I'LL HAVE A BATTERY SYSTEM, PLEASE!

But this is what you need to know

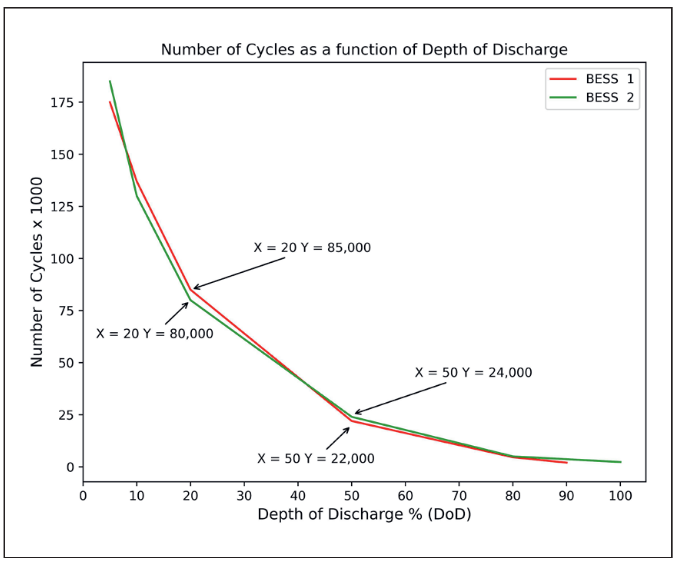
Battery Energy Storage Systems (BESSs) will be essential to the maritime industry and its transition towards full decarbonisation. Over the past few years, the interest in hybrid power solutions with batteries has increased exponentially. Choosing a BESS may seem like a simple task, but a correct execution is often much more complicated.

The use of batteries enables numerous functionalities on board a vessel, from optimising generator operations and fuel consumption, to supporting methanol engines and fuel cells during rapid power changes. On the other hand, batteries are expensive, heavy and dead within two years if not operated properly. Understanding batteries and properly defining their role in an electrical network is essential in ensuring their lifetime and return on investment (ROI) potential.

Battery specifications

But what defines a battery? Two important characteristics of batteries are the terms "C-rate" and "depth of discharge (DoD)". The C-rate describes the relationship between the rated power (in kW) of a battery and its capacity (in kWh). It represents the number of charges or discharges a battery can do in one hour. The arbitrary line between "high power" and "high energy" batteries is defined by the C-rate. High power batteries, corresponding to a high C-rate, are used when a lot of power is required for only a limited amount of time. A typical high power C-rate is between 1.5 and 5, depending on the battery chemistry (nickel manganese cobalt (NMC), lithium iron phosphate (LFP), lithium titanium oxide (LTO), and so on). High energy batteries are used when less power is required, but for longer periods of time. Here, typical C-rates are between 0.2 and 0.7.

The DoD defines how much of the total battery capacity is actually being used. There is a direct relationship between the DoD and the number of cycles of a battery, which indicates its lifetime. A DoD of eighty per cent typically means that a battery is used between ten and ninety per cent of its state of charge. Depending on the battery chemistry, at eighty per cent DoD, the battery can do a number of charge and discharge cycles, until it is considered to be at its end of life. The lower the DoD, the higher the number of cycles a battery is able to provide.

