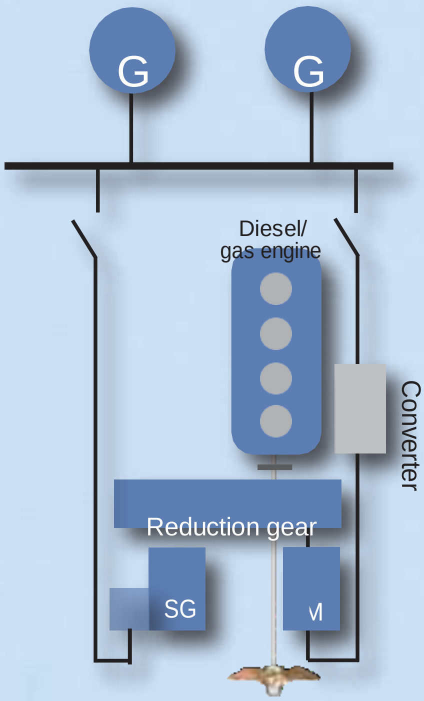
Fixed engine speed is history

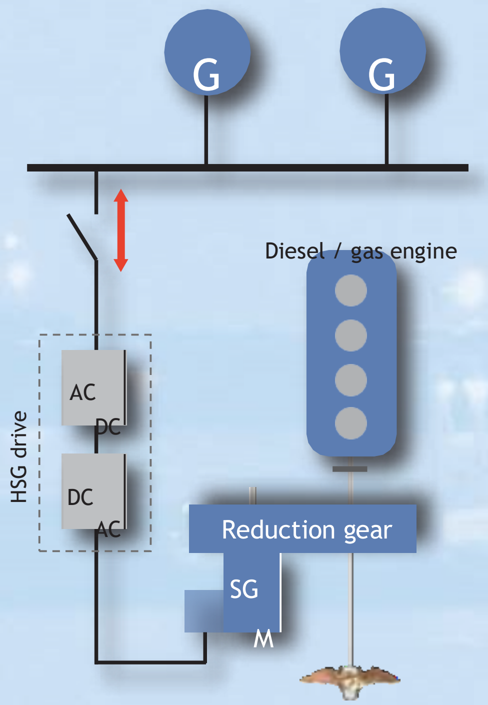
Upgrade to an electric hybrid propulsion system that significantly reduces fuel consumption and emissions – ideal for vessels that operate in a variety of modes

One of the major challenges when using a hybrid propulsion system is controlling the power flow and load sharing between the various power sources on a vessel (engines, electric motors and generators). In many instances, a shaft generator, driven by the diesel engine, is used to produce the network electrical power. The same diesel engine also drives the propeller via a common gearbox. This means that engine rpm must be kept constant to maintain the network frequency and to allow load flow and load sharing with other generators. The desired ship speed is maintained by altering propeller pitch, often with more energy produced than can be effectively used.

The Hybrid Shaft Generator (HSG) upgrade is a modification to the power electronics system which controls the shaft generator to switchboard power flow. This means that the diesel engine and the propeller can operate at variable speeds, whilst keeping the network frequency-stable and the voltage fixed.



With the HSG system the switchboards see a constant voltage and frequency at variable engine rpm.



In current hybrid systems (shown left) power generating requires a fixed engine rpm when operating the shaft generator, and does not allow the shaft generator to operate in parallel with the auxiliary gen sets.

With the HSG solution, (shown right), all generator current goes through the HSG drive which ensures that the switchboards see a constant frequency and voltage at variable engine rpm. The ability to reduce engine rpm to match the overall vessel power requirements results in lower fuel consumption and less emissions.

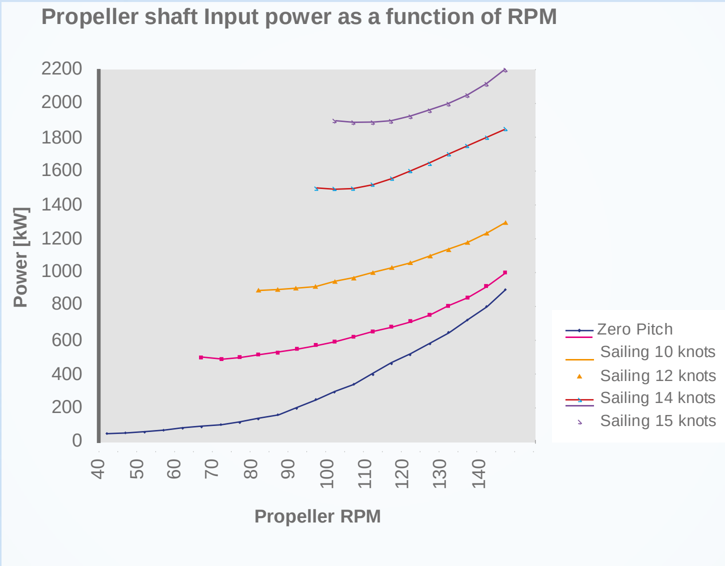
The shaft generator and electric motor can be one and the same component

