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Leveraging Technology to Deliver Performance Objectives

Battery-Driven Sustainability for Emission Reduction and Fault Mitigation in DP Offshore Vessels

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ABSTRACT

While highly regulated and operationally mature, the offshore marine industry faces growing challenges to reduce greenhouse gas (GHG) emissions and meet rising energy demands. Battery energy storage systems (ESS) have emerged as a key enabler, particularly in ferries and tugboats, where capacities now range from hundreds to tens of thousands of kilowatt-hours. The largest planned marine ESS will exceed 40 MWh for a fully electric vessel.

Integrating batteries into Dynamic Positioning (DP) offshore vessels introduces specific design and safety challenges, especially in electrical fault management. Key concerns include battery short circuits, switchboard fault currents, protection coordination, and fault ride through capabilities during DP operations. These issues must be addressed to comply with maritime classification standards while ensuring system reliability.

This paper explores the role of ESS in reducing emissions and mitigating electrical faults in DP vessels. It analyzes short-circuit behaviour, discusses mitigation techniques, and compares three case studies: a hybrid DP vessel and a fully electric ship. The findings highlight both sustainability benefits and safety-critical design considerations for future offshore applications.

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ABBREVIATION / DEFINITION

ABS	American Bureau of Shipping
Battery Cell	A single lithium ion pouch, of which there are many in a Battery Module.
Battery Module	A sealed enclosure containing a set of Battery Cells
Battery Pack	A series string of Battery Modules contained in a rack
BMS	Battery Management System integrated into the ESS
BoL	Beginning of Life
BSCL	Battery Short Circuit Limiter
CSOV	Commissioning Service Operation Vessel
DC	Direct Current
DoD	Depth of Discharge
DP	Dynamic Positioning
EMS	Energy Management System
EoL	End of Life
ESS	Energy Storage System(s)
FIFI	Fire Fighting
FMEA	Failure Mode and Effects Analysis
HVIL	High Voltage Interlock Loop
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
LFP	Lithium Iron Phosphate
Li-Ion	Lithium-ion
NMC	Lithium Nickel Manganese Cobalt Oxide
PDM	Pack Disconnect Module
PMS	Power Management System
RMS	Root-Mean-Square
SE	Series Element
SEV	Series Element Voltage
SLD	Single Line Diagram
SoC	State of Charge
SoH	State of Health

INTRODUCTION

The global maritime industry is under increasing pressure to reduce greenhouse gas emissions, with the International Maritime Organization (IMO) aiming for a 40% reduction in carbon intensity by 2030 and net-zero emissions by 2050. In response, offshore energy operators—such as Equinor, Shell, BP, and Ørsted—are driving sustainability initiatives that include both operational efficiency and investment in low-carbon technologies. Offshore vessels, particularly those equipped with DP systems, play a central role in these efforts due to their high energy consumption and continuous power requirements.

Battery energy storage systems (ESS) have emerged as a key enabler of decarbonization in offshore marine operations. They support hybrid and fully electric vessel configurations, reducing generator usage, enabling peak shaving, and facilitating closed bus operations. These strategies lower fuel consumption, emissions, and maintenance costs. For DP-2 and DP-3 vessels, batteries also enhance system redundancy, provide spinning reserve for blackout prevention, and improve engine operating profiles by allowing fewer generators to operate under optimal load conditions.

However, the integration of battery systems introduces critical design and safety challenges—particularly regarding electrical faults. Short circuits and fault current management pose significant risks in high-energy battery systems, where uncontrolled current surges can lead to severe equipment damage or fire. Compliance with classification society standards necessitates fault-tolerant architectures, precise protection coordination, and robust fault ride through capability.

Battery Management Systems (BMS) play a crucial role in addressing these challenges. By detecting, isolating, and mitigating short-circuit events, BMS improves both the safety and resilience of energy storage systems. Their integration is essential to ensure operational integrity under demanding offshore and DP conditions.

This paper examines the dual role of battery systems in achieving sustainability targets and mitigating electrical faults in DP offshore vessels. It presents a technical analysis of short-circuit behavior and fault management strategies, supported by three case studies: a hybrid DP vessel and a fully electric ship. The findings provide practical insights to guide future offshore vessel designs toward improved environmental performance and electrical resilience.

BATTERY TECHNOLOGIES FOR SHIP

The provided block diagram in Figure 1 illustrates the generic structure of battery systems in the marine industry, detailing main components like cells arranged in a series to form battery modules and sub-packs, alongside other associated systems. The ship incorporates a fully electric battery-powered configuration, where the battery is the primary power source for electricity.

Battery Type and Chemistry

Battery chemistry is the cornerstone of the emerging era of batteries. The paper will mainly focus on the Li-Ion NMC due to its exceptional energy density and wide range of marine applications, from small to large-scale. The Li-Ion NMC can provide faster charging and discharging rates, and its higher energy density means it can store more energy in a smaller, lighter package, which can provide advantages where space and weight are critical. Another battery chemistry suitable for marine applications is LFP, due to its excellent cycle life, particularly for an operation profile with deep Depth of Discharge (DoD) and good thermal stability. For a detailed comparison between different battery chemistry characteristics (energy density, no. of cycles, charge/discharge C rate, working temperature, and nominal voltage), (Andrzej Lebkowski, 2017) provides the tabulated summary.

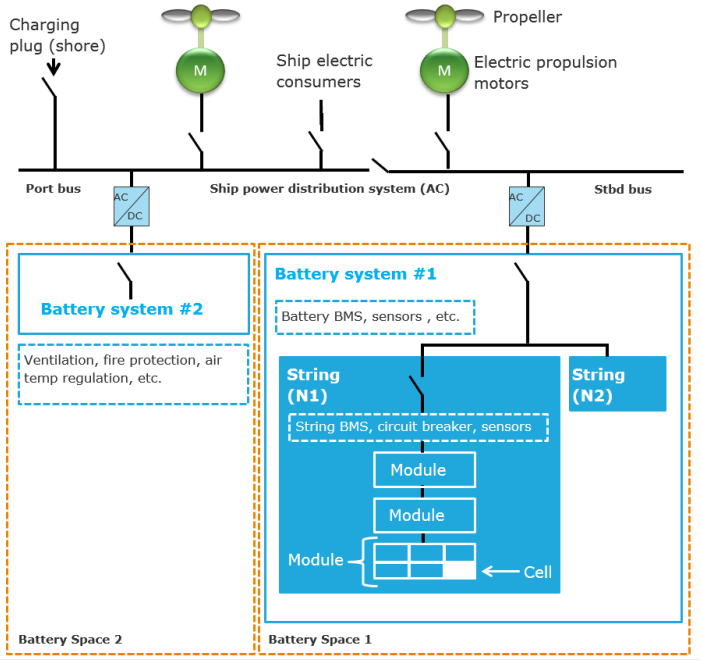


Figure 1 Block Diagram of a Generic System (DNV GL, 2016)

Charge / Discharge Characteristics

The Li-Ion battery can accommodate discharges of up to 10C (ten times the battery capacity) and achieve a full charge in as little as 30 minutes at a 2C charging rate. This ensures the ability to deliver power equivalent to that of fuel-driven engines, initiating machinery swiftly, as shown in the typical charge / discharge characteristics of Li-On NMC cells in Figure 2. The voltage at the batteries' terminals varies with their SoC and the charge or discharge current; voltage variation can be up to 20-25 percent between a typical operation point of 0.33C at 90% SoC and 10C at 5% SoC.