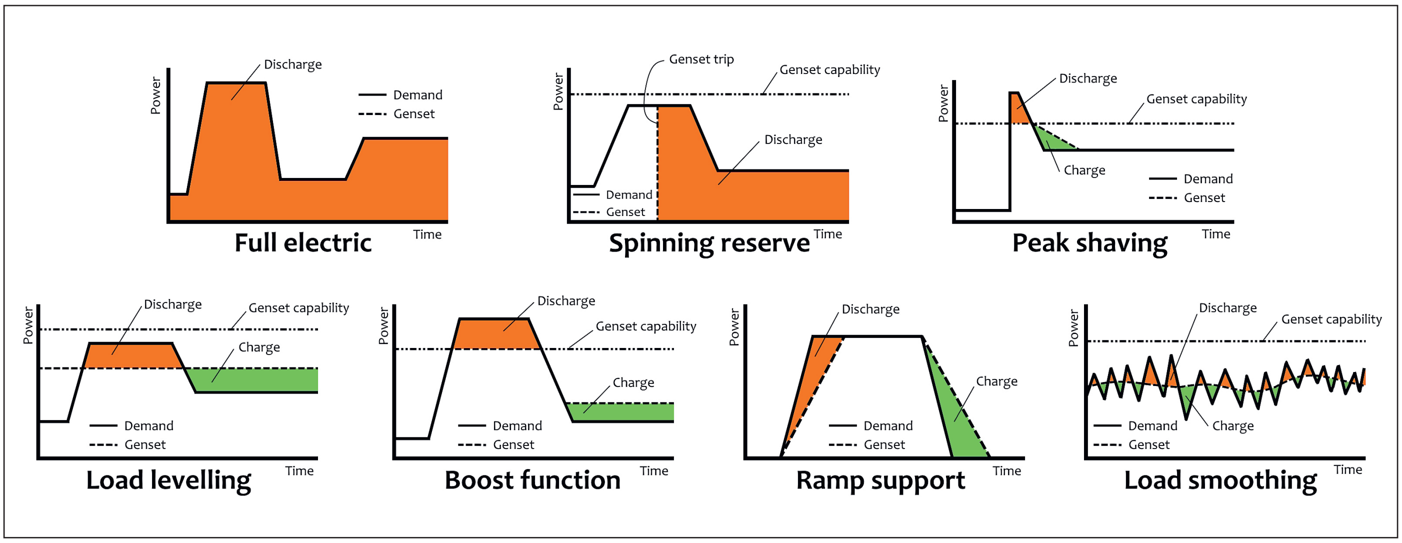


The expected number of cycles for a certain DoD for two different batteries.

The benefits of a BESS on a vessel

A battery can be employed to perform a variety of tasks on a vessel depending upon its needs. Nowadays, there are governments across the world mulling over the introduction of zero emission zones and silent operation zones, especially inside and in the vicinity of ports. A vessel can be operated with a battery in the fully electric mode to meet the vessel's load demand and keep the generators switched off to meet these regulations. To increase the vessel's redundancy, for example in the event of a fault, the battery can operate as a spinning reserve and meet most parts of the load demand until the fault has been corrected. This capability ensures that all critical and operational equipment on board can continue to perform their tasks undisrupted. Batteries can also assist in the function of peak shaving, wherein any additional load above the generator's rated capacity can be met by the battery.

In the load levelling function, the generator can be made to operate within its ideal load factor range, with any additional capacity



Various battery applications.

above this load factor met by the battery. This operation can potentially offset additional maintenance costs due to continuous operation of generators at high load factors. In parallel, the battery can also assist the generator with ramp support, whereby the battery supplies additional power during dynamic events to assist with slow ramping energy resources such as methanol engines.

