Dynamic Positioning Committee

Marine Technology Society

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DRIVES SESSION

The Evolution of Marine and Drilling Drives in Today's Market

Paul English

ALSTOM Power Conversion Ltd (Rugby, UK)

INTRODUCTION

The benefits of Diesel Electric Propulsion for Marine applications are well known and documented and the trend is still increasing. Furthermore, advancements in power switching technologies are ever increasing the number of possible solutions available for electric propulsion and other converter related applications onboard ships.

AC drive system technology has for some time been the dominant type of variable speed drive system supplied having overtaken DC drive technology.

The use of AC motor and drive technology offers the following benefits, dependent upon the solution selected:

Generally lower cost
More robust and reliable
Reduced maintenance
Physically smaller for a given rating
High levels of performance
Excellent dynamic response (comparable to DC based drive systems)
Increased motor powers and speeds available
Smooth torque/speed control over full speed range (0 to > 300Hz)
Ride through of dips in supply voltage
Good AC supply power factor over the full speed range
No significant torque pulsations
Lower audible noise levels

The aim of this paper is to firstly discuss the most appropriate AC drive technologies commercially available for marine applications and subsequently to highlight some considerations in their selection and application on board ships.

AC VARIABLE SPEED DRIVES FOR THE MARINE INDUSTRY

There is a very wide range of AC drive systems available but the 3 most common types used in the marine industry are illustrated in Figure 3.

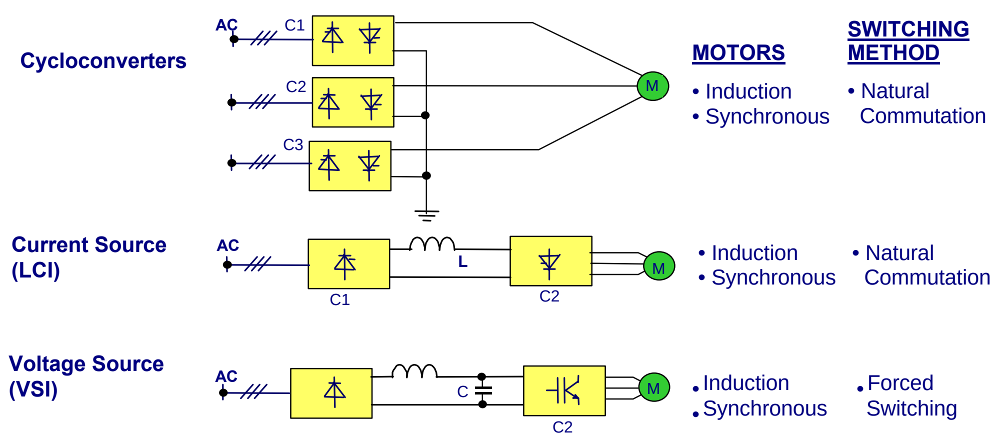

Figure 1 - Main Types of AC Variable Speed Drives

The Cycloconverter and Current Source drives are direct descendants of DC drive technology and use the same basic naturally commutated thyristor converters.

The Voltage Source drives use forced commutated power switches. A wide range of forced commutated power switches are used with 3 types being the most popular.

- Insulated Gate Bipolar Transistors - IGBTs
- Gate Turn Off Thyristors - GTOs
- Integrated Gate Commutated Thyristors - IGCTs

CYCLOCONVERTER VARIABLE SPEED DRIVES

The normal 6 pulse circuit shown on Figure 2 uses three anti-parallel converter bridges. Each bridge is the same as used for a DC drive and uses 6 forward and 6 reverse thyristors.

The thyristors are fired using natural commutation just like DC converters, except that the converter's output voltage is varied slowly up and down to convert the AC supply into a low frequency AC output.

