Choosing the right Electric Propulsion Solution

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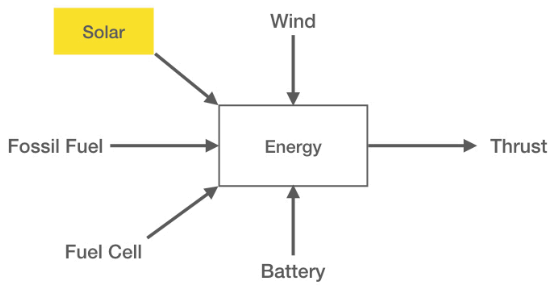
1. Introduction

Boats are normally powered by diesel or petrol engines. In recent times there is an increasing tendency to think beyond fossil fuels and go for electric propulsion. This is usually achieved by having electric motors for propulsion and batteries on board along with other sources of clean energy. These could be solar panels, wind power, fuel cells etc. The choice of the various sources is driven by cost and reliability of energy.

Fossil fuel propulsion



Electric propulsion

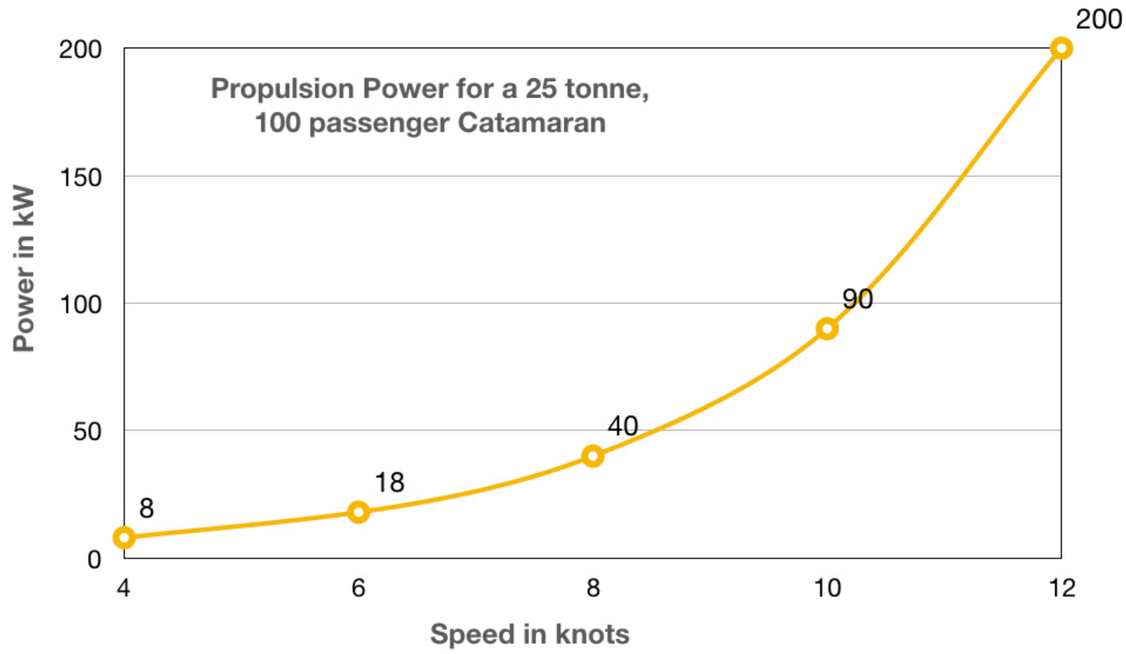
Currently the fuel cell as a source of energy in boats is technologically viable, but economically unviable. Wind propulsion is the best source of clean-energy for sea-going vessels especially larger ships. The focus of this white paper is on electric propulsion with solar, battery and with or without fossil fuel.

