Marine Technology Society

Dynamic Positioning Conference

21 - 22, October, 1997

Session 6

Propulsion and Thrusters

Essential Characteristics of Electrical Propulsion and Thruster Drives in DP Vessels

By:

Alf Kåre Ådnanes

ABB Industri AS (Oslo, Norway)

Asgeir J. Sørensen

ABB Industri AS (Oslo, Norway)

Thomas Hackman

ABB Industry Oy (Helsinki, Finland)

Session Planner

Dietmer Deter: *Nautex (Houston)*

Essential Characteristics of Electrical Propulsion and Thruster Drives in DP Vessels

Presented at the Dynamic Positioning Conference, Houston, Texas

21-22 October 1997

by

Alf Kåre Ådnanes*, Asgeir J. Sørensen* and Thomas Hackman**

ABB Industri AS*
P.O. Box 6540 Rodeløkka
N-0501 Oslo, Norway
Phone: +47 22 87 20 00
Fax: +47 22 35 36 80
E-mail: alf-kare.adnanes@noina.abb.no
asgeir.sorensen@noina.abb.no

ABB Industry Oy**
P.O. Box 185
FIN-00381 Helsinki, Finland
Phone: +358 10 22 22110
Fax: +358 10 22 22350
E-mail: Thomas.hackman@fidri.mail.abb.com

Abstract

Electric propulsion has become the preferred solution for floating production facilities, Dynamically Positioned (DP) drilling vessels, and in several shuttle tanker applications. Propulsion and positioning are accomplished by use of electrically driven shaft propellers and thrusters. The available configurations and technologies have different characteristics and the performance criteria of one project may be prioritized differently from those of another; however, some common concerns exist that should form the basis of the evaluation.

1. Introduction

Still a few years ago extensive oil and gas resources were accessible in shallow waters and could be exploited by fixed drilling and production units. In the North Sea, Gulf of Mexico, and Brazil as in several other areas, those new resources that remain are found in smaller and/or less available fields in deeper waters. These fields require new cost-effective methods to obtain acceptable economy and profit. Deep-water drilling and floating production (FP) have become possible with dynamic positioning (Dynpos, DP) or thruster-assisted position mooring (Posmoor, PM). Typical of these vessels is their great installed thruster power, often in the range of 10-40 MW. High availability of power and thruster installations, as well as safety and automation systems, are the key factors in obtaining maximum operation time for the vessel.

Initial investment costs remain an important selection criterion for the purchaser, although the life cycle cost (LCC) which includes those costs related to installation and commissioning, operation and fuel consumption, maintenance, and lost or deferred production over the lifetime of the vessel, has gained increasing attention from operators and owners. In this context, a total package philosophy with responsibility by a single supplier for vessel automation, positioning, and power systems is driven by ship and rig owners, yards, and major suppliers. The installation and operational benefits are obvious, as explained in /1/, furthermore, the propulsion and thruster drive technology exerts significant impact on operational costs and constraints and should be carefully selected to give the lowest possible LCC.

For DP vessels the thrusters are dimensioned to maintain the vessel in position even under adverse conditions; however, over extended periods they operate far below their maximum rating. Variable-speed electric thruster drives (VSD) have been found to result in substantial operational cost savings and increased availability compared with constant-speed thrusters, due to reduced low-load power and simplified under-water construction.

In this paper we present the configurations of typical diesel-electric power plants for oil- and gas-related vessels and the most important propulsion and thruster alternatives. Motor drive technologies are described and qualitatively compared, including an example of an LCC assessment.

2. TYPICAL DIESEL-ELECTRIC POWER PLANTS

2.1 Drilling Vessels

For drilling activities in deeper waters traditional mooring methods may not be applicable and the drilling vessels are increasingly often dynamically positioned and powered by thrusters in order to maintain position. DP drill ships and rigs require a large installation of thruster capacity to obtain high operational availability, and will normally be designed as DP Class 3-, alternatively as Class 2-vessels.

Increased environmental concern with respect to pollution has, in many areas, caused restrictions or taxes imposed on the emissions from burning the test production. As a consequence, drilling vessels in combination with a small production and storage plant have become an interesting alternative to a separate production facility.

A diesel engine- or gas turbine-electric power plant supplies the drilling package and the thrusters through a common power network. The power plant often has 30-40 MW of installed power. Drill ships typically have six thrusters while rigs may have 8 thrusters, each rated at 3-6 MW (see Fig. 1).

The drilling package and thrusters are normally the major power consumers. The load varies substantially depending on weather conditions and drilling operation. The need for an automation system that ensures optimal running of the power plant under all operational and loading conditions, with the required tolerance to failures, is essential.

