Reduction of fuel consumption and environmental footprint for ships, using electric or hybrid propulsion

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The use of electric propulsion in certain ship segments, such as platform supply vessels should be well known. The technologies develop continuously, and today there are several approaches to reach the "optimal design" that reduces fuel consumption and environmental footprint, simplifies design and construction with better utilization of the on-board space, and creates a better working environment for the crew. Reduction in fuel consumption and the reduced operational costs have been the driving forces for this development; and the economical benefits have shown to be significant. For no rational reasons, less attention has been paid to electric propulsion of anchor handlers, although we see a change also in this segment. This paper presents typical electrical and hybrid propulsion systems in use in offshore support vessels, and methods to assess the life cycle effects on fuel consumption and environmental footprint.

KEY WORDS

Electric; propulsion; OSV; AHTS; fuel; emissions; LCC.

NOMENCLATURE

AHTS: Anchor Handling, Tug, and Support vessels
CPP: Controllable Pitch Propellers
DP: Dynamic Positioning
DTC: Direct Torque Control®
FOC: Fuel Oil Consumption
FPP: Fixed Pitch Propellers
GCT: Gate Controlled Thyristor
HF: High Frequency
IGBT: Insulated Gate Bipolar Transistor
IGCT: Integrated Gate Controlled Thyristor
OSV: Offshore Support Vessels (general term for a range of vessel types for offshore support)
PSV: Platform Support Vessels
PWM: Pulse Width Modulation
RPM: Revolutions per Minute
sFOC: Specific Fuel Oil Consumption
THD_i: Total Harmonic Distortion of current (%)
THD_u: Total Harmonic Distortion of voltage (%)
VSD: Variable Speed (electric) Drive

INTRODUCTION

Since mid 1990's, OSVs have been equipped with electric propulsion, 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.

During this period, there has been a continuous development of solutions for the electric power plant for vessels with electric propulsion. The evolution of concepts, where the building blocks of the electric plant is adapted from the general industry applications, which has a far bigger volume of installations than the marine applications and to a large extent gives the premises for basic technology developments /5/.

Even though the suppliers of electric power and propulsion plants utilize building blocks that are based on principally the same fundamental concepts, there is a range of different configurations and preferences in the market. As the technical arguments for the concept appears to be biased and naturally to some extent influenced by a driving force to pursue a sales, it is necessary for ship owners, yards, and designers to be able to evaluate and compare this information to make the decision.

Common for all configurations, it is claimed and proven that electric propulsion will give substantial fuel reduction compared to direct mechanical propulsion for offshore support vessels. The fuel savings are shown to be in the range of 15-25% in typical operation profiles, and even up to 40%-50% in pure DP operations.

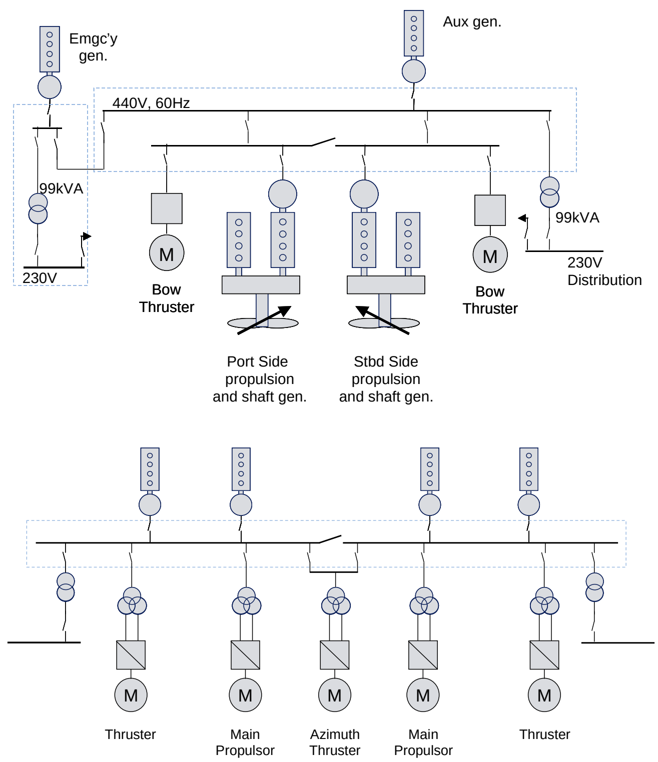


Fig. 1: Top: Conventional direct mechanical propulsion
Bottom: Electric propulsion concept for OSV

CRITERIA FOR TECHNOLOGICAL DEVELOPMENT

For many engineers, researchers, and developers, working with technology gives the daily bread and butter. Technology development is both challenging and interesting for those involved, as well as essential for the continuous improvement of the vessel's earnings and safety.