Once we decide to have electric propulsion using electric motors, it is almost always the case that solar energy can be used as source of energy, primarily as a cheap source of energy when the boat is in motion that helps reduce battery size[1]. The marginal cost of adding solar panels to get energy from the sun when the boat is in motion (grid charging is unavailable) is low. It means that the power from the sun is cheaper than either stored power from grid or power from diesel generators. If we keep the total energy per trip fixed then the solar panels on the boat reduces the battery size required to meet the operational need and since batteries are very expensive, solar panels on boat helps that way too.

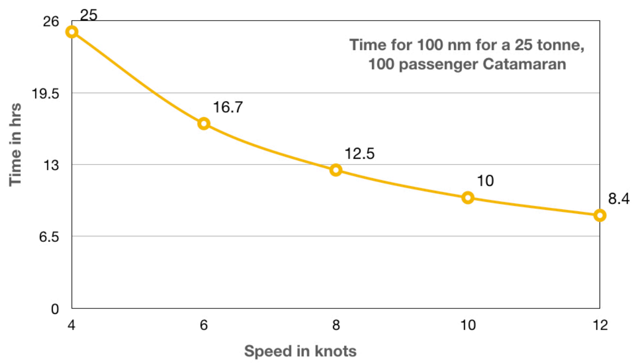
2. Speed-Power-Energy relationship

When we discuss the type of electric propulsion it is important to understand the exponential nature of speed-power relationship. As an example, a 100-passenger ferry with 25 tonne displacement is shown. It can be seen that when the speed is doubled from 6 to 12 knots the power is increased more than ten times. This determines whether a particular application can be electric propulsion or not and if yes, how the energy mix can be achieved.

[1] Sandith Thandasherry, "Solar panels – on boat or land"

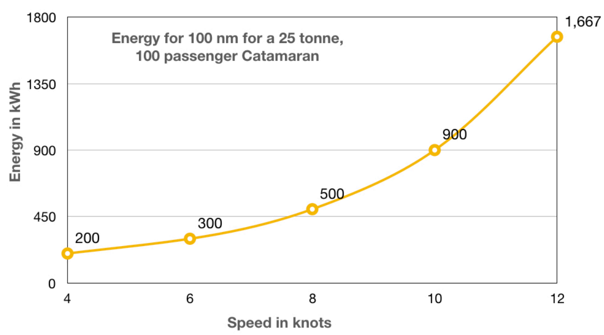


For the same boat it is important to know the energy consumption for a fixed distance (range). This for the same pair of speeds, 6 and 12 knots, increases 5.5 times.



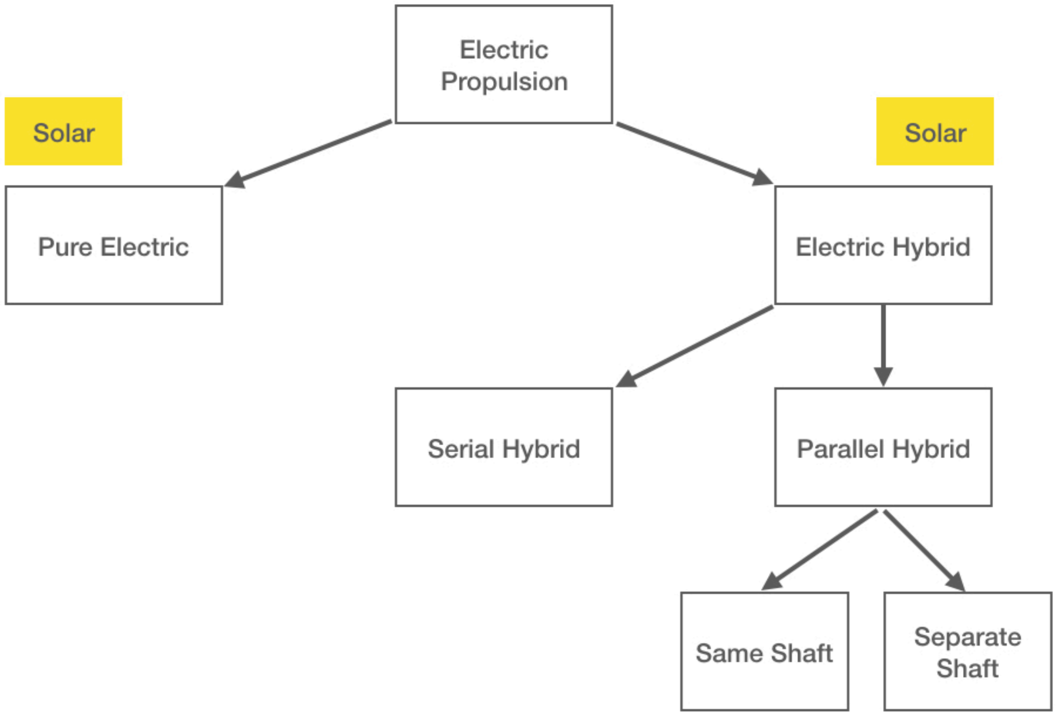
For the same distance of 100 nautical miles, the time take drops by half from 16.7 hours (6 knots) to 8.4 hours (12 knots).

