NEMOSHIP

NEW **MO**DULAR ELECTRICAL ARCHITECTURE AND DIGITAL PLATFORM TO OPTIMISE LARGE BATTERY SYSTEMS ON **SHIP**S

GRANT AGREEMENT No. 101096324

D3.1: Modular BESS definition (architecture, storage units, interfaces)

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Project summary

The ambition of the NEMOSHIP project is to develop, test and demonstrate new innovative technologies, methodologies, and guidelines to better optimise large electric battery power technology within hybrid and fully electrically powered ships. The project will act as a key enabler of the new co-programmed European Partnership Zero Emission Waterborne Transport (ZEWT) roadmap to better reach International Maritime Organization (IMO) objectives regarding the reduction of Greenhouse Gas (GHG) emissions from waterborne transport by 2030 and 2050.

To help achieve this ambition, NEMOSHIP will develop a modular and standardised battery energy storage solution that is able to exploit heterogeneous storage units and a cloud-based digital platform to enable data-driven, optimized, and safe exploitation. The project will demonstrate the maturity of these innovations at Technology Readiness Level (TRL) 7 for hybrid ships as well as their adaptability towards fully electric ships thanks to the observations collected from a retrofitted hybrid offshore vessel (diesel/electric propulsion once retrofitted), a newly designed hybrid cruise vessel (LNG/electric propulsion) and a semi-virtual demonstration of two additional fully electric vessels employed in tasks such as ferrying and short-sea shipping.

The NEMOSHIP consortium estimates that these innovations will contribute to the electrification of about 7 % of the European fleet by 2030 and the reduction by 30 % of EU maritime GHG emissions compared to a business-as-usual scenario.

The NEMOSHIP consortium is composed of 11 partners (3 RTO, 1 SME, 7 large companies) from six European countries and covers the whole value chain, from research-oriented partners to software developers, energy system designers, integration partners, naval architects, and end-users.
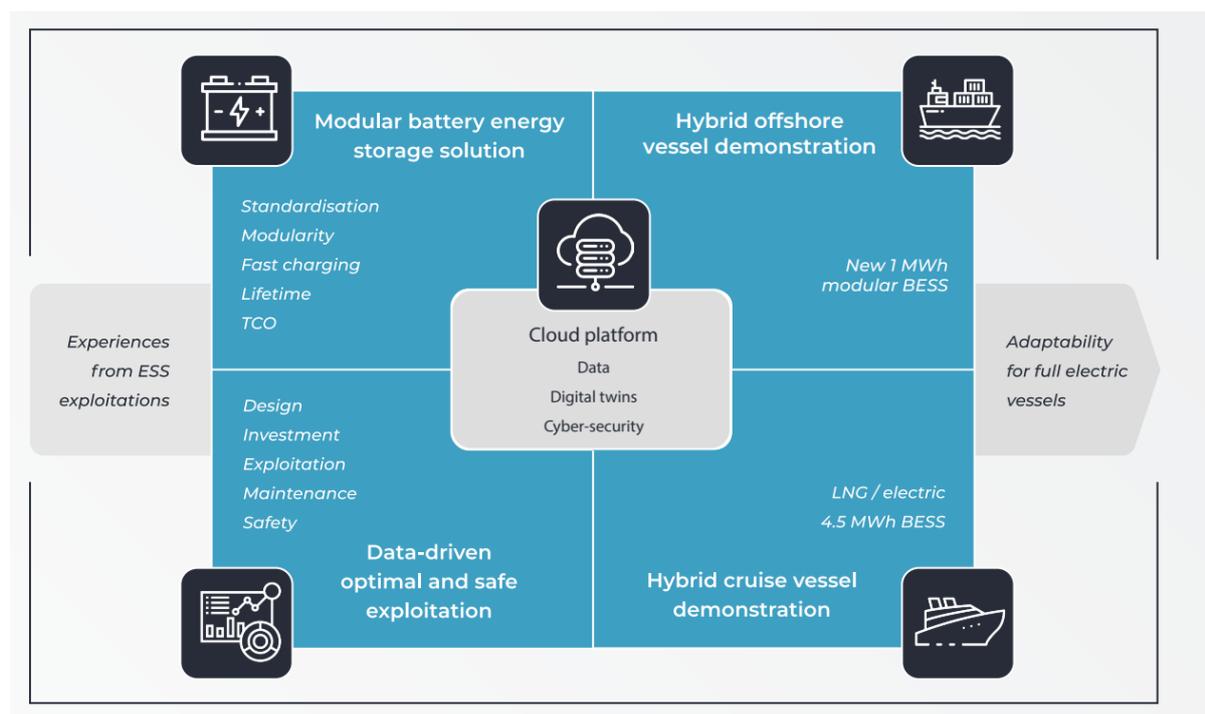

Figure 1 – NEMOSHIP objectives at a glance

Summary

The ambition of the NEMOSHIP project is to develop, test and demonstrate new innovative technologies, methodologies and guidelines to accelerate large BESS deployment and optimal exploitation toward 2030 on both hybrid and full-electric arrangement. To help achieve this ambition, NEMOSHIP will develop a 1 MWh modular and standardised battery energy storage solution that is able to exploit heterogeneous storage units and a cloud-based digital platform to enable data-driven, optimised, and safe exploitation. The project will demonstrate the maturity of these innovations at TRL 7 for hybrid ships as well as their adaptability towards fully electric ships.

This deliverable relates to Tasks 3.1 and 3.2 of the NEMOSHIP project. It focuses on the sizing and integration of the above-mentioned 1 MWh BESS that will be installed on an offshore vessel from Solstad in 2025. This battery should be able to exploit standardized heterogeneous storage units that combine High Energy and High Power batteries (HE and HP).

In the present report, the use case and vessel data collection are first described and then analysed to propose a power profile. This power profile was then used to size the HE and HP batteries, and different electrical architectures were proposed and analysed. The HP/HE sizing obtained for a 1 MWh BESS was 820/180 kWh respectively. This was later updated by Corvus Energy taking also into consideration requirements from e.g. classification society where safety is a key factor which has resulted in a slightly larger BESS than 1 MWh. Various electrical architectures were compared and the most adequate was selected for the case study considered. Two methodology to compare such architectures are detailed in the report.

The deliverable then addressed the integration of the BESS into the ship's electrical architecture with seamless control mechanisms to ensure reliable and efficient operation serving to the objectives of the NEMOSHIP project. Several PLC options were compared for the BPMS to be developed in WP4 and product from brand Beckhoff was selected, satisfying all the requirements including Simulink, class certification and Modbus TCP IP. Finally, integration relating to electrical connections and switches, thermal management system, exhaust and venting system, fire-protection system and vessel PMS interactions were addressed in details.