In evaluation of concepts, the overall performance and characteristics should be assessed rather than the individual component. The advantages of e.g. an efficiency improvement in one component may make no sense if it requires a non-optimal operation of the prime movers in order to function as intended. Utilizing fast changing technologies to obtain some improvement is normal in consumer industry, but in a life cycle assessment of a vessel, it may be painful if that particular technology is obsolete and unavailable after few years.

The driving forces for technology development and assessment should be based on the effects and results of the technologies. Generally; the following criterion will be important for the comparison of products, systems, and services, although their weighting and importance may vary over time and between various applications:

- Cost efficient building and installation
- Flexibility in design that improves ship utilization
- High safety for crew
- High safety for operations
- Continuous availability to propulsion and station keeping systems
- Reduced fuel consumption
- Reduced impact on the external environment, lower emissions
- Improved working environment for the crew
- Low maintenance costs
- Availability to maintenance during the life cycle of the ship
- Availability to maintenance in the region of operation, often world-wide
- Spare parts availability
- Remote and on-board support
- Minimizing constraints of operations leading to non-optimal performance
- Reduce negative consequences for other equipment
- High ice braking and ice management performance for ice breakers

VARIABLE SPEED DRIVES

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

It 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.

The motor controller technology has developed from the scalar U/f control system used since the earliest variable speed AC drives. Field oriented control of AC motors was developed already in the 60's but did not establish as an industrial standard before in the mid 80's when digital controllers with sufficient capacity and speed became commercially accepted. The introduction of field oriented control significantly improved performance and efficiency of the VSD, however, the control method was still sensitive to the motor parameters and time variations. A new method of vector control that was based on stator flux oriented control and direct torque control of the motor was developed around 1990, and was first introduced in large scale commercial drives production in the early 90's by ABB under the name of DTC™. DTC enables ultra fast control of the torque of the motors, with a robust algorithm that gives high controllability and efficiency with much less sensitivity to variations in motor parameters than the traditional field oriented control. As will be discussed later; the dynamic performance of propulsors and thrusters for OSV is much lower than what the modern VSD may perform, with exception of the need for fast black-out prevention where each fraction of a second is essential.

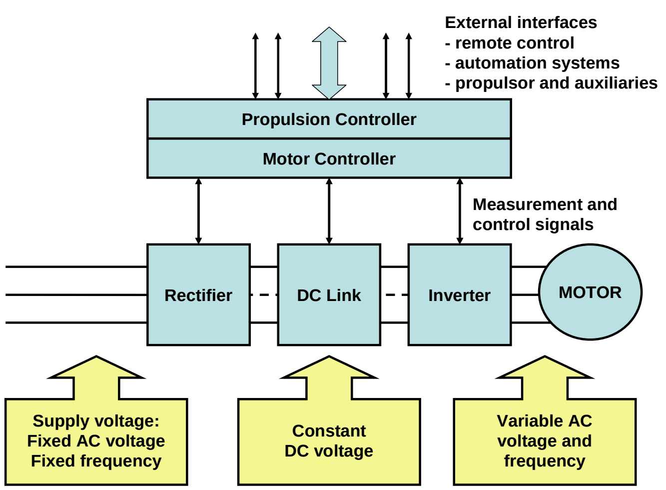


Fig. 2: The basic modules for a Voltage Source Inverter (VSI).

The key component in the frequency converter is the power semiconductor. Because of the high power, the semiconductors will only operate in the active mode in the transition between being fully off (closed) state and fully on (open) state in order to minimize the power losses.

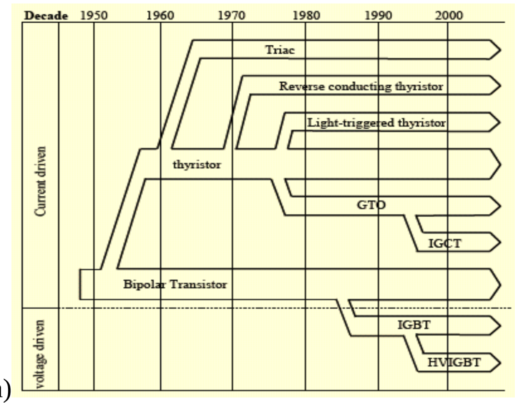
In VSI frequency converters, the components used are either passive components (diodes) or active switching components. Thyristors are only applied in special cases e.g. in configurations where it is a need to control the DC link voltage or for soft charging of the DC link, and in some cases for regeneration of power.

Power semiconductors are made for low voltage applications, i.e. system voltages up to 690V between the phases, and for high voltage applications, >1000V system voltage. Depending on configuration, typical voltage levels are 3-3.3kV and 6-6.6kV line-line voltages for high voltage frequency converters.

The IGBT (Insulated Gate Bipolar Transistor) is the dominating power semiconductor for low voltage applications and being used by all major suppliers of frequency converters. The low voltage IGBT is normally mounted in compound modules, as shown in Fig. 3(b). Each module may consist of several IGBT switching components, in parallel or separately controlled, together with free-wheeling diodes for reverse currents through the switching elements.

