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POWER AND DESIGN

Batteries as power sources in DP systems

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Abstract

The paper will present the latest experiences and rules made by DNV GL for use of batteries in battery hybrid DP vessels. The paper will focus both on new-buildings and on vessels being converted from more traditional power systems and in to battery hybrid systems. Reference will also be made to other types of pure battery and battery hybrid vessels.

The fuel saving potential will depend on how the batteries are designed in to the system, how they are used and the vessel operational profile. The paper will argue that for a DP vessel the fuel saving potential will typically be largest when the design is so that batteries can be used as spinning reserve (i.e. instead of a diesel engine). In addition to fuel saving the reduced environmental footprint will also be focused. Results from research projects will be included.

The paper will address the updated DNV GL DP rules with respect to the use of batteries as spinning reserve, and the new DNV GL Battery Power rules. The Battery Power rules set requirements to large lithium ion battery systems installation on board vessels. How these rules aim to ensure both the safety and the availability of batteries when used as a source of power in DP operation will be explained.

Contents

Abbreviation / Definition

term	*description*
battery cell	the smallest building block in a battery, a chemical unit
battery cell block	group of cells connected together in parallel configuration
battery converter	the equipment controlling the charging and discharging of the battery system
battery module	assembly of cells including electronic control
battery pack	one or more modules including complete BMS and can be used as a standalone unit
battery string	a battery string comprises a number of cells or modules connected in series with the same voltage level as the battery system
battery space	the space enclosed by structural separation in which the batteries are located
BMS	battery management system, a collective terminology comprising control, monitoring and protective functions of the battery system
C-Rate	the current (A) used to charge/recharge the battery divided by the rated amperhours (Ah)

consequence analysis	a monitoring function in the DP-control system that issue an alarm if the vessel (in its current operating mode) in the current weather conditions would not be able to keep the heading and position in the case that any of the predefined worst case failures should occur
DP	dynamic positioning
EMS	energy management system/function, a system providing monitoring and control of the energy capacities
FMEA	Failure Mode and Effect Analysis
LEL	lower explosion limit
minimum time requirement	minimum required time duration for which the residual remaining capacity as defined by the worst case failure design intent shall be available. The time requirement will normally be governed by the maximum time necessary to safely terminate the on-going operations after the worst case single failure, given the residual remaining capacity. All relevant operational scenarios which the vessel performs and/or participates in should be considered when determining the time requirements. This time requirement should be fulfilled by the design, and the way the vessel is technically configured (technical system configuration) and operated. In addition to the actual time necessary to terminate the operation, the minimum time requirement includes also the time necessary for detection and alarming by the system, and the time needed for the operator(s) to notice, make the appropriate decision(s), and initiate the termination process.
OSV	offshore support vessel
redundancy	ability of a component or system to maintain its function when one failure has occurred. Redundancy can be achieved, for instance, by installation of multiple components, systems or alternative means of performing a function
redundancy design intent	refers to redundant component groups which constitutes the overall system design for a given system operational mode and technical system configuration
redundancy group	all components and systems that is subject to a single failure as specified in [4], for the specific notations The redundancy groups will emerge as a consequence of the worst case single failure within each group. The rules do not give requirements to the number of (beyond 2) or ratio between the defined groups. The groups should be identified in the FMEA, verified by testing and incorporated in the consequence analysis.
SFOC	specific fuel oil consumption
SOC	state of charge - the available capacity expressed as percentage of the rated capacity (0-100%)
SOH	sate of health - reflects the general condition of a battery and its ability to deliver the specified performance compared with a new battery (0-100%)
worst case failure	refers to failure modes which, after a failure, results in the largest reduction of the position and/or heading keeping capacity. This means loss of the most significant redundancy group, given the prevailing operation.

Why batteries on DP vessels?

There are several and diverse incentives for installing batteries on DP vessels. Some of these originates from new international and local regulations that require emission reductions, which will drive the maritime industry towards cleaner and greener solutions. The International Maritime Organization (IMO), has adopted regulations to address the emission of air pollutants from ships, and has implemented mandatory energy-efficiency measures to reduce emissions of greenhouse gases from shipping. The IMO regulations are expected to become progressively tougher over time, and by 2025, all new ships are expected to be 30% more energy efficient than those built in 2014. Other incentives originate from vessel owners and/or operators who wants to reduce both operational cost and emissions to air.

