-CORING PROGRAMMES

Modern battery systems for hybrid and full electric vessels are becoming even more efficient and cost effective with the recent advent of module re-coring. At the end of their 5-year life, cells within the energy storage system are replaced and the modules 're-cored' and upgraded. The re-coring program is a unique feature of advanced energy storage systems that will revolutionise the way vessel owners use this technology.

The concept is based on only replacing the cells of the battery system, thus reducing the total lifetime cost of the system. Similar to rebuilding a diesel generator, a re-coring programme only replaces specific elements of the battery system, while the majority of the installation remains intact. The ability to swap out just the cells means that almost no components are thrown away or need to be recycled, greatly reducing waste.

A re-coring programme is possible as the system infrastructure is made from high quality materials and has a longer lifetime than the cells. Another key attribute to the programme is that there are no changes in shipboard integration and power management. A new battery system would require re-integration, in which costs are difficult to assess and control. The ability to re-use existing systems also ensures there are fewer issues with legacy/obsolete components and software.

With the rapid progress in energy storage solution development, many vessel owners do not want to risk having invested in yesterday's technology. With cell swap programmes, the operator will be able to take advantage of the latest cell technology, which will enhance performance, reliability and safety of the battery system. With advances in cell technology and performance, operators can always be on the leading edge of performance for the life of the vessel.

With environmental concerns an important part of many business plans, the waste reduction from a re-coring programme is a key benefit. Traditional battery systems require the entire system to be replaced at end of life. This leads to a great deal of industrial and electrical waste. While many of the components of the battery may be recycled, the cost and pressure on existing recycling infrastructure is significant. The volume will only increase as the new fleet of hybrid and full electric vessels begins to age and more battery systems are replaced.

PBES CELLSWAP

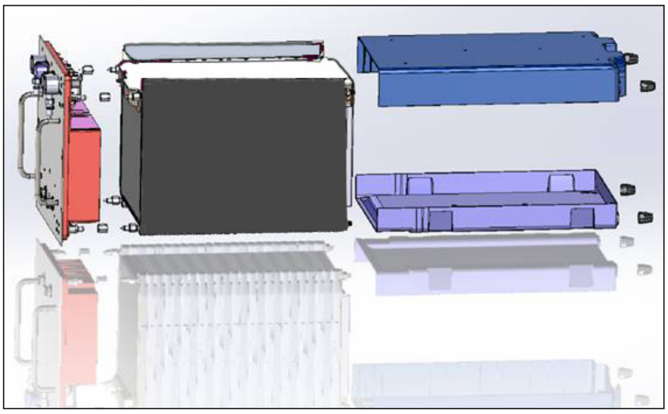

Figure 1: CellSwap components

The PBES CellSwap™ process is simple and safe, as the cell stack easily separates from the electrical controls. The new stack of cells is prefabricated and shipped to the vessel for installation by certified technicians. The front end of each module containing the electronics is detached, and the core which houses the cells is replaced with the new stack.

The CellSwap plan is a replacement for all consumable elements at the end of the 5-year lifespan of the original system, including cells and any other parts to be replaced at that time. Regular scheduled maintenance is performed on the control systems at the same time. A service technician then performs an on-site factory acceptance test (FAT), a re-commissioning and customer acceptance test (CAT) on the re-cored battery system.

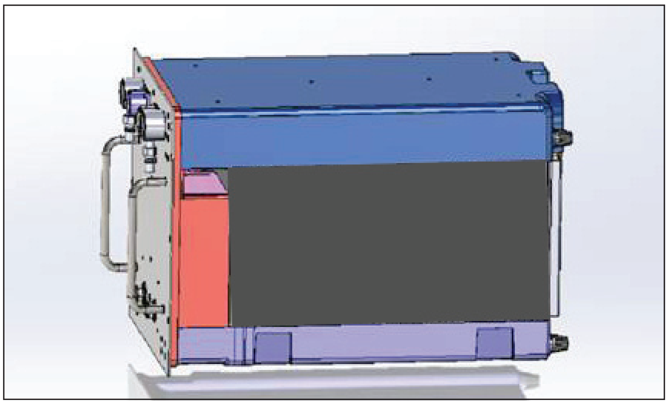

Figure 2: CellSwap assembled

Before committing to a plan, the existing battery system and working environment will undergo a full inspection by a PBES service technician. Consultation with the vessel operator on a use plan for the year in which the batteries will be replaced is also required.

LIMITATIONS AND CONSIDERATIONS

The re-coring process does not work for all batteries. The smaller 5-year system can only be employed through the use of an energy storage system that is capable of being run at far higher discharge rates than a 10-year system. This results in increased stress due to additional heat and cycles, which in turn ages the batteries faster and places greater demands on safety systems. The well documented tendency for lithium batteries to enter thermal runaway when abused means that robust cooling and thermal runaway suppression systems must be integrated into the system.

CONCLUSION

A great challenge for the hybrid workboat sector is to understand what the industry will look like in the coming years. With increasing progression in design and technology, as well as demand from operators, vessel owners need to make decisions today that are useful for the next 10-15 years. Advancements in energy storage solution technology and increased cell capacity mean that energy storage presents a powerful solution to improve operational efficiency and reduce costs. Energy storage solutions will be an integral part of the future in most marine applications, and next-generation tugboats can take advantage of this. Energy storage re-coring, combined with advanced battery design, gives the industry a glimpse into the future of energy storage today – high performance and increased efficiency, combined with an affordable and flexible business model and rapid return on investment.

REFERENCES

[1] *Insight for the European Commercial Marine Business*, *Maritime Journal Insight*, for the European Commercial Marine Business, Mercator Media Ltd, 27 April 2012 (Web 21 Febuary 2017)