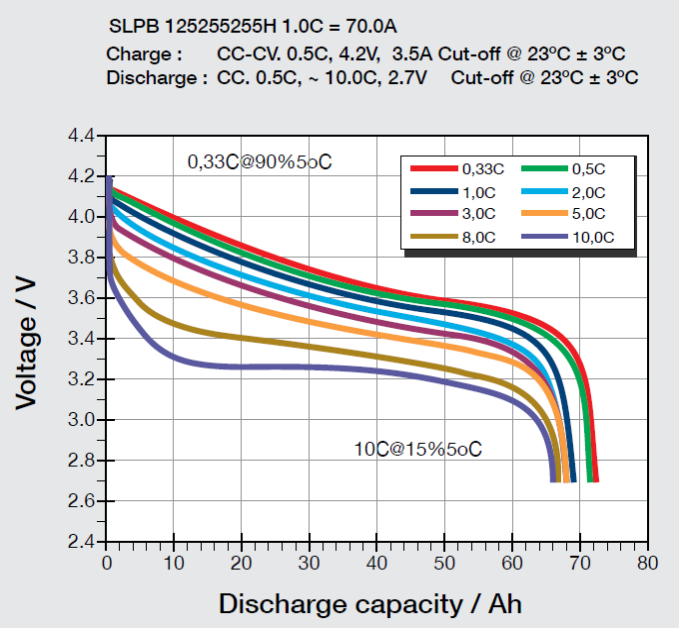


Figure 2 Charge / Discharge Characteristics for NMC Cells (ABB, 2012)

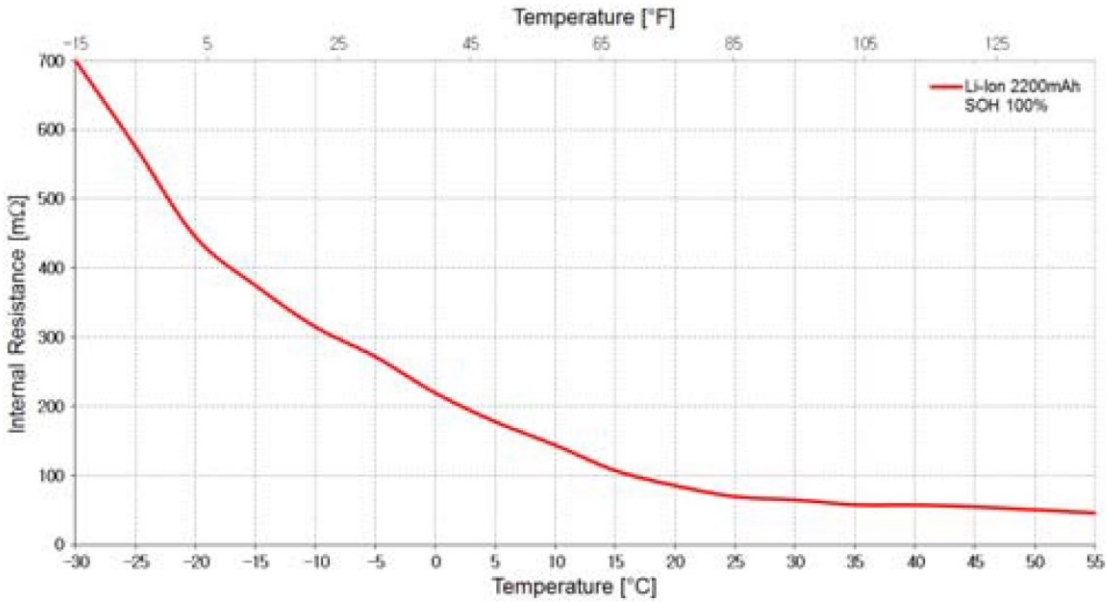


Figure 3 Internal Resistance versus Temperature for Li-Ion, 2200 mAh – load of 1C (Andrzej Lebkowski, 2017)

Resistance and Temperature

The Li-Ion battery has lower resistance in higher temperatures, which allows higher current from the battery to be charged/discharged. This in turn generates more heat and increases risk of thermal runaway. The other characteristic of Li-Ion is that in the event of a short circuit, the temperature rises quickly. In his experiment (Andrzej Lebkowski, 2017) of a Li-Ion battery, a temperature increase was observed just 10 seconds after the short circuit began. At the 32-second mark swelling of the casing commenced, followed by the opening of a safety valve and a slight release of gases and electrolytes four seconds later. The battery overheating can lead to exothermic reactions, potentially resulting in complete battery destruction, while overcharging can compromise its internal structure.

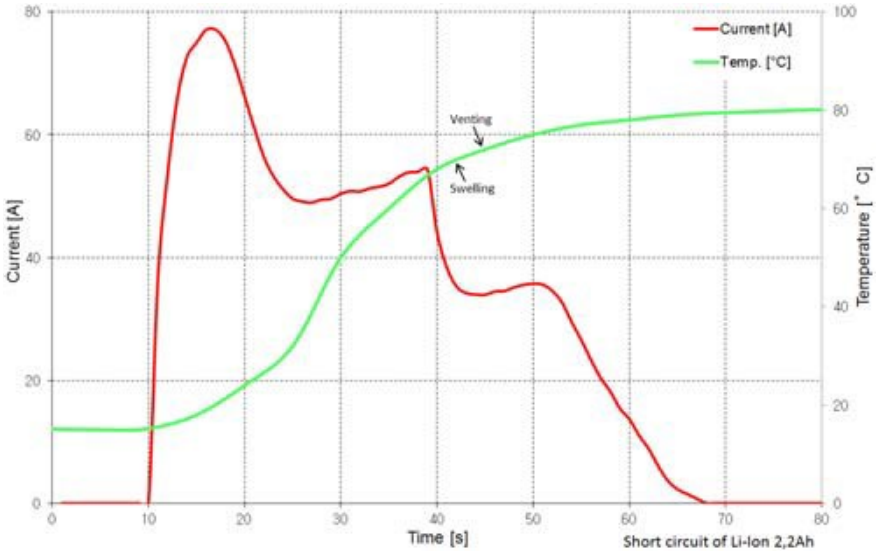


Figure 4 The Plot of Current and Temperature during Short Circuit of Li)-Ion 2200mAh Battery (Andrzej Lebkowski, 2017)

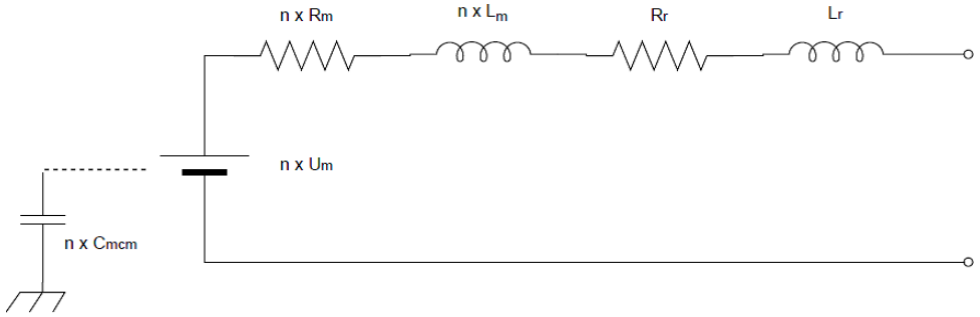


Figure 5 n-Module Simplified Electrical Model

A sample of a simplified electrical model of a battery module is shown in Figure 5, with its corresponding value in Table 1. Each battery module is protected by the fuse at its DC incomer connection, as shown in Figure 6.

Each battery pack has a maximum rated short circuit at BoL 14.9kA and a minimum short circuit at EoL 6.4 kA (Corvus Energy, 2024).

