Adapting Alternate Energy Sources and Future Loads in DC Power Systems

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Synopsis

Designing modern naval vessels to be fit to receive future extension modules is a way of futureproofing the vessel design, while at the same time reducing initial build cost. Energy storage technology is rapidly progressing, and navies should be capable of future proofing for the latest technology for operation gains.

Naval vessels have a relatively long lifetime compared to many commercial vessels and decreasing the complexity of integration or upgrade of power system modules such as batteries and fuel cells, while also allowing for higher share of pulsed high-power loads such as high energy weapons and radars during its lifetime could be beneficial.

DC power systems are marking their entry into the navy segment, where they offer advantages in flexibility and modularity of the power system, where all sources and loads are connected to one or multiple DC switchboards through converter modules.

In this paper, ways of futureproofing a DC power system design are examined, with a focus on gaining the capability to receive future power system modules throughout the lifetime of a vessel. The paper will introduce the DC power system and present possible future extensions of the power system and explore how such extensions may be integrated into it.

It will present different strategies such as design for a specific future component or be able to integrate a variety of different components. It will also explore the use cases for containerised Mission modules. Standards for DC power system will be discussed,

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1. Introduction

Vessel power systems have moved towards hybridization and integrated full electric propulsion systems, and now DC power systems for surface vessels are marking its entry. The US Navy points at frigates and destroyers as possible classes of vessels that will benefit from hybridization[1]. For smaller classes such as patrol and coast guard vessels there are several examples of hybridization, both with and without energy storage systems [2][3][4]. Recently, the German navy have selected a DC main distribution system for their newest frigates [5].

DC power systems offer benefits for flexibility and operation and enables:

- Fuel saving by employing variable speed engines with possible fewer genset online.
- Space-saving and optimal localization of equipment.
- Better power system stability and reliability.
- Easier integration of energy storage systems.

In addition, with the ability to handle more load dynamics and having more power available, the integration of new high-power sensors, Electronic Warfare (EW) equipment and laser systems is possible.

These kinds of loads are interesting because they differ significantly from the typical loads in a vessel power plant. What sets them apart from the other loads are that they typically are pulsed and stochastic in nature and with higher ramp rates, which can pose a significant challenge depending upon their power consumption and peak demand [6]. An AC system integrating such equipment will face challenges in keeping the system stable both statically and dynamically, as these kinds of

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loads needs significantly more power and ramp rate that generators are able to offer. This is one key reason why DC based system will ensure future proofing of naval vessels, as they are more capable of handling large dynamic loads.

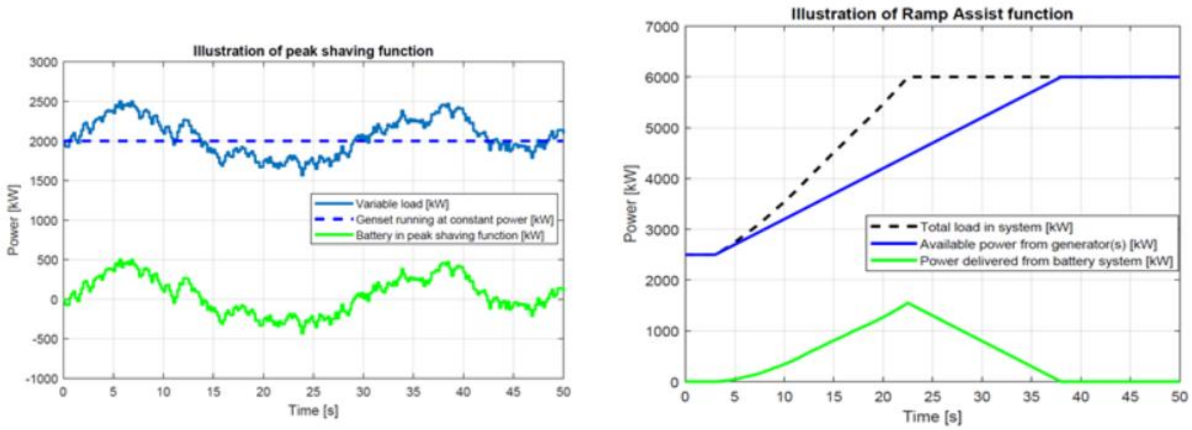

Figure 1: Illustration of BESS support function of a hybrid vessel power plant during dynamic loading.

