Sizing a heterogeneous battery system for an offshore vessel: methodology and application

Vincent PHLIPPOTEAU
Univ. Grenoble Alpes
CEA, Liten,
F-38000 Grenoble, France
vincent.phlippoteau@cea.fr

Julien DAUCHY
Univ. Grenoble Alpes
CEA, Liten,
F-38000 Grenoble, France
julien.dauchy@cea.fr

Solène GOY
CEA, CEA Pays de la Loire,
F-44340 Bouguenais, France
solene.goy@cea.fr

Guénaël Le Solliec
CEA, CEA Pays de la Loire,
F-44340 Bouguenais, France
guenael.lesolliec@cea.fr

Abstract—Waterborne transport sector is essential to our everyday life as ships deliver more than 80% of the world's trade. Electrification of waterborne transport with batteries is the focus of the current paper. Battery systems for vessels tend to be monotype and hence are oversized to meet the vessel operational profile and lifetime requirements. Heterogeneous battery systems offer a solution to that challenge by better fitting the vessel requirements. The present paper details a methodology to size a heterogeneous battery energy storage system made of high-energy (HE) and high-power (HP) battery modules. The methodology is then applied to a real case study of an offshore vessel to be hybridised with a 1MWh battery solution. The resulting HE and HP share is 18% / 82% respectively.

Keywords—Waterborne transport, batteries, high-power, high-energy, hybridisation

1. INTRODUCTION

Waterborne transport sector is essential to our everyday life as ships deliver more than 80% of the world's trade [1]. Maritime transport sector emits approximately 3% of the world's greenhouse gases emission and it is not decreasing, on the contrary, between 2020 and 2021 emissions of the sector increased by close to 5% [1]. Overall, between 2012 and 2022, it has increased by over 20% [1].

The world's fleet is made of over 125 000 ships [2] and their characteristics vary widely and so do their operational profiles. There are several options to decarbonise the waterborne transport sector, e.g. using renewable fuels to power ICE or fuel cells, battery systems, improving energy efficiency at design stage and during operations.

Electrification of waterborne transport with batteries is the focus of the current paper. Typical fuel savings potential of batteries in different shipping sectors varies widely depending on the vessel type, e.g. up to 100% for ferries, 5 to 20% for offshore supply vessels or shuttle tankers [3]. In addition to reducing CO_2 emissions, batteries can significantly enhance the operational efficiency of ships by providing an instant power supply. This allows generators to operate at optimal load, reducing fuel consumption and pollutant emissions. Furthermore, the potential for full electric mode offers a completely pollutant-free and noise-free solution, which not only benefits environmental sustainability but also improves the quality of life on board and in nearby marine ecosystems. Large batteries dedicated to maritime applications consists in connecting battery modules in dedicated packs with a standard form factor which facilitate the replacement and maintenance of the modules. Current battery systems on ships are typically of a single type, meaning that all battery modules within the system have the same characteristics (e.g. same battery technology and C rate). The C rate of a battery is calculated dividing the max power by the overall energy. It « indicates the maximum safe continuous discharge or charge rate. For example, a C-Rating of 10C means it can be discharged at 10 times that pack's capacity, which is 10kW for a 1kWh battery» [4]. In battery technology, high energy densities are obtained with the decrease of the power capability of the cell. To obtain a good power and energy density, a system relying on a single battery type will typically be oversized in power or energy for most vessels. A solution to that issue is called hybridisation where heterogeneous battery modules are integrated into a same ship. Heterogeneous energy storage systems allow to better address the vessel operational profile. The high-energy batteries (HE, lower C rate) typically provide the continuous nominal power while the high power storage (HP, higher C rate) delivers high powers and is designed for fast charging. With this combination the energy and power density of the entire system can be improved and the needs of the ship are met in a more optimal way. Moreover, the hybrid topology removes the high current stress factor from the HE battery, resulting in a longer lifetime if well controlled [5].

The paper proposes a methodology to size a heterogeneous battery storage and shows a first application to an offshore vessel case study, with a focus on the development of a mission profile for the batteries.