Module Voltage, Um	36 V – 50 V
Module Common Mode Capacitance, Cm	4 nF
Module Resistance, Rm	3.3 mΩ – 5.7mΩ
Module Inductance, Lm	500 nH
Pack Residual Resistance, Rr	1.3 mΩ
Pack Residual Inductance, Lr	1 µH

Table 1 n-Module Simplified Electrical Model

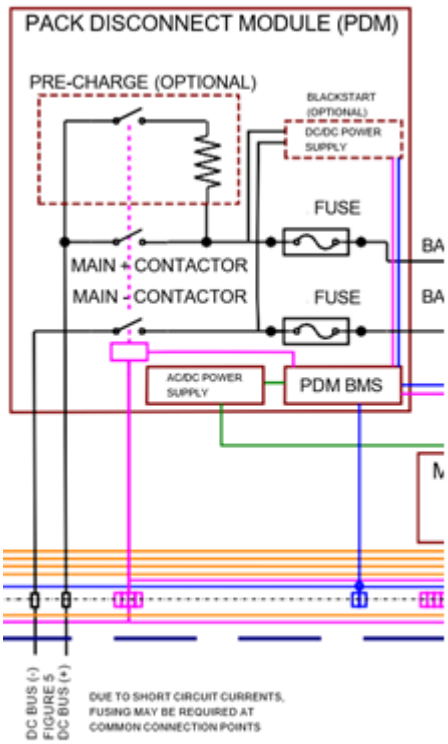


Figure 6 Diagram – Incomer DC battery with Fuse

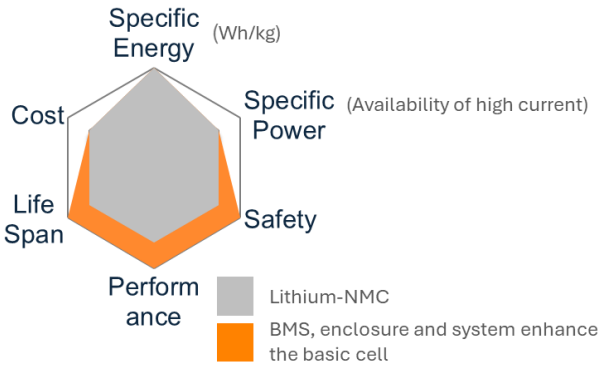


Figure 7 BMS Enhances Basic Cell Chemistry (Corvus Energy, 2025)

Energy Storage Protection

Battery Management System (BMS)

The Battery Management System (BMS) is engineered for the primary purpose of preserving batteries in a safe and healthy condition. Comprised of circuit boards, sensors, and software, it translates collected data into actionable insights for the system and users. For example, BMS provides the following function (Corvus Energy, 2024):

- Monitors the temperature of the battery cells and ambient locations within every module.
- Monitors the voltages of all cells in all modules.
- Monitors the State of Health (SoH) of each cell as a percentage of its original capacity.
- Utilizes a State-of-Charge (SoC) algorithm that accurately computes SoC even during charge and discharge and transmits the SoC value to the EMS.
- Utilizes an algorithm that computes the maximum allowable charge and discharge current based on cell temperatures, cell voltages, and SoC. These maximum allowable charge current values are transmitted to the EMS.
- Fault Detection and Protection: Actively identifying abnormalities like overvoltage, undervoltage, overcurrent, or overtemperature conditions and implementing protective measures to avert hazards.
- Communication and Data Logging: Managing interfaces to interact with the overall PMS while logging battery performance data for analysis and optimization.

BMS monitors the limit (fault, warning) for temperature and charging (overcharging, over-discharging) as well as high and low SoC as listed in Table 2 with the time delay (Corvus Energy, 2025).

Alarm	Trigger Condition	Time
Pack SE over voltage fault	4.225 V	5s
Pack SE under voltage fault	3.000 V	5s
Pack SE over temperature fault	65°C	5s
Pack overcurrent fault	T < 0°C and I > 1.05 x temperature charge limit + 5A	5s
Pack SE over voltage warning	4.210 V	5s
Pack SE under voltage warning	3.200 V	5s
Pack SE over temperature warning	60°C	5s
Pack overcurrent warning	I > 1.05 x temperature charge limit + 5A	10s
	or I < 1.05 x temperature discharge limit – 5A	
PDM over temperature warning	110°C	30s
Pack hardware over voltage safety shutdown	4.300 V	1s
Pack hardware under voltage safety shutdown	2.700 V	1s
Pack hardware over temperature safety shutdown	70°C	5s

Table 2 Alarm Threshold Value

Safety features are also crucial at the software level. Demonstrated in Figure 7, the BMS design supports safety, mitigates risks related to Li-Ion NMC cell chemistry, and enhances cell performance. This is primarily achieved through cell balancing, where the BMS monitors and equalizes the voltages and state of charge among the cells, which helps to prevent damage and optimizes the function, SoH, and lifespan of the battery system.

Hardware Safety Loop

In addition to the software threshold limit described in Table 2, there are hardware-only safety loops that prevent the battery pack from operating unsafely, even in the event of loss of software functionality. Hardware fault detection circuits will interrupt the safety loop, which causes the contactors to open. A table of the various conditions that interrupt the hardware safety loop is given in Table 3. The loss of electrical power to these circuits will also open the contactors.

Condition	Location	Description
E-stop from customer	Master Control Module	24V is not detected on the E-stop signal in.
CPU reset	Master Control Module	Master Control Module has experienced a processor reset.
Safety loop integrity	Master Control Module	Safety loop may not be functioning correctly.
Pack HVIL	Pack Disconnect Module	Pack Disconnect Module has been physically disengaged from the battery high voltage line.
CPU reset	Pack Disconnect Module	Pack Disconnect Module has experienced a processor reset.
Cell over temperature	Battery Module	The measured temperature on a cell has exceeded the hardware safety limit.
Cell over voltage	Battery Module	The measured voltage on a cell has exceeded the hardware safety limit.
Cell under voltage	Battery Module	The measured voltage on a cell has exceeded the hardware safety limit.
Module in sleep mode	Battery Module	The module BMS is turned off (can be from pack "power save" mode, turning off BMS power, or module not installed into a rack).

Table 3 Hardware Safety Loop Trigger Conditions

Current Limit

Every battery pack computes the real-time maximum allowable charge and discharge currents (Corvus Energy, 2025). These are referred to as the "charge current limit" and the "discharge current limit," respectively.

CHALLENGES IN ENERGY STORAGE IMPLEMENTATION

A critical aspect of integrating batteries into the electrical ship switchboard is understanding the maximum short-circuit current each piece of equipment can handle. Challenges in electrical ship design include short circuits in batteries, short circuit capacity protection for switchboards or protective devices directly connected to the battery, selectively coordinated systems between the energy storage and electrical ship switchboard, fault detection, and minimizing fault points, as well as fault ride through in the event of battery or equipment failure.
Overall, the safety of the battery installation is of utmost importance. Another consideration for integrating a battery into the ship design is to choose the correct location for the battery system. Large battery installations require specific space and weight distribution. Plus, class requirements dictate where onboard the ship the battery can be placed and must be adhered to even if the vessel is unclassed. Battery implementation also requires specific fire safety, which means having FiFi equipment or a freshwater tank installed for extinguishing or cooling the battery room in the case of thermal runaway or battery fire.

Ship Design – Weight, Space, Location

Battery space plays an essential role in the safety aspect of the operation, especially in the event of unwanted heat, which could result in a potential thermal runaway event or short circuit. DNV recently issued a recommendation regarding battery space and segregation. According to (DNV GL, Part 6. Ch. 2; July 2025), the energy storage capacity within one ESS space shall be limited to 5 MWh. A system larger than 5 MWh in one space will be considered on a case-by-case basis. DNV also mentioned barriers to implement in the ESS room (DNV GL, 2023).

Optimizing space and weight onboard a ship is essential for cost-effective, safe, and efficient operation. Therefore, with a larger battery size, maintaining the proper weight distribution for a ship's stability and maneuverability will be challenging. A larger battery system calls for more equipment to connect and control the battery, which increases the total weight and space requirement. Another challenge with a larger battery size is to ensure the proper segregation and protection coordination is in place to keep the short circuit capacity within the equipment limit. This further adds to the total equipment weight and space required.
The location of the battery is a critical consideration in ship design. DNV offers comprehensive and detailed guidance on battery installation for both steel and non-steel materials (DNV GL, Part 6. Ch. 2; July 2025). Even for unclassed vessels, the following requirements are essential for battery safety when integrating the battery into the electrical ship design. Essential requirements for the battery installation include:

- The battery space must be classified as a machinery space of category A for fire detection purposes.
- The battery must be located aft of the collision bulkhead. For steel vessels, the boundaries of the battery space must not be part of the vessel's outer shell (sides, stern, and bottom). For vessels made from materials other than steel, preventive measures must address the risk of water ingress into the battery space due to outer shell damage.
- The battery space must not have direct access from areas accessible to passengers.
- Openings and penetrations in the battery space boundaries must preserve the fire, gastight, and watertight integrity of the space.
- The battery space must be equipped with an integrated off-gas ventilation duct, which should connect directly to an outlet ventilation duct that leads to the open air. This outlet duct must be installed separately and independently from the battery space outlet duct as shown in Figure 8.