Table of content

List of acronyms

Abbreviations	Definition
AC	Alternating Current
AH	Anchor Handling
AHTS	Anchor Handling Tug Supply
API	Application Programming Interface
BESS	Battery Energy Storage System
BMS	Battery Management System
BOB	Battery On Board
BPMS	Battery Power Management System
BSS	Battery Specification System
CBR	Container Battery Room
DC	Direct Current
EMS	Energy Management System
ESS	Energy Storage System
HE	High Energy
HP	High Power
IoT	Internet of Things
LEL	Lower Explosive Limit
LOA	Length overall
MCM	Master Control Module
ND	Normand Drott vessel
NF	Normand Ferking vessel
NO	Normand Ocean vessel
OSV	Offshore Support Vessel
PDM	Pack Disconnect Module
PID	Proportional–Integral–Derivative
PMS	Power Management System
SDM	String Disconnect Module
SIB	Stack Interface Base
SOC	State of Charge
SOH	State of Health
TR	Thermal Runaway

1 Introduction

The ambition of the NEMOSHIP project is to develop, test and demonstrate new innovative technologies, methodologies and guidelines to accelerate large BESS deployment and optimal exploitation toward 2030 on both hybrid and full-electric arrangement. To help achieve this ambition, NEMOSHIP will develop a 1 MWh modular and standardised battery energy storage solution that is able to exploit heterogeneous storage units, and a cloud-based digital platform to enable data-driven, optimised, and safe exploitation. The project will demonstrate the maturity of these innovations at TRL 7 for hybrid ships as well as their adaptability towards fully electric ships.

This report titled "*Modular BESS definition (architecture, storage units, interfaces)*" is a deliverable of WP3 – *Modular BESS design, integration and testing*. It relates to Tasks 3.1 and 3.2 and focuses on the 1 MWh BESS that will be installed on an offshore vessel from Solstad in 2025. Considering use case and electrical architecture requirements defined in WP1, the present report defines the relevant sizing, electrical topology and interfaces for the integration of a modular BESS into the case study vessel. An objective of the task is to define as much as possible standardised and scalable interfaces facilitating a safe and simple integration process of the BESS within the vessel.

The BESS system to be sized is made of off-the-shelf components. It is a heterogeneous system as it combines High Energy and High Power batteries (HE and HP). The HE batteries typically provide the continuous nominal power, while HP units deliver high powers and are designed for fast charging. Both battery types under consideration in NEMOSHIP are from Corvus Energy.

The deliverable is organised as follows: in Section 2, the report reviews the datasets available for the Solstad case study. In Section 3 we analyse these data to develop a power profile for the battery system which is then used, in Section 4 for the HE/HP sizing. This latter section also compares electrical architectures and discusses the most adapted for the Solstad case study. Section 5 focuses on the interfaces for the BESS integration within the vessel.

2 Solstad use case

The vessel case study has changed during the work delivered for Tasks 3.1/3.2. Initially identified as Normand Ferking (NF), it was modified to Normand Drott (ND) in the first half of 2024. To carry out the analysis, data from Normand Ferking (NF) have been used in the present study; data from from Normand Ocean (NO) have also been used as this vessel has similar characteristics to NF and is already equipped with a 1 MWh battery, so historical battery data were available.

2.1 Vessels for data analysis

2.1.1 Presentation of Normand Ferking

Vessel Normand Ferking, built in 2007 (Figure 2 - IMO 9361770, MMSI 258153000), is an Anchor Handling Tug Supply vessel (AHTS) from Solstad that can be also used as a Platform Supply Vessel. This vessel was identified at the beginning of the project to be retrofitted with a 1 MWh modular BESS designed and installed during the project.

Figure 2 - Normand Ferking [1]

More information about Normand Ferking are detailed in Table 1 as well on Solstad webpage [1] and in NEMOSHIP Deliverable 1.3.

2.1.2 Presentation of Normand Ocean

The vessel Normand Ocean (Figure 3 - IMO 9678939, MMSI 257291000) is an Offshore Support Vessel (OSV) built in 2014 and currently sailing under Norwegian flag. More information about Normand Ocean are detailed in Table 1 as well on Solstad webpage [2].

Figure 3 - Normand Ocean [2]

	Normand Ferking	Normand Ocean
Built	2007	2014
LOA	89.35m	107.6m
Breadth Moulded	22m	22m
Dynamic Positioning	DP 2 from Kongsberg	DP 2 from Kongsberg
Deadweight (mt)	4559	6000
Generators	15200kW (4 x Wärtsilä 8L32)	12850 (5*2230kW + 1* 1700kW)
Battery capacity	0	1 MWh

2.2 Electrical architecture

In Solstad vessels, the electrical architecture is designed to ensure robust and efficient power distribution. For example, Normand Drott utilizes 6 diesel generators to produce the necessary electrical power (see Figure 4).

These generators feed into an alternating current (AC) grid, which is the standard for distributing electrical power on board. The AC grid supplies electricity to various critical systems, including propulsion motors, navigation equipment, lighting, and auxiliary systems. The architecture ensures redundancy and reliability, as the multiple generators can be operated in parallel to share the load or individually for maintenance purposes.
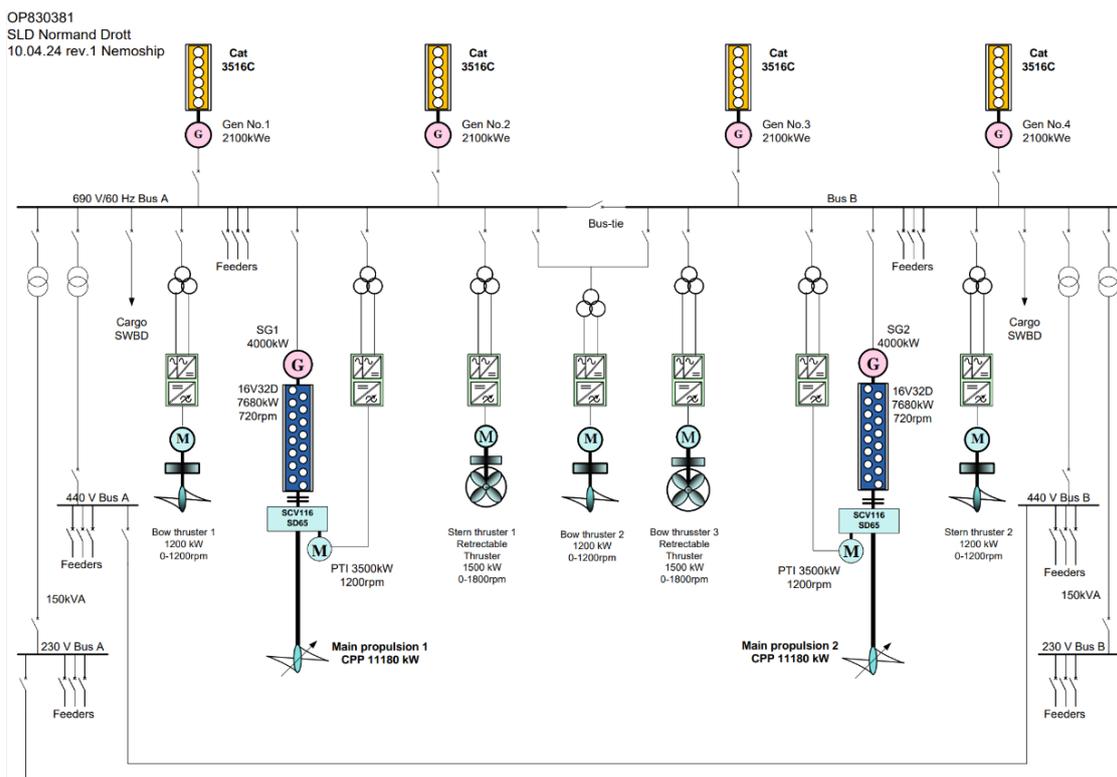

Figure 4 – Single line diagram of Solstad Normand Drott vessel

2.3 Operating modes and battery usage

In 2023, NEMOSHIP released Deliverable 1.3 (SEN) titled "*Use cases definition and demonstration requirements*". It defined the requirements, from the perspective of the end users, for the demonstration (incl. Solstad's) of both main innovations of the project. The below information come from this deliverable. Table 2 shows for each operating mode, the engine setup and loads, while Table 3 details the expected BESS modes and KPIs for the NEMOSHIP demonstration. The latter table is of particular importance as it details how the battery can be used within NEMOSHIP.