Maximising engine and propeller efficiencies

By reducing rpm on the engine and shaft line, both propeller and engine efficiency can be optimised

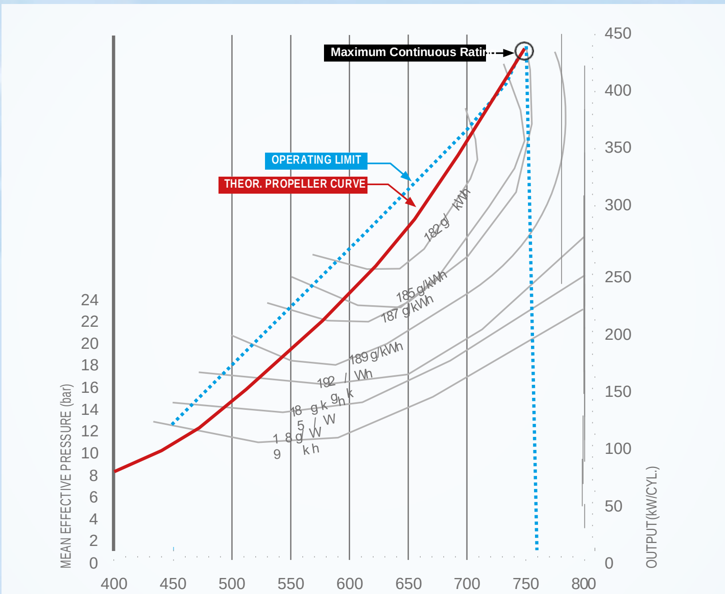
Optimising propeller efficiency

The graph shows the necessary input power as a function of propeller rpm in vessels sailing at different speeds. For example, a typical 6,500 kW CP propeller will have about 900 kW loss at fixed nominal rpm with zero pitch. With the HSG engine, rpm can be reduced to idling but fixed frequency and voltage to the electrical system is maintained, reducing zero pitch losses by 800 kW. 800 kW of power for 24 hours translates to 4,000 litres of fuel saved. If the vessel is sailing at 14 knots, the propeller efficency can be improved by reducing the rpm from 145 to 90 rpm and at the same time increasing the pitch. This will reduce the necessary shaft input power by 400 kw resulting in 2,000 litres of fuel saved every 24 hours. The potential is even greater as engine output is less.



Optimising engine efficiency

The graph shows fuel consumption based on engine rpm per cylinder. For example, based on a 200 kW output, fuel consumption can be reduced from 198 g/kWh to 188 g/kWh. This translates to a 5 per cent fuel saving.

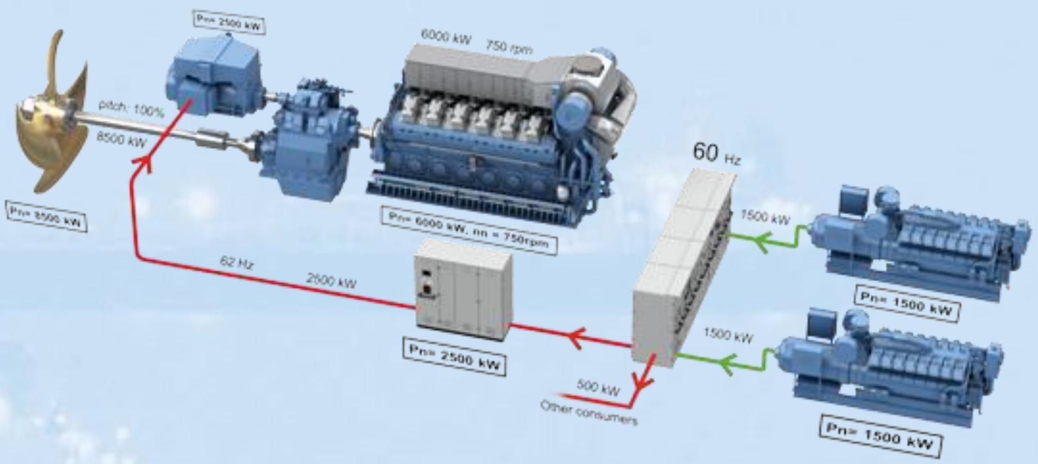


HSG – ideal for a range of vessels

A variety of operational modes ensure that you are always operating at maximum efficiency

