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Fuel Saving and Reduction of Environmental Emissions in OSV and AHTS by use of Electric and Hybrid Propulsion

Alf Kåre Ådnanes, Dr. Ing., MScEE

ABB AS, Business Unit Marine,
2 Ayer Rajah Crescent, Singapore

ABSTRACT

Electric Propulsion is used in a wide range of vessel types and applications. In Offshore Support Vessel (OSV) segment, a large portion of new buildings are equipped with electric power plant with variable speed electric motors to control the main propulsion and thrusters.

These days we also see a tendency that advanced Anchor Handling Tug Supply (AHTS) beeing more and more equipped with a combination of Diesel Mechanical and Diesel Electric propulsion (HYBRID) because economical analysis shows that potential operational benefits over the vessels life time are even higher than for Platform Supply Vessels (PSV). During the last years, the focus and restriction on environmental emissions has been, and is further expected to be strengthened. The use of electric propulsion will also contribute to reduction of green house gases due to the lower fuel consumption. New techniques for control and power conversion are made to further improve the environmental footprint of the vessels, such as the use of active rectifiers in low voltage installations

Electric propulsion can prove substantial savings in fuel costs and this will hopefully stimulate the oil industry to select the most optimum and innovative solution, and thereby also reduce the environmental impact for offshore operations.

INTRODUCTION

Since mid 1990's, OSVs have been equipped with electric propulsion /1/, Fig. 1, where the main propulsors and station keeping thrusters have been driven by variable speed electric motor drives, being supplied from the common ship electric power plant with constant frequency and voltage. Thrusters and propulsors are normally of fixed pitch propeller design (FPP) that reduces the mechanical complexity of the units, and the electric power is normally supplied from fixed speed combustion engines; diesel, gas, or dual fuel.

The electric propulsion has shown to give a significant benefit of reduced fuel consumption and environmental emissions from the fleet of PSV's and also in other ship types in the fleet of offshore support vessels with typically 15-25% savings depending on the operation profile, and 40-50% in DP operations. Electric propulsion has become the primary choice of vessel designs in many of the offshore oil and gas fields, including the North Sea and Brazil, and increasingly being specified by oil companies in new areas in order to reduce the operational costs and emissions.

With the proven fuel saving in the PSV application, it is yet some kind of paradox that the large fleet of anchor handling vessels, mainly are designed with direct mechanic propulsion system; even though the same effects that contributes to the fuel savings in the PSV vessels, are also existing and even to a larger extent in anchor handling, tug, and support vessels (AHTS). The reason for this is mainly due to the higher investment costs, which must be paid back through the day rates of the charters. If the charterer is not willing to differentiate the pricing between vessels with high and low fuel consumption, and just pick up the bill for fuel and environmental emissions, ship owners will not have many other options than to go for the cheapest solution in order to be competitive; even though knowing that this is not the optimal solution with regards to life cycle costs.