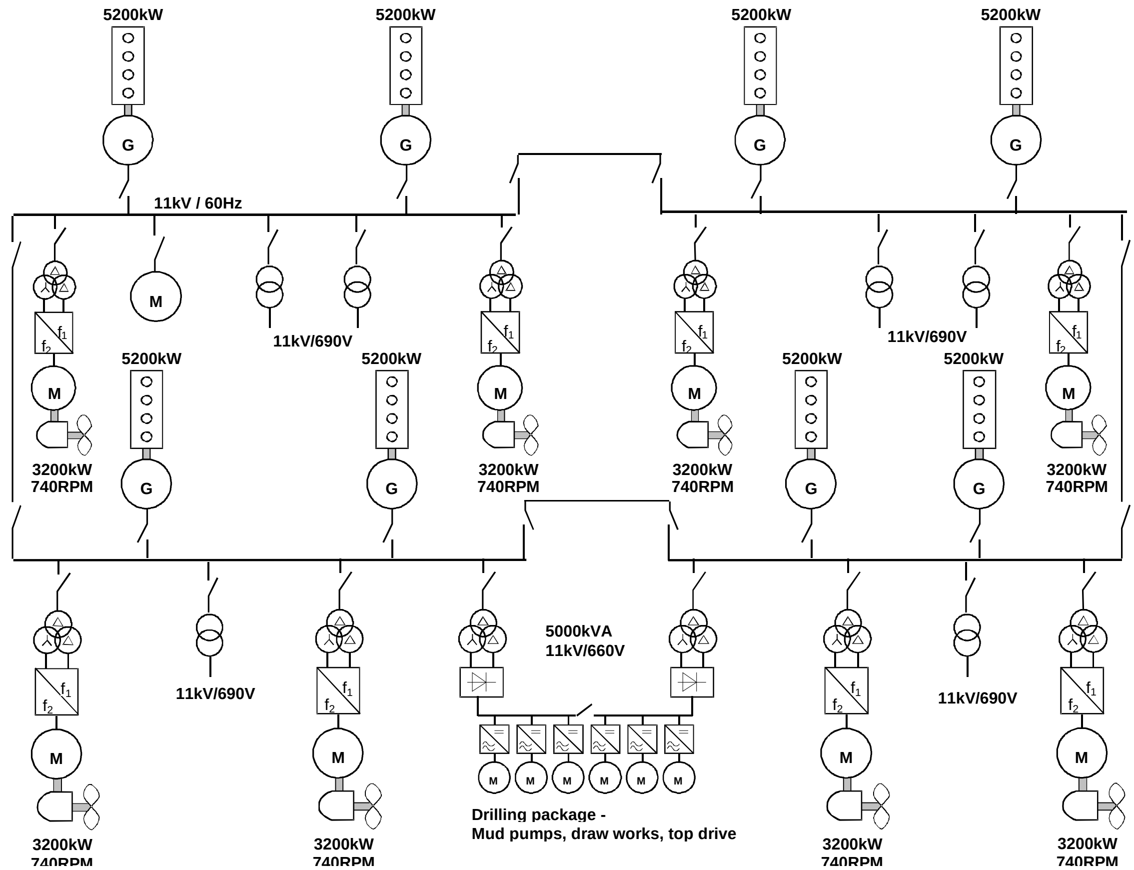


Fig. 1. Drilling vessels: A typical power system configuration for a DP Class 3 drill rig with a four-split power system.

2.2 Floating Production Vessels

Floating production, storage and offtake units (FPSOs) are characterized by the presence of a large process power load and position mooring with or without thruster assistance. The safety and cost consequences resulting from loss of the positioning system are extremely high; hence, requirements for availability call for redundant solutions, normally in accordance with Class 2 rules for PM systems and Class 2 or 3 rules for DP systems. The power configuration of a typical floating production unit with thruster-assisted PM is shown in Fig. 2. A diesel engine- or gas-turbine electric power plant supplies the process and thrusters through a common power network. The power plant is typically of 30-50 MW installed power. For thruster assistance typically 2-3 thrusters, each of 3-5 MW, are often sufficient. In DP vessels and rigs, the typical configuration includes 6-8 thrusters each of 3-5 MW. The process plant is normally the major power consumer and includes water-injection pumps, gas compressors, cargo pumps, etc. For moored vessels with inherent weather-vaning capability, the thrusters may even be switched off in calm weather.

The thruster load increases with increasing environmental load and must for safety reasons have higher priority than the process load when available power becomes low. For operational efficiency and to minimize process shutdowns, it is essential to have a vessel management system that controls the interaction between the power system and consumers optimally under all load conditions.

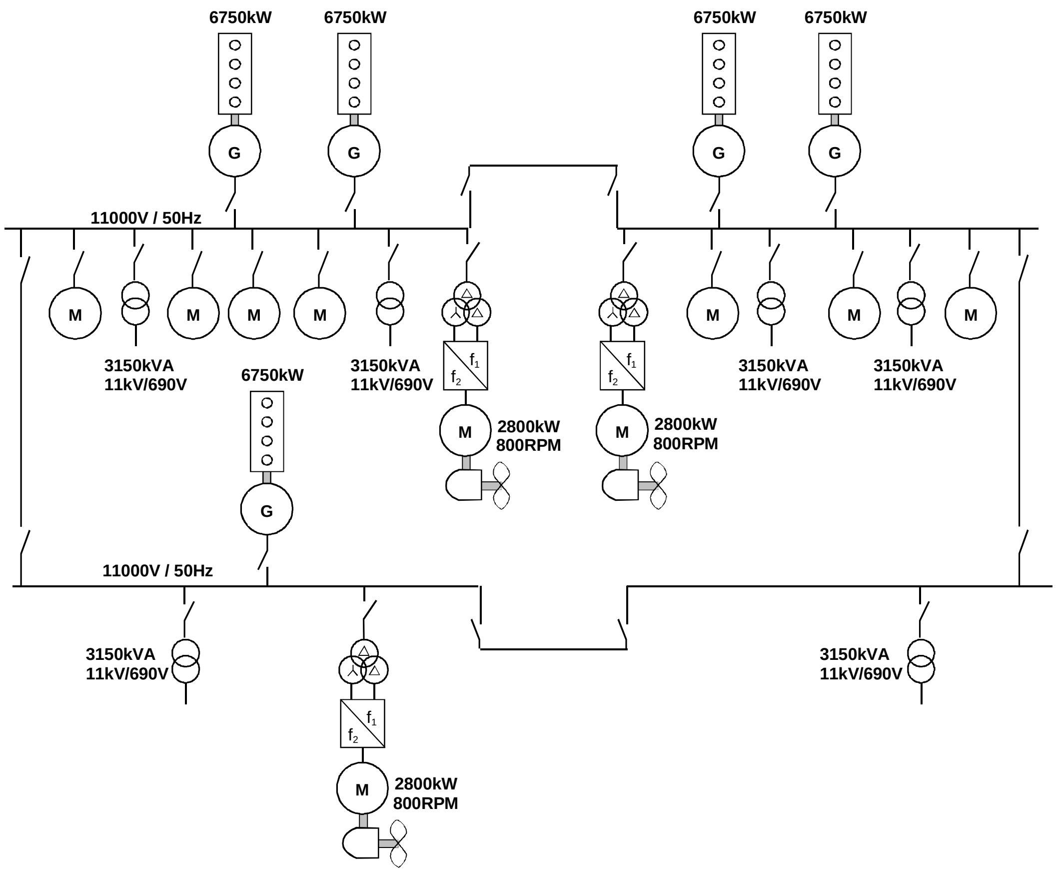


Fig. 2. Floating production: A typical power system configuration for thruster-assisted position-moored FPSOs with a two-split main switchboard configuration and emergency switchboard.

2.3 Shuttle Tankers

Shuttle tankers are used to bring oil cargo from loading facilities at offshore fields to onshore oil terminals. The transit time may be relatively short and DP operational time significant. The main propulsion plant, however, is dimensioned for maximum speed, typically 10-15 MW. Hence, in DP mode and maneuvering the main propulsion is operated only at 10-20 % of its rated power. In a vessel with a propulsion plant based on direct-driving diesel-engines this results in low fuel efficiency, high emissions, poor combustion, and thereby increased maintenance. The flexibility of the electrical system allows for better utilization of the propulsion plant, providing more economical and environmentally friendly operation. Diesel-electric propulsion has also been shown to result in substantial savings in weight and space which, in addition to better flexibility in placement of the components, frees space for the payload.

The configuration in Fig. 3 shows the diesel-electric power and propulsion system for a shuttle tanker. The main propeller is driven by a variable-speed tandem motor. Thrusters are used for transverse thrust capability in positioning and maneuvering. In the near future, shuttle tankers will feature one or two Azipod units (see Chapter 4.4) replacing both the main propulsion shaftlines, the aft transverse thrusters and the rudders.