As the time reduces, the energy required for the same distance increases at lower rate than power, yet it is exponential. This energy curve is one of the key drivers deciding the type of electric propulsion in a boat.



3. Types of Electric propulsion

Broadly there are two types of electric propulsion – pure electric and electric hybrid. In the pure electric, under normal conditions there is no need for fossil fuel to perform the boat propulsion function. The normal function includes all modes of operation speeds – slow, cruise and high.



Types of electric propulsion

4. Pure Electric propulsion

In pure electric, the only reason one might have a diesel engine is as a backup, usually as a generator, in the scenario the other sources of electrical energy are exhausted. In electric hybrid, a diesel engine is present either to provide propulsion power directly (parallel hybrid) or indirectly (serial hybrid) through generators in some more mode of operation.

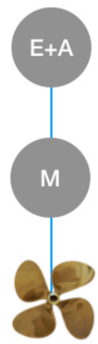
Referring to the speed-power curve, typically boats under 8 knots are pure electric and once speed is more it makes more economic sense to go for hybrid. However, there could be other reasons for keeping boats with higher speed than 8 knots as pure electric.

5. Electric-Hybrid propulsion

In electric-hybrid propulsion the diesel engines provide power not just as a backup but also during some mode of operation, usually in the high-speed mode. There are two ways to provide this propulsion power – either directly to propeller (parallel) or through motor to propeller (serial).

5.1. Serial Hybrid

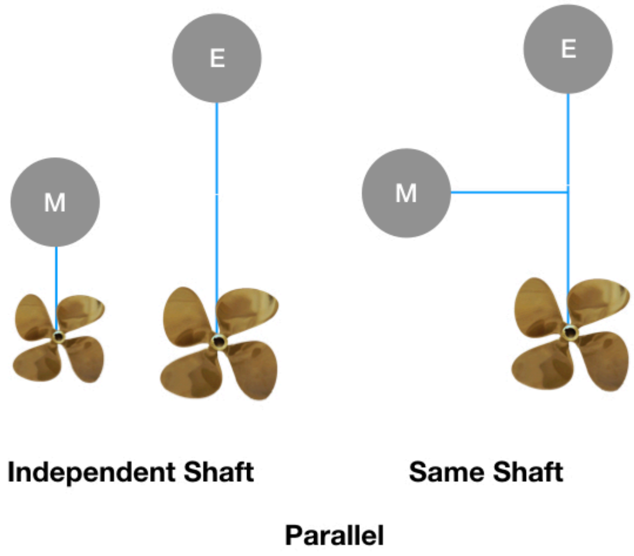
In a serial hybrid electric propulsion, diesel engines drive generators that provide electrical power. This is sent to electric motors which are connected to propellers. The engines do not directly drive the propellers. In boats, whether it is a single hull or catamaran, it is a good practice to provide two power train for redundancy in case of system failure.