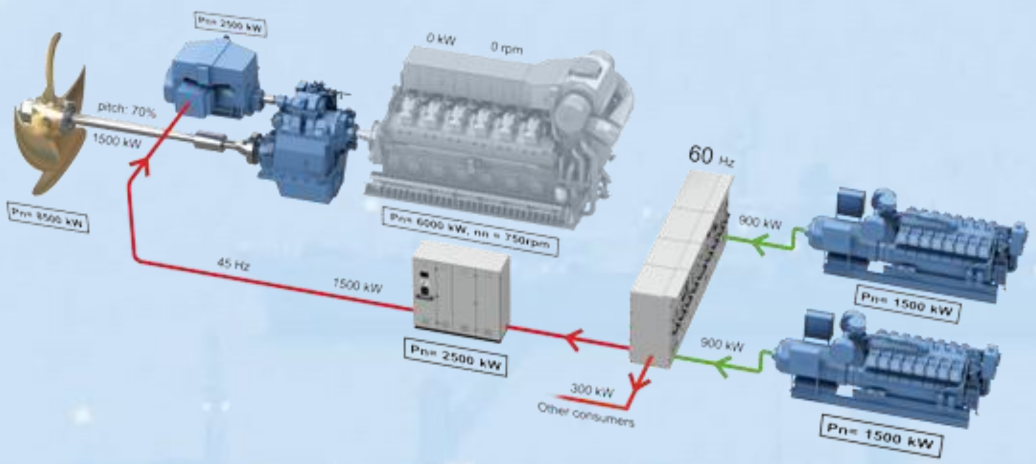
The HSG system upgrade allows for more flexible use of engine and propeller speed variations, so that both propeller and engine efficiencies can be maximised by ensuring that they are running at their most efficient point. This opens the door to various modes of operation, optimising the vessel power system to suit the operational requirements.

The illustrated modes show, in detail, the energy flow between the various components of the power system and how they are matched to the vessel's operating mode.



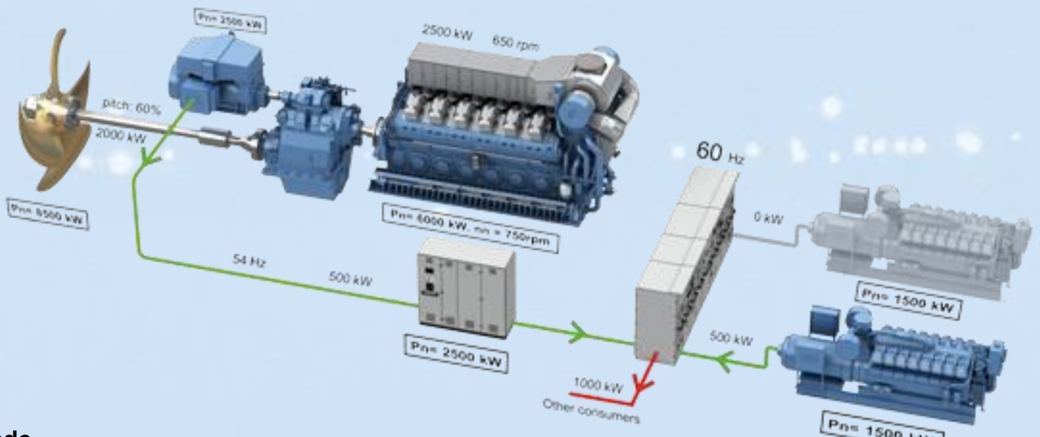
Boost mode

This mode is selected for maximum speed and harnesses most of the ship's power, including output from the auxiliary generator sets for propulsion. The shaft generator is operating as a motor with an output of 2,500 kW running in parallel with the 6,000 kW main diesel engine running at 750 rpm. This gives a total power of 8,500 kW on the propeller shaft.