For high voltage frequency converters, the GTO (Gate Turn Off) thyristor was for long times used as switching component. In high voltage converters these are used as discrete switching elements with one silicon wafer being installed in press pack (hockey-puck) housing. The GTO is of a robust design, and a highly reliable component itself, although it required a number of auxiliary components to achieve the robustness in operation, and these auxiliary components got quite high stresses from the switching of the GTO. Hence, a further development of the GTO was made by ABB during the 90's where the basic concept of the GTO was improved to reduce the need for auxiliary components, and hence not only increase the overall reliability but also reduce the power losses in the overall system. This new component is called GCT (Gate Controlled Thyristor), and when integrated with its gate control system, IGCT (Integrated GCT). All ABB IGCTs are press-pack devices. They are pressed with a relatively high force onto heat-sinks which also serve as electrical contacts to the power terminals. The IGCT's turn-on/off control unit is an integral element of the component. It only requires an external power supply and its control functions are conveniently accessed through optical fiber connections. The IGCT is optimized for low conduction losses. Its typical turn-on/off switching frequency is in the range of 500 hertz. However, in contrast to the GTO, the upper switching frequency is only limited by operating thermal losses and the system's ability to remove this heat.

As the IGBT requires a simpler gate control device, with less power consumption, a large effort has been made to make them available for high voltage. The first IGBTs were of module design, and were not considered reliable enough for demanding propulsion applications. Since IGBTs are made with multiple parallel chips, there is a difficulty - with conventional presspacks - in assuring uniform pressure on all chips; a difficulty which increases with the number of devices in a stack. Today, IGBT in press pack are available from several makers, including ABB /2/, and mainly used in power transmission and static converters, although some makers have evaluated them stable enough to be used in variable speed drives for ship applications.



(a)

IGBT Low voltage	IGBT High voltage	GCT/IGCT High voltage
(b)	(c)	(d)

Fig. 3: (a) The development of power semiconductor switches /1/, (b) low voltage IGBT module, with integrated IGBT switches and freewheeling diodes, (c) press pack high voltage IGBT, and (d) press pack GCT/IGCT.

Fig. 5 shows the most common configurations for low voltage VSI frequency converters. The rectifier may be of different types, depending on the requirements for each installations and makers' preference;

- 6-pulse diode rectifier is the simplest design, with a full bridge passive rectifier – or several in parallel if necessary to achieve the desired power level. The AC supply voltage is rectified to form a DC voltage, of approximately 1.35 times supply line voltage at full load; i.e. a 690V supply gives approximately 930V DC link voltage at full load; depending on voltage drop and commutation impedance in the supply. The 6-pulse rectifier does not need any supply transformer unless necessary to adapt the voltage. Hence, size and weight is minimized. However, the harmonic distortion from the line currents is high – in the order of 25-25% THDi, resulting in a voltage distortion THDu of more than 10%. In order to achieve the limit as specified in IEC and which most classification society now has adapted of 5%, harmonic filtering or clean power supply is necessary. A harmonic filter at the distribution switchboard will reduce the distortion at this voltage level and below, but will hardly have any impact on the distortion at the main switchboard. The main switchboard must hence be designed to tolerate a high level of voltage and current distortion, and be documented accordingly as specified in class rules.
- 12- and quasi 24-pulse configurations looks similar with two paralleled diode rectifiers; but the quasi-24 pulse (Q24) VSD transformers are made in pairs of two and two with 15 deg phase shift between the two in each pair. Depending on load conditions in the prospected operation profile and system parameters, 12-pulse configuration may meet the requirements to voltage distortion by class. For most cases, however, the worst case conditions will lead to a THDu in the range of 6-8%, which is above the limit of most of classification societies without using harmonic filters. The Q24-pulse rectifier utilizes the same rectifier topology as the 12-pulse rectifier, but since the supply voltages are phase shifted through the supply transformers, the resulting distortion at the main switchboard is reduced. At ideal conditions, where the loads of the VSDs in each pair are equal, the harmonic distortion will be equivalent to a 24-pulse configuration. Under other conditions, a partial cancellation of the largest harmonic components will occur, and the harmonic distortion will in most installations be under the 5% THDu limit in any practical operation mode. Certain constraints in operation may be necessary in order to guarantee this; however, the Q24-pulse configuration is regarded to be a cost efficient way to meet class requirements for most OSVs.
- 24-pulse configurations consists of four paralleled 6-pulse rectifiers, each supplied from phase shifted voltages through one 5-winding transformer, or two paralleled 3-winding transformers. This configuration will normally always give distortion under the 5% limit, without constraints in operation. Normally, the transformer will be larger and more expensive than a 3-winding transformer of equivalent rating, and depending on the rating of the diode rectifiers, also the size and price of this may increase. The 18-pulse configuration utilizes the same concept, but with only three paralleled 6-pulse rectifiers and a 4-winding transformer. The THDu will also here normally be within the 5% limit, however, comparing to the 24-pulse topology, the total prize and size is at the same order due to a complex transformer design. 18-pulse rectifiers are therefore rarely in use today.
- Active rectifiers with switching elements have for some time been applied in demanding industrial applications, especially where the load characteristics requires regenerative braking to such an extent that it makes it beneficial to use this energy by feeding it back to the network. For propulsors and thrusters, the regenerative energy is normally negligible in a fuel and cost of energy assessment. However, since the rectifier consists of switching devices, the current can be shaped similarly to the motor current and with much lower distortion than the currents of a diode rectifier. Even though the classical harmonic filters then can be avoided without use of drive transformers, one should note that there are ample of harmonic voltages from the switching, with high frequencies and with a high level of electromagnetic noise that must be filtered with high frequency (HF) filters. There