Hybrid DC systems are interesting, because they can be easily integrated on existing platform designs, with minimal changes in the vessel design without impacting bulkhead position. ABBs Onboard DC Grid™ (ODCG) delivers DC power for hybrid vessel power systems, were the gensets are operated at variable speed to maximize efficiency and the BESS are integrated to provide support for dynamic loading of the power plant. Current limits and ramp rates are controlled by converters, depending on available power. Protection and selectivity are handled by solid-state circuit breakers and fast-acting fuses.

The functions illustrated in Figure 1, which today already are improving the operation of many commercial vessels, will also be beneficial for naval vessels. Figure 2 illustrates how the typical naval loads such as sensors, Directed Energy Weapons (DEW) and Electronic Warfare (EW) will act towards the vessel power plant.

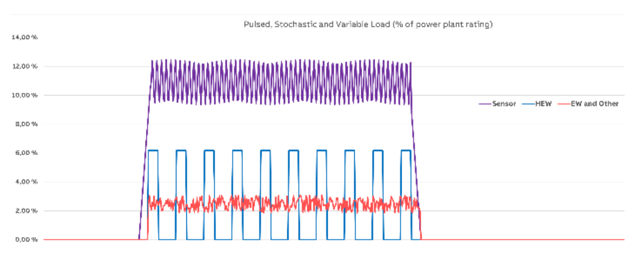

Figure 2: Illustration of how different naval loads looks like towards the power system, with power on the y-axis. Figure in-spired by presentation in [12].

From examining Figure 1 and Figure 2 it is clear that a well dimensioned Battery Energy Storage System (BESS) with functions like peak shaving and ramp assist can assist in stable operation of a vessel power plant even with high dynamic loading. Pulsed loads are interesting because for the BESS, these would look like smaller series of spinning reserve events (load rejection and/or loss of generator events).

2. Naval design of LVDC

The typical way of designing an LVDC power system for a naval surface vessel is shown in Figure 3, here the system is split into two or four similar arrangements, to have electrical redundancy. BESS is integrated into each switchboard section for increased redundancy if generator or bus transfer is lost. The LVAC supply is handled by Off-Grid Converters (OGC), that ensures smooth 440VAC to downstream consumers. The propulsion system is fed by inverter units creating variable speed to the shaftline. Variable frequency drive supplied loads can also be supplied from the DC switchboards to reduce THD in the LVAC system.

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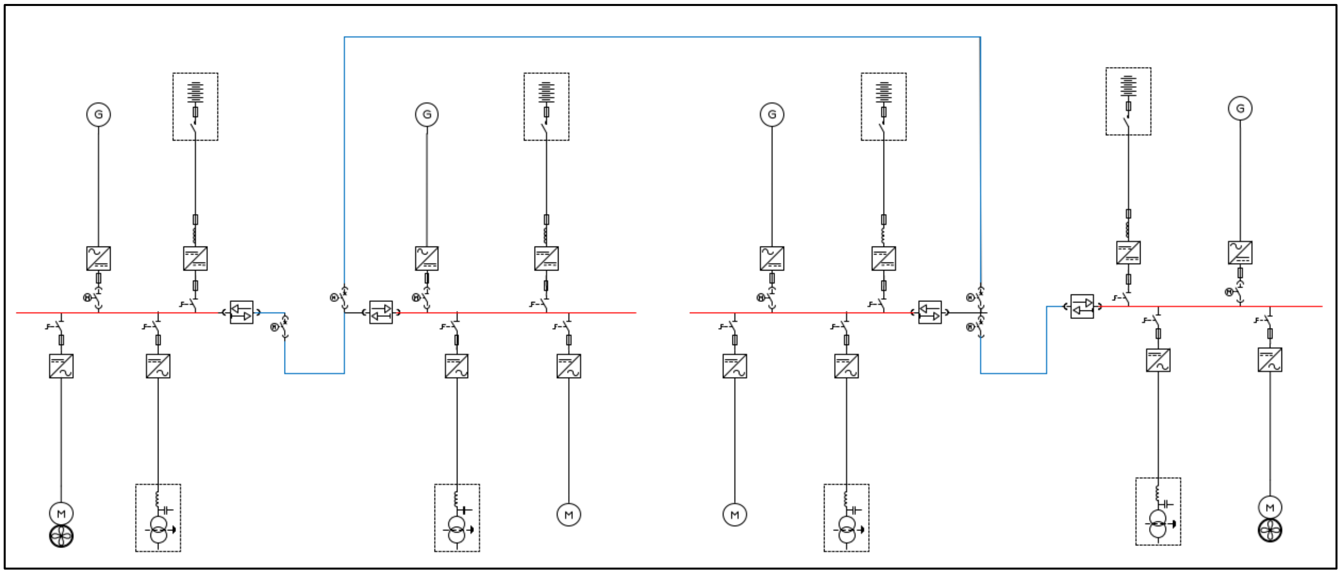