Table 2 - Power demand for Normand Ferking

Operating mode	Engine setup	Total engine load
DP operation in good conditions	2x main engines diesel mechanic	1000-1600kW
DP-Standby	2x main engines diesel mechanic	1000-1600kW
Transit slow 6 knots	1x main engine	2000-2200kW
Port hotel load	1x aux gen	400-600kW
Shifting quay	1x main engine	1200kW

Table 3 - Operational mode with corresponding BESS mode and KPIs

Operating Mode	BESS mode	KPIs
Port	Shore power with peak-shaving Full electric	Use shore power for hotel load and BESS to take any power demand exceeding the shore power discharge. Full electric for short port changes.
DP	Spinning reserve	To reduce number of engines in use while on DP close to offshore installation.
DP-Standby	Spinning reserve & full electric	To only use one engine while standby on field and improve efficiency with full electric cycles.
Transit Eco	Peak-shaving & full electric	Full electric in and out of port and manoeuvring. Peak-shaving on the load in transit over longer distance (exceeding the full electric part).
Transit	Peak-shaving	Peak shaving on the engine load while in transit to keep the engines on a better load.
Achor handling	Spinning reserve and "beast mode"	To be able to have BESS as backup and in some cases reduce engines needed. Additionally to test if the battery can increase the bollard pull of the vessel.
Towing	Peak-shaving	Peak-shaving on the engines running while towing.

The aim of the modular BESS sizing in NEMOSHIP is to quantify the share of HE and HP batteries in the overall 1 MWh system that will be installed on the Solstad case study in 2025. The first step of such work is to analyse the case study vessel mission profile and expected battery usage. In our case, the case study vessel did not have a battery system yet, so battery data from other Solstad vessels were used and more details are provided in the below sections.

As mentioned above, the vessel case study has changed during the preparation of this report. Initially identified as Normand Ferking (NF), it was modified to Normand Drott (ND) in 2024. Both vessels are anchor handling tug supply, their respective usage is shown in Table 4 using data retrieved from Maress – the duration of the datasets are 2 years for ND and 1 year for NF.

Table 4 – Share of each vessel mode for Normand Drott and Normand Ferking

Vessel operating mode	Normand Drott	Normand Ferking	Comment
Port	43.5%	46%	Equivalent
Transit Eco	12.8%	14%	Equivalent
AH	10.2%	9%	Equivalent
Transit	9.2%	9%	Equivalent
Idle	7.3%	0%	Not equivalent
DP	6.1%	6%	Equivalent
Standby	6.1%	14%	Not equivalent
Towing	4.1%	2%	Not used very often
Mob/Demob	0.6%	0%	Not used very often
Transit Max	0.1%	1%	Not used very often
Mixed	0.0%	0%	Not used very often

From Table 4, we note that their usage is very similar, except that ND spent 7.3 % of the time in 'Idle' mode and 6.1 % in 'Standby' mode, compared to NF, which spent 0 % of the time in 'Idle' mode and 14 % in 'Standby' mode. We do not expect these differences to impact significantly the results of the study.

3   Data analysis and definition of battery usage profile

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4   Battery sizing and architecture design

This section of the report concerns the sizing of the battery and design of the ship microgrid architecture for Solstad use case. The first part of this section describes the battery sizing in terms of energy content. The question that we have to answer is how to split the 1 MWh battery into two batteries, one oriented "energy" and one oriented "power". The second part of this section deals with the selection of the electrical architecture to connect both batteries to the vessel microgrid. Next, results are presented for the optimization of the BESS, incl. high-energy battery, high-power battery and power electronics interface, in terms of efficiency, cost and lifetime following the tool described in Task 2.2. These results complement the initial sizing with further insights and theoretical considerations. Finally, practical considerations on the actual architecture are described.

4.1 Battery sizing

Section temporarily removed

4.2 Electrical architecture

Section temporarily removed

4.3 Design optimization of electrical architecture

Section temporarily removed

4.4 Adaptation of electrical architecture for modular BESS

4.4.1 Overview of electrical and control architecture for modular BESS

The integration of BESS into the ship's electrical architecture with seamless control mechanisms ensures reliable and efficient operation serving to the objectives of the NEMOSHIP project. The control architecture oversees the energy distribution between the power system of the ship and the configured HE and HP BESSs. This architecture integrates several key systems; Battery Power Management System (BPMS), Energy Management System (EMS), vessel Power Management System (PMS) and Corvus Energy Battery Management System. All systems are important in ensuring that there is continual and efficient operation, control, and monitoring of the energy usage on the ship.

The PMS is the power management system of the whole vessel, and it controls all power sources including diesel generator sets and other sources if available.

The EMS is an external controller that aims to ensure an energy efficient and reliable operation of power sources by controlling the conversion devices (DC/DC & DC/AC converters), including the converters of the heterogeneous battery system developed.

The BMS is an embedded electronic device part of the battery energy storage system provided by Corvus. It controls the functional states of the batteries and interacts through industrial communication protocols such as MODBUS.

The BPMS is a controller dedicated to energy and power balancing between both battery systems installed (HP and HE). The vessel's PMS should not be confused with the BPMS. For certification reasons mainly, the BPMS must not be intrusive on the architecture and communications between the PMS and the EMS. It uses the states of the batteries sent by the BMS to compute power setpoints for both systems and send it to the EMS.