2. METHODOLOGY: SIMPLIFIED METHOD TO SIZE A HETEROGENOUS BATTERY STORAGE SYSTEM

The methodology to size a heterogeneous system consists of 3 steps as described below:

- Step 1 - Vessel and BESS modes: It consists in understanding the operational modes of the vessels and clarifying how the battery could contribute to it (i.e. BESS modes).
- Step 2 - Mission profile: Define a reference mission profile that will be used for the sizing of the heterogeneous battery system. It consists in first, analyzing the current vessel usage and adapting it so that it represents how we would like to use the battery after installation. The definition of the battery modes from the Step 1 will feed into this.
- Step 3 - Determine the energy vs power split: the energy vs power split is determined using the data from the mission profile in Step 2. An energy vs power plot is the basis for this calculation. The HP battery will cover the situation where power is needed but not a lot of energy while the HE battery will deliver the rest of the profile where higher energy is required and power is lower. An illustrative example is shown in Figure 1 and Figure 2 with case A where the energy vs power split is clear while it is less straightforward with case B. Examples such as Case B indicate that hybridization may not be always relevant. Then any constraints relating to the battery type, overall power etc. should be taken into account. If the split is not clear cut (e.g. Case B), further steps are required, disaggregating the continuous/baseload profile from the peaks and using an adequate C rate for each and selecting the HE/HP share(s) allowing to meet the maximum power of the profile.

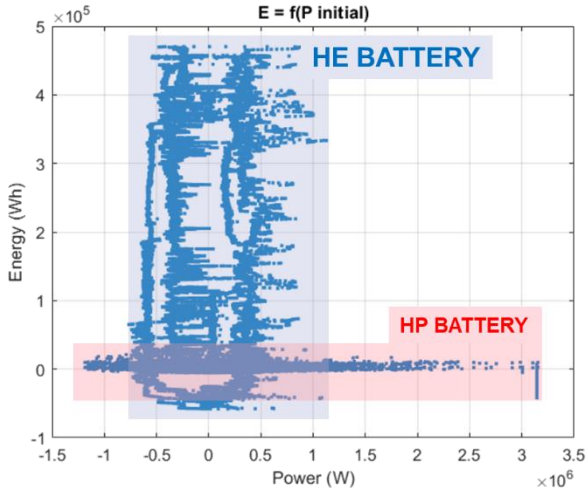

Figure 1 - Case A / Example of energy vs power plot

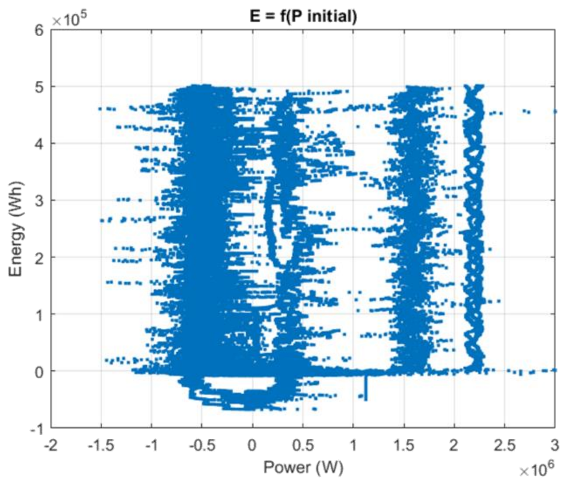

Figure 2 - Case B / Other example of energy vs power plot

3. Application to a case study

The section below describes the application of the above methodology to the case of an anchor handling tug supply (AHTS see example in Figure 3), focusing more particularly on the first steps, namely the data analysis and the definition of an adequate mission profile for sizing.

3.1. Case study specificities: contraints and vessel/BESS modes

The case study in this paper focuses on installing a 1MWh battery system made of Corvus batteries. The batteries considered as HE are the Corvus Dolphin Energy with a C rate of 0.5 and the HP ones are the Corvus Orca with a C rate of up to 3. C rates over short period of time (10 seconds) were assumed to be at 1C for the HE and 5C for the HP. SOC range is assumed to be 30 to 80%. More details of the batteries considered are available in Table 1.

Table 1 – Batteries characteristics

	Corvus Dolphin Energy module	Corvus Orca Energy module
C rate continuous	0.5C	Up to 3C
Single module size/increment	8.3kWh/50V DC	5.6kWh/50V DC
Single pack range	116-199kWh 504-1195V DC	38-136kWh 350-1200V DC
Max. gravimetric density - pack	168Wh/kg	77Wh/kg
Max. Volumetric density - pack	217Wh/l	88Wh/l

Figure 3 - Example of an AHTS vessel [6]

The vessel modes for the AHTS under consideration are the following:

- Port
- DP/DP standby: This mode is needed close to an offshore installation to maintain the vessel position and heading by using its own propeller and thrusters. Within a 500-meter zone around the installation, it is required to have redundancy if anything happens on one side of the switchboard.
- Transit: Transit eco, transit and transit max are the different types of modes for whenever the vessel is moving.
- Towing and anchor handling: Towing mode is when the vessel is towing another object. Anchor handling mode is when the vessel is out on the oil field setting and tensioning the anchors of a floating rig or another floating object that have anchors to set.