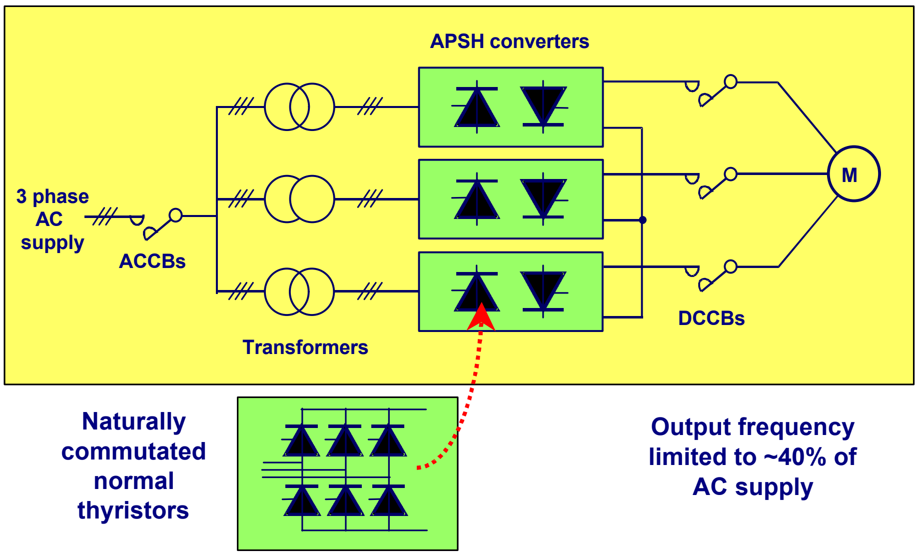

Figure 2 – 6 pulse Cycloconverter Circuit

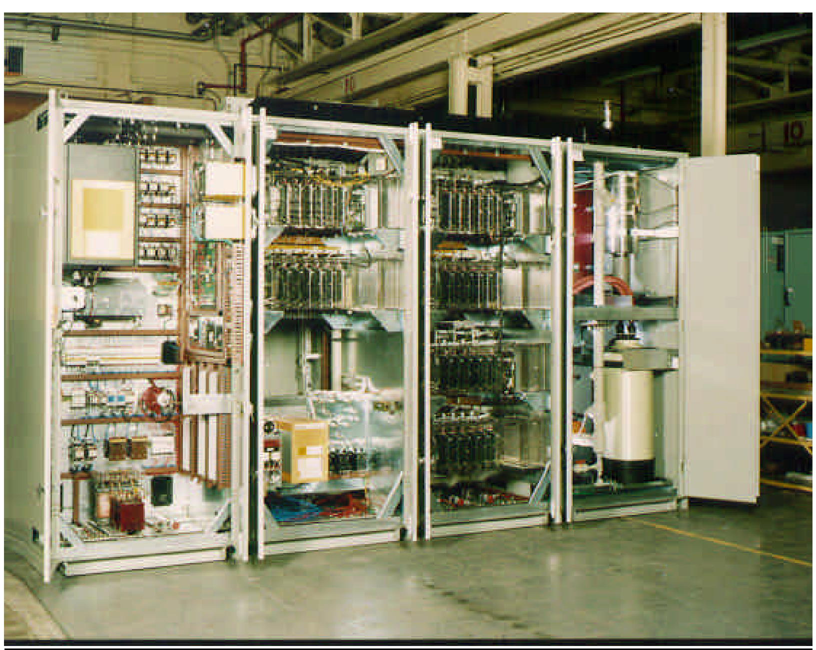

Figure 3 – 5.6MW Water Cooled Cycloconverter Construction

Features

Good performance at low speeds with low torque pulsations
1000:1 speed range
Can easily provide large overloads (e.g. 250% and field weakening)
Can inherently reverse and regenerate
Multiple bridges give high ratings
Excellent dynamic response performance
Ratings typically up to 30MW, 500rpm, 4000Vac

Limitations

Output Frequency limited to 40% of AC supply frequency
Complex AC supply effects

Application

Ideally suited to applications requiring large powers at low speeds and high dynamic performance. Most commonly used in the marine industry for Ice Breaking applications.

Cycloconverter drive technology was ideally suited to the extreme requirements of the US Coast Guard Icebreaker "Healy" pictured below during icebreaking trials. The vessels has twin shafts each rated at 11200kW, each shaft being powered by two 5600kW Cycloconverters capable of providing 175% FLT for 30 seconds at zero speed.