To meet these the environmental challenges of the future the maritime industry need to think innovatively and explore new solutions for alternative energy sources, alternative fuels, and new environmentally friendly technologies that can offer cost-effective emission reduction options. Electrification and energy storage enable a broader range of energy sources to be used. Renewable energy such as wind and solar can also be produced and stored for use on ships either in batteries or as hydrogen.

A 2011 study by DNV GL demonstrated that energy storage technologies represent a substantial potential for improving both fuel economy and reducing emissions within the maritime industry. One of the conclusions of the study were that ship types with large load variations on main or auxiliary machinery, and/or high redundancy requirements, and/or low utilization of engines for long periods of time are typically well suited for hybrid power systems. The study shows that fuel savings of 10-25% can be realized, although heavily depending on operational profile and power system configuration.

Several ship types have requirements to redundancy in power generation for certain types of operations. This is particularly relevant for ships with redundant Dynamic Positioning (DP) systems installed. The requirements to traditionally DP notations (i.e. Enhanced Reliability notations excluded) do not allow for redundancy to be dependent on start of generators and the redundancy requirements must therefore be ensured by the machinery being in operation at any time (this is often referred to as spinning reserve). The specific fuel oil consumption and the emissions from an internal combustion engine are dependent on the engine load, see illustration in Figure 1. From this figure, it can be seen that running engines at low loads generally leads to higher specific fuel oil consumption. This correlates also with higher specific emissions and normally also with increased maintenance costs. Typically, engines are calibrated for optimum performance at 60%-85% of the engine load.

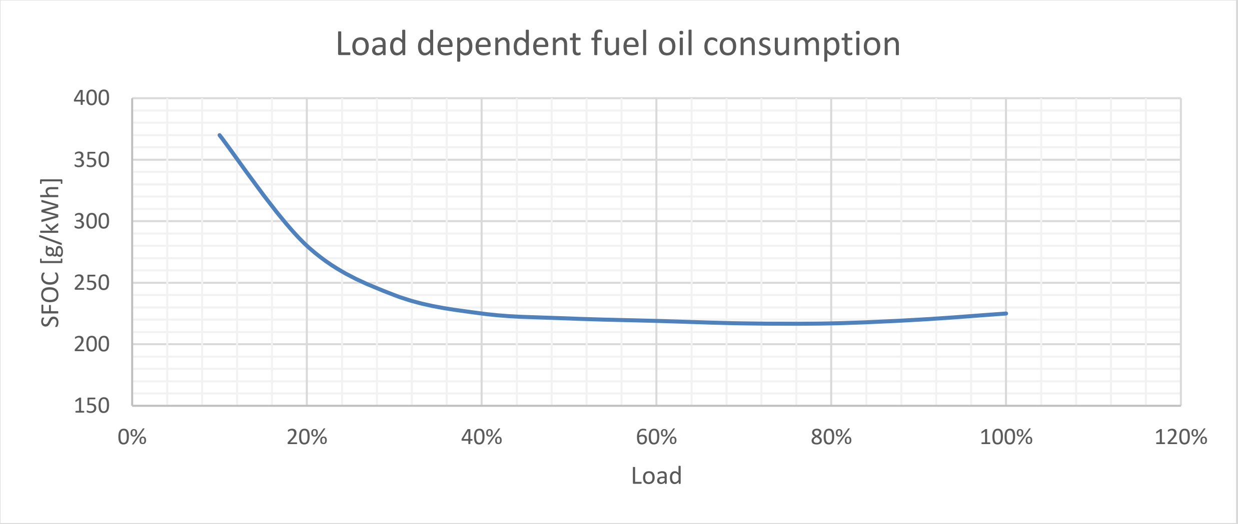

Figure 1 Typical load dependent fuel oil consumption

Introducing Li-Ion (Lithium-Ion) batteries to fulfil the requirement spinning reserve, can make it possible to have fewer engines running, which can lead to reduced fuel consumption, emissions, engine running hours and maintenance costs. More about the requirements for acceptance of this later in this paper.

In addition, the load variations during DP operations can sometimes be quite large (e.g. due to wave impact or industrial mission equipment). With a battery connected to the vessels power plant then the battery can also be utilized for peak shaving such that the engines can operate with a stable load, see illustration in Figure 2. This is done by letting the engines operate at constant load, or as an average of total load demand, and let the fluctuations be covered by the battery. Estimates up to 4% fuel savings depending on the engine, vessel and operation have been presented by some industry players.