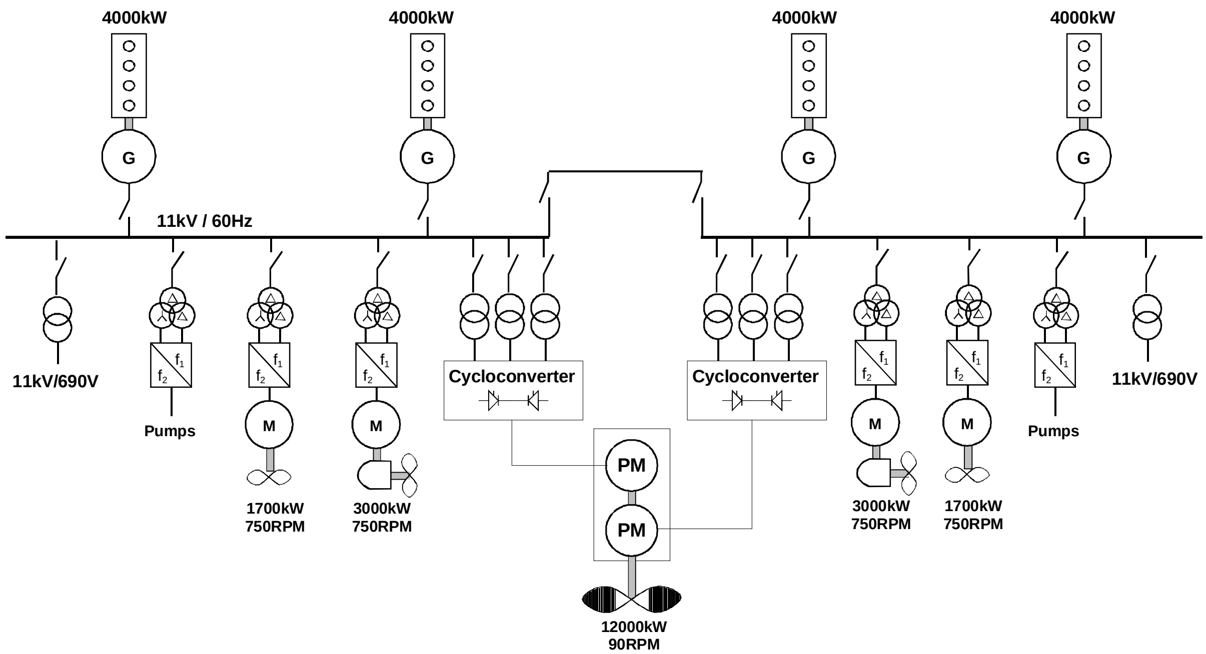


Fig. 3. Shuttle tankers: A typical power system configuration for a DP shuttle tanker.

2.4 Service Vessels

Service vessels are traditionally equipped with two large direct diesel-driven propulsion shaftlines dimensioned for high transit speed, as well as for a high bollard thrust. Electrically driven fixed-speed tunnel and / or azimuth thrusters fore and aft are normally used to provide the necessary transverse thrust for maneuvering and positioning. Since service vessels are often intended to operate in standby and/or DP service over a large portion of their operational time, the use of variable-speed electric thruster drives for propulsion and positioning may result in substantial operational savings. Even though the savings alone, due to the vessel´s operational profile, may not justify the additional investment costs /2/, the flexibility in equipment location and improved maneuverability have resulted in true diesel-electric service vessels, e.g. multipurpose service vessel - ice-breakers.

The propulsion may consist of two main propulsion azimuth thrusters or Azipods, in combination with smaller tunnel and azimuth thrusters for transverse thrust capability, as shown in Fig. 4. Since the Azipods are rotatable over 360 degrees, aft side thrusters are made redundant.

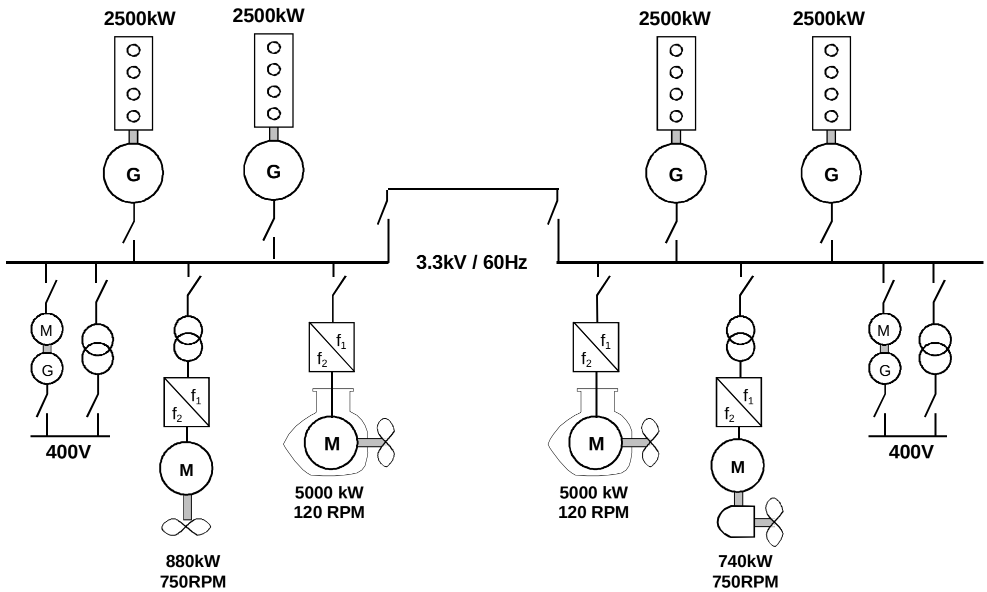


Fig. 4: Service vessels: A power system configuration for a supply vessel.

3. ESSENTIAL CHARACTERISTICS FOR PROPULSION AND THRUSTER DRIVES

In a diesel-electric power and propulsion system, the thrusters are critical for the overall performance of the vessel. The priority of importance for the characteristics are dependent on the actual vessel and operational profile. The most essential design parameters in most cases are described below.

3.1 Main Dimensions

Normally great attention is devoted to the weight and dimensions of the equipment to be installed on ships and rigs. Water-cooled converters and motors often result in the most compact solution, not only due to the size of the equipment itself, but also to the fact that air ducting and conditioning to remove heat from air-cooled equipment is space-consuming and expensive.

3.2 Installation and Interfacing

Installation work and interfacing are expensive and critical during the late stages of construction. Use of high voltage reduces the currents of the distribution system and the amount of cable that must be installed. In one case with a drilling rig, savings of 40 tons of cable were calculated by using high-voltage thruster drives instead of corresponding low-voltage drives. Using field bus communication dramatically reduces the amount of cabling for the yard and increases system flexibility for modifications and extensions.

Technical solutions that allow for late installation of cost-intensive equipment reduce the capital costs in the construction phase.

3.3 Integration Aspects

The trend in recent projects shows that the time from order to installation has become shorter. Less than one year from order to installation of equipment is not unusual, often in parallel with detail design. The need for standardized and well-proven, but flexible solutions is obvious. Physical and functional integration between power, vessel management, and positioning system has resulted in a significant reduction of installation, commissioning and sea-trial time, due to less interfacing problems and built-in compatibility between all pieces of equipment and sub-systems.