Figure 4 - USCG Icebreaker "Healy"

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CURRENT SOURCE VARIABLE SPEED DRIVES

As a minimum, these use 6 normal thyristors for the input converter and 6 normal thyristors for the output converter. This gives a minimum of 12 normal thyristors required for the basic 6-pulse circuit shown on Figure 7.

The thyristors of the input bridge are fired using natural commutation and are controlled to keep the current at the required level in the DC link reactor.

This type of drive normally uses synchronous motors and this discussion focuses on this application although, if a capacitor bank is added at the motor terminals, squirrel cage induction motors can also be used, with added complexity.

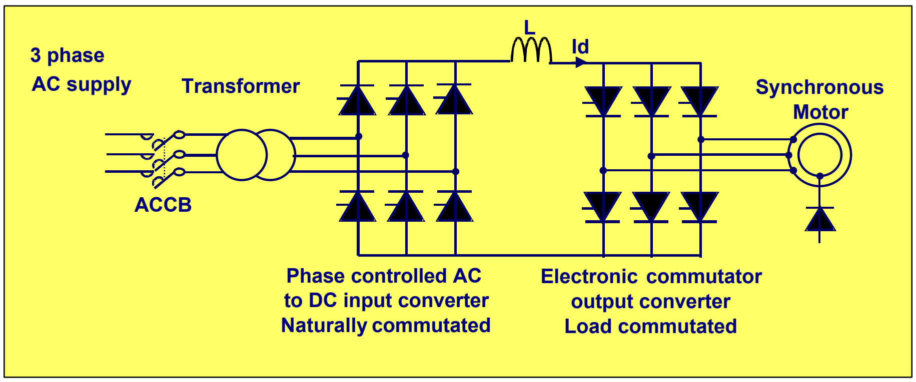

Figure 5- 6 Pulse Synchronous LCI Schematic

The thyristors of the output bridge are fired in step with the rotation of the motor and act as an electronic commutator. This works by using the back emf of the motor to also give natural load commutation of these thyristors. This gives 6 steps of stator current per motor cycle.

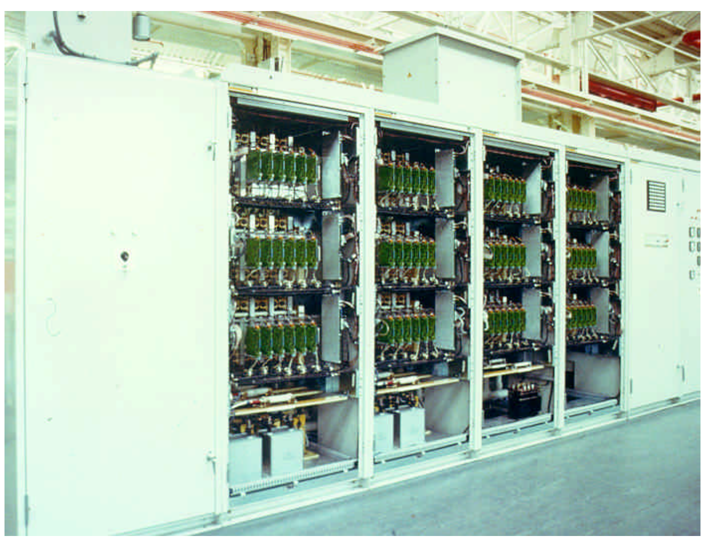

Figure 6 - Water Cooled Synchronous Converter Construction

Features

- Output frequency can exceed AC supply Frequency, eg 80Hz
- Uses Series thyristor to achieve very large ratings
- Can reverse and regenerate
- Simple and reliable
- Ratings typically up to 100MW, 5000rpm, 10000Vac

Limitations

- Reduced performance at low speeds with increased torque pulsations
- Normally used in a 10:1 speed range

Application

- Ideally suited to normal high power ship propulsion applications such as the cruise liner market.

  The pictures below show the RCI Cruise Liner "INFINITY" and her two 19MW Mermaid PODDED Propulsors. Each PODDED propulsor houses a synchronous motor which in turn is fed by dual channel load commutated inverters (LCI's)

Figure 7 - RCI Infinity

Figure 8 - 19MW Mermaid Propulsors

LOW VOLTAGE – VOLTAGE SOURCE INVERTER DRIVES

Probably the fasting growing drive technology in the marine propulsion market as costs continue to reduce and power ratings increase.