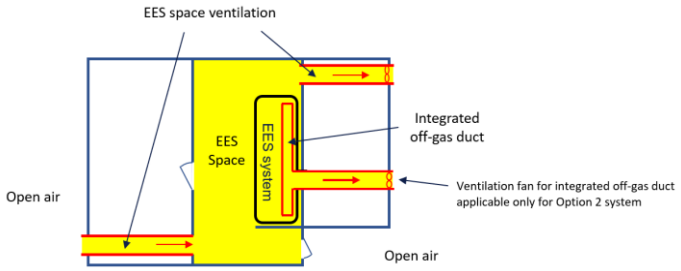


Figure 8 Ventilation of battery space and integrated off-gas duct (DNV GL, Part 6. Ch. 2; July 2025)

Fire Safety

The integration of electrical energy storage into the electrical switchboard introduces the potential risk of thermal runaway and battery fire. Classification societies, such as DNV, regularly update their guidelines on battery fire safety and protection. The battery space must be protected by a fixed fire extinguishing system capable of extinguishing a battery fire or controlling it while continuously cooling the battery room. According to the latest guidelines, two types of systems are recommended (DNV GL, Part 6. Ch. 2; July 2025):

1. Water-based: Designed to discharge fresh water for 60 minutes using a dedicated freshwater tank.
2. Combined systems: Designed to discharge both a gas-based and a freshwater-based water spray system, with separate and independent components. The gas agent, quantity, and composition must comply with class rules. The water spray system must supply freshwater through its nozzles for 30 minutes at a flow rate of 5.0 liters per minute per square meter.

Electrical – Protection and Short Circuit

To allow safe operation, fuses are installed to protect against short circuits because short circuits can result in dangerously high levels of current flow through a circuit. When a short circuit occurs, the resistance in the circuit drops dramatically, allowing a surge of current to flow unrestricted. The semiconductor fuses are able to handle enormous power within a small physical size. In the battery-connected configuration to DC distribution, a short circuit could lead to fault currents that exceed the short circuit capacity of the DC/DC converters. High-speed fuses are chosen to protect each converter for the following reasons (Stig Olav Settemsdal, Espen Haugan, Ketil Aagesen and Bijan Zahedi, 2014):

- safely interrupting high prospective fault currents in extremely short times
- limiting the value of excessive current to pass through the device
- limiting the thermal energy ($\int i^2 dt$ or I^2t) passing through the device during fault interruption
- The fuses are dimensioned so that they can clear any fault in their protection zone, even with the lowest possible energy level.

To safeguard against short circuits and protect both the DC/DC converter and input power cables, fuses or appropriate circuit breakers are installed at the supply side of the cabling. Within the DC/DC converter itself, standard fuses are incorporated to shield it, limit potential damage, and prevent harm to adjacent equipment. The DC/DC converter also features internal protection mechanisms designed to safeguard both the DC/DC converter and the energy storage in the event of faults, such as short circuits and overcurrent. The DC/DC converter unit has two sets of DC fuses: output DC fuses on the energy storage side (b) and DC fuses on the DC bus side (a). See the overview diagram in Figure 9 and Figure 10 (ABB Oy, 2025). The fuse on the output DC bus protects the DC/DC converter and cable in the event of a cable short-circuit situation. DC fuses on the DC bus side protect the module and the DC bus against short circuits.

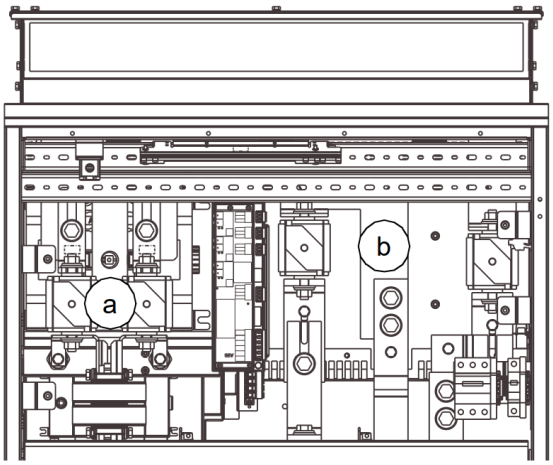
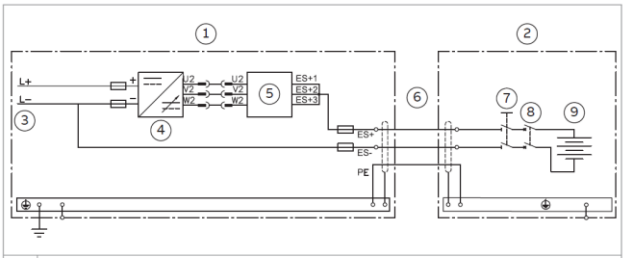


Figure 9 DC/DC Converter with DC Fuses (a) (b)



1	DC/DC converter cubicle
2	Energy storage cabinet
3	Drive DC bus
4	DC/DC converter module
5	Filter module
6	Cabling between DC/DC converter unit and energy storage
7	Energy storage disconnecting device
8	Energy storage protective circuit breaker
9	Energy storage

Figure 10 Simplified Main Circuit Diagram DC/DC Converter

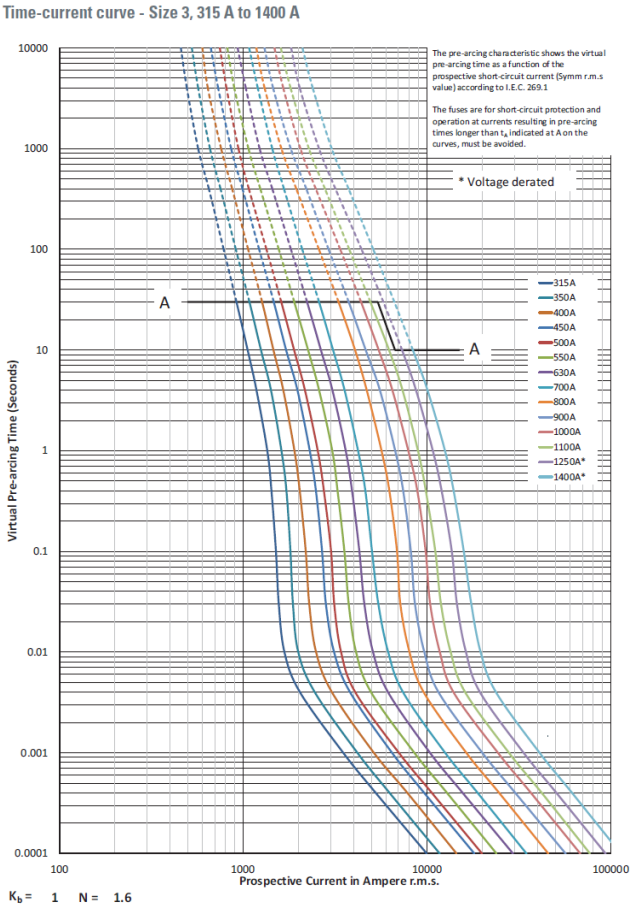


Figure 11 Example DC Fuses (DC bus side or ESS side)

Verification of the circuit breaker, fuse, or contactor operation requires conducting short circuit calculations that consider the impedances of the converter, filter, cabling, and energy storage, as well as the minimum and maximum state of charge of the energy storage. Additionally, it is essential to account for the effects

of battery aging on impedance. The example of DC fuses Time-current curve characteristics with its RMS prospective short-circuit current and pre-arching time is shown in Figure 11. The 170M type Bussmann series fuses are rated at 1250 V a.c. (IEC) or 1300 V a.c. (UL) (Eaton Electrical Products Limited, 2023).