Series

5.1. Parallel Hybrid

The parallel hybrid is a system where engine and motors directly run the propellers. It could be same or independent shaft-propeller system. This system is cheaper than serial hybrid and chosen when the use of electric power is for a limited period of operation.



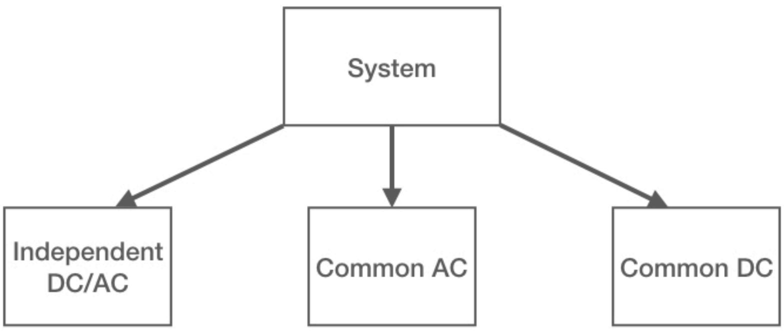
5.1.2. Independent Shaft

This approach is common when electric propulsion is added as retrofit. It also makes the system completely redundant from the diesel shaft. This is also common when the two modes of operation – electric (low speed) and diesel (high speed) have big gap so much so that the propeller inefficiency for two different modes becomes significant.

5.1.3. Same Shaft

In this approach the propulsion shaft is common and both engine and motors drive it in parallel with some clutch mechanism. This is more expensive than independent shaft although propeller and shaft is common because clutch mechanism is complex.