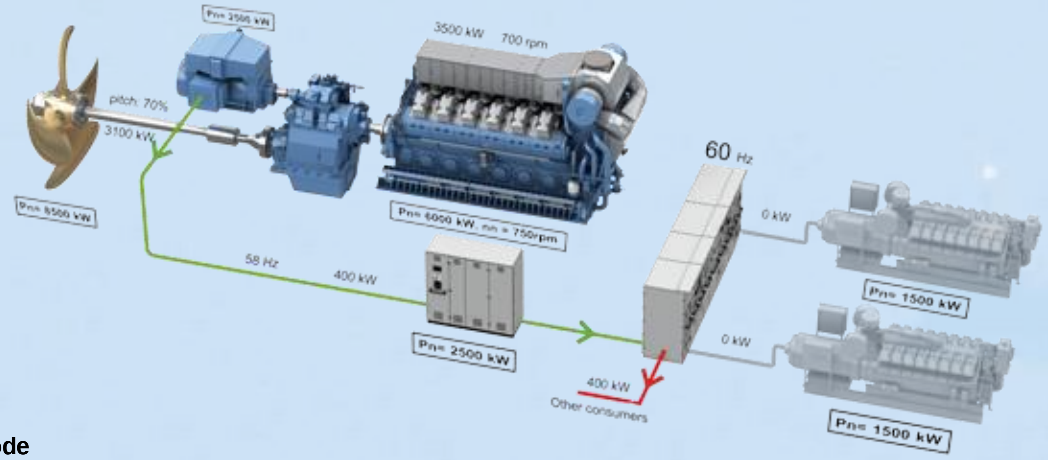
Diesel-electric mode

For vessels on standby or waiting in harbour, diesel-electric mode is an economic setting that doesn't require the main engine. The two auxiliary gen sets are running at 50 per cent power providing 900 kW each to the system. In this case, 300 kW is used for hotel loads and 1,500 kW is available for propulsion. In this mode, the shaft generator is running as a motor with the HSG system controlling the shaft speed.



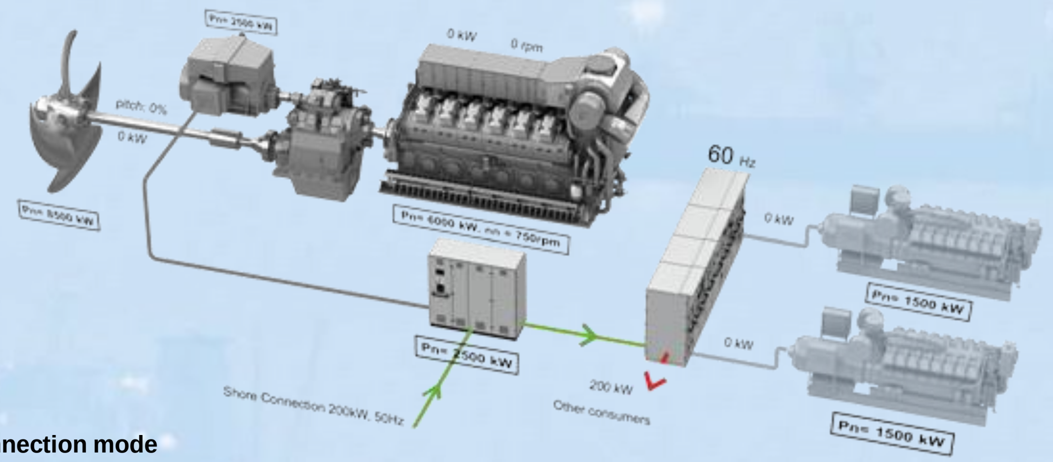
Parallel mode

This is a new efficient way of running two engines, where the power required for propulsion and hotel loads exceeds that available from the generator sets alone. With the main engine running at around half power, and variable rpm to optimise propeller efficiency, the shaft generator is feeding 500 kW into the electrical system in parallel with one auxiliary generator. The HSG system keeps the frequency fixed at 60 HZ.



Transit mode

This mode is a new setting available with the HSG upgrade, and is used to optimise propeller efficiency for the required speed. It allows the main engine to run at variable speed with the shaft generator supplying the ship's electrical needs. Therefore, both auxiliary generators can be shut off.

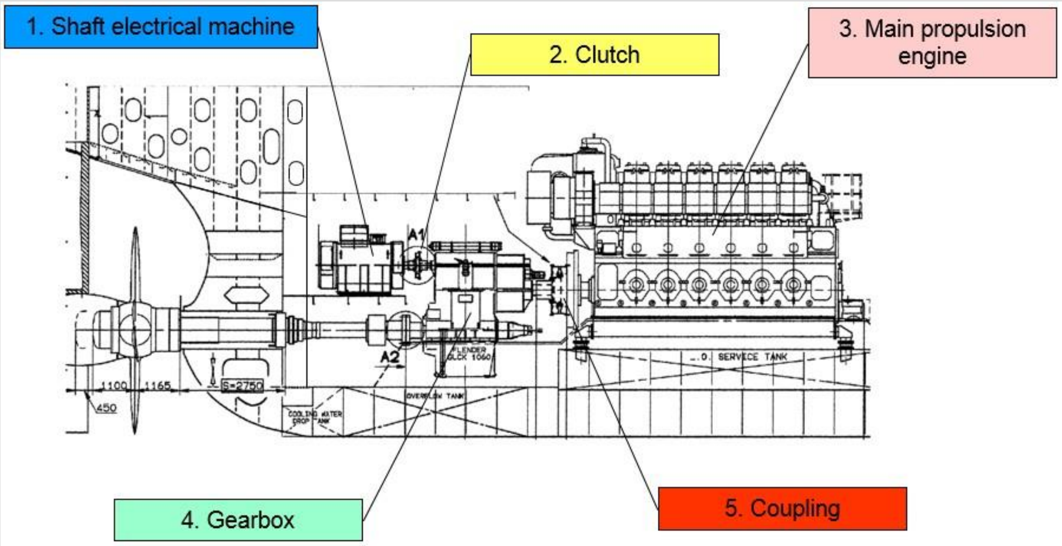


Shore connection mode

As its name suggests, shore connection mode is utilised when the ship is in harbour and connected to the normal shore power supply (50Hz), if available. The hybrid shaft generator drive is able to convert the shore supply frequency to match the ship's 60 Hz power system. The HSG can also synchronise against the power grid to avoid "black out" during changeover. There is no need to run any of the auxiliary gen sets, which will save fuel and reduce emissions. In addition, noise and vibration levels on board are reduced to a minimum.