These converters use a simple input rectifier to give a fixed voltage DC link via an LC filter. This fixed DC voltage (VDC) is switched on/off very rapidly in the output inverter.

The output line voltage has 3 possible states (+VDC, 0, -VDC) and the timing is varied by Pulse Width Modulation (PWM) to give sinusoidal motor currents, with very low levels of motor torque pulsations.

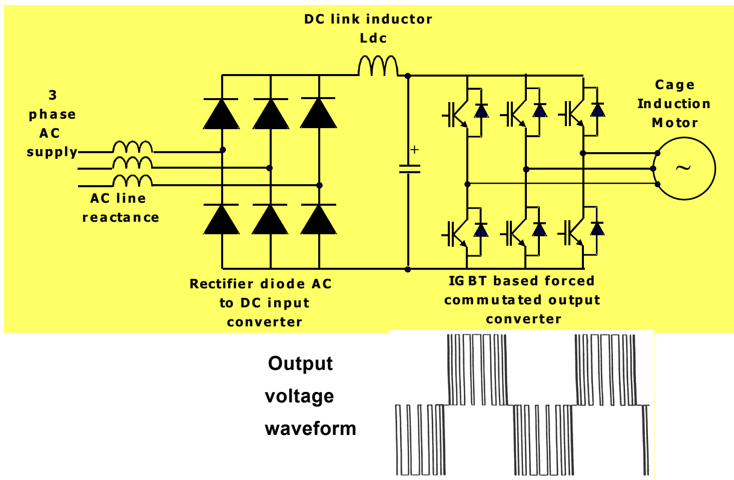

Figure 9 - IGBT Based PWM Converter Circuit

Figure 10 - 2400kW MV3000LC PWM Converter Construction

Liquid Cooled Azimuth Thruster Drive

Features

- Output frequencies to more than 300Hz
- Constant performance at all speeds/loads with low torque pulsations
- 1000:1 speed range
- Very dynamic responses possible
- Reduced impact on AC supply (i.e. dips and harmonics)
- Ratings typically up to 3.5MW, 2000rpm, 6900Vac

Limitations

- Extra equipment required for regeneration
- Standard motor insulation requires evaluation to ensure suitability

Application

- An excellent all round drive technology, not only ideally suited to low to medium power ship propulsion applications but also to the wide range of auxiliary drive requirements onboard (e.g. winches, cranes, pumps etc)

The Caballo de Mar is fitted with 2 x 1430 kW 12 Pulse MV3000 drives for main propulsion.

Figure 11 – Caballo de Mar

COMMON DC BUS VARIANT

One very popular variant is to use several inverters on one DC link. This is called a Common Bus DC link system.

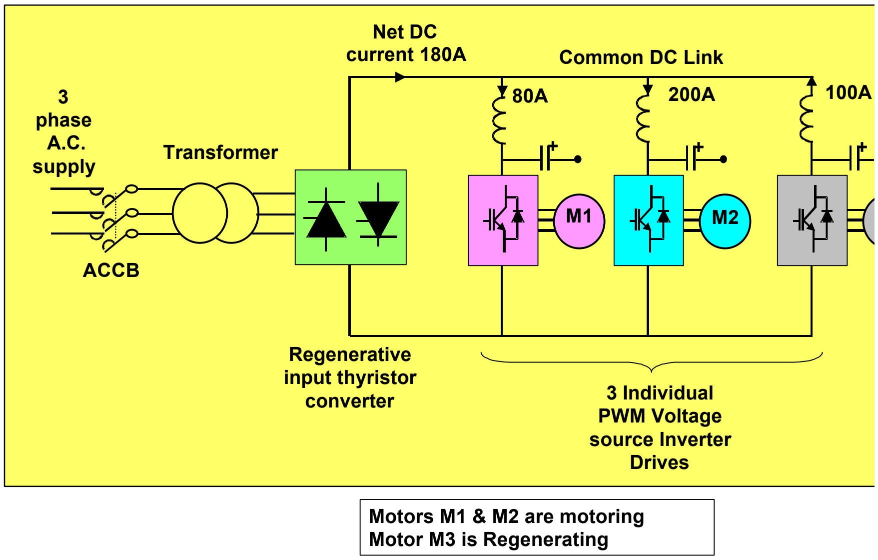

Figure 12 - Common DC Bus System Schematic

Already widely used on land in process line applications (eg: paper mills) the use of common DC bus technology has already been employed on board drilling vessels to feed the process drives associated with the drilling process (eg: top drives, mud pumps etc).