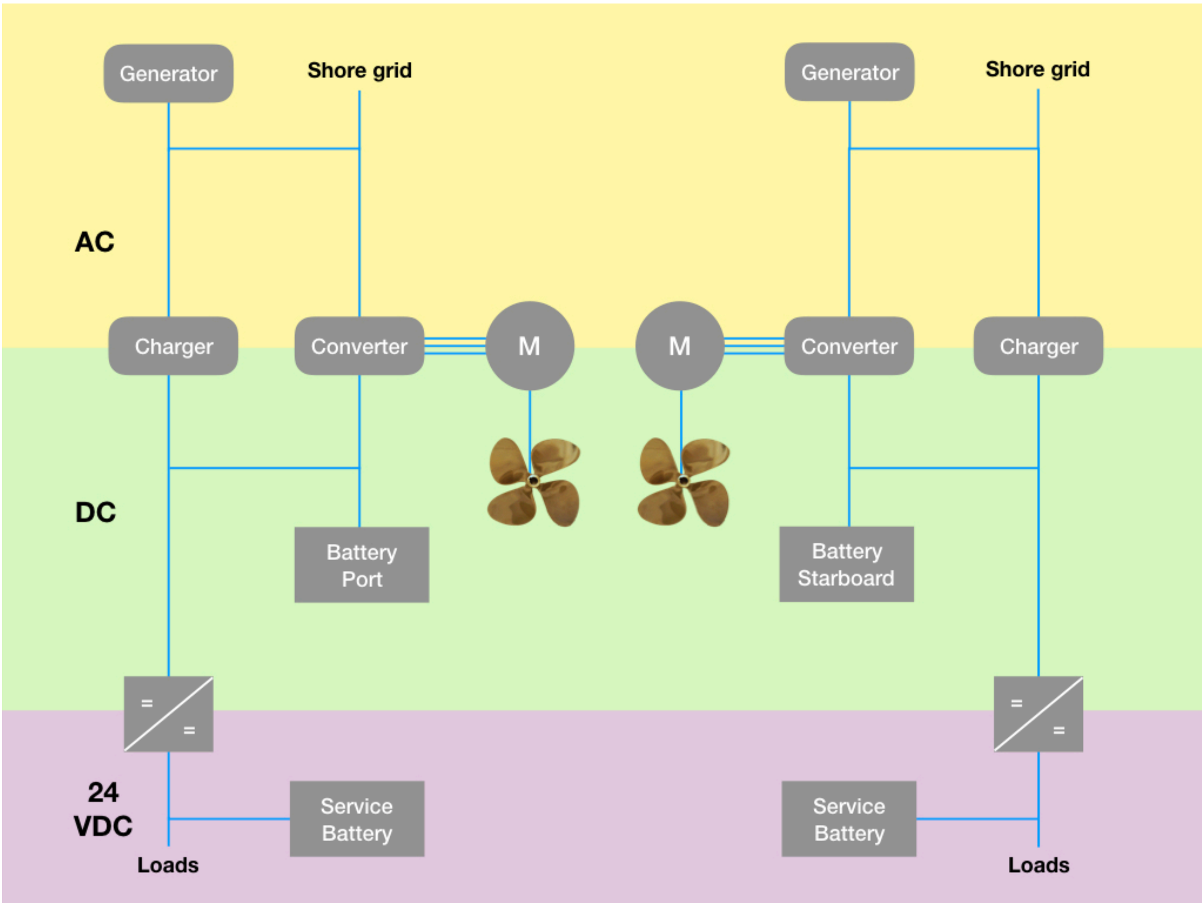
6. Types of Electric System



There are three possible approaches to the system design - Independent DC/AC, Common AC and Common DC. Here AC and DC refers to type of electric current - alternating and direct.

6.1. Independent DC/AC

In this system, there is no electrical contact between the two sides This achieves complete independence and redundancy. The advantage of not having any electrical connection between two systems is that even if there is a failure in one side, it does not affect the other. ADITYA, India's first solar ferry, is an independent DC/AC system for maximum safety and reliability. ADITYA, however, does not have generators, hence no fuel on board, and is a pure electric boat.



Port and Starboard systems are completely independent and not connected electrically