For each vessel mode, a BESS mode is defined, showing what services the battery could provide – this is summarised in Table 2.

Table 2 - Vessel operating modes and corresponding BESS modes

Vessel operating mode	BESS mode	Comment
Port	Shore power with peak-shaving Full electric	To be able to 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 the number of engines in use while on DP close to offshore installation.
DP-Standby	Spinning reserve and full electric	To reduce the use of engine and increase efficiency by doing full electric cycles charged by one engine activation..
Transit Eco	Peak-shaving and full electric	Peak-shaving on the load in transit over longer distance (exceeding the full electric part). Full electric in and out of port and maneuvering.
Transit	Peak-shaving	Peak shaving on the engine load while in transit to keep the engines at a better load.
Anchor handling	Spinning reserve and "beast mode"	To be able to have BESS as backup and in some cases reduce the 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.

3.2. Overview of operational data available

The following data sources were used for the present study [7]:

- Corvus Lighthouse. The Corvus Lighthouse logging system aims at providing monitoring and guidance to shipowners on how the BESS is operating to help achieve its designed lifetime. The logged data is sampled at about 1 second sampling rate. The Lighthouse data logging portal reports the parameters including current, voltage, State of Charge (SOC), state of health (SOH), temperature, etc. at cell, module and pack level. Maress [8]. Maress is a webpage and database-based system that collects data gathered from several existing data sources associated with vessels. 'Maress Monthly' displays the vessel operational routes and important fuel variables including fuel used, fuel saved, increased efficiency, CO_2 saved, and shore power used for the last month. The logged data are sampled at about 1 day sampling rate, with the fuel consumption in each mode (Port, DP, StandBy, Transit, etc.).
- Data from various offshore vessels from the Solstad fleet [6] were combined depending on availability.

3.3. Definition of the operational profile

Two operational profiles were defined for this case study:

- A profile reflecting the current use of the vessel
- A profile reflecting how we would like the battery to contribute; this profile aims to reflect the improvements expected with the new battery (e.g. new battery mode for a given vessel operational mode). The latter will be used for sizing the heterogeneous system. This second profile is obtained by adapting the first one.

As the target AHTS vessel does not have a battery system yet, historical battery usage data from another offshore vessel (vessel 2) equipped with a battery capacity of close to 1MWh were analysed over a period of about 12 months. This was coupled with the vessel 1 (AHTS) operational mode share of Table 3 (in percentage for the operating modes described in Table 3).

Table 3 - Share of each operational mode (as percentage of the time)

Vessel operating mode	Share of the time (over 363 days)
Port	46%
DP	6%
DP-Standby	14%
Transit (eco, normal or max)	24%
Anchor handling and towing	11%

When examining the vessel 2 historical data, we observe that the battery is little used as the state of charge (SOC) remains at 81%, with some "spikes" between 30 and 80%. These “spikes” are in fact the battery usage during “port” mode. In “port” mode, the boat goes only with its batteries (SOC decreases), when SOC reaches 30%, gensets enter in service to supply power to the load and also recharge the batteries.

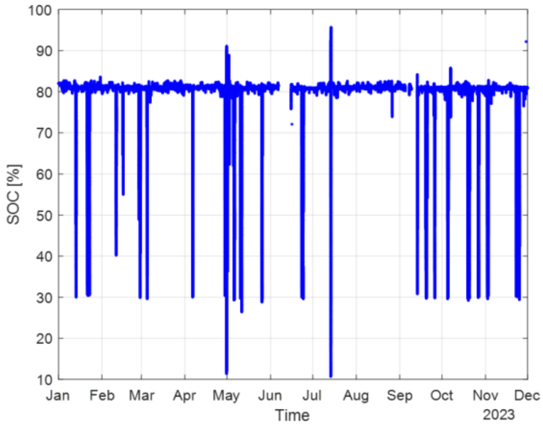

Figure 4 - Overview of vessel 2 SOC vs time

The mission profile in Figure 4 was not reflecting the way we wanted to use the battery to be installed on vessel 1, thus the operational profile had to be adapted as explained in Section II. This step is necessary to make sure the sizing is in line with the expected use of the battery. Discussing with the NEMOSHIP consortium partners, it was decided to use the full electric mode in Standby and Transit (when the vessel navigates near the port); the main idea in this mode is to use the gensets at high load, where pollutant emissions are the lowest and genset efficiency the highest. Final strategies to manage genset and batteries are not yet developed, but this profile for the battery is the most challenging profile, where the batteries supply the whole load when they can. These charging/discharging cycles were added to the profile. The final BESS operational profile is available in Figure 5.