Common DC Bus solutions afford the following benefits:

- Soft run up of all DC link capacitors
- AC supply regeneration can be more economically provided with a single input bridge of higher rating.
- AC supply current is reduced when load diversity dictates that some motors regenerate whilst others motor.
- High ability to ride through AC supply dips
- Up to 240 small AC inverters have been used from a single DC link

MEDIUM VOLTAGE -VOLTAGE SOURCE INVERTER DRIVES

The low voltage, Voltage Source Inverter PWM drives have proved so successful that a challenge has existed to apply this technology at medium voltages up to 6.6kV. This increase is desirable to further increase power ratings and reduce cable sizes and costs.

A typical construction for the 2 level circuit using water-cooled IGBTs is shown in Figure 13.

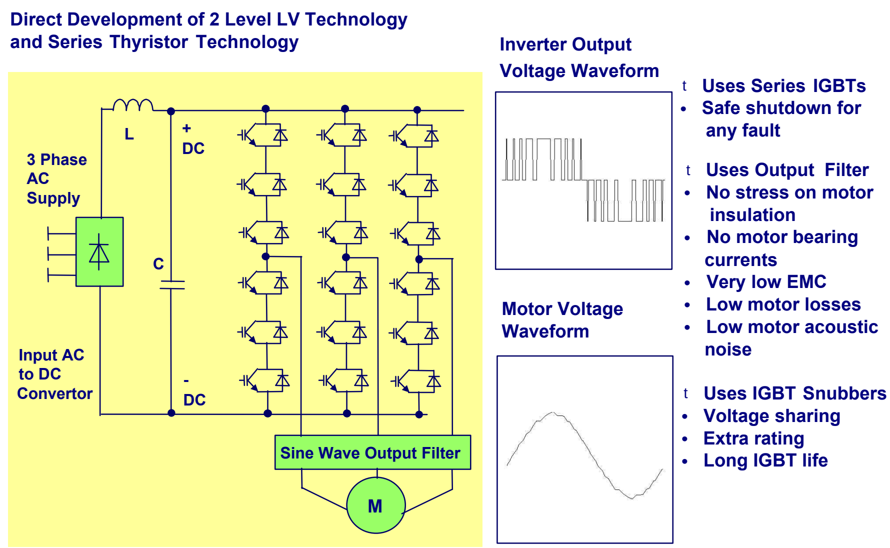

Figure 13 - 2 Level, Medium Voltage PWM Converter Circuit

Multi-level PWM circuits are also available to further improve motor waveforms and increase redundancy but these will not be discussed in this paper.

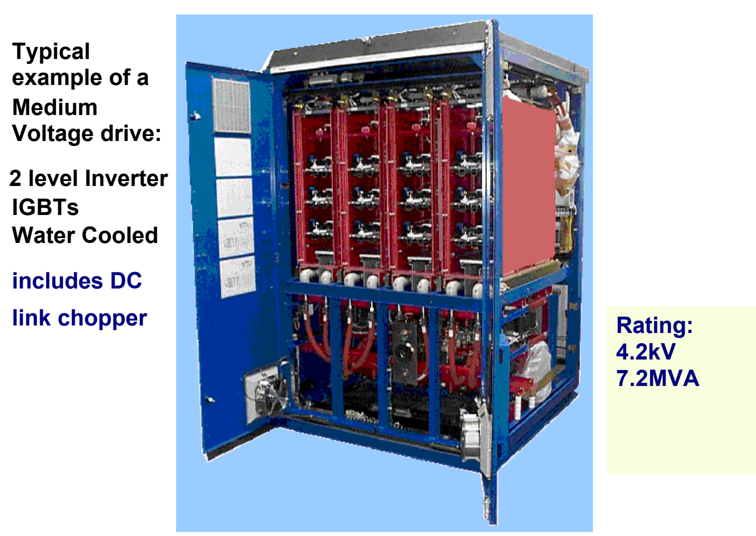

Figure 14 - 4160V, 7.2MVA, 2 Level PWM Converter Construction

Features

- Output frequencies to more than 300Hz
- Constant performance at all speeds/loads with low torque pulsations
- 1000:1 speed range
- Very dynamic responses possible
- Reduced impact on AC supply (i.e. dips and harmonics)
- Reduced cabling costs
- Ratings typically up to 20MW (Commercially up to 6MW), 2000rpm, 6600Vac