3.4 Reliability and Availability

Access to the power plant, propulsion, and thrusters is a key factor in achieving maximum operational time. Not only should the reliability in terms of mean time to failure be high, but also the downtime for repairs must be short to achieve high availability. An FMEA- or equivalent study should be performed to verify the level of theoretical availability and to pinpoint the areas where redundancy is either lacking or not useful.

3.5 Built-in Diagnostics and Maintenance

Built-in and also remote diagnostics with modular design help the maintenance personnel in identifying and repairing failing parts. Underwater equipment normally requires much longer times for repair than on-board equipment, and should, as a consequence, have the simplest and most robust mechanical design.

3.6 Drive Efficiency and Harmonic Distortion

To maintain the fuel consumption at the lowest level possible, it is not enough for the equipment to have high energy efficiency, because a poor power factor (cosphi), high start-up current, and high harmonic distortion level may mean that more generators must be connected to the network, resulting in more running hours with lower power load for each diesel engine. In addition to increased fuel consumption, the need for maintenance will also increase. Reversed power during regenerative braking may cause voltage fluctuations and network instability if not accounted for during the design phase. If the amount of regenerated power is high but the potential for energy consumption is low, such problems can be avoided by using braking resistors instead of regeneration.

3.7 Drive Performance

The requirements for dynamic performance of the propulsion system of a vessel operating in open waters are normally far below those met in other industrial applications such as paper mills, rolling mills, etc. Since blackout situations should be avoided, however, the large drives should react very rapidly to power reduction after failures in the power system. They should also be able to be restored to normal operation with a minimum of delay after such failures. In DP mode, smooth control of the thruster at low speeds, and a capability to rapidly reverse the direction, are often essential.

3.8 Life Cycle Cost (LCC)

Price is an important factor for most shipowners and contractors. Price may, however, be regarded differently by including operational and maintenance costs than by comparing installation costs only. LCC has been used to evaluate the total costs over the lifetime of the vessel. Even though the analysis may contain many parameters that are somewhat uncertain, it will often be a good indication of the best solution.

4. PROPULSION AND THRUSTERS

4.1 Shaft Propellers

In a diesel-electric power and propulsion system, the shaft propellers are normally driven by variable-speed electric motors. The horizontal motors may be directly connected to the shaft, which results in a simple and mechanically robust solution, or via a gear coupling which allows for increased rotational speed of the motor and results in a more compact unit.

Shaft propellers are used mainly in shuttle tankers and other vessels in which the propulsion power required is too high for conventional azimuth thrusters. By use of high-lift rudders, shaft propellers may also be used to provide a certain degree of transverse thrust.

4.2 Tunnel Thrusters

Tunnel thrusters produce fixed-direction transverse thrust and are often used in vessels in which shaft propellers are amply dimensioned for the longitudinal thrust needed in DP operation. The motors are normally vertically mounted with an L-shaped gear or horizontally mounted with a Z-shaped gear where the geared transmission allows for higher rotational speed and smaller motor constructions.

Tunnel thrusters may be of the variable-speed fixed-pitch (FPP) type or equipped with constant-speed controllable-pitch propellers (CPP). The FPP solution has a simpler mechanical construction since the pitch transmission can be omitted. Furthermore, low-thrust losses will be reduced from levels typically 15% of rated power to essentially zero. The FPP thruster must be driven by a variable-speed thruster drive.

4.3 Azimuth Thrusters

Azimuth thrusters are rotatable devices for production of thrust in any direction. Although it is optimized for positive-thrust direction, it should have a certain degree of negative thrust capability as well, to maintain dynamic thrust capacity without performing continuous azimuth rotation. The electric motor is normally vertically mounted and drives an L-shaped gear transmission. With regard to azimuth thrusters, a variable-speed thruster motor drive and FPP simplify the underwater mechanical construction and reduce low-thrust losses significantly.

Conventional azimuth thrusters are used with power ratings up to 5-7 MW.

4.4 Azipods

In the Azipod a variable-speed electric motor is located in a compact podded unit. The fixed-pitch propeller is mounted directly on the motor shaft. Since a gear is avoided, the transmission efficiency is higher than in an azimuth thruster. Like the conventional azimuth thruster, the Azipod is freely rotatable and may produce thrust in any direction. The electrical power is transferred to the motor via flexible cabling or sliprings for 360-degree operation. Since the propeller pitch is fixed and there is no gear transmission, the mechanical construction is simple and robust.

Azipod units have been in operation for more than 5 years in service vessels and tankers. Current newbuilding installations include 4 cruise vessels and an offshore construction vessel (two 5 MW units). The concept is presently being evaluated for use in other oil- and gas-related vessels as well, as main propulsion and for dynamic positioning.

Azipod units are available in power ranges up to 25 MW. A total of 10 (ten) 14 MW units are currently on order for four cruise vessels. The larger units provide access into the pod for visual inspection.

5. Drive Technologies

5.1 Constant-speed Motor Drives

The constant-speed motor drive is used with controllable pitch propellers (CPP). The motors are usually cage-type induction motors and may be designed with pole-changing switches to allow for two operating speeds. When started direct-on-line (DOL), the induction motor has a large starting current transient, typically 5-7 times the nominal current, with significant shaft torque transients and voltage drops in the network. To maintain voltage drop within the limit specified by rules and requirements, a minimum running generator capacity often must be defined to be able to start a large motor. Star-delta switching is often used to provide higher starting torque with reduced transients, but is often not the best solution. Soft-starting devices such as auto-transformers have been shown to give better results. Solid-state soft starters are not commonly used for high power levels.

5.2 SCR DC Motor Drives

In the very beginning of the development of power electronics, the silicon-controlled rectifier (SCR) for direct-current (DC) motors was the only possible VSD alternative. In the most common high-power applications, a full-bridge thyristor rectifier feeds the DC motor with a controlled armature current. Similarly, the field is excited with a regulated field current. The torque is controlled accurately and with low ripple if the armature inductance is high, but this, on the other hand, reduces the dynamic performance since the time constant of the armature increases.

Since the armature current is controlled by use of the firing angle of the thyristor devices, the AC currents will be phase-shifted with respect to fundamental voltage. Normally, a minimum firing angle of 15 degrees is applied to obtain controllability, reducing the power factor (cosphi) to between 0 and 0.96, in proportion to motor speed. A low power factor increases losses in the generation and distribution system and more generators may have to run than the active power of the load would require.

The DC motor must have a commutator to transfer the DC current to the armature. Wear and tear on brushes and commutator is a source of failure and maintenance and also limits the standstill torque performance. When accounting for this and also for the fact that the practical limit for DC motor drives is 2-3 MW, the application of DC thruster drives is limited, with the exception of retrofits, in which existing installations are reused.