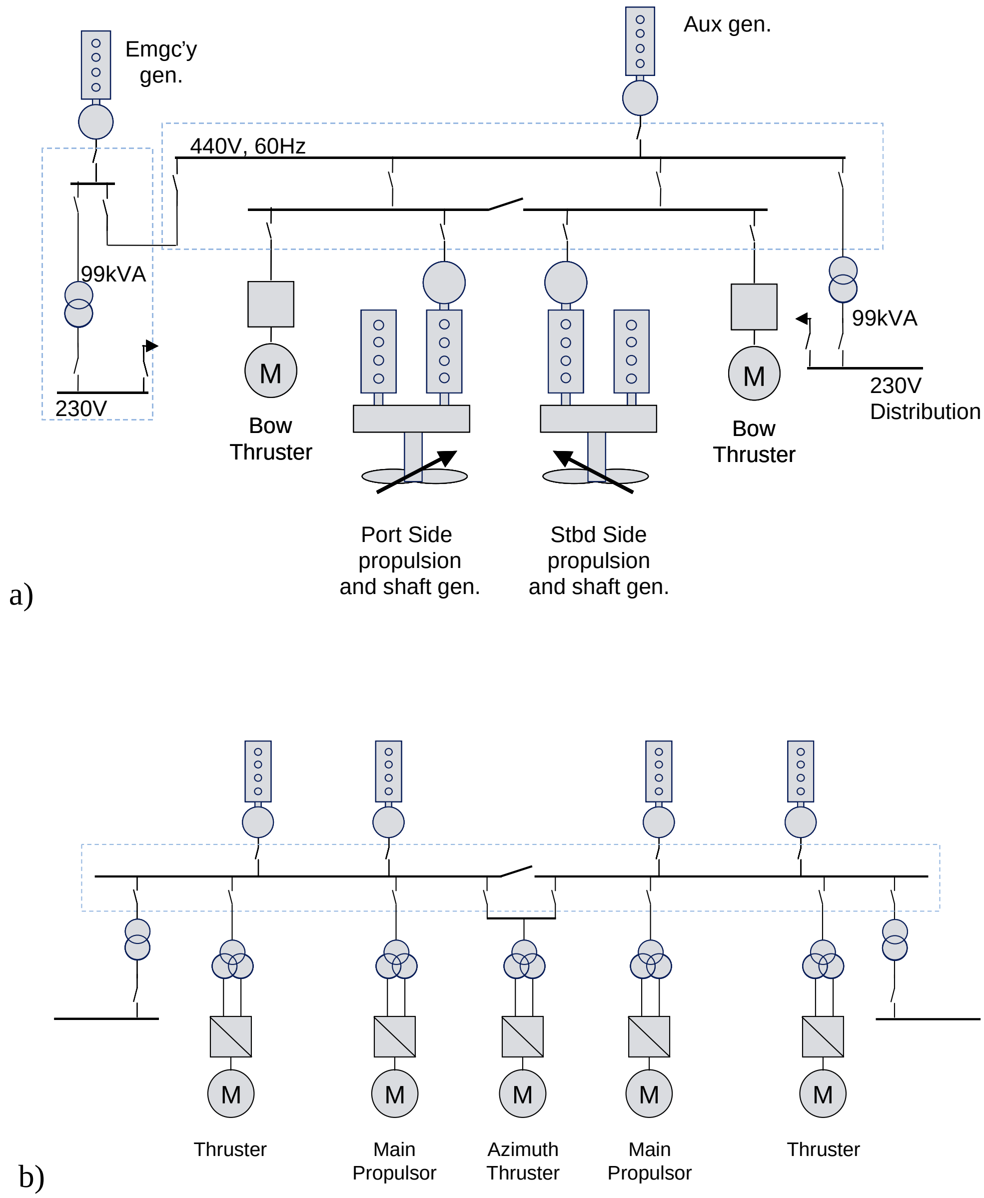

Fig. 1: a) Conventional direct mechanical propulsion, and b) electric propulsion concept for OSV.

THE ENVIRONMENTAL CHALLENGE

Not many years ago, the environmental aspect was rather absent in the marine industry. In the global agreements on green house gases, the marine industry has “been lucky” not been involved in the balance sheet and limitations of emissions. But this is changing.

Not only is the industry themselves now a driver for fuel reduction, as it has a clear economical benefit too, but also the society will not allow the marine industry to be unaffected of the common environmental challenges.

So far, IMO and legislative restrictions have mainly been made on NO_x, SO_x, and particle emissions, which are local or regional concerns, but severe enough for the affected areas. It is though clear signs, that also CO_2 emissions from the marine industry will be included in the coming global greenhouse gas reduction agreements.

While waiting for the regulations to come, it is worth to notice, that fuel saving and emission reduction is cost saving already today. Studies, as /2/, shows that there are a ample amounts of measures that can efficiently reduce the fuel consumption and emissions with profitable payback with today’s fuel prices. It is therefore not only an issue of technological development, but also a need to further increase the awareness in the industry, and ensure that the one who pays for the initial investment, also directly gets the benefit of cost saving.