Figure 3: Illustration of a DC power system with redundancy splits showing power generation, energy storage, auxiliary power propulsion load and the solid-state breaker.

BESS can be connected to the DC system with either DC/DC converters or directly through a fused feeder. However, the use of DC/DC converters is generally preferred as the batteries can be operated regardless of their State-of-Charge (SoC). Directly connected batteries are typically used where BESS is the main source of power, such as a zero-emission ferry or now on smaller unmanned platforms.

As discussed in [7], all DC switchboards should be connected in normal operation, i.e. the solid-state DC breaker closed, as the number of generators online can be optimized for better fuel efficiency.

For combat mode, or as requested, the system can be split into redundancy zones. Load sharing is done by voltage droop control, and a power and energy management system (PEMS), a very capable redundant, distributed control system coordinates all control functions for all operating modes as required.

The protection of a DC power system is handled differently than a conventional AC power system. Each converter unit in Figure 3 is protected by its own fuse. In case of internal fault in the converter, the short-circuit current provided by the energy stored in the capacitors of other converter units will quickly, within microseconds, make the fuse operate and segregate the faulty converter from the rest of the system. In case of faults on main bus bars in either the link (red) or grid (blue) section, protection signals from solid-state breakers and current measurement Current Transformers (CTs) will identify the fault location and open correct breakers. If switch-disconnectors or disconnectors are used, solid-state breakers and converters can block short-circuit current to allow bus-ties and feeders to open.

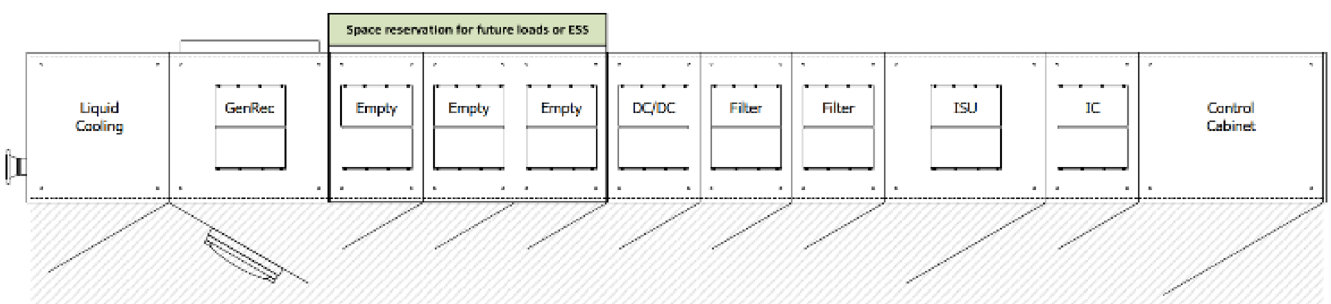

Figure 4: Illustration of cabinet drawing for the system in Figure 5 with space reservation for future modules. Can be installed with modules or just busbars passing through

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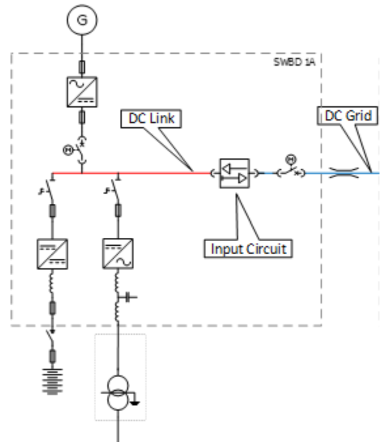