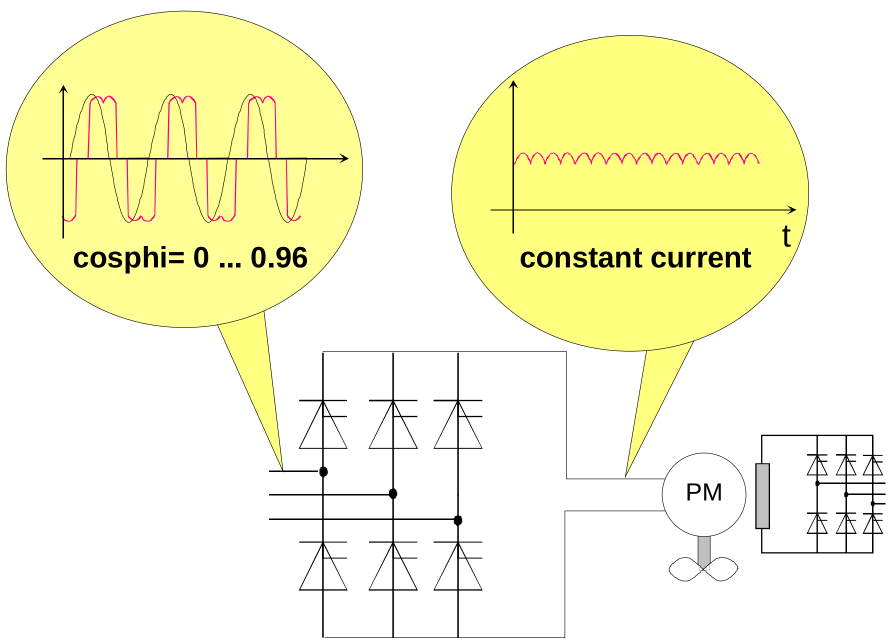


Fig. 5: DC drive (SCR).

5.3 CSI with Alternating Current (AC) Synchronous Motor

The current source inverter (CSI), occasionally referred to as a load-commutated inverter (LCI) or Synchro, is characterized by a DC current link fed by a thyristor-controlled rectifier and smoothed by an inductor. The thyristor rectifier results in a speed-dependent varying power factor which is high (0.9) at nominal motor speed and decreasing toward zero for low speeds. The supply current contains harmonics that must be regarded during the system design and should normally be reduced by use of a 12 pulse, 6-phase configuration.

The DC link current is directed through the motor phases by controlling the thyristors of the inverter stage. A 6-step current waveform is obtained, resulting in motor harmonics and torque ripples. The CSI requires a certain counter induced voltage (EMF) from the motor to perform commutation. Hence, it is mainly used in synchronous motor drives in which the motor can be run with capacitive power factor.

At lower speeds, typically below 5-10% of rated speed, the EMF is too low to perform a natural commutation. In this speed range, the CSI is run in pulsed mode in which the current is controlled at zero level during commutation of the inverter output stage. Since the current and hence the torque are forced to zero level, the torque pulsation at the motor shaft is large in this operational area. The torque ripple and hence shaft vibrations should be carefully regarded in the propulsion system design to reduce vibrations and acoustic noise. These may have a detrimental effect on geared thrusters operating in DP mode.

Due to the large time constant in the DC link inductor, the dynamics of the CSI is not as good as in alternative AC drives.

The CSI is used in large synchronous motor drives, up to 40-60 MW. ABB has delivered more than 150 CSI drive units for industrial installations, e.g. for gas compressors, but has so far not found it beneficial to apply this technology for marine propulsion.

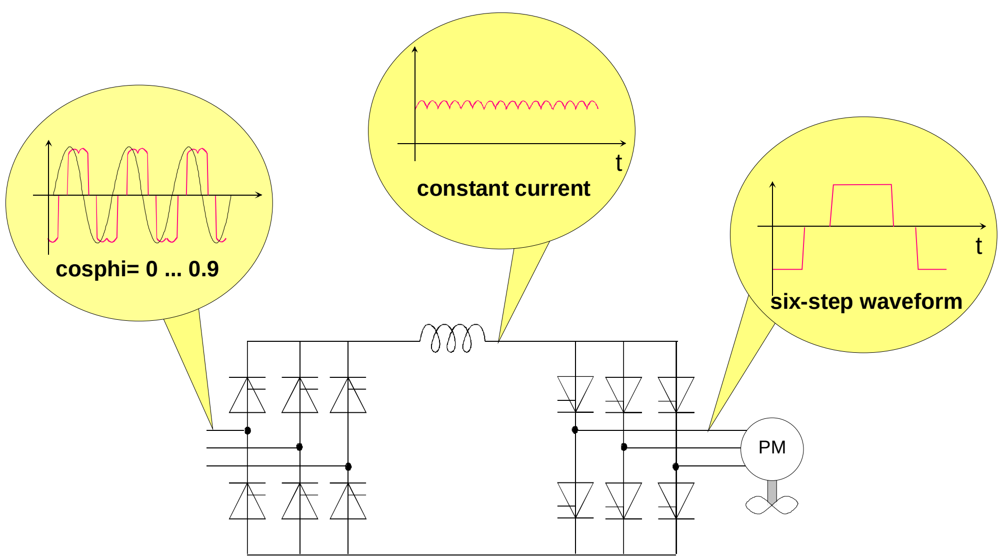


Fig. 6: CSI (LCI) Drive.

5.4 Cycloconverter with AC Synchronous Motor

The cycloconverter (Cyclo) is a direct converter without a DC link (see Fig. 7). The motor AC voltage is constructed by selecting phase segments of the supply voltage by controlling the antiparallel thyristor bridge. A 12-pulse configuration with reduced line harmonic is drawn, but the cyclo can also be supplied in a 6-pulse configuration. In 6-pulse configuration, the feeding transformers can be substituted with reactors when the supply voltage matches the inverter voltage.

The motor voltage is controllable up to about one third of the supply frequency (about 20 Hz); thus it is most applicable in direct shaft drives without gear. The motor voltage contains a lower level of harmonics than the CSI, and the motor power factor may be kept high (unity in synchronous motor drives).

The supply power factor is motor voltage-dependent and is about 0.76 in the field weakening range. The content of line harmonics is speed-dependent and must be carefully regarded in system design when the motor drive is large compared with the installed power.

ABB has supplied Cyclo propulsion systems with synchronous motors for more than 30 vessels to control conventional shaftlines, as well as Azipods. The Cyclo is available in a power range of 2-30 MW per drive motor.