The DC/DC converter connected to the DC bus and installed in the DC switchboard has its short circuit equipment rating. For example, the short-circuit withstand strength of an ABB switchboard has been rated as follows (IEC 61439-1) (ABB Oy, 2025):

- Rated peak withstand current (I_{pk}): 143 kA
- Rated short-time withstand current (I_{cw}): 65 kA/1 s

The DC/DC converter is designed for use on a circuit capable of supplying no more than 100,000 RMS symmetrical amperes at a maximum of 600 V when the input cable is protected with T-class fuses.
Rated short-time withstand current (Icw) refers to the RMS. The value of short-time current, as declared by the assembly manufacturer, is that the assembly can withstand without sustaining damage under specified conditions defined in terms of current and time. Various values of Icw for different durations (e.g., 0.2 s, 1 s, 3 s) may be assigned to an assembly.
The rated peak withstand current (Ipk) represents the peak value of the short-circuit current, as declared by the assembly manufacturer. This means that the assembly can withstand the specified conditions.

BATTERY CLASS NOTATION FOR THE DP OFFSHORE VESSEL

ABS, from their notation and symbol document (ABS, 2023) provides the Battery notation "*ESS-LiBATTERY*." This notation is assigned to marine and offshore assets with a lithium-ion Battery system used as an additional power source with a capacity greater than 25 kWh where the batteries are used as the emergency power source.
Whereas DNV, in their document (DNV GL, Part 1. Ch. 2; July 2025), depending on the primary power source of the propulsion, power generation, and auxiliary system, provides 2 Battery class notations, "*BATTERY (POWER)*" and "*BATTERY (SAFETY)*."

The notation of "*BATTERY (POWER)*" applies when the Battery is used for electrical propulsion of the vessel. Under this notation, different applications, such as all-electric and hybrid vessels will exist. One example of the hybrid vessel application is as a redundant source of the main power and for dynamic positioning. The DNV notation "*BATTERY (SAFETY)*" refers to when the Battery is only used for peak shaving and/or load leveling and is not used for main propulsion power.

There are two main applications of Battery as the main power with the ABS class notation "*ESS-LiBATTERY*" and DNV class notation "*BATTERY (POWER)*," The first is as the backup generator, and the second is as for blackout prevention and or Fault ride through.

Battery in the DP Operation

ABS, in their document (ABS, 2024) lists the benefits of Battery (Li-ion Battery) systems in marine and offshore industries as the primary source of electrical power, emergency source of electrical power, and transitional source of electrical power. Indicated Battery applications include:

- The primary source of power for the propulsion system
- Using Battery for port transit or in zero emissions areas
- For load leveling/peak-shaving to supply/absorb demand peak so that the generator sets can operate at a near-constant load
- Additional power in case of generator shutdown
- Battery as a standby power source so that fewer generators need to be in operation
- For blackout prevention, fault ride through, and blackout recovery

- For DP vessels to supply thrusters and as a backup in DP mode and standby or for Fault ride through on DP2/DP3 vessels operating in closed bus, complying with redundancy criteria

In (Irwan Kwik, 2023), the three cases of DP Vessel ESS utilization are clearly described, including their annual fuel savings and the reduction of gas emissions per year.

Battery Reduces the risk of a complete blackout

Class societies such as DNV accept the Battery as the redundancy/running machinery upon special consideration. The Battery shall be designed to provide the intended power and energy when needed, including post-failure. The system design for the blackout is verified by doing the FMEA analysis of the power plan, including its control, monitoring, and protection systems. The automatic blackout recovery will be analyzed and tested (depending on the class notation) on individual switchboard sections. The recovery time for such DP control systems is to receive the thruster-ready signal within 45 seconds. The complete blackout of the power generation must not happen; therefore, the minimum power sources belonging to two different redundancy groups shall always be connected and running/live (for example, the running genset and or connected batteries) (DNV GL, August 2022).

Battery Design FMEA and Fault Ride Through:

The fault ride through is the capability of a vessel's DP system power plant and control systems (for a closed bus operation) to recover from the effects of a fault anywhere on the main and distribution systems (e.g., on a main switchboard bus segment or a primary feeder circuit) without significant malfunction before the bus-tie breaker opens to isolate the faulted side of the system during a "limited" time or voltage drop. The design defines "Limited" time to stabilize the system (ABS, 2024)**.**
For any DP vessel implementation (DNV GL, August 2022), the verification tests for DP redundancy are based on the FMEA of the corresponding class notation. A useful resource, the FMEA identifies typical failure modes for a closed bus-tie and corresponding effects, explaining possibilities in detail with figures. An example includes examining the scenario of sharing load between two or more generators when the bus tie is closed.

FUTURE SHIP DESIGN AND CASE STUDIES

Future Electrical Ship Design

Larger Battery Dimension

Future electrical ship design will present challenges due to the increasing size of batteries required to supply the energy demands of electric vessels. In 2013, Incat announced the construction of the largest lightweight battery-electric ship, featuring a 40 MWh energy storage system. (Incat Tasmania Pty Ltd., 2023). The ferry was delivered and officially launched on May 2, 2025, carrying 2,100 passengers and 225 vehicles across the River Plate between Buenos Aires and Uruguay. A battery weighing over 250 tonnes will significantly contribute to short-circuit currents, requiring extensive electrical equipment or DC/DC converters and/or other short circuit management systems, such as a Battery Short Circuit Limiter (BSCL) , to limit and maintain the short circuit levels within equipment ratings.

Safety Design Philosophy and Battery Test Standard

Due to the high demand for energy storage applications in the marine industry and the need to promote higher safety design standards for marine batteries, class societies have incorporated and updated their safety measures for batteries. An illustration of a chain of events leading to fires in electrical energy storage systems is provided in Figure 13 (DNV GL, 2023). This report comprehensively describes each threat and incident, along with possible barriers and guidance to mitigate fire risks.

The (DNV GL, 2013) guidelines outline typical battery system performance tests, such as cell balancing, State of Charge (SoC) validation, charging/discharging behavior, and capacity checks. These guidelines also provide standards for battery system safety tests, including external short circuits without a Battery Management System (BMS) as per IEC62281/UN38.3, and internal thermal events as specified in IEC62619. Additionally, environmental tests for battery systems are detailed, covering vibration, drop, heat, cold, corrosion, flame retardant, Electromagnetic Susceptibility (EMS), and Ingress Protection (IP) in accordance with IEC60092, IEC62281, and IEC60529.

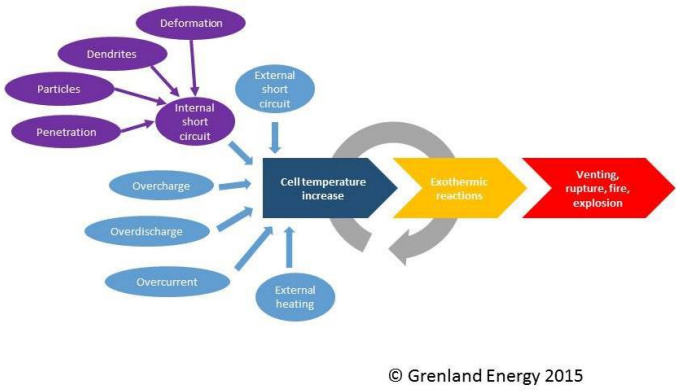


Figure 12 Overview of Factors for Increased Temperature Battery Cell (Grenland Eergy)

Cells	Internal short circuit
	High Impedance
	Insulation fault
	Electrolyte leakage
Modules	Temperature Sensor failure
	Voltage sensor failure
	Control failure
	Internal short circuit
	Internal open circuit
	High Impedance
	Insulation fault
	Cooling system leakage
	Loss of cooling
Sub-Packs	Contactor does not open when required
	Contactor does not close when required
	Current sensor measurement error
	Connector high impedance
	Leakage of cooling connector
	Sub-pack enclosure leakage/damage
	Mishandling of battery system.
Packs	Contactor does not open when required
	Contactor does not close when required
	High level sensoring failure
	Internal pack imbalance
	Temperature imbalance within pack
	Battery life too short
	Energy losses too high