The operational profile of the battery was condensed into a 48h period to reduce computing time. A vessel will not experience all these modes within just 48 hours. However, from the perspective of the battery system, this 48-hour profile is valuable for simulation purposes as it represents the range of loads that the battery might be expected to handle over the course of a year.

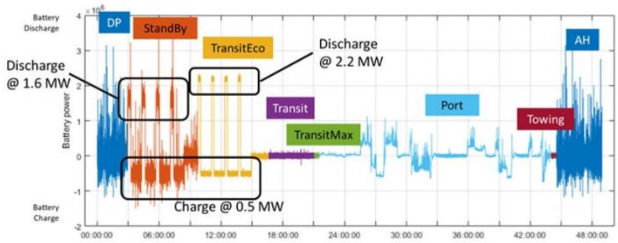

Figure 5 - Modified BESS operational profile

3.4. Results

In this case study (Figure 5), there was a need for both energy and power so the split was not as clear as in case A (Figure 1) for example. The analysis resulted in a HE pack of 180kWh and a HP pack of 820kWh.

4. Discussion, conclusions and next steps

The paper details a methodology to size a heterogeneous battery system for the maritime sector and applies it to an offshore vessel case study. The paper highlights the importance of correctly defining the mission profile of the battery and the need to adapt it to reflect the foreseen use of the battery. In the case study considered, an offshore vessel, the optimal HE/HP share was of 82% HP and 18% HE.

This case study came with some pre-defined constraints/specificities:

- The total battery capacity is 1MWh, 3MW.
- HE and HP batteries were both of type Lithium ion NMC / graphite. The heterogeneity was brought by the different C rates in the case study.

Other case studies could look at the following relevant aspects:

- Use of different battery technologies for HP battery : e.g. LTO batteries (typically 10-20C, around 20000 cycles), or supercapacitors (up to 10000C, 1000000C but very low energy density), or LFP batteries (up to 10C for "High power LFP batteries", 6000 cycles).
- Not limited to 1 MWh: With a larger battery capacity, such as 5-6 MWh, the HE battery should be able to supply the full power (3 MW). This would enable optimized control strategies, as either the HP or HE battery can fully meet the power demand.
- Ageing of the HE and HP pack. Impact is difficult to estimate in the present case, as the power sharing between HE and HP battery is very linked with the sharing strategies which will be developed later in the project. However, as the HP battery pack is the largest part of the BESS (82%), its lifetime would be similar/close to an equivalent battery system made with only HP modules.
- Safety/classification societies requirements
- Accounting for other parameters in the selection process, e.g. cost, volume/weight as HP batteries are typically more expensive than HE batteries and they have a lower gravimetric/volumetric density. Cost of each battery type could be considered in a scenario where capacity is not that constrained and trade-off may be observed between energy/power and costs and space used.
- Analysis of the most suitable electrical architecture for the HE and HP pack. A possible architecture can be made of battery packs connected in parallel with one power converter associated to each group of batteries, so that the operation of the group is decoupled from the others. However, adding a converter has an impact on the cost, weight and overall losses of the system. Overall, in addition to the number of converters, other parameters to account for in such exercise are flexibility, controlability, compatibility with ship types and DC/AC grid, use of off-the-shelf components, number of converters and safe behaviour of the system. So an analysis should be carried out evaluating the different topologies and assessing which one is best with regards to the case study constraints and objectives.

Finally, with heterogeneous BESS, the control aspect is essential to ensure efficiency, safety, longer lifetime. Many operating strategies for hybrid storage systems exist such as filtering, rule-based limitation of the operating window or optimized load splitting. The control of a heterogeneous BESS is a key topic addressed in the NEMOSHIP project and several Tasks are dedicated to it. Battery power management system (BPMS) algorithms are being developed to increase heterogeneous BESS autonomy, lifetime, efficiency among others and they will be demonstrated on a real hybrid offshore vessel.

ACKNOWLEDGEMENT

The NEMOSHIP project has received funding from the European Union's Horizon Europe Research and Innovation programme under grant agreement No 101096324. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or or the European Climate, Infrastructure and Environment Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

Co-funded by the European Union

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