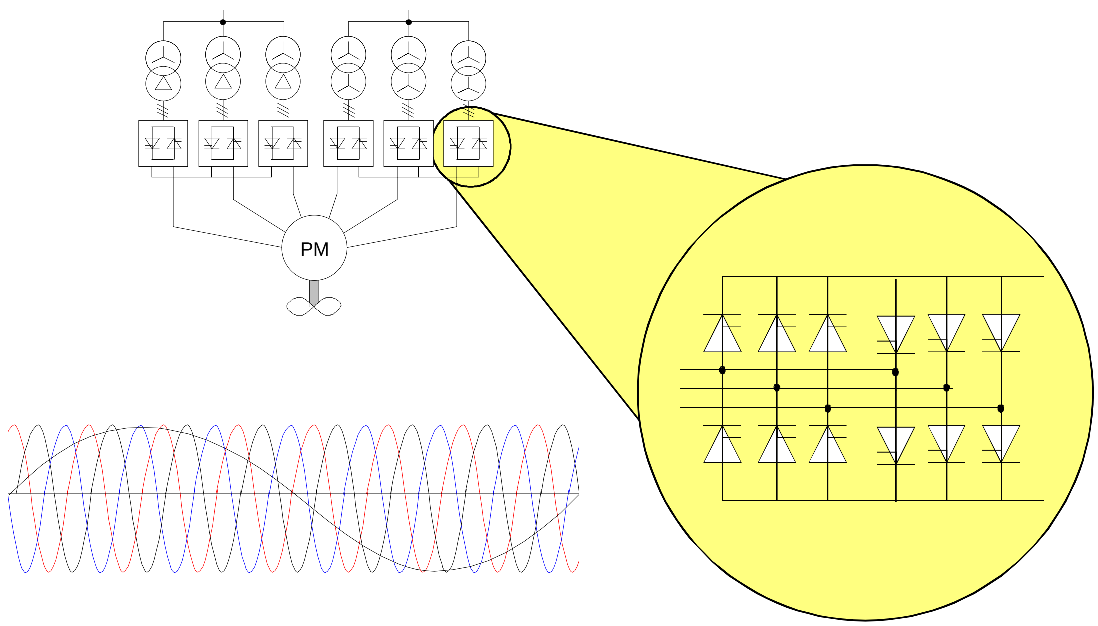


Fig. 7: Cycloconverter drive with input and fundamental output waveforms. The output voltage is constructed by selecting phase segments of the supply voltage.

5.5 PWM Inverter with AC Induction Motor

The PWM (Pulse Width Modulated) drive, often also referred to as VSI (Voltage Source Inverter) is characterized by its DC voltage link which is fed from the power system by a diode rectifier. A capacitor bank is used to smooth the DC link voltage and to minimize the effect of harmonic distortion from the output (inverter) stage on the supply.

The diode rectifier results in a near unity power factor (0.95) which is maintained at a constant level at all motor speeds. Since a minimum of current is drawn, the content of line harmonics is lower than that of the CSI or Cyclo, and is proportional to motor speed. The deep commutation “notches” associated with controlled thyristor converters are also brought to a minimum. The line harmonics can be further reduced by using three-coil transformers to feed a converter in a 12-pulse configuration.

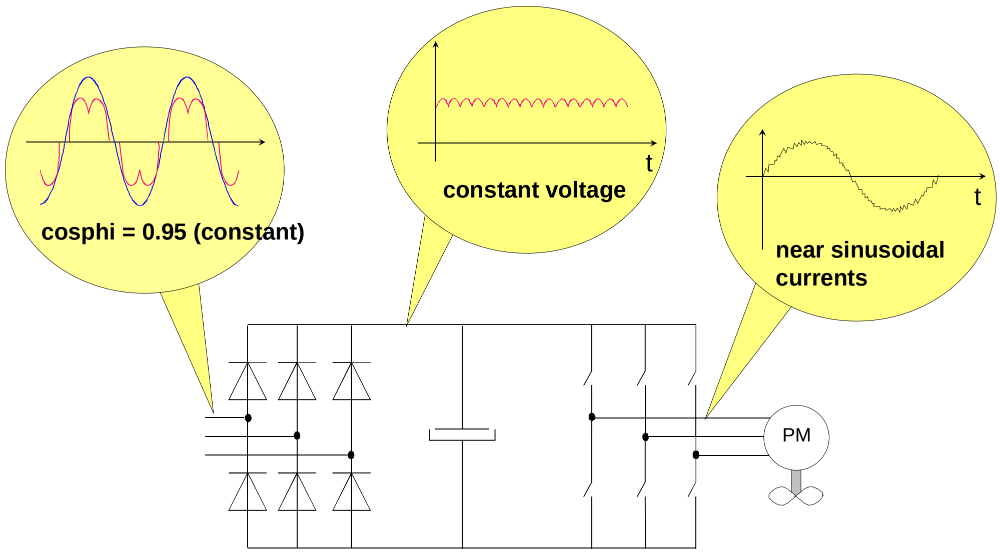


Fig. 8: Two-level PWM drive.

The AC voltage into the motor is generated by the inverter stage by chopping the DC voltage into AC waveforms with a PWM pattern. Several methods are used to generate the PWM, and ABB has developed the Star modulation scheme which is optimized for reducing harmonic distortion in motor currents, and the new Direct Torque Control (DTC) technology for high-precision control without speed sensors.

The VSI PWM has a large output frequency range with excellent dynamic performance; hence, in geared propulsion drives, the VSI PWM offers cost- and weight-effective solutions by utilizing its ability to drive higher-speed (900-1200 rpm) cage induction (asynchronous) motors. The torque is smoothly controlled at all speeds, including zero speed, with speed feedback in a vector-controlled scheme.

The low-voltage VSI PWM converter is typically designed in a two-level output, as shown in Fig. 8. Medium-voltage versions usually feature a three-level, neutral-clamp converter that increases the voltage capacity and improves the motor voltage waveforms.

The network current waveform is determined by the rectifier, which for a VSI PWM is usually a full-bridge diode rectifier. The rectifier in Fig. 8 represents a six-pulse configuration used where the converter is directly connected to the network. The dominant harmonic currents are of the 5th, 7th, 11th, and 13th harmonic order. The harmonic distortion can be further decreased when using 12-pulse configuration with a dual feeding via a three-coil transformer, hence cancelling the 5th and 7th harmonics. Where a transformer is necessary for voltage adaption, the 12-pulse configuration may always be specified. Using PWM drive and 12-pulse configurations, the resulting harmonic distortion will often be below the limits defined by rules and guidelines without additional filtering.

ABB delivers PWM VSI drives for electric propulsion under the trade names ACS600 (low voltage) and SAMI Megastar (medium voltage). At present, about 40 vessel deliveries (including a total of more than 130 PWM propulsion, thruster, or Azipod drive converters), are in operation or ordered. Also the large drive converters control induction motors and are presently available in units up to 8 MW (3,300 V).

5.6 Other Variants

In addition to the most significant topologies mentioned here, other variants are occasionally also seen, such as CSI with PWM current output, step-wave with multiple transformer output and extremely low motor voltage distortion, and VSI Pulse Amplitude Modulated (PAM) converters with a thyristor-controlled DC link voltage and a 6-pulse voltage output. The use of these technologies is limited and normally only seen in special applications.