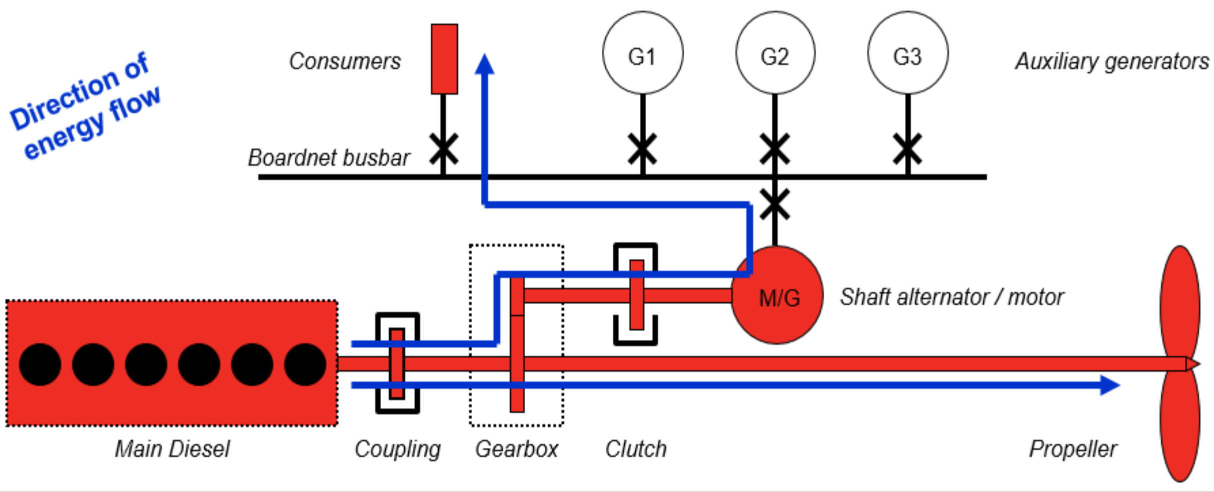
POWER TAKE OUT (PTO) / POWER TAKE IN (PTI) / POWER TAKE HOME (PTH)

Marine shaft generators are often required to operate in a multi-function role. They could operate as an alternator to provide the vessels primary electrical power supply. This is the conventional use of an alternator for Power Take Out (PTO). They could operate as an electric motor to provide a short/medium term power boost alongside the propulsion engine. This is known as Power Take In (PTI). Alternatively, the shaft generator could operate as an independent method of propulsion, when the main engine is out of commission. This is normally a very short term or emergency use known as Power Take Home (PTH). The following drawing shows a typical ship's arrangement and layout of a shaft electrical machine.



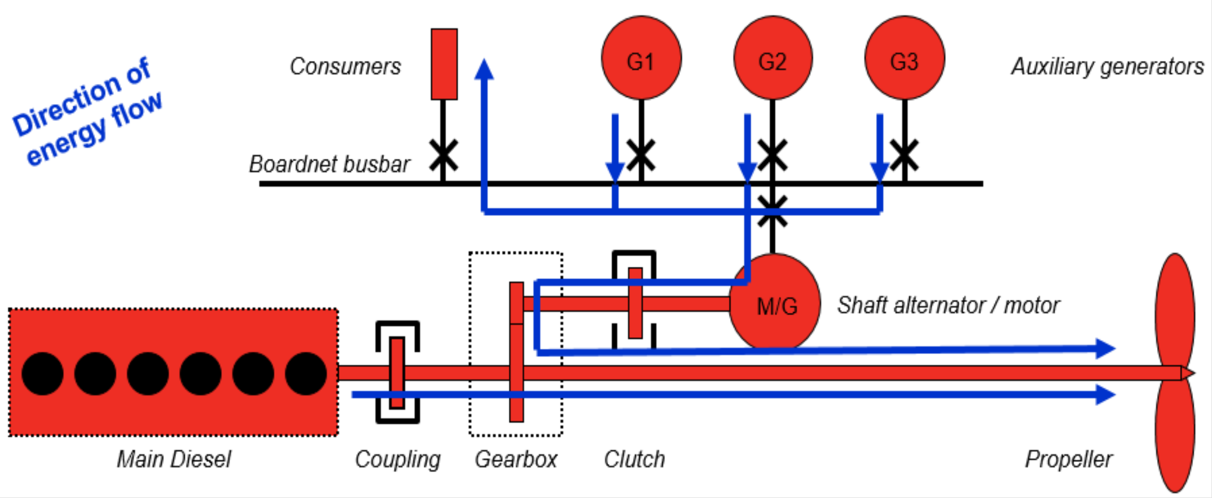
PTO (Power Take Out) mode of operation

The shaft generator is operating as an alternator, driven from the main propulsion engine, providing the primary power supply for the vessel electrical systems. The following drawing shows a typical PTO layout with power flow direction.