Table 4 Failure modes in "Battery System" (DNV GL, 2013)

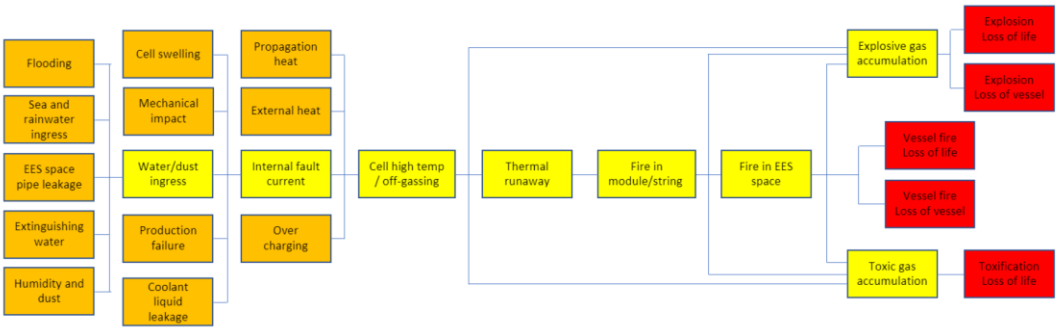


Figure 13 Chain of Events for Fires in Electrical ESS

A list of factors contributing to increased battery temperatures, as shown in Figure 12 (DNV GL, 2016), highlights the primary risks that battery suppliers must mitigate. This includes implementing robust Energy Storage Protection measures, as discussed in the previous section. To further enhance safety, Table 4 provides a detailed list of potential battery failures for battery installations.

By adhering to these comprehensive standards and continuously enhancing the safety design philosophy, energy storage implementations in the marine industry can achieve both design performance and elevated safety standards.

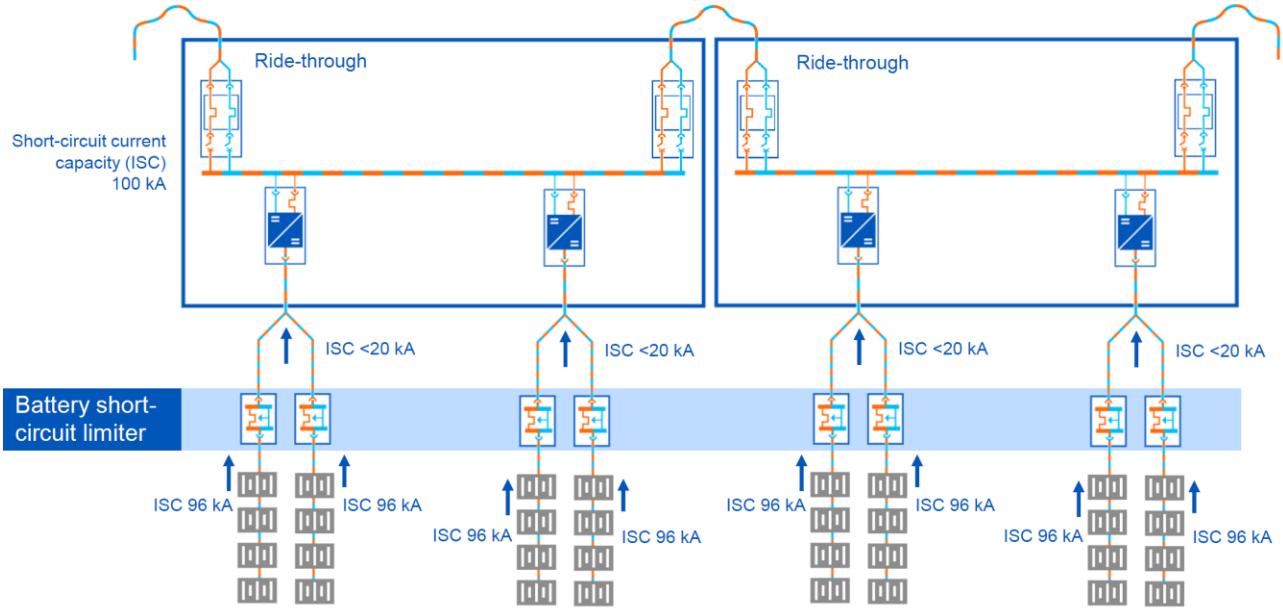


Figure 14 Case Study of connecting 20MWh Battery using BSCL / implement the Large Scale of ESS (The Switch, 2023)

Short Circuit Management

As discussed in the section Electrical – Protection and Short Circuit regarding short circuit rating limitations, fuses can provide protection due to their ability to reduce and break the short-circuit current's peak value and energy. The rated capacity of the short circuit DC/DC Converter must comply with the short circuit of the connected equipment, which is another requirement to consider when connecting to and controlling a large battery installation.

Another potential solution for managing and mitigating short circuits is to connect additional battery packs to the BSCL to limit the short-circuit current. Connecting the BSCL via a DC/DC converter to the DC-Hub or DC switchboard is optional. The BSCL can act as an ultra-fast electronic fuse, disconnecting or reconnecting critical faults within 10 microseconds. This configuration of the BSCL broadens the possibilities for incorporating safe, large-scale energy storage in future electrical ship designs. The BSCL provides instant short-circuit protection at the battery level, allowing the integration of more batteries with fewer DC Switchboards or Hubs. This results in a more compact system architecture, with increasing advantages as the battery system scales. Figure 14 shows an example of a case study done by the company The Switch, regarding connecting a 20 MWh battery using BSCL.

Case Studies

This section reviews technical solutions for connecting ESS to the DC switchboard, using simplified single line diagrams for three vessels: a 40 MWh fully battery-powered Buquebus ferry; an anonymous 4,2 MWh battery hybrid DP-2 offshore vessel with DNV "BATTERY (POWER)" and "DYNPOS (AUTR)" notations; and a 25 MWh battery Bibby Marine eCSOV (Commissioning Service Operation Vessel), a DP-2 with DNV "BATTERY (POWER)" and "DYNPOS (AUTR-CB)" notations.

The ESS to DC switchboard connection impacts key aspects of ship design, including weight, space, location, fire safety, electrical protection, and short-circuit prevention. The case studies illustrate

configuration options to connect the battery to the DC switchboard that ensure safety, while optimizing for cost-effective and efficient operation.

Vessel 1 – Ferry 40 MWh (DNV - Fully Electric)

1. Battery dimension:

Description	Details
Battery Dimension	Total capacity = 41171 kWh

2. Single Line Diagram:

The simplified Single Line Diagram (SLD) for Vessel 1 is shown in Figure 15.

It is a fully electric ferry with a 4-split configuration. Batteries are equally divided among the buses, with each bus connected to others to allow for greater shared power.