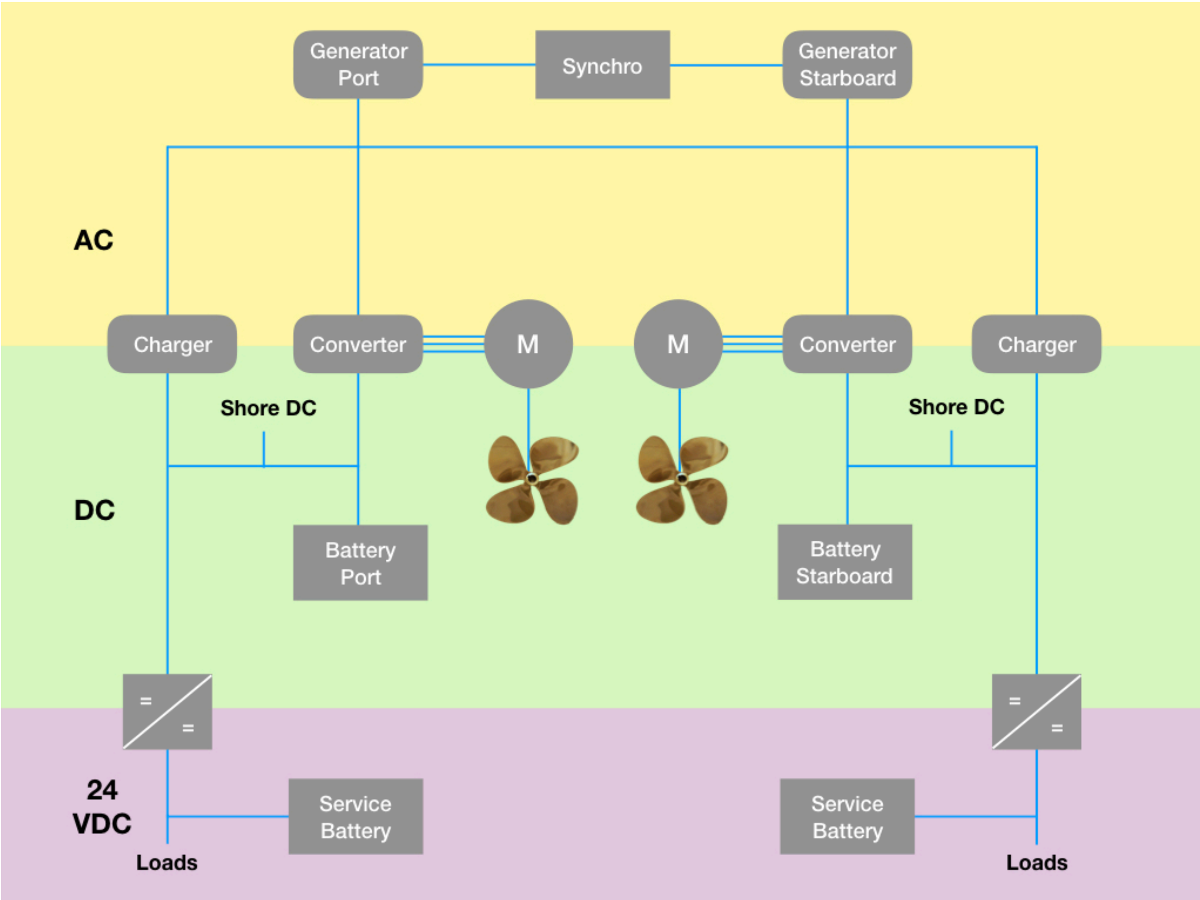
Motors will usually have higher power than service speed since motor efficiency does not drop like engine when it operates outsides its normal continuous rating (NCR). This means that even if one battery back is unavailable during failure of one side, using the other battery, the boat can be brought to safe shore using a single battery and motor operating at higher power. Interconnecting the two sides for using both batteries only to take the boat to safe shore might be reasonable in scenario where boats operate in sea and safe shore is far away. This is usually not the case for inland boats.

However, if there is an option needed to connect the port and starboard systems to run both the motors with one battery bank intact. In that scenario only two possibilities arise - Common AC and Common DC.

6.2. Common AC

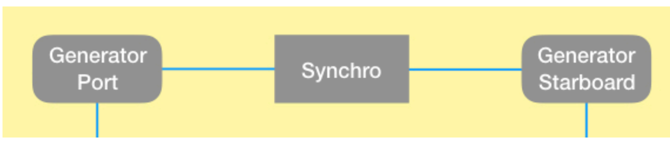
In this system, the AC bus is interconnected whereas DC is independent. The generator is connected to the AC bus. There are two reasons why a generator is placed in an electric boat. Firstly, to provide the energy if the boat has a high-speed mode along with cruise speed. In high speeds, the generator provides the required power, either completely, or partially. The second reason is to provide redundancy to system if the DC system (Power Management System) fails. In that scenario the generator should be able to run the boat directly.

In this scenario, generator redundancy is not needed as boat can operate without generator also. We can add more generators for redundancy. It can be added as 100% backup where the second generator is on standby and is used when the first one fails. This increases the cost of generator by 100%.



Common AC with single generator

Instead of a single generator, one can add two generators with synchronisation as well. It adds to little bit of complexity. Compared to a single generator of bigger size, this would be 50% more expensive. There is an advantage in having two generators synchronised. It gives option to save fuel by sizing them running them at maximum efficiency point in different load cases.