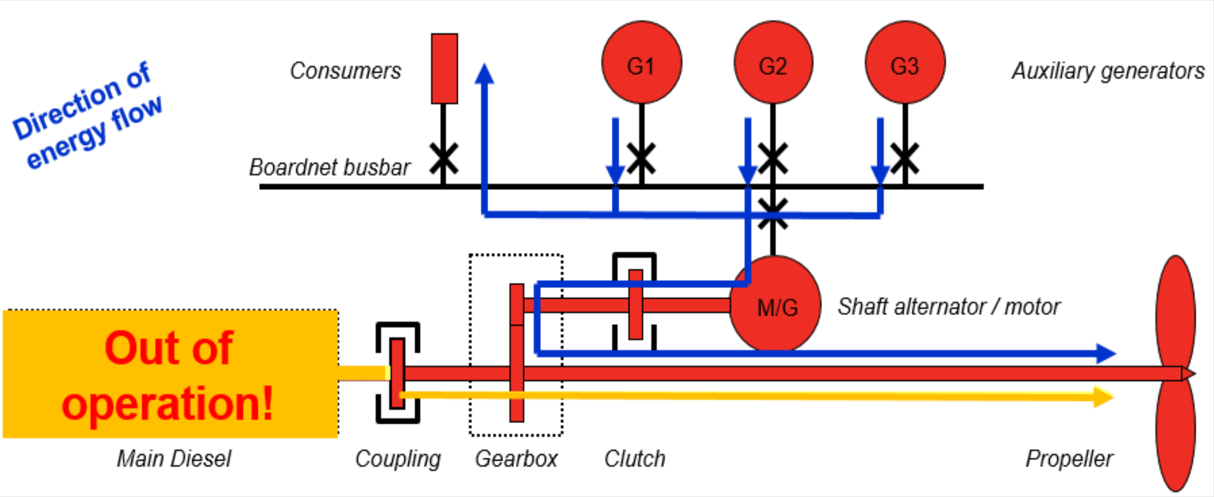
PTI (Power Take In) mode of operation

In this mode of operation, the shaft generator is operating as a synchronous motor (electrical power being supplied by the vessels auxiliary diesel generator sets). It can either provide a boost in power, working alongside the main engine to increase vessel speed, or it allows the main engine to reduce power, thereby lowering fuel consumption and wear on the main engine. In this PTI mode of operation, the shaft generator does not require a self-starting capability, because under normal circumstances, it will already be spinning as an alternator before switching over to motor mode. The following drawing shows a typical PTI layout with power flow direction.



PTH (Power Take Home) mode of operation

As with PTI, the shaft generator is operating as a synchronous motor in this mode of operation. However, this time it is providing 100% of the ship's propulsion power. In emergency situations, this could be due to failure of the main engine or the main engine requiring critical, unplanned maintenance. In other cases, this can be a normal mode of operation. Occurrences such as the main engine requiring routine maintenance or the main engine being stopped when the ship is entering port. Unlike PTI mode, in this mode of operation, the shaft generator needs to have a self-starting capability to run up as a motor from zero speed. The following drawing shows the layout of a typical PTH application with power flow direction.



Self-Starting Methods for PTH

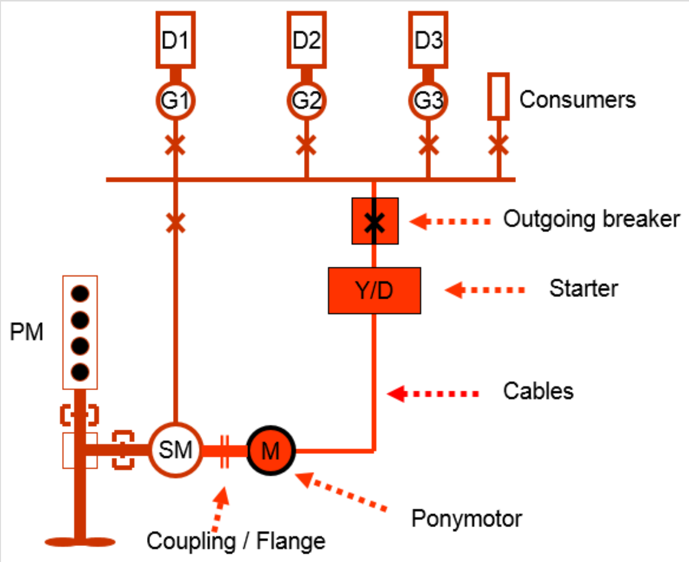
In many cases the PTH mode of operation is required comparatively few times during the lifespan of the shaft generator. Therefore, primarily for reasons of cost, an alternator is adopted for use as a motor and so will not have the inbuilt robust rotor design (particularly the damper cage) and excitation system needed to generate the necessary torque for starting from zero shaft speed, when compared to a designated synchronous motor. Consequently, a method of soft-starting has to be applied to the shaft generator during start up and in the case of AvK products, some modifications to the machine are also necessary.