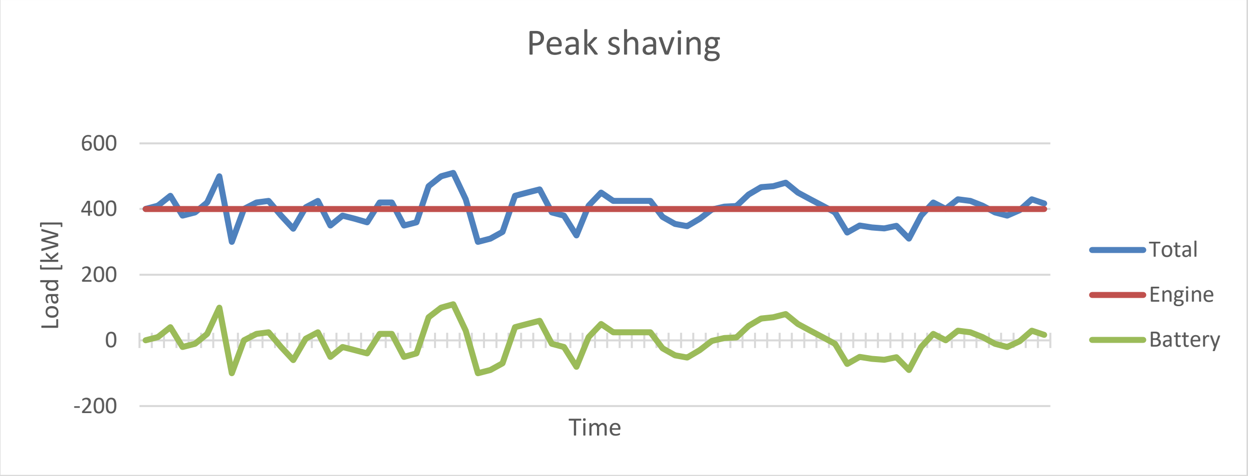

Figure 2 Peak shaving of load fluctuations

By August 2018 more than 30 offshore vessels in DNV GL Class are already in operation or currently being retrofitted with large Li-Ion battery systems.

As briefly mentioned, along with the reduced fuel consumption (as a result of running fewer engines during operations) comes also other operational benefits due to the introduction of batteries. Some of the most important of these are:

- Less running hours on machinery, providing less consumption lubrication oil and less maintenance (e.g. longer time between service intervals)
- Depending on design the batteries can provide robustness to designs and less consequence of some common failure modes
- More flexibility and better working conditions, e.g. with respect to maintenance. E.g. when combined with closed bus-ties on a design with multiple engines rooms, it may be possible to do maintenance on equipment in cold and quiet engine rooms while the thrusters connected to the same redundancy group is still available for DP.

As previously mentioned this is heavily depending on operational profile and power system configuration. An example of an operational profile (taken from a DNV GL simulated OSV case study) is shown in figure 3:

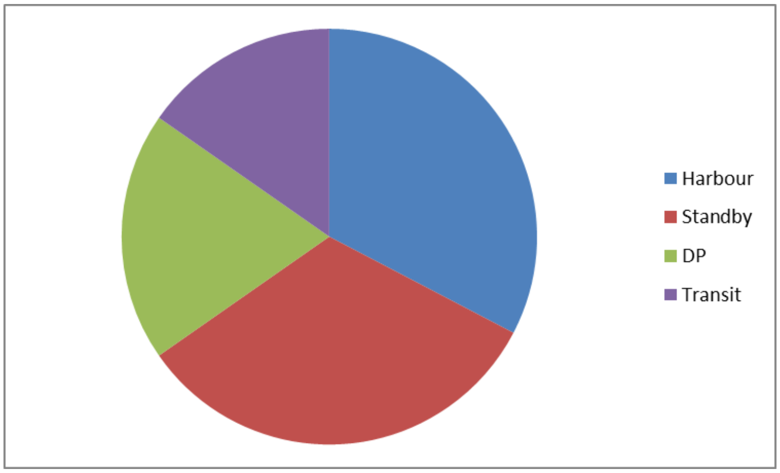

Figure 3 Load dependent fuel oil consumption

Based on the above discussions the biggest potential for reaching the incentives is anticipated to be in the modes where you are able to shift from a situation with many engines running on low load, to a situation with few engines running on higher load. This is based on the engine efficiency, SFOC, see example in figure 1. For DP operations requiring redundant DP system both rules and operational procedures, have requirements for spinning reserve, i.e. for the redundancy to be based on running machinery. It is quite common that DP design and operations are based on open bus-ties and running all available engines to maximize spinning reserve and running redundancy. Due to this DP modes are typically identified as the modes with the biggest potential for savings (i.e. cost, fuel and emissions) on DP vessels. This has also been experienced in real cases. Some experienced numbers documenting this is provided later in this paper.