Figure 5: Notional SLD detail for a combatant damage zone BESS integration

3. Fit-to-Receive LVDC Designs

Fit-to-Receive LVDC designs means being able to integrate future loads and sources, increase energy/power consumption or generation with the same power system design or to give opportunities to connect mission modules as required. Some examples of fit-to-receive BESS have been discussed where basically the DC/DC cabinets would be there but not the actual Line Replaceable Unit (LRU)/Converter as shown in Figure 4. This is an example of a cost saving measure to await future BESS technology. In addition, the future-proofing of large BESS could also incorporate a Solid-State Circuit Breaker to make sure that the system can cope with the peak short-circuits from a BESS. Another example would be that cabinets are in the design; however, the subsystem function is not designed yet. Then, the same cabinets and inverters could be used for: Inverter Unit (INU) for variable speed motors, Inverter Supply Unit (ISU) for static conversion to LVAC or shore connection and DC/DC for future DC based loads.

4. Containerized Mission modules

Another simple way to future-proof a platform today is to install future feeders to Mission Bays / Hangars as can be seen in Figure 6 and Figure 7.

In this example, each Grid connected DC breaker has a capacity of up to 6 MW, directly connected to the Onboard DC Grid™ patented Grid zone protection that enables selective design with DC ACBs instead of fuses. ABB always recommend installing those and a fibre optic cable for the PEMS system to be futureproof. This creates flexible and changeable capabilities on the other end of the cable in either the Hangar or Mission Bay.

These capabilities can include:

- Containerised ESS
  - High power for pulsed loads
  - Energy for silent and zero emission operations
- Containerised Gensets
  - Double damped high-speed gensets for silent operations
  - Retrofit for under-dimensioned powerplants
- Load bank for genset testing
- Fuel cells for
  - Zero emission operations
  - Silent operations powered by F76
- High power demanding DEW
- High power demanding sensors, radars, sensors
- Desalination and tropicalization

Overall, the tactical benefits of using DC power and electrical propulsion with a variety of available or future Energy Storage Systems (ESS) can result in improved dynamic performance and optimal uptime on sensors and mission systems. One common denominator is that ESS are typically DC based.

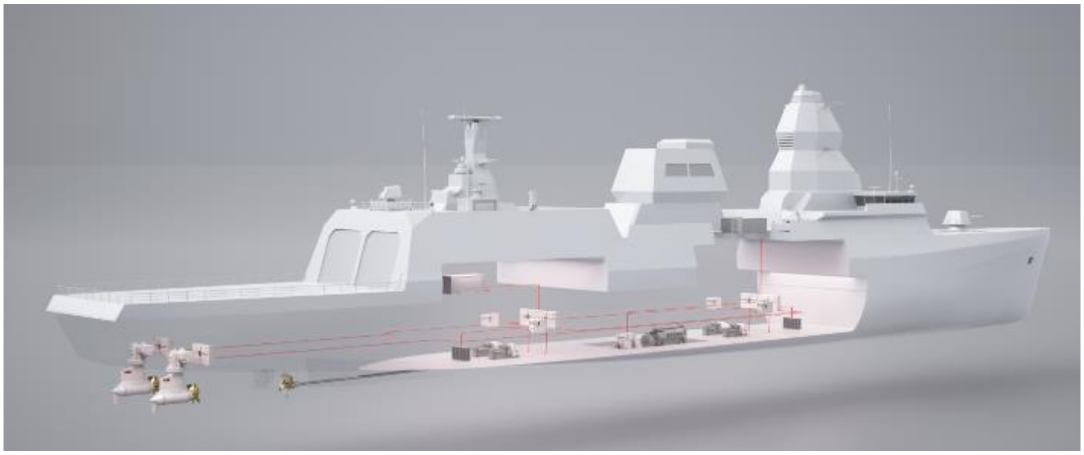

Figure 6: ABB Rendering of Wingpod concept as presented by BAE systems during Euronaval 2022.

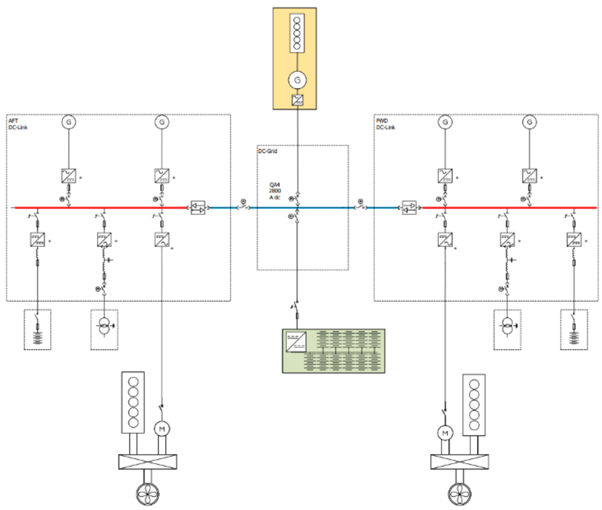

Figure 7: Illustration of integration of containerized mission modules into a DC power system.