Due consideration must be afforded by the ship's design engineers to the paralleling of the shaft generators with the ship's electrical system, ensuring voltage, phase and frequency is matching. Once the machine is paralleled and now running as a motor, the excitation system needs to be controlled to enable it to develop sufficient torque and power to drive the gearbox and therefore, the propeller.

There are a number of different methods that can be employed for starting the shaft generator when it is used in PTH mode as a motor. STAMFORD alternators are not suitable for PTH operation. This Application Guidance Note continues to describe five of the most well-known solutions; however, Cummins Generator Technologies do not offer any of these five motor starting methods on AvK alternators.

1. Pony Motor Start

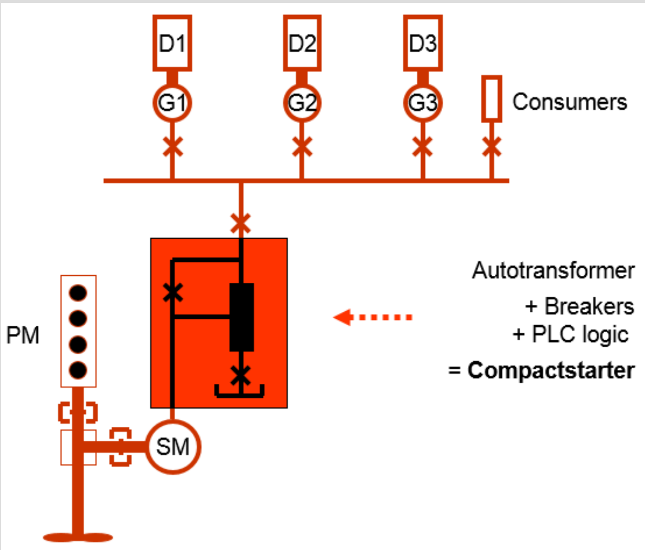
The shaft of the electrical machine (shaft generator) is physically connected and driven up to speed by an additional (smaller) electric motor, which will then disengage once synchronous speed is achieved. The following drawing shows a typical arrangement and the equipment needed.



The starter for the pony motor could be Star/Delta, Electronic Soft Starter, Autotransformer or Inverter/VFD, fed by the auxiliary generators G1, G2, G3 as shown.

2. Auto-Transformer Start

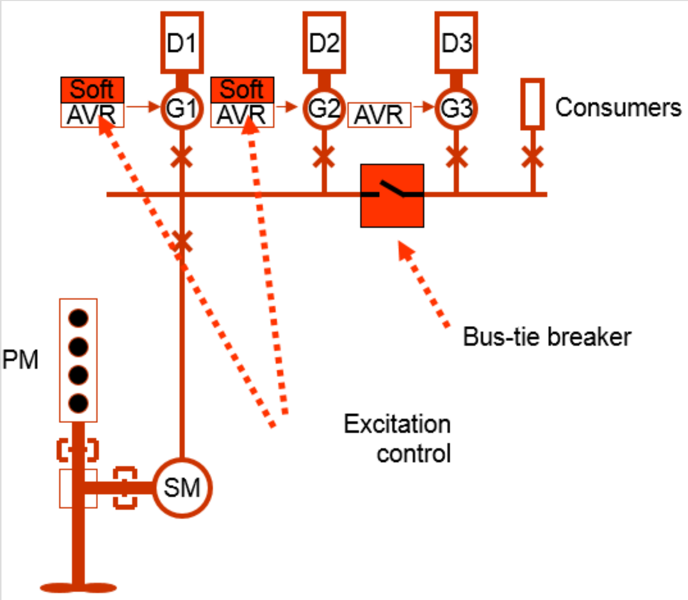
An auto-transformer is used to reduce the voltage level supplied to the shaft generator main terminals, thereby restricting the inrush current to acceptable levels. However, it is important to ensure that sufficient inrush current is provided to produce the necessary breakaway torque to turn the shaft generator's shaft. This current level is best determined during the commissioning process on-board the vessel. The following drawing shows a typical arrangement and the equipment needed.