Redundant DP operations are often performed in relatively low weather conditions, resulting in low energy consumption. When combined with operational modes requiring redundancy in running machinery the result is that operations are performed with a relatively high number of engines running on low load, and consequently with low engine efficiency. To maximize the potential savings the number of generators should be reduced to a minimum. This can however only be done if at the same time the DP redundancy requirements are complied with in order to maintain the required safety levels. One of the main effects of this is that DP vessels where the DP system is based on open bus-ties (i.e. the power systems in the different redundancy groups are not connected, and hence, operates independently) must have minimum one generator set running in each redundancy group. This is due to the fact that with today's battery technology, the installed energy will normally be relatively low, and therefore it is not be realistic to operate redundancy groups on batteries only (at least not based on traditional equal thruster allocation). For vessel with DP systems based on closed bus-ties (i.e. the power systems in the different redundancy groups are connected, and hence, can operate as one system) power can be shared between the different redundancy group. In this mode, the number of running generators may be reduced as low as one running generator during redundant DP operations, i.e. when the total power consumption can be provided by one generator. It is therefore the case that in order to maximize the potential savings the power systems should be designed to be able to base the redundant DP operations on closed bus-ties. The requirements for using batteries to power DP systems are discussed later in this paper. For more information on DP systems based on closed bus-ties see [10].

(Even though it is not the discussion topic in this paper the authors would like to mention that they believe that there exists a potential for adjusting the current requirements and practices for design and operation of redundant DP power systems to be able to take full advantage of the battery technology.

Among this could be the specification of an integrity level for closed bus-ties for DP equipment class 2 systems.)

Battery Technology

Currently, Li-Ion battery technology dominate as battery energy storage technology for propulsion of maritime vessels. The Li-Ion battery technology is developing fast, and on short and medium sight significant increase in cycle life, energy density and current ratings are continually being realized. The main benefit with using Li-Ion batteries compared to traditional Lead Acid and NiCd is that the energy density of a Li-Ion battery is 5-10 times greater than a Lead Acid/NiCd (Nickel–Cadmium) battery.

A battery system is typically build up with battery cells (both serial and parallel connected). These cells are then assembled in modules that again are put in series to achieve battery strings with the needed voltage level. One or more strings in parallel will be the total battery system.

There are different variants of lithium ion cell chemistries. What we have seen so far is that Li-ion NMC (Li-ion system with a cathode combination of nickel-manganese-cobalt) has been mostly used. Other vessels use Lithium iron phosphate cells and the Lithium Titanate (LTO) seems also to be promising.

A lithium battery cell needs to operate within specific voltage and temperature levels to ensure a safe and durable operation. The battery system must therefore have a Battery Management System (BMS), which performs control, monitoring and protective functions. If the batteries operate outside the safety limits, the BMS will activate an electrical disconnection of the battery system.

The operating temperature of a battery cell must be kept within a specific temperature window. When the temperature is higher than the designed operational temperature the degradation of the battery cell accrue and the lifetime will be reduced. If the temperature becomes too high the electrolyte will start to vaporise flammable gasses, and if heated further the battery cell can go into a thermal runaway (exothermic reaction) which then can lead to self-ignition of the flammable gasses.

If a battery cell is charged at a too low temperature, lithium plating can occur. This will shorten the lifetime of the battery and increase the probability for an internal short in the cell. The safe temperature window is depending on the type of lithium battery chemistry and is typically between 0°C to 60°C (32°F to 140°F). Additionally, the lifetime of the battery cell is heavily depending on the cell temperature during charging and discharging. The optimum operating temperature is normally around 20°C to 25°C (68°F to 77°F).

Equally important as the temperature, is it to keep the voltage of a lithium battery cell within a specific voltage window. If the charging voltage becomes too high, excessive chemical reactions or side reactions will occur and the cell becomes thermally unstable. If the discharge voltage is too low the negative electrode can be damaged and lithium plating can grow from one electrode to the other leading to internal short circuit in the battery cell. The voltage window is depending on the type of lithium battery chemistry and is typically between 2.5V to 4V for a battery cell.

The charging and discharging current must also be controlled. When the current is going in or out of the battery system, the battery cell is heated and the temperature of the battery cell will increase. The amount of current that a battery cell can handle (typically called C-rate) will depend on the battery system construction and the charge/discharge time.