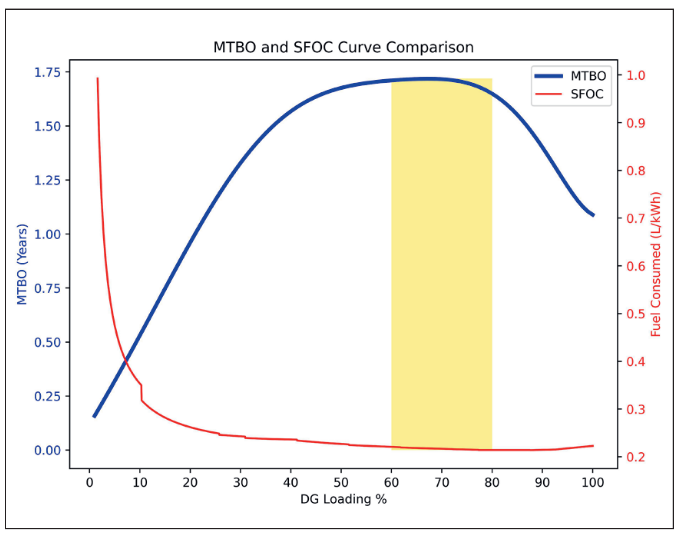
Design considerations

When designing a vessel, a load balance study needs to be conducted by engineers for the different modes of operation. This is done in order to determine the best combination of distributed energy resources (DERs) on the grid. This process can often be a daunting task given that these designs must take into account the worst case scenarios that the ship may experience. A potential issue can be that the generators are oversized for a typical operation as the vessel may not operate with such high load demands on a regular basis. Consistent operation of diesel generators at low load factors makes them susceptible to wet-stacking. This can drive up maintenance costs as several components will need to be replaced more frequently. This then reduces the number of available operating hours for that generator. The minimum time before overhaul (MTBO) curve provides an idea as to how many operational hours can be achieved by the generator when operated at a certain load factor on average, before heading into long term maintenance.

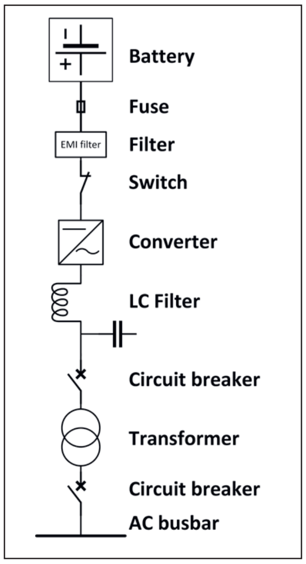
The energy management system serves as the brain of the vessel

The MTBO curve estimates that consistent operations with an average load factor from sixty to eighty per cent can minimise generator maintenance costs and increase the availability of the generator for operations. This availability for an additional number of hours benefits the vessel owner with the ability to continue their commercial operations uninterrupted. At the same time, the specific fuel oil consumption curve of a diesel generator indicates that at low load factors in the range of ten to thirty per cent, fuel consumption is quite high for the minimal energy it delivers. Whereas at high load factors in the range of sixty to eighty per cent, the fuel consumed is relatively lower for the much higher energy it delivers. With this knowledge, maintaining a high load factor can be seen as beneficial for both fuel and maintenance cost savings.

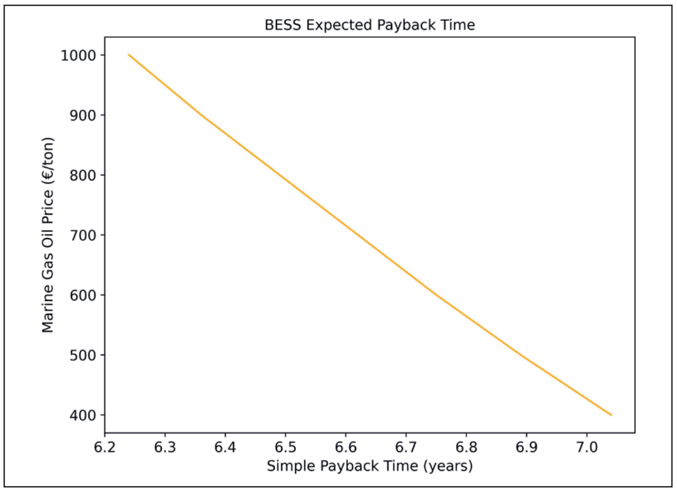
The average load factor of a generator can be increased by charging the battery alongside the existing load demand and then using this stored energy in the battery at a later time for a number of the different tasks previously mentioned. With this approach, the use of a battery can offset the need for operating an additional generator



The minimum time before overhaul (MTBO) and specific fuel oil consumption (SFOC) curve for a certain vessel.



BESS connection to an AC busbar including all in-between components.



The impact of changing marine gas oil prices on the expected payback time including the generator maintenance savings with an optimised EMS.

on the vessel, thereby reducing maintenance costs, fuel consumption and finally greenhouse gas (GHG) emissions.