This section provides an overview of the general electrical and control architecture, emphasizing the ways in which various systems interact and communicate with one another to maximize energy management. An overview of the electrical and control architecture for architecture-1 is presented in Figure 5 to show how the overall system control operates. The EMS controller sends the converter-level control parameters, as seen. However, in accordance with the internal BPMS algorithm, BPMS oversees reading the State of Charge (SoC) data from each battery pack and producing a split value that specifies how much power should be taken from which BESS.
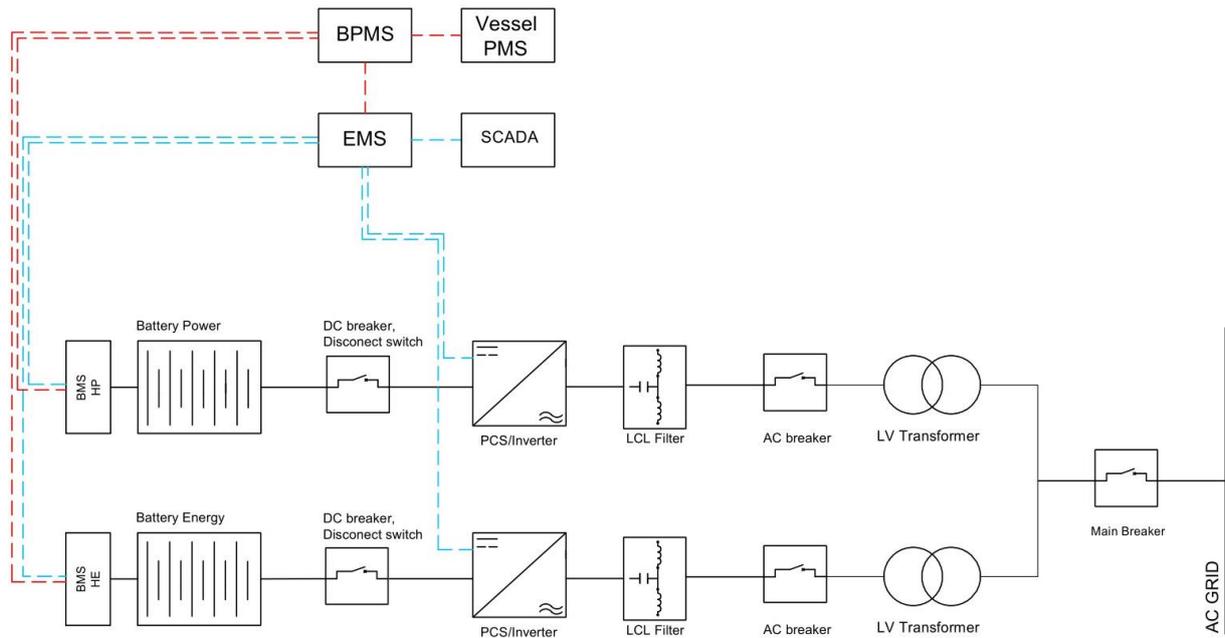
Figure 5 – Overview of electrical and control architecture for architecture 1

4.4.2 Control architecture and communication links

The control architecture (EMS & BPMS) for the modular BESS on Normand Drott vessel is designed to ensure efficient flow of power between BESS and the rest of the electrical grid of the vessel as per the efficiency optimization algorithms. This section provides information about the data exchange between systems to monitor and control the operation of BESS.

Figure 6 illustrates the hierarchical placement of control systems involved. Above all, vessel's PMS controls all means of power onboard the vessel including diesel generators.

Figure 6 – Hierarchical placement of systems

The main variables exchanged between systems are depicted in Figure 7. The global power demand is monitored by the EMS controller and shared with the BPMS. Upon receiving the parameters, the BPMS

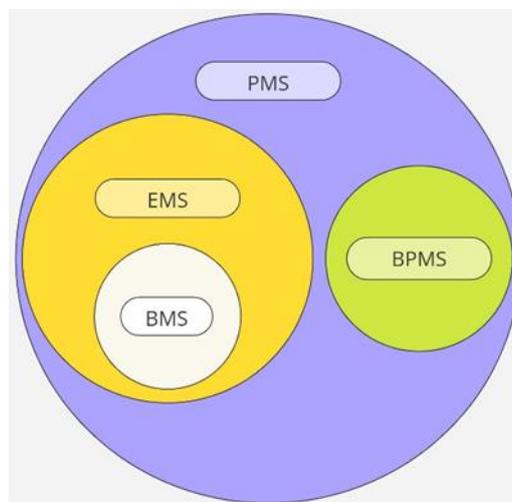algorithm evaluates the data and share the split values (setpoints for battery drivers) for both battery types as the outcome of the algorithm.
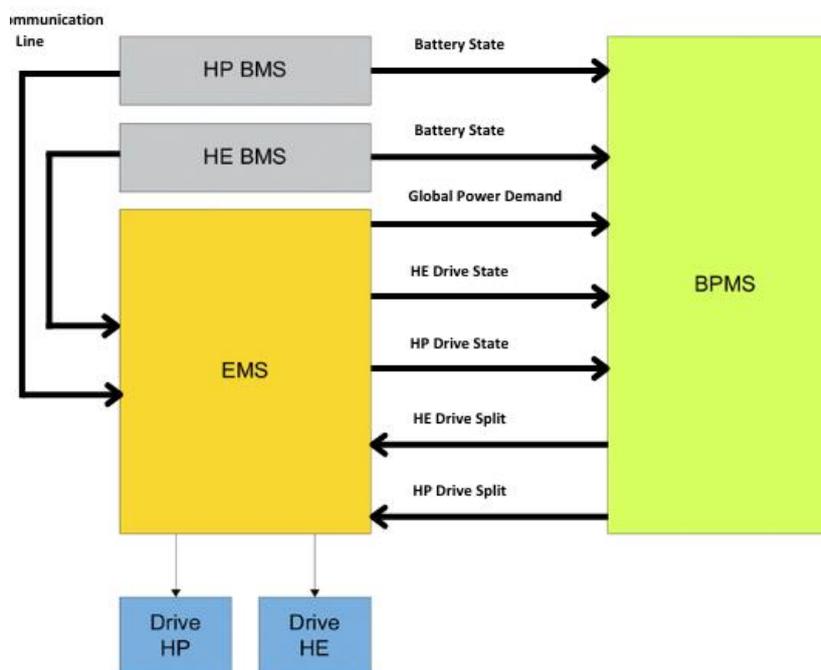
Figure 7 – Main variables exchanged between systems

4.4.3   System hardware requirements

This section provides the justification behind the choice of hardware components in the control architecture that was selected in the previous sections. The EMS, provided by Wärtsilä, consists of a central control, a router, a human machine interface and a switch unit for a remote control. BMS and hybrid drive systems transfer information through the switch, which is connected to a remote-control panel. This control unit has the function of receiving all this data and transmitting it to the EMS router, enabling real-time communication and control of the system. BPMS is, however, operated using a different control panel that has a controller PC and a human machine interface as well. Several brands of PLC were examined (Table 5) to determine their Modbus TCP/IP Protocol support, compatibility with Simulink PLC Coder and DNV Approval.