VARIABLE SPEED DRIVES FOR ELECTRIC PROPULSION

The variable speed drive (VSD) for propulsors and thrusters is one of the most essential components in a power plant for electric propulsion.

The VSD consists of:

- Electric motor, normally asynchronous (induction) motors, but also synchronous motors for the high power range. Other types of motors used in special applications; such as permanent magnet motors and DC motors.
- Frequency converter, converting the fixed voltage and frequency of the network to a variable voltage and frequency needed to adjust the speed of the electric motor.
- Optionally line filters or transformers, depending on configuration for reducing the harmonic distortion of currents flowing into the network and voltage adjustment where applicable.
- A control system, consisting typically of a motor controller and an application controller for the propulsion / thruster control, taking care of the control functions as well as monitoring and protection of the VSD.

For the power level needed for OSV propulsion, the Voltage Source Inverter (VSI), Fig. 2, is the dominating topology of frequency converters and used by most suppliers to this market. DC drives, Current Source Inverters (CSI) and Cycloconverters are rarely used and being phased out from new buildings of OSVs. Therefore, this paper only considers the VSI in various configurations.

The voltage source inverter consists of a rectifier, a DC link with voltage smoothing capacitors, and an inverter unit as the main components. The DC link may where required be equipped with a breaking chopper to dissipate wind-milling power from the propeller in rapid speed variations or in crash stop conditions of the vessel.

As the propulsors and thrusters are driven with electric power, they are essentially decoupled from the power source, which can in principle be anything that produces electric power. This opens for the use of new power sources, but also for flexibility in adapting to new sources that should be available in the future, throughout the life time of the vessel.

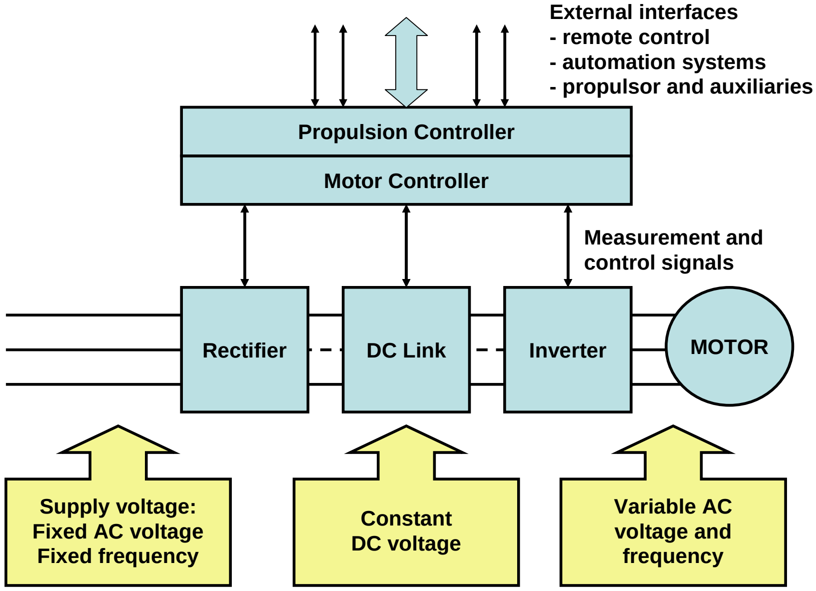

Fig. 2: The basic modules for a Voltage Source Inverter (VSI).

SYSTEM CONFIGURATIONS FOR ELECTRIC PROPULSION

As previously shown, the basic topologies for the VSD are relatively similar among the various suppliers to the application of electrical propulsion.

From a ship application perspective, one of the main technical differences are related to how these products are put together in a system configuration for electric power generation, distribution, and propulsion / station keeping. Several system configurations are applied, of which the most common ones are shown in Fig. 4. For each main configuration, there may be several variants for optimization to the actual requirements for each vessel.