The BMS should also monitor/calculate the batteries State of Charge (SOC) and State of Health (SOH). The term SOC describes the energy available for use in the battery system dependent on specific conditions (i.e. within a certain power range). A fully charged battery system has a SOC of 100%. The term SOH reflects the general condition of a battery and its ability to deliver the specified performance compared to when the battery was new (ranges from 0-100%, 100 being the performance when the battery is new.)

To calculate the available energy in a battery system both the SOC and SOH must be considered. The available energy is needed to give a clear indication of how far a ship may go on its remaining battery energy (e.g. what is the actual DP redundancy in terms of time) and for ensuring that a hybrid system gets its maximum potential fuel consumption benefits.

The most critical safety related failures in a battery cell are those that can lead to an internal short circuit in the cells, and which consequently can lead to a thermal runaway. A proper designed BMS should prevent this scenario. However, mechanical abuse or defects in a battery cell originating from the manufacturing process are hard to mitigate for. Manufacturing defects can produce a short circuit which is not detectable by the BMS. It is therefore important that the battery system is designed such that the consequence of an internal short in a cell is acceptable from a safety point of view. Hence the design of a module should inhibit thermal propagation from cell to cell.

Requirements for battery system and certification is given in the DNVGL Battery Power class rules [1].

Safety consideration for Li-Ion battery installation

The location on the ship where the battery system is installed is referred to as the battery space. This can be a dedicated room with only the battery system inside or a larger room where more equipment is located. When designing the battery space some specific considerations should be addressed, such as reducing the risk of mechanical damage, external fire, internal fire and handling of potential off-gassing.

To minimize the risk of mechanical damage to the battery system, the battery space should be located aft of the collision bulkheads and the boundaries of the battery space shall be a part of the ship's structure (or similar). Heat sources or high fire risk equipment should as far as possible not be located inside the battery space in order to reduce the probability for a thermal event. For example, the battery system should not be in the same room as the combustion engines. The battery space should have walls with sufficient fire insulation properties such that a fire outside the battery space do not spread directly in to the battery space, e.g. A0 and A60 walls. In case there is a thermal incident with the batteries, the room and the equipment inside the space could be lost. Hence, the battery space should not contain redundant systems supporting propulsion and steering. As a battery cell has a risk of going into a thermal runaway and releasing flammable, toxic, and corrosive gasses, the battery space should have its own dedicated ventilation.

A fire extinguishing system should be installed in the battery space. There exists no established standard fire extinguishing medium for lithium battery fires. However, many different mediums are available e.g. water mist, water based foam, Novec, FM200, etc. The challenge is to find an extinguishing system that puts out the cell/module fire and at the same time cools down the surrounding modules such that the fire does not spread. DNV GL recommend the use of a water based fixed fire extinguishing. Such a system should help cool down the battery modules to an extent that the fire does not propagate.

Requirements for safe battery installations are given in the DNVGL Battery Power class rules [1]. When installing Li-Ion batteries larger than 20kWh in one space it is required to have the class notation Battery(safety), or Battery(power) which also incorporates the battery safety requirements.

Battery power depending propulsion systems

For vessels with battery systems providing power to main or important functions, like e.g. dynamic positioning, it is important that the capacities of the batteries are monitored. This monitoring system is often referred to as an Energy Management System (EMS). The EMS shall provide a reliable measure of the available energy and power, taking into consideration the batteries SOH and SOC.

When the batteries are used as one of the main sources of power it is important that the electrical circuits are arranged with discrimination between the circuit breakers such that a downstream fault (e.g. short circuit) do not lead to black out of the whole electrical power plant. To achieve this, it is important to consider that a battery power converter (DC/DC or AC/DC converter) typically will limit the maximum short circuit power (typical 1.2 – 1.5 times nominal power), and by that will add some additional challenges in the relay coordination which also need to be managed.

Requirements for designing electrical propulsion systems with batteries is given in the DNVGL Battery Power class rules [1]. Vessel that are using batteries as one of the main power sources for electrical propulsion are required to have the class notation Battery(power). A vessel using the batteries as "spinning reserve" in DP systems must also have the notation Battery(power).