Table 5 – Comparison of PLC brands for BPMS in the context of the deliverable case study

Brand	DNV Approved	Simulink PLC Coder Support	Modbus TCP/IP	Comments for our case study	Suitability for our case study
ABB	🟩	🟥	🟩	Not suitable for our case study due to lack of Simulink support. Coding via Codesys through Simulink is possible but carries a high risk.	🟥
Siemens	🟩	🟩	🟩	Siemens equipment is not suitable for COTS (commercial of the shelf) purchase by other integrators except Siemens.	🟥
Schneider	🟩	🟥	🟩	Not suitable for our case study due to lack of Simulink support.	🟥
Phoenix Contact	🟩	🟩	🟩	Simulink supports an obsolete version of PLC programming software (PCWorx), making it less ideal for current applications.	🟨
Beckhoff	🟩	🟩	🟩	Suitable for the project. Although the interface is relatively complex, Beckhoff PLCs are reliable and have marine certification, making them a strong candidate for this application.	🟩
Omron	🟩	🟩	🟩	Suitable for the project. Omron PLCs have Simulink support and appropriate class approvals, making them a viable option.	🟩
Rockwell	🟥	🟩	🟩	Not suitable for our case study due to lack of DNV approval. Simulink supports RsLogix, which is obsolete; the current software is Studio5000.	🟨
B&R	🟥	🟩	🟩	Suitability for our project in terms of class approval status depends on the product chosen. Coding can be done only with ANSI C or IEC 61131 structured text.	🟨

After evaluation of the options, we selected Beckhoff as the appropriate hardware for our case study's BPMS, satisfying all the requirements including Simulink, class certification and Modbus TCP IP. The system architecture for the BPMS control cabinet and communication interfaces is depicted in Figure 8 and Figure 9.
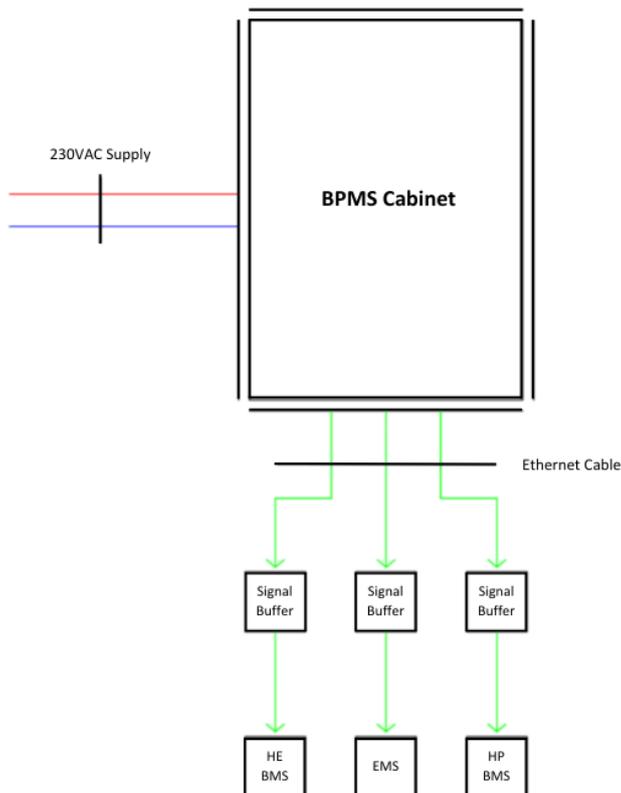
Figure 8 – Control cabinet connection diagram with RS485 only
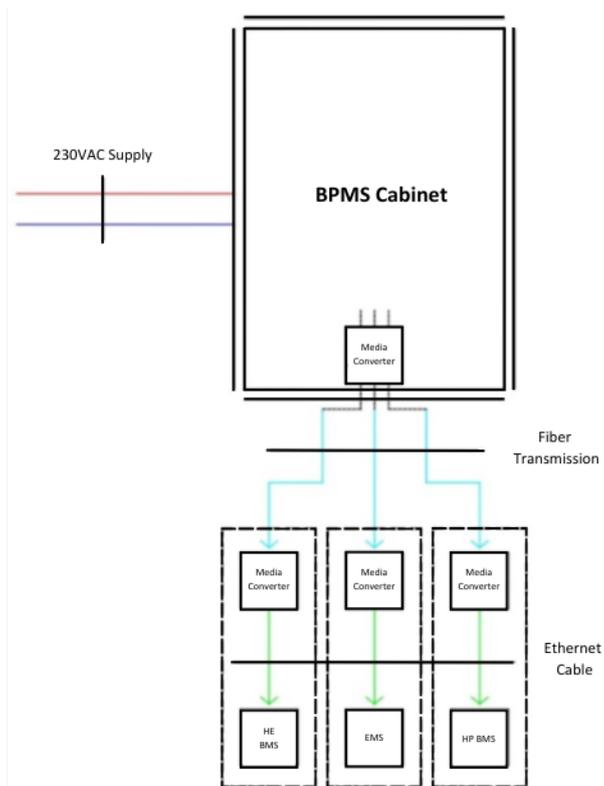

Figure 9 – Control cabinet connection diagram with fiber optic

At the physical level, fiber optic or RS485 serial connection can be employed in the implementation of the Modbus communication interface. Out of these two, this communication circle will select one after a careful consideration of the signal quality and speed thoughts. Below is a brief overview of each method:

- **RS485 serial communication**: The HE BMS, Wärtsilä Router, and HP BMS control cabinet are interconnected using RS485 cables in this manner. Depending on the length of the cable between the Elkon control cabinet and the devices to communicate with, signal buffers can be used for maintaining signal fidelity.
- **Fiber optic communication**: The media converters in the control cabinet are connected to media converters in the HE BMS, EMS cabinet and HP BMS using fiber transmission lines in this manner. This configuration ensures maximal speed when transmitting data. But there is a need of media converters to change the electrical impulses to optical and the optical signals to electrical impulses for positioning fiber transmission. In addition, the battery container could not provide a reasonable placement for the media converter.

Figure 10 and Figure 11 illustrate the two earlier mentioned alternatives for the physical communication structure application. When long communication lengths are needed, the second choice is better because data can be sent through the fiber optic cable over a longer range without signal decrement. On the contrary, in applications that are meant to cover short distances, the application of media converters, which convert electrical signals to optical signals and vice versa, adds on further costs and may not be justifiable. Not even signal buffers will all be required in the application and therefore it was decided to follow the first communication option based on the Solstad's view.