The main challenge in system design is to meet the class requirements and ship specific requirements at a minimum total cost including equipment and installation costs, and with a best possible life cycle economy. Each vessel may have its own specific requirements, e.g. whether space is a scarce resource or not in the design. Propulsion transformers are large and heavy equipment, and the 6-pulse, active rectifier, and the Q12-pulse with phase shifted main voltages are examples on “transformer-less” solutions, but not without other penalties.

The 6-pulse and Q12-pulse solutions normally will require some kind of harmonic filter installations, unless significant restrictions and constraints of operations shall be applied, which may cause deterioration of the fuel economy of the prime movers and limitations of operational windows for the vessel. The Q12-pulse solution in particular depends on a complex main switchboard with two feeders to each frequency converter for balanced loads that is a necessity for maximum performance. Each feeder will carry a 6-pulse current that to some extent will enter the respective generators on the switchboard, or flow through the two primary sides of the distribution transformers, and give additional losses that to some extent will counteract the benefits of avoiding the losses in the drives transformer.

The active rectifiers increase the number of active components in the installation, and the complexity of the installation as each of the rectifiers requires a HF harmonic filter that introduces resonance modes of the installations that should not be excited by the switching frequency of the rectifier. Also, the size and costs of the frequency converter itself will increase, as well as the power losses in the rectifier, counteracting at least partly the benefits of the transformer-less design.

Hence, there exists no one “ideal” design for all vessels. The different solutions have different characteristics, and only when considering the requirements and limitations for a vessel design, the best solution can be applied.

HYBRID CONFIGURATIONS

An alternative to the full electric solution is the combination of mechanical and electric propulsion systems, the so-called hybrid propulsion, Fig. 5. Here, the vessel can be operated in either;

- Full electric propulsion, for low speed maneuvering, transit, and DP
- Full mechanic propulsion, for tugging and high speed transit
- Hybrid (combined) electric and mechanic propulsion, where electrical equipment can be used as booster for the mechanical propulsion system, used to obtain maximum bollard pull.

In terms of installation costs, such hybrid solutions will be cheaper than pure electric solutions, and will in fuel cost calculations be quite similar in fuel consumption to the electric solution. Therefore, several of the new AHTS designs are based on such hybrid solutions, especially for AHTS vessels with high bollard pull.

However, one should not disregard the increased mechanical complexity of such hybrid systems, where it is required that the crew more actively and manually selects operational modes optimal for the conditions. In pure electric propulsion systems, it is much easier to automatically optimize the configuration of the power and propulsion plant, ensuring that the system always will operate closest possible to optimal conditions without or with reduced manual interactions.