The shaft generator is started as an asynchronous motor with this method and therefore, requires some modifications to the excitation system of the machine. These modifications are explained later on in this AGN.

3. Excitation controlled start (single propeller)

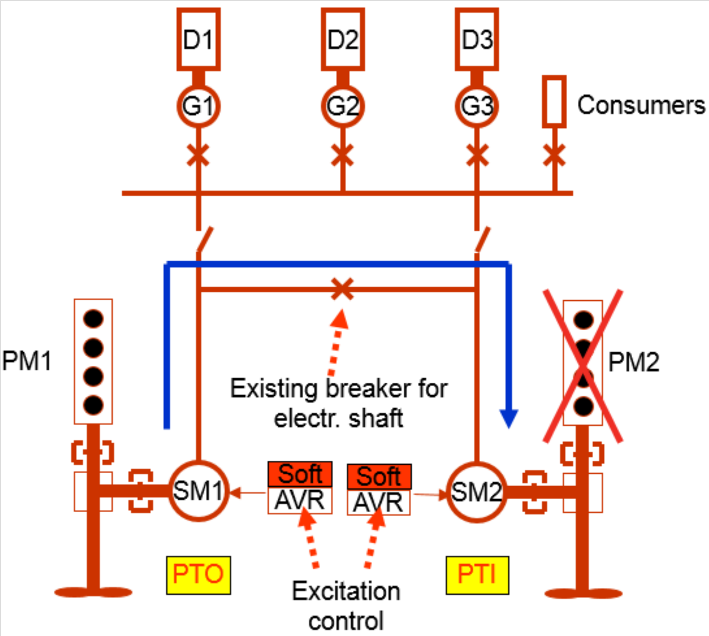
There are two systems to consider with regard to excitation controlled starting; single propeller system and twin propeller system. In this case, the inrush current can be limited by using a Stator Current limiting feature on the AVR's of the auxiliary generators. However, in order to isolate the vessel's consumers during machine start up, the main bus requires a tie breaker to avoid any risk of under voltage interference with consumer equipment. The following drawing shows a typical arrangement and the equipment needed.



As with the Auto-Transformer Start described in Option 2, the machine is started asynchronously and so requires some excitation system modifications.

4. Excitation controlled start (twin propeller)

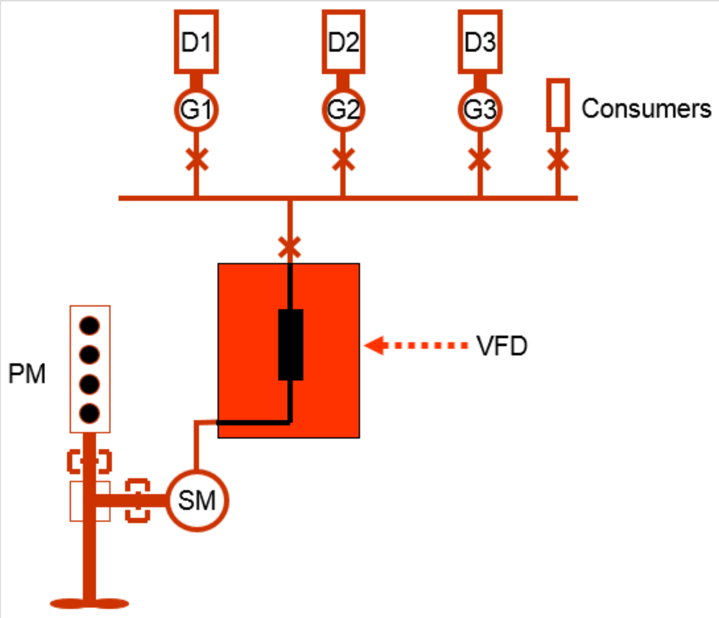
This scenario is very similar to that described in Option 3, above. However, this time the ship has twin propellers, twin main engines and two shaft machines. Instead of the Stator Current limiting capability being performed by the auxiliary generators, this time it is present on each shaft machine, allowing one shaft machine (operating in PTO mode) to start the second machine (operating in PTI/PTH mode). The consumers on board are completely isolated from both shaft machines during start up. The drawing on the next page shows a typical arrangement and the equipment needed.



With two identical shaft generators, it is possible to swap over the PTO and PTI/PTH modes of operation from one side to the other.

5. Variable Frequency Drive (VFD) Start

Here the shaft generator is controlled through a Variable Frequency Drive unit, which gradually rotates the generator shaft, ensuring the current is limited but the correct amount of shaft torque is delivered, until synchronous speed is achieved. The shaft generator can be started as a synchronous motor. The following drawing shows a typical arrangement and the equipment needed.



This system can also be applied to twin propeller vessels