The cabinet, or any external circuitry, will be powered from 220/230VAC lines. Inside the cabinet, there is also a power supply that supplies 24V to the PLC. A UPS and battery system will be used to back up the PLC operation in order to maintain stability and reliability. The power supply will provide 24 VDC output to power the PLC. Both the power supply and the UPS communicate with the PLC to monitor any malfunctions that may occur.
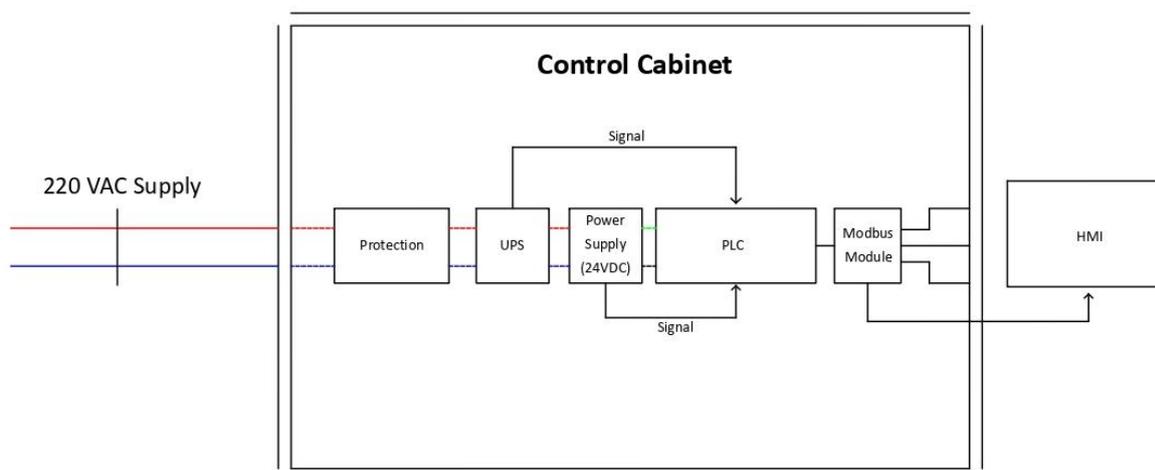
Figure 10 – Control cabinet layout
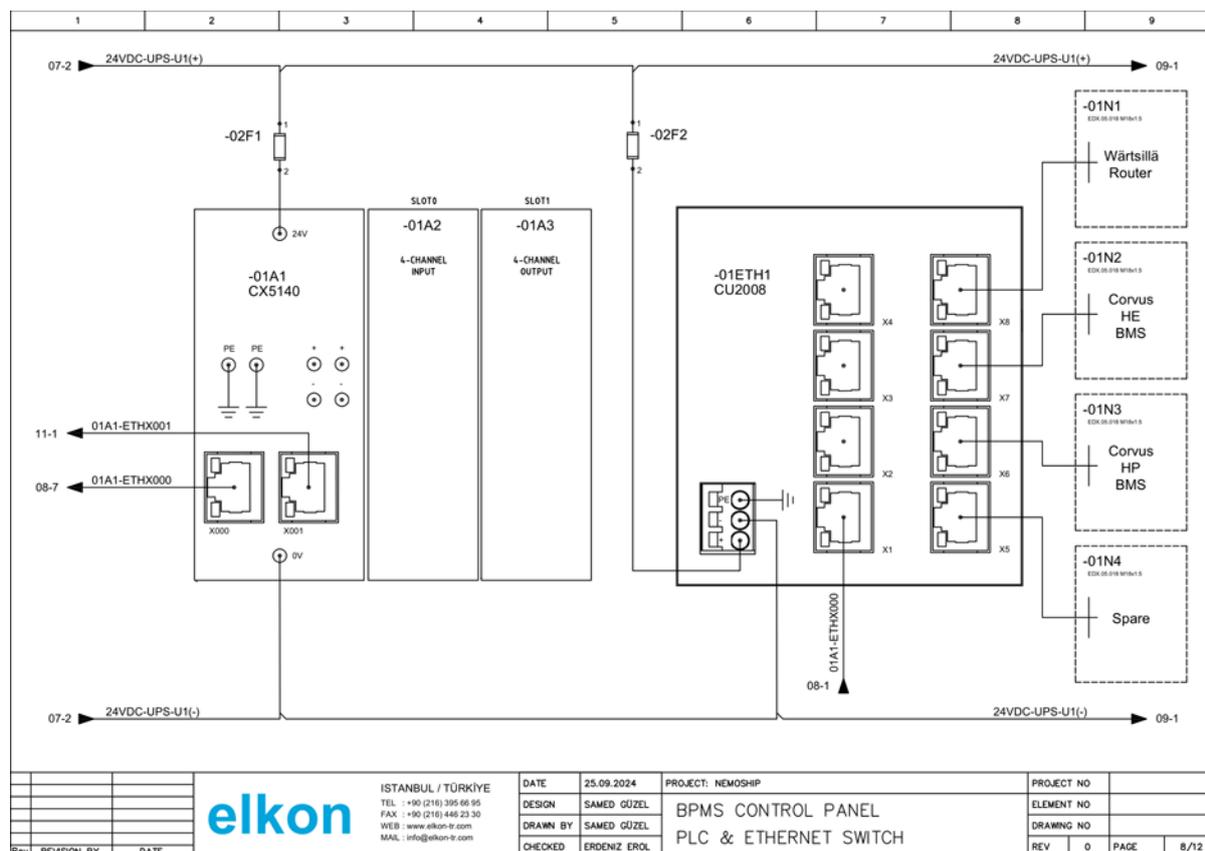
Figure 11 – BPMS control panel

In Section 4, the electrical and control architecture have been defined for the Normand Drott case study. Next step is to focus on the integration of the BESS itself in the vessel, which is addressed in the next section.

5 Standardised and scalable interfaces for BESS integration into vessel

The objective of this section is to define as much as possible standardized and scalable interfaces facilitating a safe and simple integration process of the BESS within the vessel. It mainly includes

- Electrical connections and switches
- Thermal management system
- Exhaust and venting system
- Fire-protection system
- Vessel PMS interactions

In the below Section, requirements from D1.4 are listed and details are provided on how these have been addressed.

5.1 Electrical connections and switches

5.1.1 Electrical integration & interfaces

Each stack of the Corvus Dolphin Energy NxtGen features a Stack Interface Base (SIB), which is mechanically secured and electrically bonded/grounded to the deck of the containerized battery room (CBR). For the Orca ESS, the racks are bolted together at bonding points and connected to the steel structure of the CBR with an earthing wire at each end of the array(s). For the CBR, an external ground point is added for easier connection for the system integrator.

R2.21 The electrical interface shall include appropriate protection devices, such as circuit breakers, fuses and surge arrestors, to safeguard the vessel´s electrical system against overloads, faults, and voltage transients. Breakers must be easily accessible.

For the Orca ESS, each pack has a pack controller. The pack controller is comprised of two components: The Pack Disconnect Module (PDM), which contains fuses, contactors, current sensors, filters, and voltage sensors, and the Master Control Module (MCM) which contains the main control and communications processor for communication with the modules within the pack and the EMS. The fuses in the PDMs are 500A. For the Dolphin Energy NxtGen, the string fuses are in the String Disconnect Modules (SDM), with a rating of 160A each.

The BESS is scalable in the sense that increasing the number of packs of Orca Dolphin Energy NxtGen will simply be a matter of increasing the number of cables for connection to the battery packs and vessel. Size of cables will remain the same and other interfaces such as data communication will also remain the same.

R2.25 The main power connectors shall have an integrated safety interlock securing that connection/disconnection can only be performed when the storage units contactors are open.

Both the Dolphin Energy NxtGen and the Orca ESS feature procedures for safe lock out of power flow. For the Dolphin Energy NxtGen, each string can be physically locked out from being electrically connected. The SDM Lockout Procedure can be reviewed in Corvus Energy Document *20003610 Dolphin NG Energy ESS User Manual.* Similarly, each pack of the Orca ESS can be physically locked out by placing the PDM in service position. The PDM Lockout Procedure can be reviewed in Corvus Energy Document *1008484 Orca ESS User Manual*.

R2.26 Cables and connectors shall be sized to support maximum operational charge/discharge currents at maximum operating temperature and should have adequate IP protection depending on their location.