is limited experience by use of active rectifiers in weak electric power systems as found on vessels, and in complex systems with many drives and a range of operating conditions, it is challenging to perform a complete system analysis of any modes and configurations in order to detect and avoid possible resonance effects from the numerous combination of paralleled HF filters. As the switching elements are more costly than diode rectifiers, the cost of the frequency converter increases, and its losses will also be higher; reducing the benefit of avoiding losses in the drive transformer.

The DC link, Fig. 5, consists of a DC capacitor, in order to smooth the DC link voltage to reduce the voltage ripple from the rectifier to an acceptable level for the output stage of the frequency converter, and to filter the high frequency distortion from the switching elements in the inverter and avoid that these are injected to the supply network.

If regenerative power is expected from the load, e.g. in crash stop conditions of shaft propellers, the power will be absorbed by the DC link causing voltage rise of the capacitors unless the power can be fed into the supply network by an active or regenerative rectifier, or dissipated in a load resistor bank. For thrusters and Azimuthing propulsors, regenerative voltage is seldom of a concern, as one may restrict these loads to only operate in motoring mode. In shaft line propulsion, or in Azimuthing propulsors where crash stop or equivalent to crash stop maneuvering is made by reversal of the propeller RPM, there are certain conditions where the propeller wind-milling effect may create reverse power; see Fig 4.

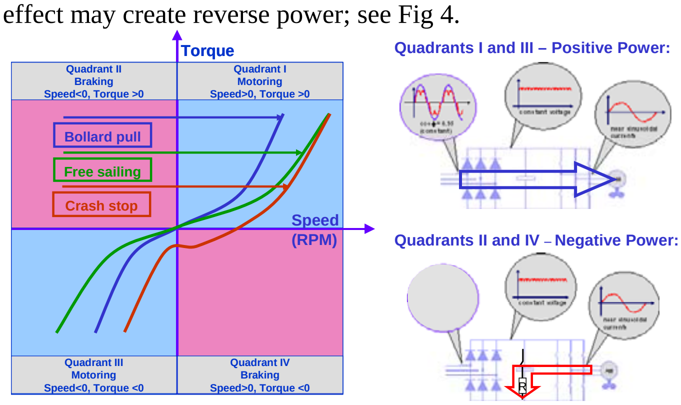


Fig. 4: Regenerative power from the propeller may occur when reversal of speed (RPM) is used in crash stop or equivalent to crash stop maneuvering, such as with shaft line propellers. Braking resistors may then be used to dissipate the regenerated energy, which normally is insignificant from an energy consumption perspective in electric propulsion.

The inverter module is normally a full bridge IGBT inverter in low voltage VSIs, Fig 5, with 6 IGBT switching elements each with an anti-parallel freewheeling diode for reversing the currents through the switches. The switching elements in each of the three legs of the inverter must operate in inverse mode, where one IGBT always is controlled off to avoid short circuiting the DC link. The objective of controlling the IGBTs is to feed a voltage vector to the stator winding that forces the currents and flux in the machine towards the targeted amplitude and phase angle. Depending on the control scheme, there are different ways to achieve this, such as field oriented control with PWM or hysteresis control, and direct torque control. The characteristics of these methods will be discussed later.

FUEL SAVING BY VARIABLE SPEED CONTROL OF FIXED PITCH PROPELLERS

The key characteristics of the electric propulsion that leads to reduced fuel consumption are:

- Variable speed control of the propeller, reducing no-load losses of the propellers to a minimum compared with classical fixed speed, controllable pitch propellers
- Automatic start and stop of diesel engines, ensuring that the load of the diesel engines are kept as close to their optimal operating point as possible within the limitation of operations /4/.

The classical design of an offshore support vessel, including the AHTS, is to use fixed speed propellers with controllable pitch. As shown in Fig. 6, this is compared to variable speed control of the propeller a very inefficient way of controlling the thrust, due to the high no-load losses of the fixed speed propellers. This alone, contributes to most of the savings in electric propulsion of offshore vessels. As also seen, the utilization of the thruster capacity in DP operations is very low for most of the operational days in the North Sea, even though this is regarded to be a harsh environment.