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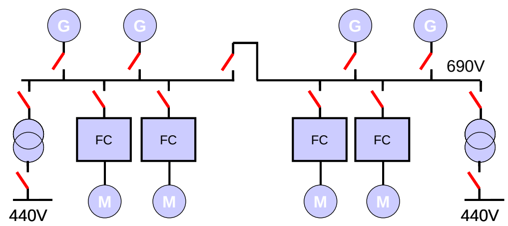
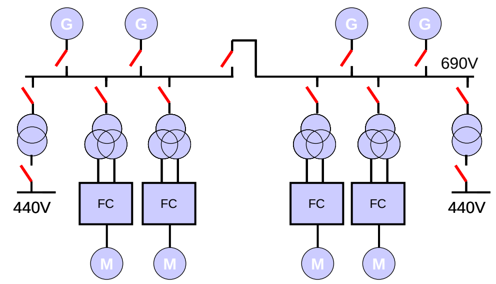
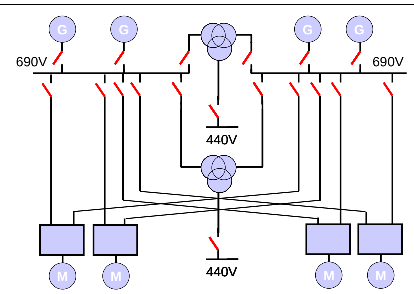
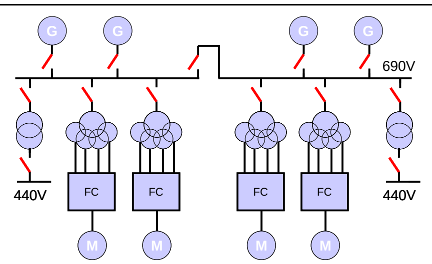
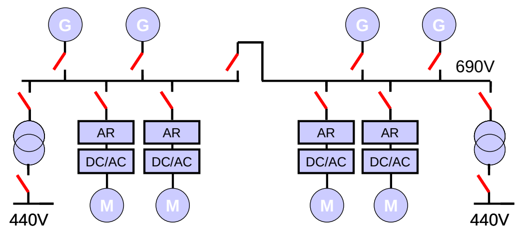
<tr><td>
</td><td>6-pulse:
• No drive transformers
• Harmonic filters needed to get THD<5%
• Weight: Low
• Footprint: Low
• Operational constraints: Medium
• Total efficiency: Approx: 90-91%</td></tr>
<tr><td>
</td><td>12- and quasi 24-pulse
• 3-winding transformers, phase shift for Q24
• Harmonic filters for 12-pulse, not Q24
• Weight: High
• Footprint: High
• Operational constraints: Low/medium
• Total efficiency: Approx: 90%</td></tr>
<tr><td>
</td><td>Quasi 12-pulse with phase shifted mains voltages /5/:
• No drive transformers, oversized distribution transformers for power transfer
• Weight: Medium
• Footprint: Medium
• Operational constraints: High
• Total efficiency: Approx: 90% included harmonic losses in generators and distribution transformer</td></tr>
<tr><td>
</td><td>24-pulse:
• 5-winding transformers (or 2 x 3-winding)
• No harmonic filters
• Weight: High
• Footprint: High
• Operational constraints: Low
• Total efficiency: Approx: 90%</td></tr>
<tr><td>
</td><td>Active rectifiers:
• No drive transformers
• High frequency input filters for harmonics
• Weight: Low
• Footprint: Medium
• Operational constraints: Low / Medium
• Total efficiency: Approx: 90-91%</td></tr>
<tr><td>Glossary:</td><td>690V: Main switchboard voltage
440V: Main distribution voltage
G: Generator
M: Motor (Propulsors and thrusters)
FC: Frequency Converter
AR: Active Rectifier
DC/AC: Inverter</td></tr>
</table>

Fig. 4: Alternative system configurations with main characteristics. 690V Main SWBD voltage is shown, high voltage, e.g. 6.6kV is used when generator capacity typically exceeds about 10MW.

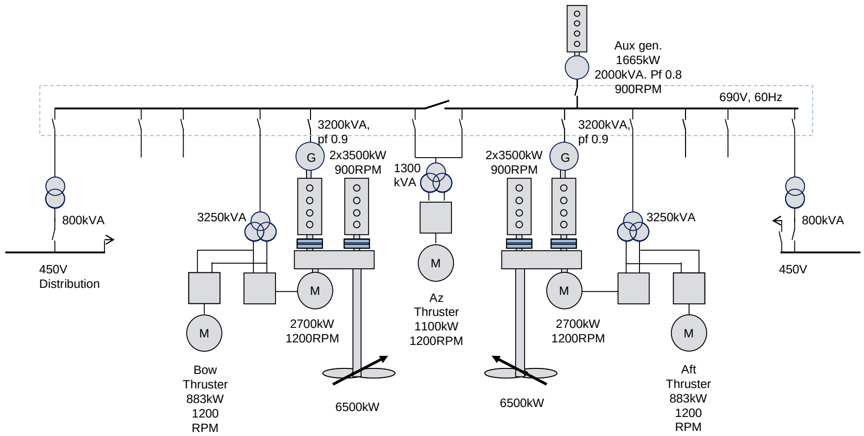


Fig. 5: Hybrid electric and mechanical propulsion for 200+ metric ton AHTS.