The Corvus Energy containerized battery room features all internal cabling, pre-wired, leading up to connection points for vessel interfaces. Placement and number of penetrations is dependent on the final location of the ESS and the door, but in general, Roxtec penetrations are used for DC-cabling, auxiliary power and control and signal cables. The DC-cable penetrations are separate from the penetrations for auxiliary power and control cables. For the Orca ESS, two single core cables (2 x 1x185 mm^2) (+/-) from each pack are going to terminals easily available close to the Roxtec penetrations. Similarly, for the Dolphin Energy NxtGen ESS, two single core cables are connected to each SDM and routed to terminals close to the corresponding Roxtec penetration. DC-cabling from power electronics to terminals inside the CBR is system integrator scope.

5.1.2 AC power to the pack controller

According to DNV-RU-SHIP Pt.6 Ch.2. Edition July 2023 amended October 2023, clause 2.3.4.3 and 2.4.1.3, the gas detection system and the ventilation fan shall have power supply from two separate supply circuits, one from the main source of power and one from the emergency source of power. As such, two external AC power supplies are required for the Corvus Energy containerized battery room. Each supply shall be 3 phases, 230V, and is delivered to the Corvus Energy containerized battery room by systems integrator. External AC power is required for starting up the Pack Controller as well as all other Pack Controller functionalities in addition to AC power to the PDM, SDM and other equipment in the containerized battery room (fans, sensors, heaters etc.).

5.1.3 Emergency stop (E-Stop)

According to DNV-RU-SHIP Pt.6 Ch.2. Edition July 2023 amended October 2023, clause 2.4.3.1, gas detection at a level of no more than 30 % Lower Explosive Limit (LEL) shall lead to automatic disconnection of the EES system. The Corvus Energy containerized battery room is fitted with an internal safety relay, which handles the input from several sources, such as gas detector alarm, emergency stop pushbuttons (local and external) and fire alarm shutdown signal. The safety relay sends the E-Stop signal to the battery packs. The E-stop is a critical safety feature of the BMS. The Corvus Energy BESS takes an E-stop signal in and directly cuts relays that interrupt the power to contactors in the disconnect modules, there by disconnecting every string from the DC bus. The E-stop can also be activated through the EMS/PMS.

5.2 Thermal management system

As introduced in NEMOSHIP deliverable D1.4, thermal management is essential to the safe and optimum function of a BESS. Requirements of thermal management aspects are listed below.

R2.12 Thermal management systems, including cooling and ventilation shall be implemented to maintain optimal operating temperatures and prevent thermal stress on critical components.

R2.13 The thermal interfaces of the electric vessel shall be designed to manage heat dissipation effectively, considering the power electronics, electric propulsion systems, and energy storage systems onboard.

R2.14 The battery thermal management system must keep the cell temperature and humidity within the manufacturer limits; moreover, it should allow control of the temperature and humidity in the container for the different operating mode specifications regardless of the environmental conditions.

R2.15 Thermal interfaces shall comply with relevant class society rules and industry standard for heat dissipation. It is foreseen that DNV class society rules will be used for the Solstad vessel (DNV GL Rules or Classification: Ships).

5.2.1 Battery management system safeties

Several features of the Corvus Energy BESS Battery Management System (BMS) act to help prevent battery damage (threshold values differ from the Orca Energy and Dolphin NG Energy packs and actual values are listed in the BESS integrator manuals):

- Monitors the temperature of the battery cells and ambient locations within every module.
  - Transmits a warning if cell temperature exceeds a certain threshold.

- Transmits a fault and interrupts the current if cell temperature exceeds a higher threshold.
    - Has dedicated hardware-based safety loop to open the string contactors and interrupt the current if cell temperature exceeds an even higher threshold.
- Monitors the voltages of all cells in all modules
    - Transmits a warning if any cell voltage is exceeded by a certain threshold or falls below another threshold.
    - Transmits a fault and interrupts the current if any cell voltage is exceeded by a certain threshold or falls below another threshold.
    - Has dedicated hardware-based safety loop to open the string contactors and interrupt the current.
    - Has balancing features that adjust the voltage of the cells dynamically so that all cells in the pack are kept within a small range of each other (cells are said to be "balanced"). There is no requisite rest period for balancing to occur.
- Monitors the state of health (SOH) of each cell as a percentage of its original capacity.
- Utilizes an advanced SOC algorithm that accurately computes the SOC even during charge and discharge and transmits the SOC value to the EMS.
- Utilizes an advanced 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.

The BMS will issue an alarm if it requires attention. Additionally, the BMS transmits alarms to the EMS/PMS, where they may be viewed on the alarm screens in the bridge and/or the engineering room.

An *alarm* is a signal indicating an abnormal condition in the BMS. There are two levels of alarm in the system: fault and warning.

A *fault* is an alarm that will cause the BMS to automatically disconnect the pack from the DC bus. Faults do not automatically clear; the command to reset alarms must be activated by the operator (and sent by the EMS). The presence of a fault on the pack indicates that the pack is not operational. Other packs in the BESS are independent and unaffected and will continue operation.

A *warning* is an alarm that indicates a potential unsafe condition or a reduction of functionality. It will automatically clear when the condition itself is no longer present. Warnings may escalate to a fault if the condition persists.

5.3 Exhaust and venting system

5.3.1 Mitigation of thermal runaway

As detailed in Deliverable 1.4, the most dangerous event that can occur to any lithium-ion battery system is called "thermal runaway". This could happen if the battery is subjected to external heating, serious mechanical damage, or abusive usage, including overcharging. If thermal runaway starts, a battery cell releases hot, toxic, flammable gases. The Corvus Energy BMS is designed to prevent the onset of thermal runaway due to overheating or abusive usage, but in the extremely unlikely event that it does occur, the Corvus Energy BESS includes mitigating measures to manage the event.

Each battery cell in the Corvus Energy BESS is isolated within the battery module with a proprietary mechanical and thermal structure that effectively prevents the high temperatures of one cell from

causing other cells within the module to overheat. This means that if a cell enters thermal runaway, there will be no propagation to any other cell in the system.

Lithium batteries do not produce any type of gas under normal operating conditions. However, if a cell does experience thermal runaway, then it will release a significant amount of gas. The Corvus Energy BESS battery modules are sealed units with built-in emergency exhaust channels. These vent ports are connected to a dedicated exhaust duct integrated with the Corvus Energy BESS battery modules, which channels the gases to that they can be directed out of the battery space and out of the installation. Downstream piping does not need to contain a blower or another active evacuation mechanism. During a venting scenario, the module pressure will be enough to drive most of the gases to the exit. The Corvus Energy containerized battery room have internal ducts connected to the battery exhaust channels, leading up to flanges on the container wall for further routing to open air. According to DNV-RU-SHIP Pt.6 Ch.2. Edition July 2023 amended October 2023, clause 2.2.5.1 and 2.2.5.2, areas in open air within 1.5 m of the opening of such ducts are classified as extended hazardous area zone 2 with respect to explosion hazard, and areas in open air within 3 m are considered toxic zones. The end of such ducts must be designed so that water cannot enter the system, and the piping design must mitigate against blockages (e.g., freezing). Consideration should be given for drainage of any water (e.g., moisture) that may accumulate in the ducts.