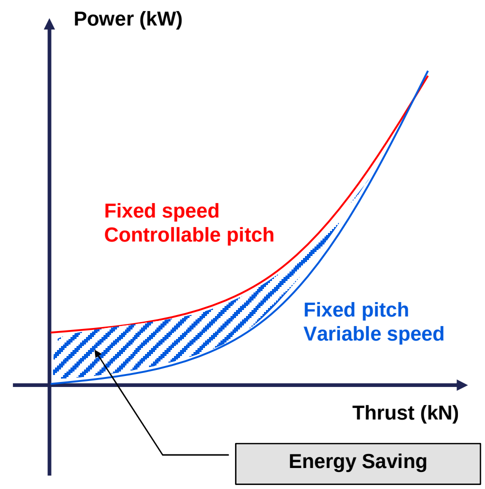


Fig. 6: Comparison of shaft power vs provided thrust rom fixed speed controllable pitch propeller (CPP) and variable speed fixed pitch propeller (FPP), and an example utilization of the thruster capacity in DP operations in the North Sea.

The other major effect comes from the possibility for more optimal loading of the diesel engines when using a number of small engines compared to one or few larger /4/. Fig. 7 shows that by automatic start and stop of the engines, depending on the load, the more optimum loading for reduced fuel consumption can be achieved.

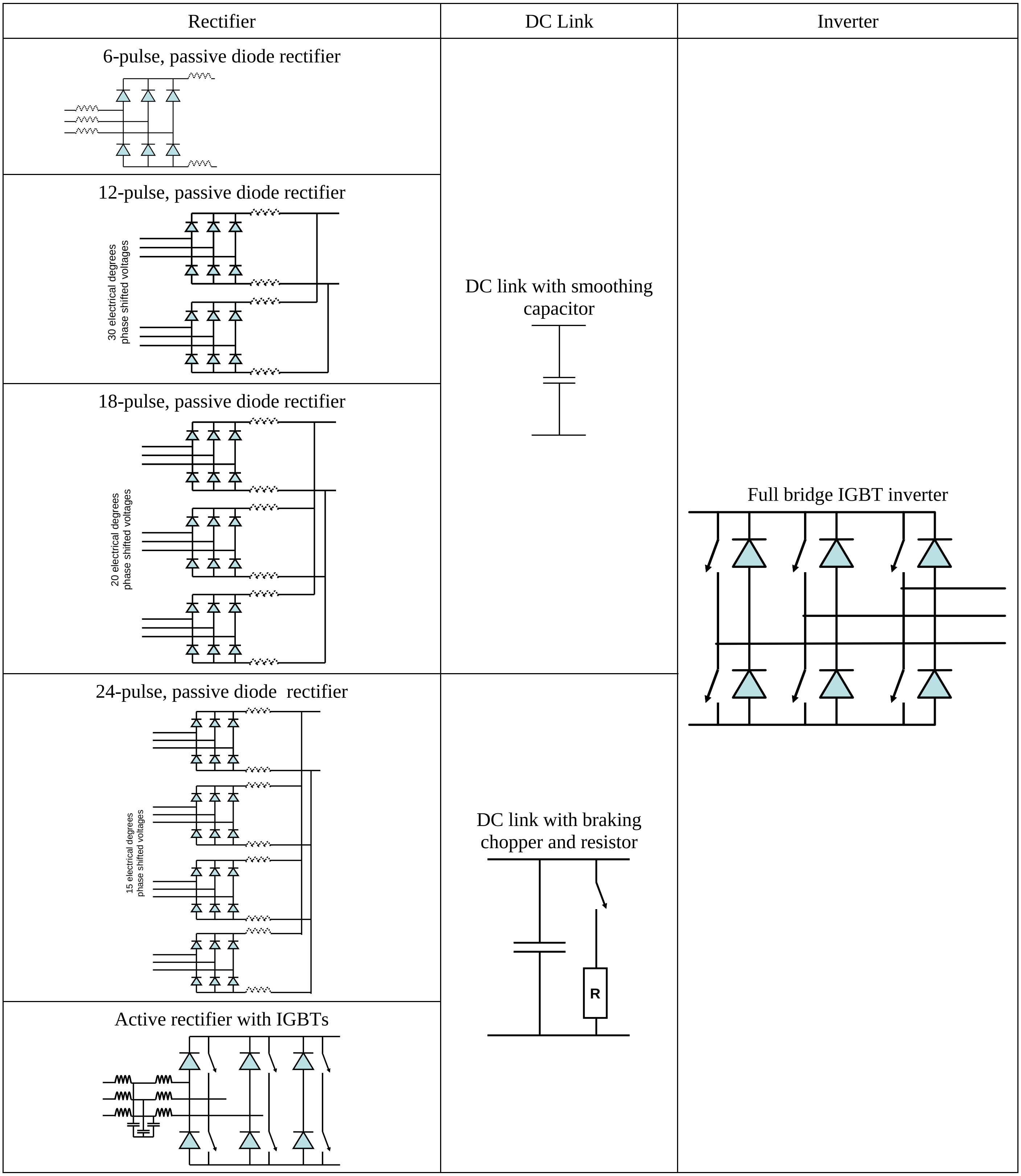


Fig. 5: Description of basic modules for typical low voltage, two level VSI frequency converters.