Changes to the electrical power system

When adding a battery to an existing vessel, there are some things that need to be considered. First of all, the electrical converter. Since the electrical power system on board is most likely an alternating current (AC) system, and the battery is a direct current (DC) component, a bi-directional conversion between AC and DC is required. Based on the AC voltage level, battery power and the AC short-circuit current, a suitable converter will need to be chosen. Often, the converter needs to be oversized when compared to the battery power, in order to be able to deliver enough short-circuit current to trip its own circuit breaker. The battery voltage is typically chosen to match the converter's DC voltage limits.

> The simple payback time is typically anywhere between six to nine years

There are topics on the AC side of the converter that will need to be addressed as well. One of these is the impact of the new converter on the power quality of the electrical power system. Since the AC voltage is created by the means of switching transistors instead of a rotating component, there is an unavoidable distortion in the current caused by this switching. Through the impedance (resistance at a specific frequency), there is a direct relationship between the current and the voltage. This results in a distorted voltage waveform, so proper filtering is required to compensate for the distorted current. Typically, an LCL (inductor-capacitor-inductor) filter is used, often in combination with a transformer. The benefit of the transformer is that it provides galvanic isolation between the battery and the rest of the electrical power system. If properly specified, the transformer can replace the second inductor of the LCL filter as well. Apart from potential non-compliance with class rules, poor power quality will result in higher losses and an increased risk of component failure.

To achieve the best results from a BESS, a well-designed energy management system (EMS) is required. The EMS serves as the brain of the vessel when it comes to prioritising the use of the different DERs and meeting load demands. The EMS is responsible for making the best decisions when a particular energy source is operating, so that fuel consumption and maintenance costs are minimised. It is also critical for the EMS to monitor the limited lifespan of a BESS, in comparison to a generator, so as to also optimise the frequency and extent of use of the BESS to achieve the highest return on investment.

The economics of operating a BESS

The key measures of a successful battery system on board marine vessels are the simple payback time and its return on investment. These parameters vary across different vessels, their operating modes and their energy demands. The variable costs of operating a vessel include the cost of maintenance of diesel generators and the fuel they consume.

It is important to note that when a battery is recharging without a shore connection, it is dependent on the diesel generators on board. This scenario indicates that the original load profile of the vessel will now change to accommodate the battery's demand. The changed load profile will result in additional fuel consumption due to the higher energy delivered by the generators. However, this consumption is offset by the BESS in the different applications it can offer. Academic research on hybrid vessels estimates the expected fuel savings to range between five and twelve per cent, subject to the BESS' operational patterns and extent of use.

Marine gas oil prices in the market are currently not high enough to make a substantial monetary gain from reduced fuel consumption.

Given this situation, most gains will need to be made from lower diesel generator maintenance costs and their reduced operation times. Some shipping companies have claimed a possible fifty per cent reduction in annual maintenance costs per generator with an improved load factor operation between sixty and eighty per cent. Yet, given the size of the batteries that are required for these vessels, they can seem prohibitively expensive for most vessel owners. With fluctuating fuel prices and given all the variables discussed, the simple payback time is typically anywhere between six to nine years. With a typical designed operational lifetime of about ten years, the return on investment therefore can vary between one to four years. The actual useful life of the battery is also subject to its ageing characteristics, the number of cycles it has run, and the effort put in to maintain its mechanical and electrical integrity.

Future perspective

With a variable return on investment, it is not guaranteed that vessel owners will get a significant return on their investment. However, there are expected climate focussed regulations by policy makers in the form of increased fossil fuel prices and a charge for emissions via programmes such as the European Union Emissions Trading System (EU ETS). Therefore, vessels will need to adopt alternative technologies to decarbonise. Taking this eventuality into account, alongside the previously mentioned benefits of a BESS, a BESS can definitely provide additional value to any vessel. It is important to understand batteries and the role they play in the electrical power system, as choosing a battery system is not a simple task. But with the early involvement in the design process of electrical system integrators such as Alewijnse, this task can be made substantially easier.

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