Batteries in DP systems

When batteries are implemented in to redundant DP systems with the intention that the stored energy shall be part of the required redundancy also the battery addition must comply with the main philosophy in the existing regulations. We will therefore start with a brief recap of the main philosophy for the redundant DP class notations. These important principles, in which the integrity of redundant DP systems is based upon are required by both DNV GL class rules and the IMO guidelines. Reference is made to [2], [3], [7], and [8]. The most important of these principles are duplication of equipment (i.e. redundancy) and single failure tolerance (i.e. ability to maintain station without disruption after the occurrence of any relevant single failure).

For DNV GL DP equipment class 2 systems the following single failures are to be considered:

- Any active component or system
- Static components as specified in the rules, ref. [2] and [3]
- Other static components which are not properly documented with respect to protection
- A single inadvertent act of operation, if such an act is reasonably probable
- Systematic failures or faults that can be hidden until a new fault appears (often referred to as hidden failure)
- Common cause failures, when found relevant
- Automatic interventions caused by external events, when found relevant

For DNV GL DP equipment class 3 systems the following single failures are to be considered in addition to those listed for DP equipment class 2:

- Any static components in the DP system
- All components in any watertight compartment, from fire and flooding
- All components in any one fire-subdivision, from fire or flooding

On top of these principles there are two more basic requirements that need to be understood, namely that of the *post worst case single failure capacity monitoring (i.e. the consequence analysis)* and the principle of the *minimum time requirement.* The minimum time requirement relates to the principle that the post worst case single failure capacity must be available sufficiently long to safely terminate operations (see definitions and abbreviations for a more detailed definition of the minimum time requirement). The consequence analysis shall provide a warning to the DP operator when a failure will cause loss of position in the prevailing weather conditions.

In traditional DP systems, based on running engines, the minimum time requirement has typically not been a difficult requirement as such systems typically will be able to operate for hours after any failure relevant for the given class notation. However, batteries are time limited energy sources and when these are to be considered as part of the DP redundancy their capacity must be considered in respect to all above mentioned principles and requirements. The batteries will in this respect be considered as a generator with a limited energy capacity (analogous to a gen.set with a limited fuel tank).

Minimum time requirement shall be documented in form of a time budget and will be evaluated by the class society. The result will be an important part of the vessels DP design intention and shall be part of the required DP philosophy document, required by [2] and [3]. A vessel may have several minimum time requirements defined based on its intended operations. Sufficient conservatism should be applied in the specification of the minimum time requirement, specifically as the termination normally will be dependent on crew decision processes and manual intervention. If it is intended to use some of the time available on batteries to wait for a potential successful standby start of a rotating generator (i.e. before the safe termination process is initiated) this time must be added to the minimum time requirement budget.

When batteries are considered as redundant sources of power in DP systems, the consequence analysis alarm must also be given when the available energy after failure is insufficient for safe termination according to a given time limit (i.e. the minimum time requirement). This limit may be set by the operator, so that it can be adjusted per the corresponding minimum time requirement for the prevailing operation, or a more conservative value if chosen. The c consequence analysis calculations should be based on the prevailing weather conditions and experienced operating pattern, e.g. mean net power consumption for the actual operation. The failure mode(s) causing need for the largest power contribution from the batteries after failure must be considered (including the potential need for power to other systems than the DP system).

Class requirements and IMO guidelines are not specifying the size of batteries (Except for the Enhanced Reliability notations specified in [3], more about this later). This is the same principle as for generators, engines or thrusters, where the rules do not specify size. Sizing of equipment should be decided by owner/designer and be based on parameters such as operational profile and intended area of operations. The fact that the modes where batteries are the most important part of the redundancy are the modes with a low number of running generator sets, and that this in addition normally correlates with low weather conditions, will often make it possible to achieve sufficient time for safe termination based on reasonably sized battery packages. Both battery system power (i.e. kW) and energy (i.e. kWh) must be considered and it must be taken in to consideration how much of the battery (installed kWh) that will actually be available after a failure. There are normally several parameters that will limit the how much energy that can be considered as part of the redundancy, and available for safe termination, and this must be taken in to consideration in design when sizing batteries. Typical examples of this include that:

- in DP operation the battery will not be 100% charged when a failure occurs (e.g. due to this not being healthy for the battery, and/or that parts of the energy are used for other purposes like e.g. peak shaving
- battery energy may also be needed to support other functions during the termination process
- it cannot be considered that the battery system will be able to provide power all the way down to 0% state of charge. This may also be combined with reasonable conservatism in form of a safety factor
- the battery will deteriorate over its intended life span, therefore the expected capacity at the end of the battery life should be used as the basis

The detailed requirements for adding batteries as part of Dynamic Positioning systems can be found in [2] and [3]. These details will not be cited in this paper. However, to provide an overview Batteries in DP rule principles can be summed up in below principles:

- The rules apply when the battery energy shall be considered as part of the redundancy for safe termination
- The Battery(Power) notation shall be applied. This will take care of battery system requirements (on a component level) including battery management and battery energy management system, and safety requirements including fire safety
- The philosophy is to consider a battery as a “generator with a limited fuel tank”
- The energy in the battery must be closely monitored (energy management system)
- Battery monitoring is required at the DP control station (includes remaining time)
- The online energy level shall be provided to the DP control system so that this can be incorporated in the online consequence analysis
- Minimum time requirement(s) shall be specified and incorporated in the DP control system online consequence analysis
- Uncertainties shall be accounted for by conservative time estimates, (e.g. in the accuracy of SoC (State of Charge), SoH (State of Health), and/or the minimum time requirement).

As mentioned above, the DNV GL Enhanced Reliability DP notations will set minimum requirements also to battery size, both in terms of power and energy. The reason for this is that these notations accepts that capacity represented by standby start may be considered as part of the post failure capacity available for safe termination (i.e. power represented by standby start can be incorporated in the DP control system online consequence analysis). Such acceptance is based on technical requirements to enhance the reliability of standby start as compared to traditional DP notations. For detailed requirements on this see [3]. Enhanced Reliability notations based on traditional generator sets will have a design and mode specific capacity available immediately after failure (before the capacity represented by stand-by start becomes available). To ensure that similar capacity will also be immediately available when batteries are part of the DP redundancy the rules have requirements to battery capacity based on design and operating modes. When batteries are used in combination with standby-start of generator sets, the battery power and energy shall in general be so that the DP system, in all intended technical system configurations, immediately after failure of any combination of generators/batteries subject to a relevant single failure (i.e. before any standby-start), can produce minimum 1/3 of the power available before failure. The system shall, without considering contribution from standby start, be able to deliver this power level in a time period equal to the specified minimum time requirement.

The FellowSHIP research project

FellowSHIP is a research collaboration between DNV GL, Wärtsilä Norway and Eidesvik that since 2013 has provided knowledge in the operation of a maritime battery system. The first phase of the project was initiated in 2003 and investigated the feasibility of on board Fuel Cell (FC) technologies, resulting in the development of the first classification rules for maritime FCs. During the second phase, a 320kW Molten Carbonate Fuel Cell (MCFC) was fitted on board offshore supply ship Viking Lady (Figure 4) for auxiliary power requirements. Built in 2009 with dual-fuel engines and conventional diesel-electric propulsion, her energy system was gradually hybridized with full-scale energy conversion and storage technologies. Finally, during the third phase in 2013, a 442kWh capacity Li-ion battery was added to the power train, converting the ship to battery hybrid-electric propulsion. Since then the ship has been in operation in the North Sea and sailing as a full-scale “test laboratory” with extensive monitoring of real-life operational conditions and performance to optimize operations and prove reliability and safety.

Figure 4 Viking Lady 442kWh – 900kW – Peak Shaving (& various test modes)

The battery-hybrid installation on Viking Lady was extensively tested during sea trials in 2014. It was found that significant fuel savings and emissions reductions are achieved with the battery-hybrid operation, however, appropriate battery sizing and implementation of optimal power-management strategies are required.

The test results for the full operational profile of Viking Lady show that a 10-15% annual reduction in fuel consumption, 25% reduction in NOx emissions and 30% reduction in GHG emissions can be realised in normal operations. Savings are primarily achieved through running fewer generator sets in DP and transit mode. However, it is important to note that the potential savings will vary from ship to ship depending on generator type and size, battery size, operational profile, power management strategies etc.

Experiences from a ship owner Eidesvik.

Eidesvik is a Norwegian ship owner. They operate in offshore logistics, seismic and underwater operations. Eidesvik was the first company in the world to introduce battery hybrid solutions for propulsion of several of their vessel. In addition to Viking Lady that got its battery hybrid solution in 2013, the Viking Queen (battery retrofit 2015), Viking Energy (battery retrofit 2016) and Viking Princess (battery retrofit 2017) has been operated with significant reduction in fuel oil consumption.

The Viking Queen has a hybrid functionality that uses the batteries for peak shaving in all operating modes. In addition, she has a load levelling mode (start-stop), where the engines run at optimal load and charge the batteries. When the batteries are fully charged, the engines are turned off and the vessel run on their batteries only.