5.3.2   Ventilation and thermal management

To maximize the lifetime of the BESS it is important to ensure that the temperature of the battery space is maintained at 15-20 °C and that any excess heat is being removed. The Corvus Energy BESS uses forced air cooling to remove any excess heat from the battery modules. When Corvus Energy sets up the Battery System Specification (BSS), calculations are performed for the heat rejection from the battery modules, and this is then used to set up the required cooling in the battery room. For NEMOSHIP project the battery room will be a containerized type (BOB – Battery on Board) delivered by Corvus Energy and the cooling in the container will be configured by Corvus Energy. The standard cooling system consists of two fan coil units, which recirculates the internal air in the container. This solution requires chilled water at 6 °C supplied by the vessel. One or more temperature sensors located at suitable locations inside the container measures the temperature, and a PID controller compares the measurement to adjustable setpoints. The PID controller adjusts the opening of control valves, hence controlling the flow of the chilled water.

Ventilation and cooling are two separate systems in the Corvus Energy containerized battery room. According to DNV-RU-SHIP Pt.6 Ch.2. Edition July 2023 amended October 2023, clause 2.3.4.1-2.3.4.4, a dedicated extraction ventilation fan of non-sparking type shall be installed to ensure under-pressure in the EES space. The fan shall have a capacity of no less than six air changes per hour. The ventilation fan will not be running continuously but will start automatically upon gas detection. The fan may also be started and stopped by use of external control signals, or local pushbuttons next to the door on the outside, and inside the container.

5.4 Fire protection system

Marine fire-fighting systems for containerized energy storage systems are specifically designed to address fire hazards on ships or marine vessels that are equipped with energy storage systems. These systems are crucial for ensuring the safety of the crew, cargo, and the vessel itself.

According to DNV-RU-SHIP Pt.6 Ch.2. Edition July 2023 amended October 2023, clause 2.5.3.1, the EES space shall be protected by a fixed fire extinguishing system that can extinguish the EES fire or control and provide continuous cooling of the EES space. Moreover, clause 2.5.3.2-2.5.3.5 describes the accepted systems as either a fixed water-based fire extinguishing system, or a combination of a gas based and freshwater based water spray system. The water-based system shall be designed to discharge fresh water for 60 minutes operation, while the combined system requires 30 minutes of freshwater supply.

The Corvus Energy containerized battery room is designed with nozzles and internal piping leading up to a flange on the container wall for connection to vessel water mist system. The water mist system in the container is based on the XFlow water mist system for full protection and consist of three open water mist nozzles mounted in a dry pipe system. It requires a flow of 38.7 l/min with a pressure of 9.84 bar measured at the section valve outside the container. Pump unit(s), section valve(s), strainers, and switchover from freshwater to sea water is system integrator scope. With the requirement of 60-minute duration of freshwater discharge the water supply must come from the vessel and cannot be self-contained and independent from the vessel.

5.4.1 Vessel PMS interactions

The Corvus Energy BESS incorporates a BMS designed to maintain the batteries in a safe and healthy state. This applies to both the energy and power type BESS. The BMS has integrated sensors that measure the voltage of every cell, sensors that monitor the temperature of the battery cells, and sensors that measure the overall voltage and current.

5.4.2 Control of the BESS

The energy flow between generators, batteries and propulsion is managed by the EMS provided by the system integrator – the company that typically provides the switchboards, generators, converters, variable speed drives, etc. As is typical for any battery systems, the Corvus Energy BESS does not directly control the electrical current into or out of the batteries; the BESS is only a reservoir to store energy. Control of the energy flow into and out of the BESS is determined by the equipment on the DC bus to which the BESS is connected.

The BESS communicates charge and discharge limits to the EMS. It is important for the effective functioning of the propulsion system that the EMS knows how much energy it can draw from (or store) in the batteries, as well as the limits to the instantaneous power that it can demand (or supply). For this reason, the BESS communicates with the integrator´s EMS over a digital communications channel called Modbus TCP. Modbus TCP is a vendor-neutral, open communication protocol very common across many industries.

The Corvus Energy BESS implementation of the Modbus TCP protocol is designed so that there is no need for additional systems to consolidate the information from the individual strings in a pack. In

fact, an array of packs connected to the same DC bus can be controlled as a unit, automatically coordinating contactor connections, aggregating data and alarms.

5.4.3 Data logging

To provide effective customer service and maintenance, and to optimize operation, the internal operating parameters of the Corvus Energy BESS are stored in the battery management system memory. A service technician can retrieve the logged data via each pack controller unit or from the local network access port. For Dolphin NG Energy BESS, each pack controller has an Ethernet port dedicated to providing remote off-vessel data logging. This dedicated port implements a secure, encrypted IoT (Internet of Things) protocol to send operating data to a secure data center. For Orca Energy BESS there is a separate unit named Lighthouse which serves the same purpose. For security and safety, this IoT channel cannot be used to push data onto the battery management system – it is purposely designed to be a one-way channel. Corvus Energy employs many data compression strategies to ensure efficient transfer of data and reduce load on the internet connection.

The off-site data storage is not required for day-to-day operation nor is it part of the safety systems. Due to those reasons and the reality of current vessel internet connection reliability, the BESS is designed to buffer data for later transmission during times when connectivity is lost or degraded.

The off-site data repository assists Corvus Energy service technicians to diagnose any issues. Moreover, Corvus Energy systems automatically process the off-site data repository and can provide advance indication of need to service or maintenance. The data are also monitored for proactive acting if needed and basis for annual advisory reports to ship-owners.

5.4.4 Ground fault detection

As a safety feature, the Corvus Energy BESS performs a ground fault check upon start-up. The system performs this check through comparison of the battery voltage before and after the ground fault check relay to chassis is closed. Note that continuous ground fault monitoring during pack operation is not a function of the BESS and additional continuous ground fault monitoring is implemented by the systems integrator.

6 Conclusion

Following data collection and analysis from various Solstad vessels, a power profile was developed for the case study considered. This profile has guided the sizing of the HE and HP batteries, ensuring it meets the specific energy and power demands. As the battery capacity must be 1 MWh, and a high power is requested during a long time (which means high energy), the sizing leads to a large HP battery (820 kWh) and a relatively small HE battery (180 kWh). Following a comparison of several electrical architectures, the best option chosen was to have an electrical DC/AC converter for each HE and HP battery. Another approach to identify electrical architecture was also presented, using multi-objective optimisation (NSGA-II algorithm). This shows the diversity of techniques that can be used depending on the case study specificities.

Following-up on Deliverable 1.5, the second half of the deliverable addressed the integration of BESS into the ship's electrical architecture with seamless control mechanisms to ensure reliable and efficient operation serving to the objectives of the NEMOSHIP project. First, an overview of the electrical and control architecture control was given. Several PLC options were compared for the BPMS

to be developed in WP4 and product from brand Beckhoff was selected, satisfying all the requirements of our case study, including Simulink, class certification and Modbus TCP IP. Finally, integration relating to electrical connections and switches, thermal management system, exhaust and venting system, fire-protection system and vessel PMS interactions were addressed in details.

Both the BESS and the control algorithm (from WP4) will be installed on the Normand Drott vessel by mid-2025, which will be followed by an evaluation period of several months duration.

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Appendix A – Additional data insights

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