6. COMPARISON

6.1 Fixed-speed CPP vs. Variable-speed FPP

The characteristics of a DOL-started fixed-speed CPP thruster and a variable speed FPP thruster are compared in Table 1.

Because of a lower power factor and higher starting transients more diesel-generators should, in general, be connected to the power network with fixed-speed thrusters than with variable- speed thrusters, and hence:

- Average loading will be lower with more running hours.
- Fuel costs, wear and tear, and maintenance will increase.
- Larger dimensioning of the power plant may be necessary.

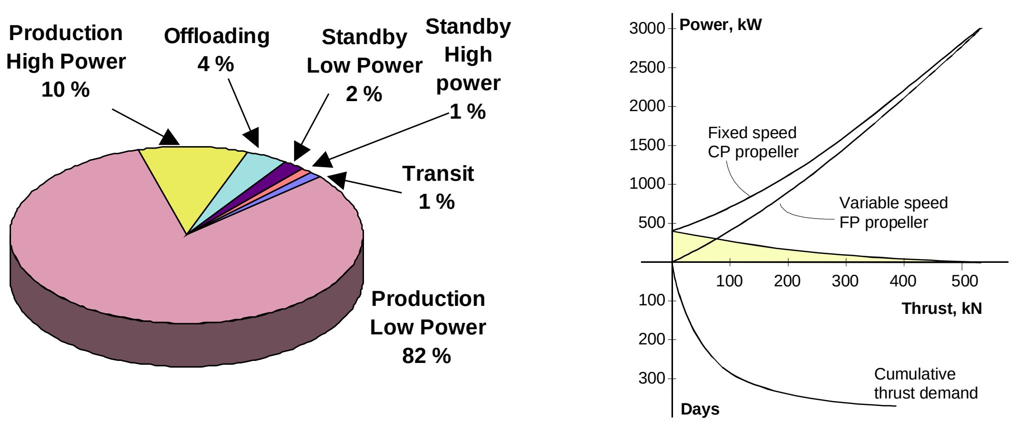
Table 1: Qualitative comparison of constant-speed CPP and variable-speed FPP azimuth thrusters.

	Constant-speed Controllable-Pitch	**Variable-speed [1]) Fixed-Pitch**
Start-up amps	Typ. 5 x rated current	≈ 0 (transformer inrush)
Amps at zero thrust (Fig. 11)	≈ 0.4 x rated current	≈ 0
Cosϕ - full load (Fig. 11)	≈ 0.85	> 0.95
Power consumption, low thrust (Fig.12)	≈ 0.15	≈ 0
Drive efficiency at full thrust (Fig. 12)	≈ 0.96	≈ 0.94

Dynamic response (power, torque)	3-5 sec	< 50 ms
Short circuit contribution	Yes	No
Harmonic distortion	≈ 0	Yes
Start-up torque transients	Typ. 2-3 x rated torque	≈ 0
Mechanical complexity	Higher	Simple
Electrical complexity	Simple	Higher

[1]) VSI PWM drive with cage induction motor

A thruster drive has two prices: one before and one after installation. The equipment cost of the variable-speed drives will often be higher than that of the constant-speed controllable- pitch propeller. Maintenance cost and fuel consumption will, however, be reduced since in DP operation the thruster power is usually only partially utilized. Fig. 9(a) shows the operational profile for a floating production unit. During 84% of the time less than 15 % of the thruster capacity is utilized (82% during production and 2% during standby). Fig. 9(b) shows for this particular case that the no-load losses of the fixed-speed CPP is 300-400 kW under these conditions. The fuel saving potential is obvious.



(a): Typical operation modes in the North Sea.

(b): Typical CPP and FPP characteristics and cumulative thrust demand.

Fig. 9: Operation modes and thrust demand for floating production.

The LCC analysis shown in Fig.10 indicates that the reduction in fuel consumption alone offers acceptable pay-back on the installation investments [3]. In addition, reduced maintenance of thrusters, reduced running hours of engines, and simplified operation will be achieved.

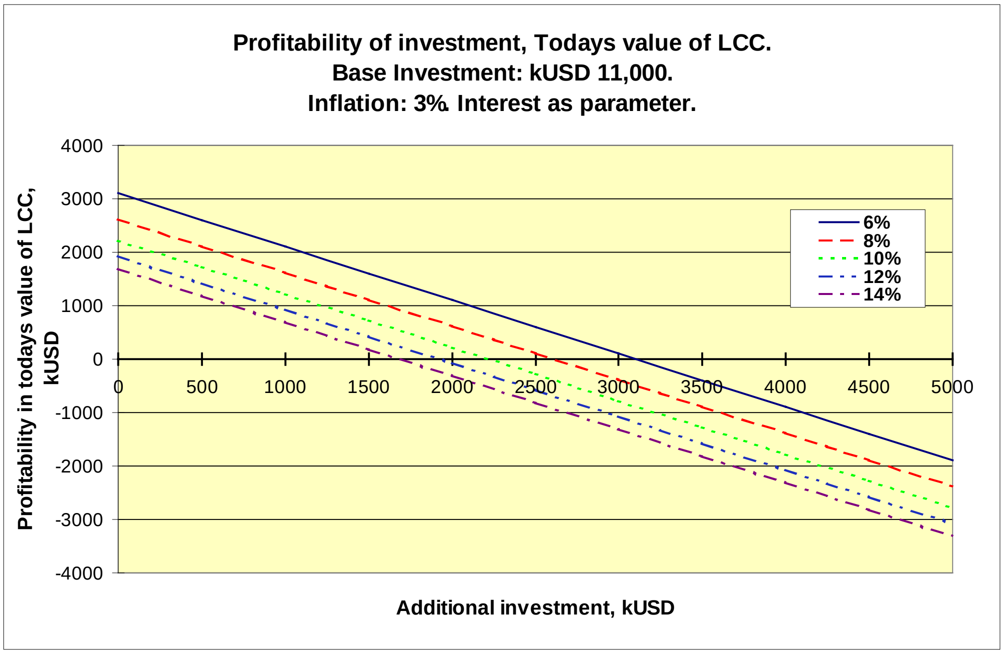


Fig. 10: Investment analysis (Life Cycle Cost - LCC) for variable-speed FPP thrusters vs. constant-speed CPP thrusters for a floating production vessel. The curves show the profitability of the difference in investment between a constant-speed and a variable-speed thruster drive configuration. For this special application, the difference in investment cost is kUSD 2-2.5, hence at break-even with an interest rate of 10%.