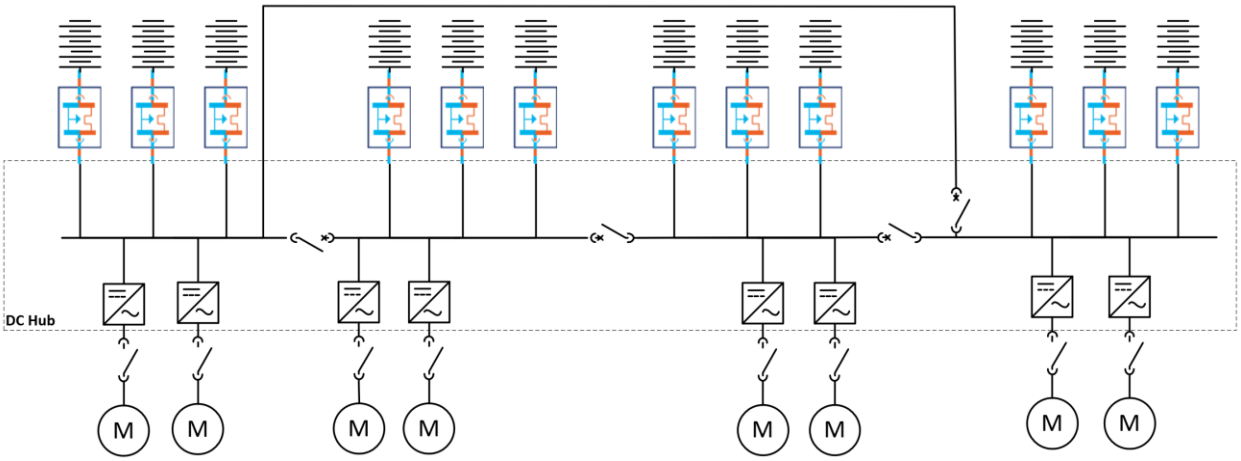


Figure 15 Simplified SLD - Ferry 40 MWh (Fully Electric)

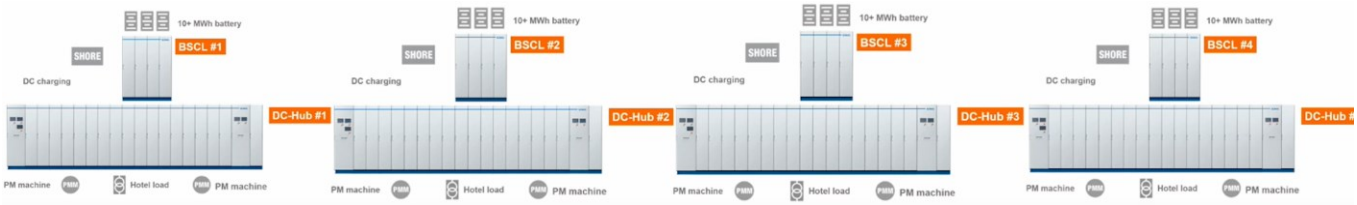


Figure 16 Electric Ferry 40 MWh ESS with BSCL

Instead of ESS connecting directly to the DC bus or to the DC/DC Converter, it is connected to the ultrafast electronic fuse, BSCL, which provides short-circuit protection and can disconnect or reconnect in critical faults within 10 microseconds. This approach helps ensure safety and reduces the equipment's footprint, which may also ultimately lower the CAPEX for vessel installation.
Figure 17 and Figure 18 shows the general arrangement of all electrical equipment, including the propulsion control system, 40 MWh batteries, BSCL, DC Hubs, Transformers, Electric motors, and waterjets.

The ferry is expected to be fully charged in 40 minutes, rated at 16000A DC and 8000A (Clean Shipping International, 2024).

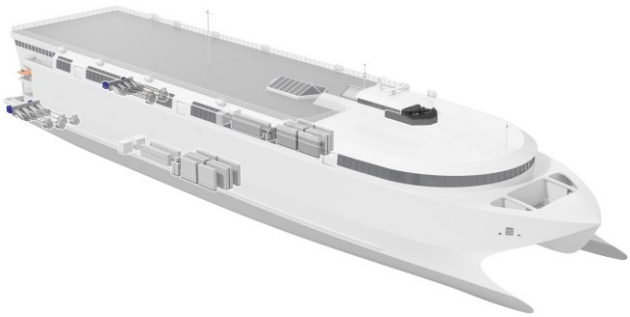


Figure 17 General Arrangement–Electrical Equipment ESS 40 MWh

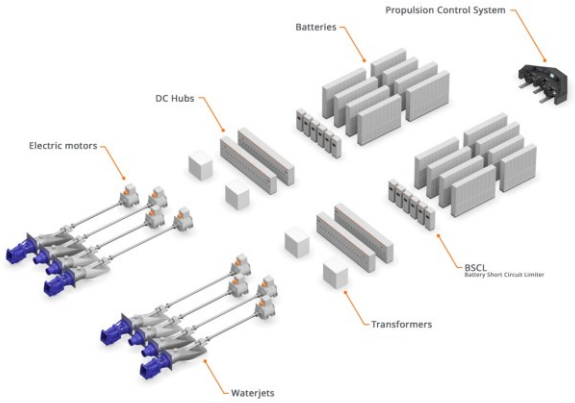


Figure 18 Electrical System Configuration with ESS 40 MWh

Vessel 2 - DP-2 (DNV - "BATTERY (POWER)", DYNPOS (AUTR))

1. Battery Configuration and Profile:

Description	Details
Battery Configuration	Total capacity = 4228 kWh

2. Single Line Diagram:

It is a DP offshore hybrid vessel equipped with a 4.2 MWh ESS configured in a 4-split configuration. The simplified Single Line Diagram for Vessel 2 is shown in Figure 19. It has a DNV notation system BATTERY (POWER) and DYNPOS (AUTR). The DP-2 vessel may have a closed bus-tie mode approved based on the minimum requirements in the DP class, although it does not have an approved notation for closed bus-ties. The vessel has a certain extent of redundancy in its technical design. This configuration offers a greater possibility of power in the event of a blackout or fault.

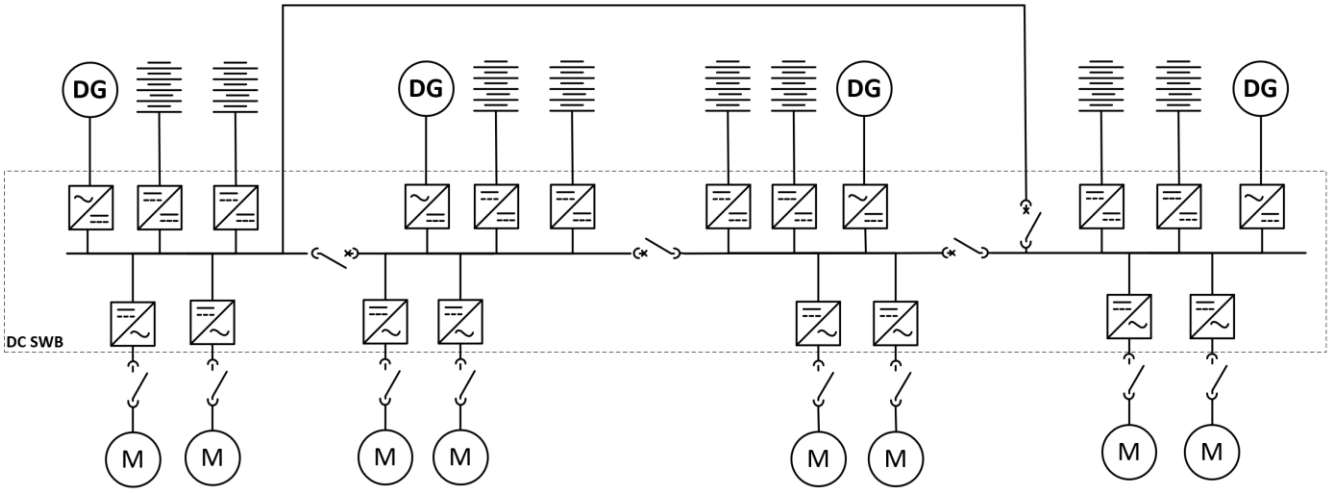


Figure 19 Simplified SLD - DP-2 Vessel (DNV notation "BATTERY (POWER)", DYNPOS (AUTR))

The 4.2 MWh ESS connects to the DC bus via the DC/DC converter, which offers protection in case of a short circuit up to the rated capacity of the switchboard. Since the battery is small, it doesn't need a large equipment footprint. The ESS is designed to deliver instant power equal to one generator's capacity for 15 minutes. This instant power supports operations during a blackout or to recover from a Fault (Fault Ride Through).

Vessel 3 – DP-2 (DNV - "BATTERY (POWER)", DYNPOS (AUTR-CB))

1. Battery Configuration and Profile:

Description	Details
Battery Configuration	Total capacity = 24598 kWh

2. Single Line Diagram:

The simplified Single Line Diagram for Vessel 3 is shown in Figure 20.