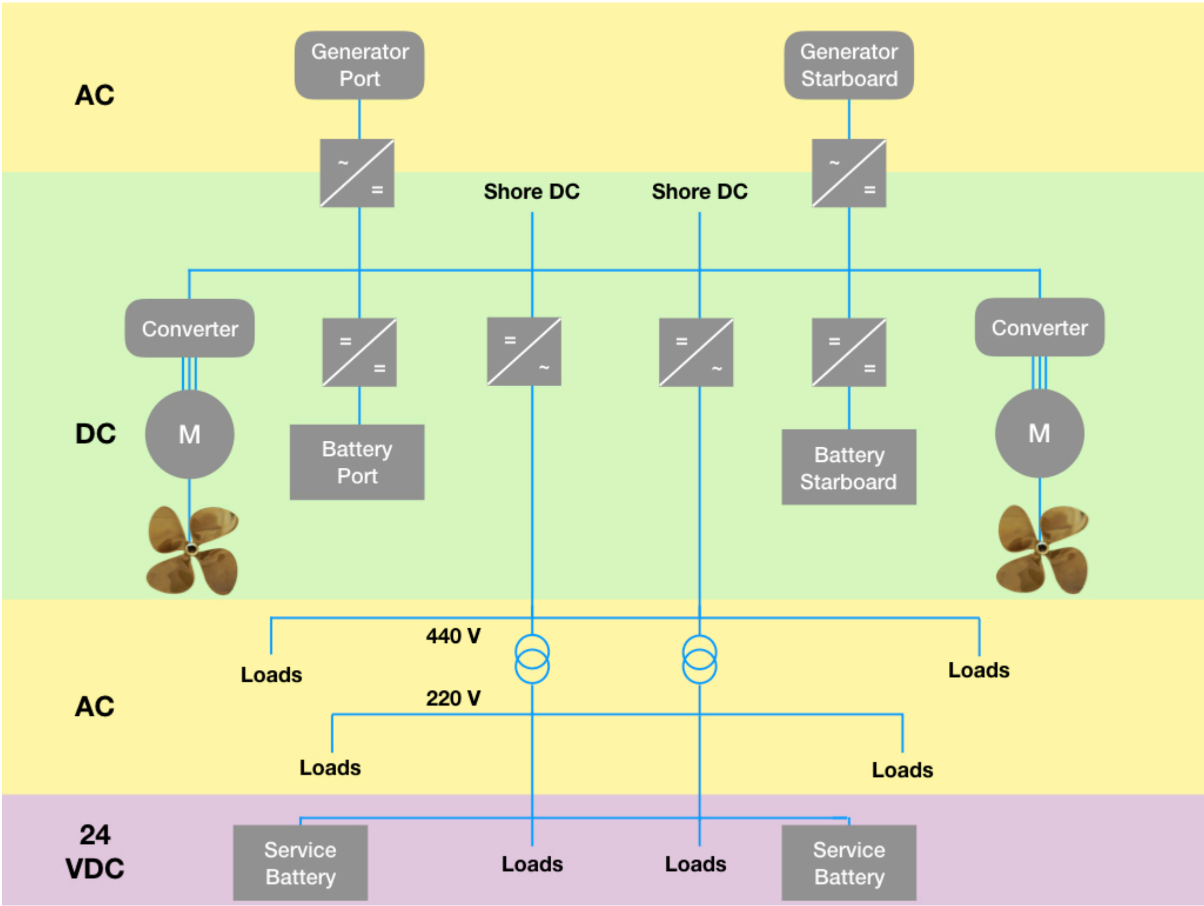


Two generators with synchronisation

Common AC is simpler than Common DC with lesser number of components (converts, etc.), lighter weight, and more reliability. It is also the system that is used in boats.

6.3. Common DC

In a common DC system, the DC side is also interconnected. This means that both battery bank acts parallel and maintain same voltage. The Power Management System (PMS) becomes more complicated. The redundancy of the system is very difficult to achieve as the fuses separating the DC system will blow off if there is an issue in one side and transfer to other side DC bus has low impedance. This is usually the system on large ships where there are multiple generators running where synchronisation becomes challenging.



Common DC with DC bus interconnected

A limitation of this system is when the DC system (PMS) fails. In that scenario the generator should be able to run the boat directly. However, If the DC system fails the boat will not be able to run by generators.