Limitations

- Extra equipment required for regeneration
- Output filtering required for some standard induction motors

Application

Ideally suited to medium power ship propulsion applications.

Pride Africa is fitted with 7 Medium voltage VDM5000 IGBT variable speed thruster drives rated up to 4500 kW.

Pride Africa Gusto 10,000 Drill ship

HARMONIC DISTORTION ELIMINATION TECHNIQUES

One of the major considerations when designing the converters for a given ship system is the effect they will have on the supply system. All converters will impose some harmonic distortion on to the supply network which, if left untreated, could adversely affect the operation and life of any other equipment connected to that supply.

There are several ways to minimise converter generated harmonics on-board ships, the two most common being:

- Harmonic Filtering

  Can be prohibitive in terms of cost and space. Design can also be complex due to the interactions of several drives on the same system working in a variety of combinations

- Designing Harmonics Out

  To design the power system such that the Total Harmonic Distortion (THD) does not exceed pre-defined levels without the need for additional filters. Optimisation of transformer impedances and generator reactances can reduce THD but by far the most dramatic improvement can be achieved by increasing the pulse number of the converters beyond the nominal 6 pulse arrangement.

  The magnitude of potential improvements by increasing pulse numbers is illustrated using classical values in the table below.

Harmonic number	**6 Pulse**	**12 Pulse**	**18 Pulse**	**24 Pulse**
5	20.0%	-	-	-
7	14.3%	-	-	-
11	9.1%	9.1%	-	-
13	7.5%	7.5%	-	-
17	5.8%	-	5.8%	-
19	5.2%	-	5.2%	-
23	4.3%	4.3%	-	4.3%
25	4.0%	4.0%	-	4.0%
Total RMS value	**29.0%**	**13.2%**	**11.0%**	**5.9%**

Modern technology is such that 12 pulse is already the standard for the vast majority of medium to low power drive systems. We will now consider the implication of increasing beyond this to further reduce generated harmonics.

18 Pulse Configuration

The 18 pulse circuit requires 3 secondaries for the transformer, requiring a special transformer design.

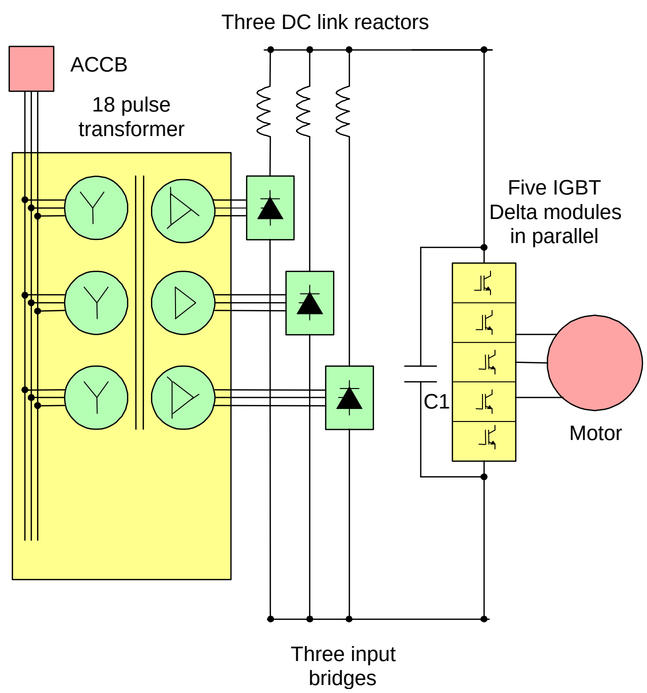

Figure 15 - 18 Pulse VSI Converter Schematic

There are 4 principal disadvantages of this design compared to a 24 pulse design

- If a transformer failure happens all output is lost.
- If a diode bridge failure happens and running is done on any two secondaries the AC supply harmonics do not cancel and high harmonic currents will occur. This is significantly higher than the comparable failure modes of the 24 pulse system.
- The transformer design is complex and the different winding impedances can easily lead to poor current sharing between the 3 secondaries.
- The improvement in net harmonic current distortion is relatively small over a 12 pulse solution and the THD is nearly double that of an equivalent 24 pulse design.