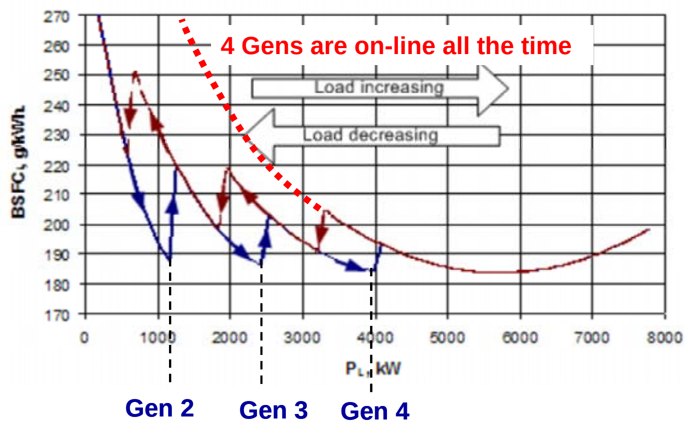
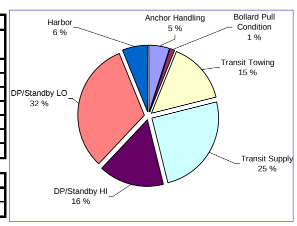


Fig. 7: Fuel consumption per kWh produced energy. For four equal sized diesel engine sin parallel, with automatic start and stop functionality of power management system, compared with one large diesel engine providing same total power (red dotted line) /4/.

For a 200+ tonn bollard pull anchor handling vessel (AHTS), the fuel consumption has been calculated to be close to 1900 metric tons lower with electric propulsion. The operational profile is regarded to be typical for operations (note: not in contractual terms, but in load condition), as shown in Fig. 8.

	Hourly Fuel Oil Consumption kg/h		
	Base Case D-Mech	Electric Propulsion	Operation Profile
Anchor handling	2280	2295	438
Bollard Pull Condition	2451	2795	88
Transit Towing	1898	2053	1314
Transit Supply	1276	1036	2190
DP/Standby HI	1377	1020	1402
DP/Standby LO	1015	620	2803
Harbor	26	25	526
Total FOC kg/year	11 293 005	9 396 661	
Total FOC m.t./year	11 293	9 397	
Difference, m.t./year	0	1 896	



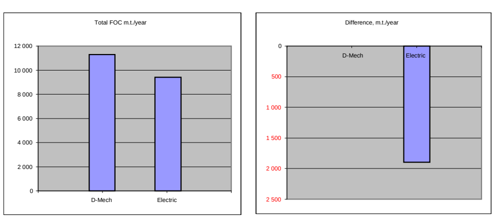


Fig. 8: Fuel consumption for 200+ ton bollard pull AHTS, a calculated comparison between electric propulsion and direct mechanical propulsion.

The installed propulsion power in AHTS is higher than in normal offshore supply vessels, hence the cost of the propulsion systems and installation is also higher. In traditional AHTS designs, the design is very much optimized on the building costs, and to obtain the guaranteed bollard pull. The operational costs have been less weighted in design and selection of concepts.

With today's high costs of fuel, and increasing environmental concern, this is about to change, and now there are several vessel designs brought forward, where the operational costs, and especially the full consumption is focused at.

An alternative to the full electric solution is the combination of mechanical and electric propulsion systems, the so-called hybrid propulsion, Fig. 9. 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.

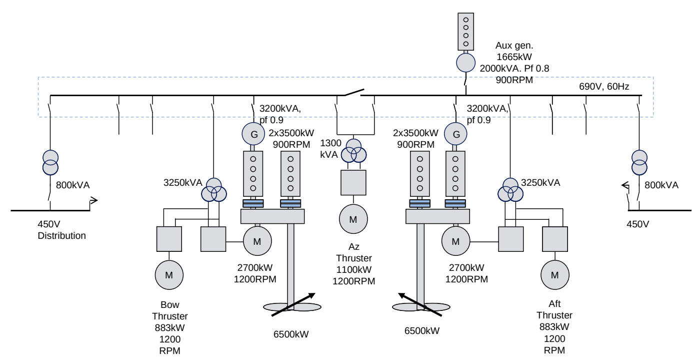


Fig. 9: Hybrid electric and mechanical propulsion for 200+ metric ton AHTS.