A NEW ELECTRIC POWER SOURCE INTERFACE

The electric power sources, i.e. the generators, produces 60Hz (or 50) at a standard voltage of typically 450 or 480V, 690V, and in larger installations, 6.6kV or 11kV. This is based on traditional design, where standard industrial components have been applied.

But with the use of electric propulsion system and frequency converters, that nevertheless transfer the majority of the electric power, it is not necessarily the optimal interface for the electric power source. This could equally well be a variable frequency, or voltage, or fixed DC voltages. We can call it the "EPSI"; the electric power source interface.

In ship applications, typically 80% or more of the generated power is rectified already in order to control the speed of the propulsion motors and thrusters. Why not then redefine the EPSI to a new standard that better suits the frequency converters, such as DC; e.g. 1000VDC or 4500VDC.

An example of a configuration where a DC voltage is used as the EPSI; and with the potential to connect multiple power sources into the grid with very different characteristics and control dynamics is shown in Fig 6.. This is yet not a solution available today, as there are certain issues regarding selectivity and fault tolerance in the DC distribution that needs to be clarified with class societies. The configuration, though, has a lot of advantages, such as higher efficiency, flexibility for future power sources, and fewer single points of failures (except the DC distribution).

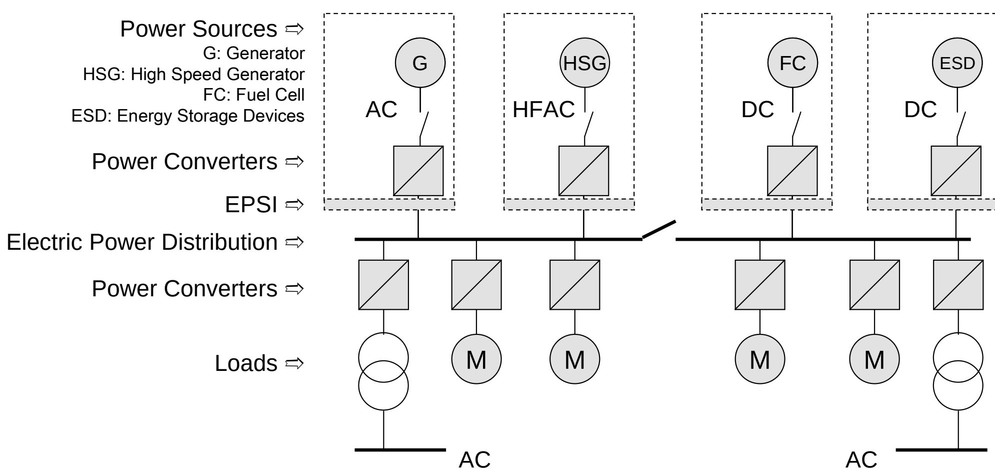


Fig. 6: Future: Defining a new standard for electric power source interface (EPSI); e.g. 1000V or 4500V DC; simplifies the use of multiple power sources and decouple the control and basic electric characteristics of them.

HARMONIC MITIGATION

Frequency converters are inherently non-linear components due to the switching characteristics of the rectifier components, meaning that they do not draw sinusoidal currents from the network, even though being fed by sinusoidal voltages.

The non-sinusoidal currents into the rectifier consist of a fundamental voltage, and a series of harmonic components with a wide content of frequencies which depends on the rectifier type and system configuration. For the type of converters that have the highest level of distortion in the currents, typically those with 6-pulse, 12-pulse, and Q12-pulse rectifiers, the level of harmonic distortion in the currents may lead to voltage distortion above the class limits. Most class societies now have adapted the IEC 60092-101 requirement,.

When the limit of the applicable regulation will be exceeded with the decided frequency converter and system configuration also after optimizing the design of the generators and transformers in the plant, there are still several ways to manage the harmonic distortion level.