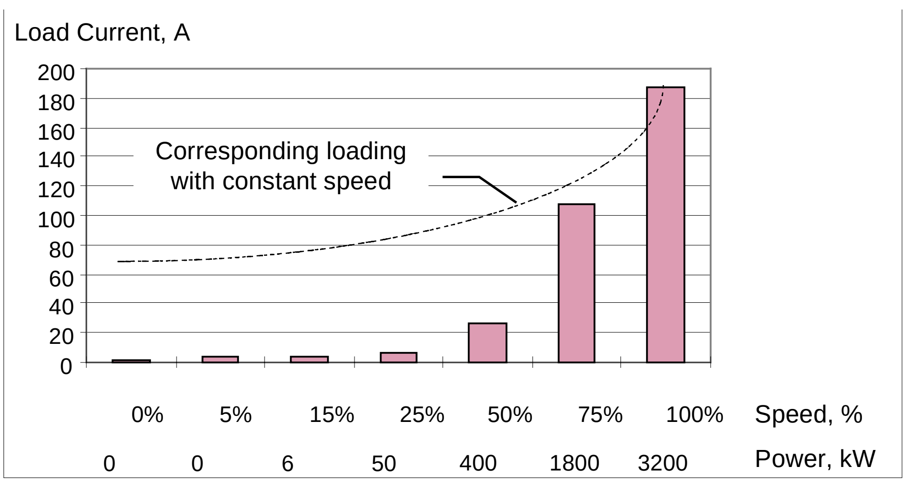
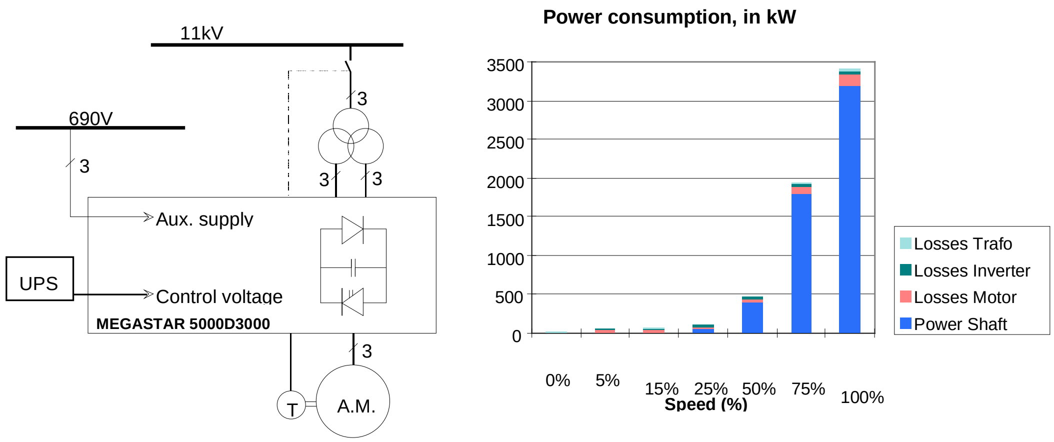


Fig. 11: Drive load current for a 3200 kW PWM variable-speed drive (VSD) compared with a constant-speed CPP thruster.



(a): Schematics of PWM converter drive. *(b): Shaft power and loss contributions to power consumption with VSD.*

Fig.12: High-efficiency, low-loss variable-speed drive (VSD) with PWM converter.

6.2 Variable-speed Drive Technologies

A technical comparison of the alternative variable-speed drives cannot be completely inclusive, since their characteristics are highly dependent on the actual application, voltage level, cooling method, etc. Table 2 presents some qualitative differences among the most important technologies. Details may vary.

7. CONCLUSION

Diesel- or gas turbine-driven generators form the power plant in a vessel with DP or thruster-assisted position mooring. Existing electrical techniques feature a flexibility that enables design of the power plant to meet the requirements for drilling ships and rigs, floating production, shuttle tankers, and service vessels. The evident trend during recent years is that variable-speed AC thruster drives form the preferred solution compared with constant- speed thrusters. The reasons are the improved operational economy with reduced fuel consumption and less mechanical maintenance, as well as the much smoother electrical and mechanical starting transients with a variable-speed motor drive. Fuel savings can be significant, since the vessel operates over much of its time under low weather-load conditions, but the system must be designed for the most adverse weather load. A life cycle cost assessment shows that the savings in fuel consumption over the vessel's life time alone may justify the additional investment in variable speed drive technology.

Table 2: Qualitative comparison among variable-speed drive alternatives.

	SCR DC motor drive	**Cyclo-converter** [1]	**CSI (LCI)** [2]	**VSI PWM** [3]
Amps at low speed	F(torque)	F(torque)	F(torque)	≈ 0
Cosϕ	0 .. 0.9 (≅ prop. speed)	0 .. 0.76 (≅ prop. speed)	0 .. 0.9 (≅ prop. speed)	> 0.95 (≅ constant)
Dynamic response (power, torque)	< 100 ms	< 100 ms	Slower	< 50 ms
Torque ripple	Smooth	Smooth	Pulsating	Smooth
Zero-speed crossing	Discontinuous	Smooth	Pulsating	Smooth
Efficiency at full load	Lower	High	High	High
Harmonic distortion: - at low speed - at full speed	 F(torque) F(torque)	 F(torque) F(torque)	 F(torque) F(torque)	 ≈ 0 F(torque)
Short circuit contribution	No	No	No	No
Motor matching required	Some	Some	Yes	No
Commutator	Yes	No (slipring)	No (slipring)	No

[1] With brushed synchronous motor
[2] With brushed synchronous motor
[3] With cage induction motor

Various thrusters and thruster drives with different characteristics are available. Rotatable thrusters with fixed-pitch propellers and variable-speed motor drives (azimuth thrusters, Azipods) have the flexibility to produce the required thrust in the preferred direction and with high efficiency and precision. These advantages have been utilized in most of the recent projects for DP- or thruster-assisted, moored drilling and production vessels.

Azipods have been proven to be reliable, efficient, and space-saving devices used in tankers, cruise vessels, ice breakers and service vessels. Their potential for use in oil- and gas-related vessels is found to be apparent and is evaluated in several new building projects.

References

1. Ådnanes, A.K., Risdal, E. : *Faster to the field with a better total solution using unified power and automation system*, IMECE'97, 3rd International Marine Electrotechnology Conference & Exhibition, CHINA, 29. May 1997.
2. Garen R., Deinboll O., Sørensen A., Ådnanes A.K., Kuuskoski, J., Stenersen, D., Klokk S.: *Comparison of power and propulsion concepts for supply ships and FPSO's*, paper no. 21, 1st international conference on diesel electric propulsion, 20-23 May 1996, Ålesund Norway.
3. Sørensen, A., Ådnanes, A.K.: High performance thrust allocation scheme in positioning of ships based on power and torque control, DPC, 21-22 October 1997.
4. Ådnanes, A.K.: *Variable Speed FP vs. Fixed Speed CP*, IMCA'96, 31. Oct.- 2. Nov. 1996, Houston.
5. Wilne, T.: *Thruster reliability: The problems and effects of components failures and drive selection*, paper no. 16, 1st international conference on diesel electric propulsion, 20-23 May 1996, Ålesund.
6. NORSOK STANDARD:*E-CR-00, Common requirements electrical systems.* Internet: http://www.nts.no/norsok/e/ecr00102/ecr00102.htm