PROPULSION CONTROL METHODS

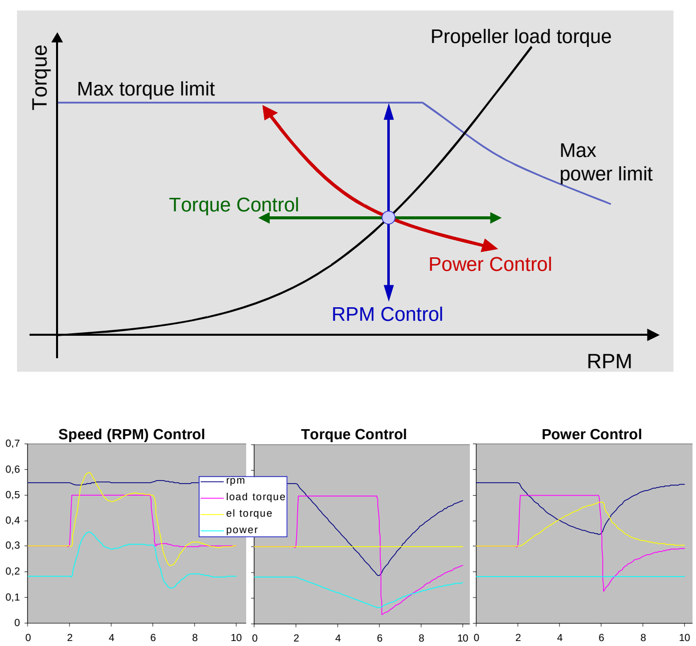
The essence of any motor control is to achieve a good torque control of the motor drive. When torque control is achieved, the motor controller can be regarded as a torque amplifier with a time lag, and the time lag is depending on the applied motor control algorithms, and the motor's own electrical dynamics.

Then, it is easy to adapt the motor drive to various types of outer control algorithms, and the most normal for variable speed control, is to create a closed loop speed (RPM) control of the propulsor or thruster drives, where the set-point from the remote control system is regarded as an RPM set-point.

However, one could also use other approaches to control the propeller, by interpreting the remote control signal as directly being the torque reference to the torque controller of the VSD, amplified by the motor control algorithm, and even to use the set-point as a power command to the VSD, controlling the torque to keep the shaft power equal to the remote set-point.

RPM control, torque control, and power control have all been applied in various applications. Their differences can be observed by the characteristic behaviors in Fig. 10. Since a closed loop RPM control uses the PID controller to minimize the deviation between reference speed and actual speed, load variations at the propeller will instantly result in torque and hence power variations at the shaft. These power variations will immediately be reflected on the power taken from the power plant, and result in frequency variations and possible dynamic overload of the prime mover if the load variations are high. This is primarily a problem of concern for ice breaking OSVs, where load variations are sudden and may be very high, but also for ships operating in high waves the load may vary quite significantly.

If using the remote set-point as a torque reference, the load torque variations will not be reflected in the torque produced by the VSD, which is controlled to follow the set-point only. As seen in Fig. 10, this may give large variations in the propeller RPM and will therefore also give power variations at the shaft and hence in the power plant, since the load power is proportional to load torque and RPM.



(a)

(b)

Fig. 10: Characteristics of RPM (speed) control, torque control, and power control of a propulsor or thruster, (a) in RPM-torque frame; (b) in time frame.

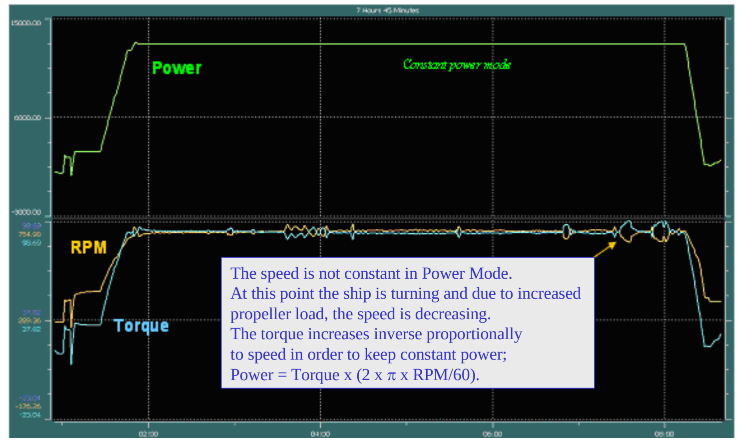


Fig. 11: Logging from sea trial, showing that the load power is constant when operating in power control mode, even though the load torque may change significantly by effects from waves and course changes.

Power control is based on a control algorithm where the remote set-point is regarded to be the commanded power (kW) set-point to the propeller, and the VSD controller will then control the load torque to produce a power to the motor shaft which equals this set-point. Any load variations will be counteracted by keeping the motor shaft power constant, as seen in Fig. 10, and the load power of the prime movers will therefore be minimized. The power control works well within the constraints and limitations of the components in the VSD, as shown in Fig. 11; which is a real logged characteristics of a propulsion drive system in heavy seas and during course changes where the load varies significantly – without causing load power variations of the prime movers.