A harmonic filter can be applied. There are two main different types for harmonic filters; passive LC filters (alternatively damped LCR) and active filters /1/. For ship applications, passive filters are more commonly applied, due to their lower costs; especially since they can be used at lower voltage levels in the distribution system to filter the voltage distortion not necessarily in the complete installation, but for the sensitive equipment only.

ACTIVE RECTIFIERS

Active rectifiers are primarily used for three purposes;

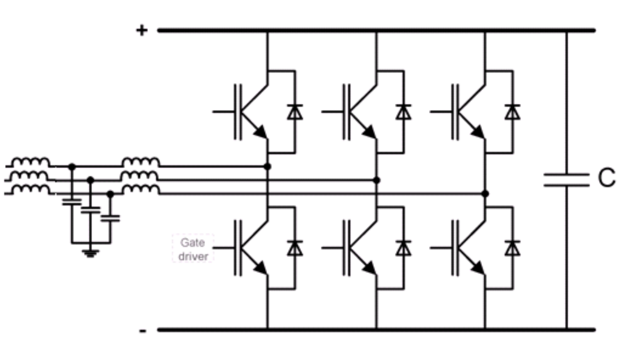
- Feeding power back to the network
- Reducing network voltage distortion
- Reducing weight and footprint compared to standard and multi-pulse drive systems; this has been the main driver for installation of active rectifiers in ship applications.

Active rectifiers have been widely used in industrial applications for several years, but not as much in ship systems as there have been some concerns on using rectifiers that can feed power and noise back to a relatively weak network on board the vessel. However, the latest years, active rectifiers have been more used also in ship applications, both for thrusters and propulsors, as well as various auxiliary systems.

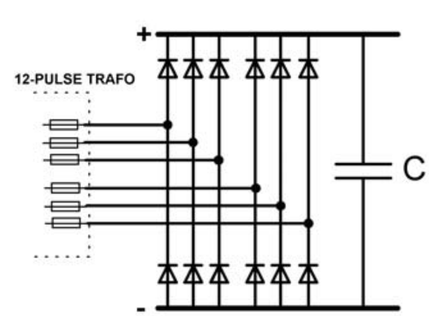
It should be noted and carefully considered, though, that the use of active rectifiers in weak networks, e.g. ship applications, requires special attention to system engineering.

In the active rectifier, Fig 7 a), the actively controlled IGBTs are shown, in contrast to the passive rectifiers with uncontrolled diodes in Fig 7 b). The IGBTs are used to control the network current to nearly sinusoidal; not that the LCL filter is required to filter out the switching harmonics in the input current, and that therefore the active rectifiers are not without the use of harmonic filters, however, the filters are normally integrated in the drive line-up and hence not so visible for yard and owner.

For the system integrator, this is essential to consider, as these filters may have resonance points in the high frequency areas, but also in the lower frequency spectrum that can be cumbersome to handle should there be passive rectifiers in the same network, which normally is the case.



a)



b)

Fig. 7: a) Active (IGBT) rectifier. b) Passive (diode) rectifier.

CONCLUDING REMARKS

In design of PSV, electric propulsion has become the new standard.

Although the same characteristics, with even higher potentials for saving, are present in AHTS vessels, still the majority of AHTS are made with conventional propulsion. This is mainly due to the lack of awareness of that the one party paying for installation, is not liable for fuel costs, and vice versa. This leads to non-optimal solutions, with higher fuel consumption and more environmental emissions than necessary.

New configurations are available; hybrid designs are used for reducing the difference in investment costs and make more flexibility in operations, although also more complicated for operation; and active rectifiers are used to reduce the footprint of the electric equipment.

This paper has presented the most commonly applied solutions in electric propulsion with the objective to give the decision makers background information to better understand the concepts and to make the most beneficial selection for the specific vessel's requirements; and hopefully contributed to a higher awareness of the environmental impact of the use of vessels. Further, that there not necessarily is a contradiction between economy and environmental awareness – fuel saving is both cost reduction and environmental beneficial.

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