Figure 5 Viking Queen 652kWh – 1600kW – Peak Shaving & Load Leveling (Start-Stop)

Viking Energy and Viking Princess has in addition to the Viking Queen hybrid solution also a mode where they can use the batteries as spinning-reserve in DP operations (Both vessels are DP 2). The Viking Energy was the first vessel in the world using batteries as spinning reserve in DP.

Figure 6 Viking Energy 652kWh – 1600kW – Spinning Reserve, Peak Shaving & Load Levelling (Start-Stop)

Figure 7 Viking Princess 511kWh – 1600kW – Spinning Reserve, Peak Shaving & Load Levelling (Start-Stop)

Eidesvik have reported their experience with the battery installations on these three vessels [6], and some of the main results of these reporting's are summed up below.

Viking Queen

Viking Queen is equipped with batteries which are being used for:

- Peak Shaving
- Load Levelling (Start-Stop)

There has been reported some technical start up challenges but the installation is now showing good results. For this vessel, the Eidesvik reports a total of 10-12% fuel savings across the operational profile.

Viking Princess

Viking Princess is equipped with batteries which are being used for:

- Spinning Reserve
- Peak Shaving
- Load Levelling (Start-Stop)

Learnings from the Viking Queen installation project was utilized and the retrofit process was therefore more carefully planned. The total process was somewhat longer. Also with this project there have been some challenges in operation, however less than on the Viking Queen and the installation showed results immediately. For this vessel, updated lifetime calculations made it possible to increase the battery capacity (i.e. increased utilization of the installed batteries).

For Viking Princess, the owner reports a total of 15% fuel savings (includes Battery Power – «Spinning Reserve») across the operational profile.

Viking Energy

Viking Energy is equipped with batteries which are being used for:

- Spinning Reserve
- Peak Shaving
- Load Levelling (Start-Stop)

Also in this project learnings from the Viking Queen project was utilized, leading to less challenges and the installation was showing results immediately.

For Viking Energy, Eidesvik has reported more detailed results:

- Dynamic Positioning mode (spinning reserve and peak shaving): 27,0% fuel savings
- Transit mode (peak shaving): 7,6% fuel savings
- In port / Standby mode (Start/stop function): 21,5% fuel savings
- Total across the operational profile (all modes): 17% fuel saving
- Total number of running hours on the generator sets are reduced with 36% (significantly reducing the cost for maintenance and lubrication oil)

It should be noted that the reported results are vessel specific changes, experienced before and after the installation of the battery systems. The results have not been adjusted in relation to other parameters which potentially can influence the results. Examples of such parameters could be changes to the operational profile, crew awareness/behaviour, and weather conditions). The results are collected over a significant time period, which should help level out some of the potential variations related to operational profile and weather.

Conclusions

The development of battery technology, which has mainly been done within other industries, have made it possible also to successfully introduce batteries in to the maritime industry. The main drivers in the maritime industry have typically been to reduce fuel consumption and emissions to air. On top of this also other benefits are targeted, like e.g. significant reduction in running hours on machinery.

Class societies and authorities have developed rules for safe implementation, including how to arrange a system with batteries as spinning reserve in redundant DP systems. So far, these rules have mainly been used in conversion projects. i.e. converting a traditional electrical propulsion DP system in to a battery hybrid DP system. Results from the first projects demonstrates that the targeted benefits have been achieved. Some of these results are presented in this paper.

The results from the first projects is clearly indicating that the maritime industry is learning fast and the ability to be able to deliver according to requirements are improving. Even so we would like to list some important focus items as learnings from the completed and ongoing projects with DNV GL:

- Establish a clear and unambiguous DP philosophy
    - Very important for all players involved in a project
    - Reduces risk for misunderstandings and big mistakes in projects
- Time to terminate must be stablished
    - Conservative (realistic) estimates are required to ensure sufficient safety margins
    - Important to involve owner/operational personnel
- System integration between vendors can be a challenge (e.g. who does what)
    - Typically related to power management, battery management and energy management functionality
- Some battery vendors not very familiar with the maritime approach and DP redundancy thinking
    - Land based industry thinking, e.g. MTBF instead of Redundancy
    - Not familiar with maritime equipment standards and classification rules
- Independent safety systems, monitoring and consequence analysis logic need to be focused on
- New design concepts should be agreed with class as early as possible
- Testing is useful and very important. These testing should incorporate tests reflecting the changed pre-failure load conditions (e.g. generator sets being heavily loads before failure, as opposite to the traditional situation with low load before failure occurs)

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