It is a Bibby Marine electric CSOV with DP-2's DNV notation BATTERY (POWER) and DYNPOS (AUTR-CB). It is designed with ESS as the primary power source and to operate in a closed bus-tie configuration. The battery packs are electrically and physically divided into a 3-split for enhanced redundancy and safety. The battery system will be complemented by dual-fuel methanol engines, a combination that will significantly reduce CO2 emissions from the vessel while reducing daily operational costs. It is scheduled for launch in 2027, featuring a 25 MWh ESS (gCaptain, 2025).

It will be the first fully electric offshore vessel capable of charging batteries while maintaining DP during offshore operations. This vessel marks a significant milestone in the decarbonization of the maritime industry. The vessel's power distribution system uses a DC architecture. The connection between the ESS and the DC switchboard is not specified at this time; however, it is unclear whether it will use a fast electronic fuse BSCL or a DC/DC converter. Given the ESS capacity of 25 MWh, it may be beneficial to use the BSCL to optimize the footprint while ensuring electrical safety and short-circuit protection.

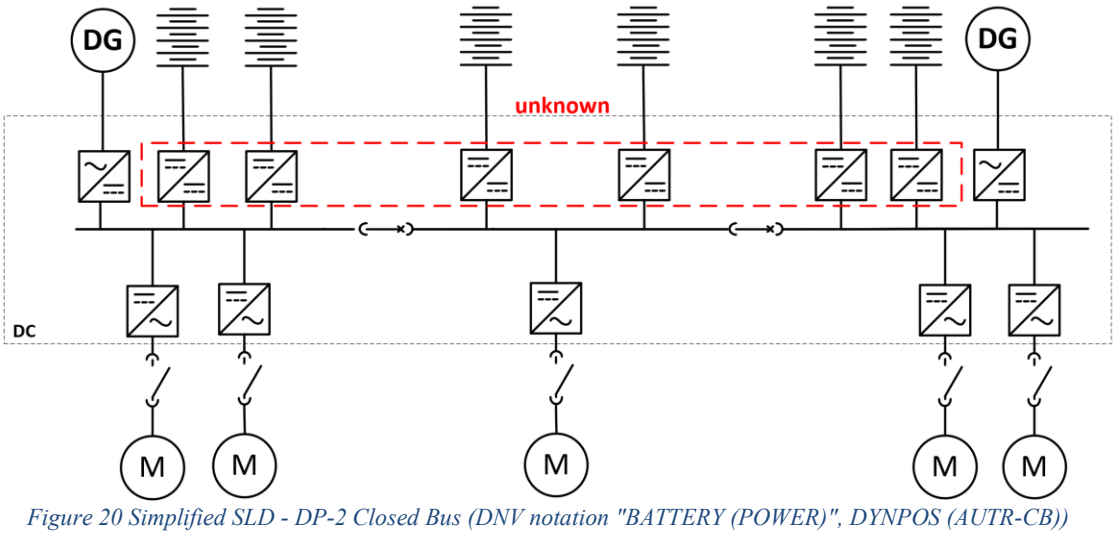


Figure 20 Simplified SLD - DP-2 Closed Bus (DNV notation "BATTERY (POWER)", DYNPOS (AUTR-CB))

Figure 21 and Figure 22 shows the general layout of all electrical equipment, including the bridge and control system, generators, 25 MWh batteries, switchboard, transformers, electric motors, and propulsion.

With the DNV notation DYNPOS (AUTR-CB), the vessel has approved DP mode(s) based on closed bus-ties. The vessel also has additional functionality and equipment compared to vessel 2, which does not have the qualifier -*CB* (Aleks Karlsen, 2023):

- APSP (advanced power system protection) (single barrier system)
- Two bus-ties between redundancy groups
- The protection system shall ensure bus-tie discrimination during arcing faults and other relevant failure modes within the overload range
- Synchronization functions must be designed with very high reliability
- Transformer pre-magnetization
- PMS robustness, including the automatic blackout recovery function of DP system (45 sec.)

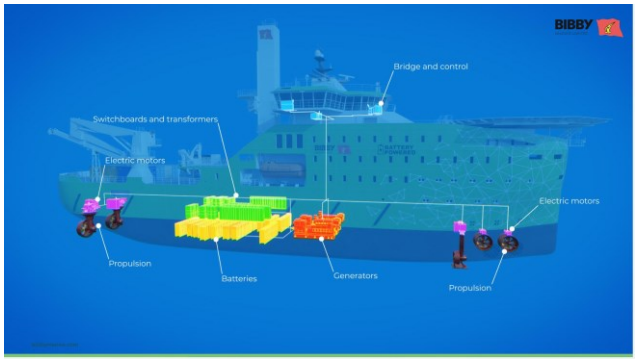


Figure 21 General Arrangement–Electrical Equipment ESS 25 MWh

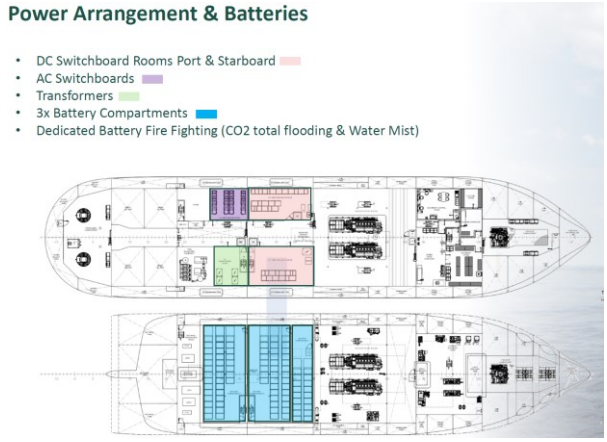


Figure 22 Power Arrangement & Batteries

Future electrical ship designs for DP offshore vessels will include larger-capacity battery systems, which, as a result, will present challenges in ship design and short-circuit management. The comparison of three cases demonstrates different battery implementations in ferry and DP offshore vessels. Lessons learned from the ferry industry can be applied to the offshore sector to encourage safer and more efficient adoption, while still maintaining the higher safety and redundancy standards required of offshore DP vessels.

CONCLUSION

The integration of batteries into electrical ship design represents a significant shift towards achieving lower carbon emissions and increasing energy efficiency in the marine industry. However, this transition is not without its challenges, particularly in addressing safety concerns related to short circuits and thermal management.

Battery implementation presents unique challenges, such as resistance and temperature factors that can lead to thermal runaway and short circuits. Understanding these traits is crucial for implementing effective safety measures and reducing risks.

Battery applications in the offshore industry must meet classification standards to operate safely, especially with redundant systems like DP-2 and DP-3.

Classification Societies assign the Battery notation based on the battery usage in the electrical propulsion vessel.

The integration of Battery Management Systems (BMS) is crucial for ensuring the safe and efficient operation of battery-powered electrical systems. BMS monitors key parameters such as temperature, voltage, and state of charge, allowing for proactive fault detection and protection mechanisms. Additionally, hardware safety loops and current limiters add extra protection against short circuits and other potential hazards.

Battery energy storage systems (ESS) play a crucial dual role in supporting both sustainability and electrical fault mitigation in DP offshore vessels. By reviewing three vessel configurations—a fully electric ferry, a hybrid DP-2 vessel, and an electric-first hybrid DP-2 CSOV—this paper demonstrates the various approaches to integrating ESS within marine electrical architectures, each with its own design, safety, and operational trade-offs.

Key findings highlight that connection methods (BSCL vs. DC/DC converters), battery capacity, class notations, and redundancy levels all affect system safety, space requirements, and adherence to DP-specific standards.

Looking ahead as the scale of energy storage systems continues to grow, innovative solutions, like BSCL that limit and maintain the short circuit levels within equipment ratings, offer promising opportunities to improve safety and reliability. By tackling challenges related to short circuits and applying effective mitigation strategies, the future of electrical ship design has great potential for sustainable and efficient maritime transportation.

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