24 Pulse Configuration

To achieve the lowest harmonic distortion levels 24 pulse systems frequently offer the best solution. To implement the 24 pulse solution two standard 12 pulse units can be housed in a common enclosure, thereby minimizing the AC supply cabling to the ACCB and reducing the impact of increased transformer dimensions.

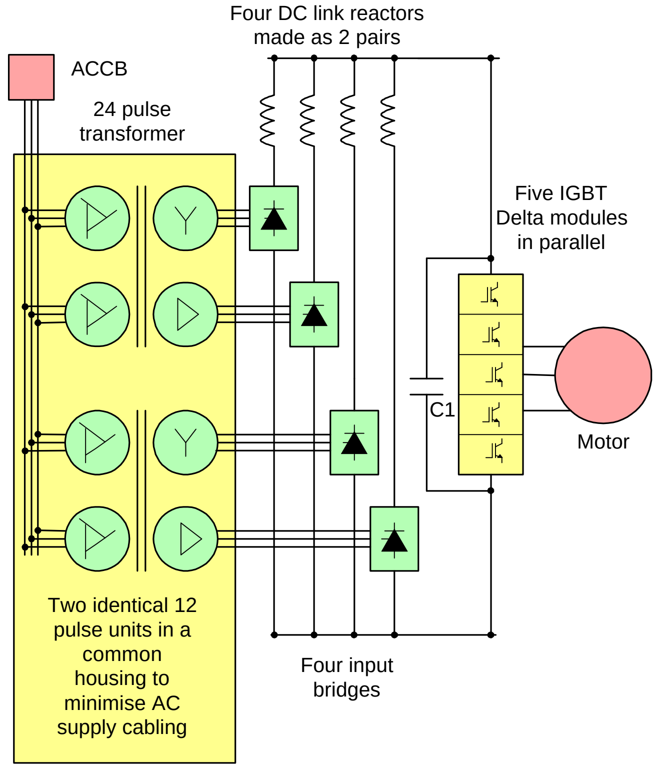

Figure 16- 24 Pulse VSI Converter Schematic

Each of the two transformers is identical and the 24 pulse is achieved by reversing the phase rotation for one unit this can be seen on Figure 16. The use of only 2 circuits per transformer core ensures that the turns ratios and impedances are very well matched. This is essential for correct current sharing between the 4 diode bridges.

If a failure of one of the transformers did occur the faulty unit can be disconnected inside the unit and the other unit can then operate to provide a 50% output power to the motor. For this condition the design ensures that the AC supply harmonics will be at the 12 pulse level. As the power is reduced to 50% this will be give an acceptable level of AC supply harmonic distortion. The level will be 0.5 times the 12 pulse level = 6.6%

Similarly if a fault in a diode bridge occurs the drive can run at reduced power as a 12 pulse system.

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CONCLUSION

Variable speed drives continue to develop very rapidly and their application on board ships is ever increasing.

The PWM Voltage Source Inverter configurations are dominating the market and are now also available at medium voltage. It has long been established in on-shore applications and now the numerous benefits provided are being recognized by the marine marketplace. With drive ratings at low voltages now nearing the 4MW mark it fulfills the majority of commercial propulsion requirements. Alternative AC technologies are then only required for the few specialist or particular large applications exhibited in the military and cruise type markets.

Diesel Electric now offer's a real challenge to mechanical solutions for all sizes and applications of DP vessels. Their are true operating cost savings to be achieved when combining VSD FPP thrusters with the Dynamic Positioning system modes such as Relaxed DP making electric propulsion the first choice of many new build projects.