4.1. Mission Module – BESS

Complete and self-contained BESS solutions for marine vessels have been announced by ABB [8] as shown in Figure 9. In this system, the batteries, converter, control, interface, and auxiliary equipment is placed in a container for easy installation onboard a vessel. This is a solution for both retrofit and newbuild projects. Note that for example China based CATL recently release a 6,25 MWh LFP BESS in a 20’’ container [9]. The containerized BESS will have the same functionality as conventional BESS in a DC power system: spinning reserve, ramp assist and peak shaving. The use case could be for zero-emission operation or assisting the power plant in dynamic load conditions. If considering a midsize Anti-Submarine Warfare (ASW) Frigate with combined hotel load and propulsion of 1 MW, then around 5 hours of ASW in low knots can be achieved with merely one container. The containerized BESS would be easily interchangeable if not needed or for upgrade of battery technology.

4.2. Mission Module – Genset

This use case could be discussed for retrofit, adding special capabilities to a Multirole Frigate such as double damped high speed gensets for silent operations. This genset would be placed far up, preferably in the boat deck and far away from the water for longer Structure Bourne Noise (SBN) travel path from hull to water.

For vessels with under-dimensioned power plants, not suitable for taking in future loads or with one genset out due to service, a containerized genset module could be beneficial. Naturally simple on paper and normal caveats for fuel, exhaust, selectivity, installation, Selective Catalytic Reduction (SCR) etc. applies, however certainly plausible. In commercial vessels, DNV has published the class guideline DNV-CG-0588 for containerized gensets.

Figure 8: Illustrative model of a containerized ESS module from SH Group.

Figure 9: ABB visualization of containerized ESS for an offshore support vessel.

4.3. Mission Module – Fuel cell

One example of a 3 MW fuel cell concept system can be seen in Figure 10 below. Naturally hydrogen and the size of the 2022 version can be discussed with Naval eyes.

As we move into the future it is expected that the industry will develop into more power dense solutions in the future if the safety, supply, density, and stability of the fuel can be overcome and comply with Naval standards.

Figure 10: Conceptual model of a containerized fuel cell module [10].

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5. Interoperability – DC standards

The draft version of US MIL 1399-300-4 outlines a standard for LVDC with the simple goal of ensuring standardised interfaces. Considerations of pulsed power can be seen below.

- The maximum rate that a load can increase or decrease its power consumption.
- The maximum current drawn by pulsed loads in the power system.
- The maximum and minimum pulse width of the load.
- The recovery or recharge time between each pulse.
- The length of the pulse series.

Integration of significant pulsed loads or high ramp rate loads needs to consider operational limitations implemented in the vessel power and management system with regards to the points above.

However, it should be noted that commercial Marine already have integrated various 1,000 VDC system from various OEMs by just means of Electrical Engineers speaking and agreeing. In addition, the Danish company SH Defence have worked out several of these interconnection standards in their Cube™ System[11] as depicted in the earlier Figure 8.

While a new standard may have appeal to navies, however it also comes with the risk of slowing innovation and benefitting from the benefits of established proven systems.

6. Conclusions, Future work

This paper indicates some solutions to futureproof Naval platforms that can be considered in the initial platform designs for footprint and weight allocation on surface ships. The successful integration of future loads such as laser weapons, advanced sensors, fast charging systems for unmanned systems etc. will see benefits of having hybrid DC power systems, preferably with energy storage systems. This is because DC power system with integrated energy storage allows faster load dynamics than AC systems. Mission modules in the form of containerized BESS or Gensets can easily be integrated into a DC power system. There maintain perceived challenges in the industry relating to the safety of BESS on a combatant, such as the implications for firefighting. Many of these issues have been overcome, however their remains a lack of awareness and understanding within the naval community and time and resources should be invested on this topic.

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