Power control is found advantageous at high propeller loads in most ship applications, such as free sailing and transit modes. RPM control gives some faster dynamic performance, and is normally used in operation modes with lower load on the propellers, and at high dynamic requirements, such as maneuvering mode and station keeping. For ice braking vessels, power control is a necessity, since the loads of the propeller may vary excessively and very fast, e.g. when the propeller hits ice blocks. Torque control is rarely used today, as speed (RPM) and power control are better alternatives for the various operational modes.

Research has shown that the use of power control may also give significant achievements in power stability of the network and reduction in load variations for the prime movers in station keeping conditions. Until today, there has not been reported any successful use of such control schemes in DP systems, and the slower response of the VSD drive in power control mode may be one explanation to this.

Note that it is necessary to include additional control and monitoring functions to achieve safe and reliable control of the propulsors and thrusters in all operating modes, however, it is beyond the scope of this paper to describe all these in details.

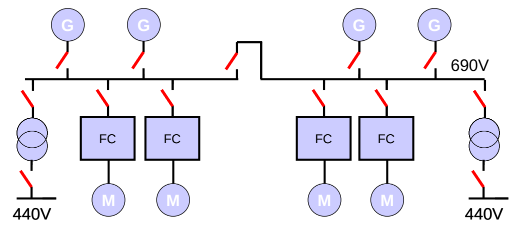
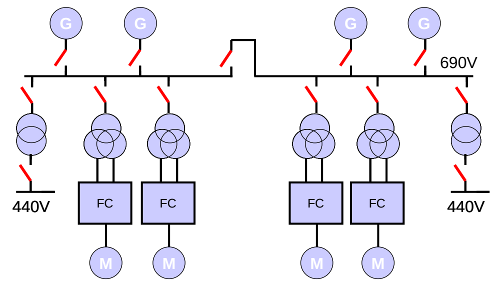
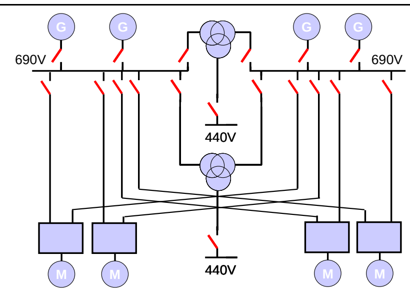
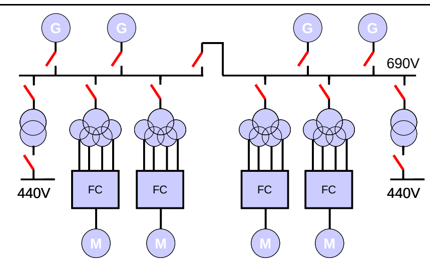
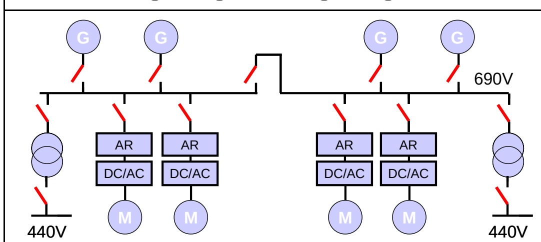
	6-pulse: • No drive transformers • Harmonic filters needed to get THD<5% • Weight: Low • Footprint: Low • Operational constraints: Medium • Total efficiency: Approx: 90-91%
	12- and quasi 24-pulse • 3-winding transformers, phase shift for Q24 • Harmonic filters for 12-pulse, not Q24 • Weight: High •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

Fig. 12: 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.

SYSTEM CONFIGURATIONS

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. 12. 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.

Note, that in the configurations of Fig. 12, there are not shown thrusters with change-over feeder from the two switchboards or switchboard sections. Change-over supply is often used in OSVs for retractable Azimuthing thrusters in order to be able to provide power to this even with a fatal failure of one of the main switchboards. It should be noted that some class societies do not approve such change over circuits for calculation of DP capability after loss of the primary supplying switchboard-

CONCLUDING REMARKS

OSVs and gradually AHTS vessels are built with electric propulsion in order to reduce fuel oil consumption, environmental emissions, and operational costs. Most vendors utilize similar basic components and solutions, even though the composition of systems and preferences in design may differ to some extent – often depending on the maker’s available technologies.

For AHTS, traditional designs have been strongly optimized on obtaining the guaranteed bollard pull, with minimum building costs, which has resulted in vessels which are highly fuel consuming, and with substantial environmental emissions, especially CO_2, than what could have been achieved with electric propulsion.

Much of the same savings may be achieved by using hybrid electric and mechanic propulsion, at a lower building costs than with pure electric propulsion. The increased complexity and need of operator interactions to select the most optimal configuration for varying operation

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.

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