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DYNAMIC POSITIONING CONFERENCE
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THRUSTERS AND DRIVE SYSTEMS

Discoverer Enterprise Propulsion System Case Study

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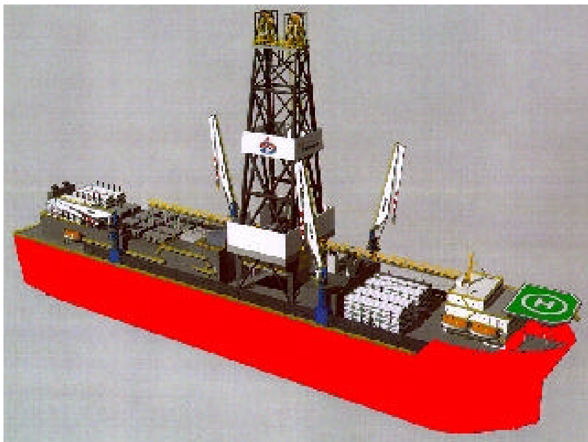
Discoverer Enterprise, the Vessel

To maintain legal title of offshore leases, the owners of these leases must commence drilling within a fixed time period. For the many deepwater fields discovered around the world in the 1980's, this lead to a pressing need in the 1990's for drilling fleets capable of operating at greater depths than ever before.

Houston-based Transocean Offshore Inc., a world leader in drilling, took the initiative by planning a fleet of new vessels designed specifically for such work. The first of this fleet was the discoverer Enterprise.



Ship characteristics	
Length, oa	254.4 m
Length, bp	240.0 m
Breadth	38 m
Depth	19 m
Service speed	14 knots
No.of passengers	200

Discoverer Enterprise is designed to work in water depths up to 10,000 Feet (3500m), and in addition, to penetrate up to 35,000 ft (10,660m) into the sea bed. This represents a massive drilling load - Thousands of tons of drill-string components to be manoeuvred in and out of position for every drilling.

The fleets designers chose a monohull design. With shorter build time than a semi-submersible rig, a monohull would be ready in time to exploit the market opportunity, and with wider choice of drydock facilities world-wide for low maintenance costs.

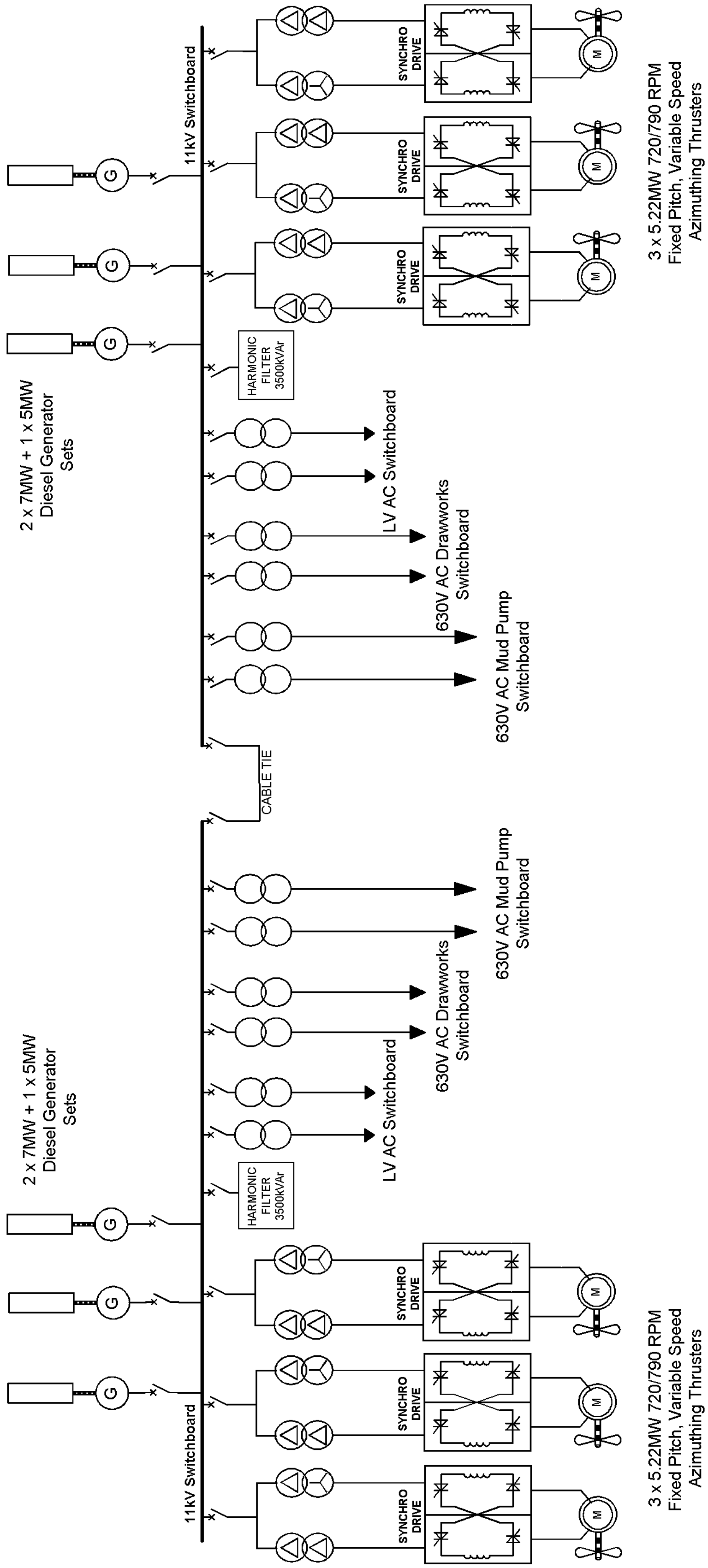
The ability of a large monohull to carry higher payload and so operate without costly support vessels was also a key factor to minimise total costs for the vessels operators.

Cegelec were chosen as the contractor for the vessels power distribution, thruster drives, and drilling systems.

Cegelec's Scope of Supply

Cegelec were contracted to supply the following items of plant for the vessel:

- 11kv Switchboards
- 11kv Harmonic Filters
- 11kv/480V Service Transformers and Switchboards
- 11kv/630V Drilling Transformers and Switchboards
- Azimuth Thrusters Drive Systems including Associated Transformers, Drives and Motors.



Single Line Diagram of 11kV Power System

The main power system on the vessel is generated at 11kV by a total of 6 Diesel Generator Sets (4 x 7MW and 2 x 5 MW).

This power is distributed by two 11kV Vacuum Switchboards connected by a cable tie.

Each side of the power system is a mirror image of the other side, each including three diesel engines, three thruster drive systems, a harmonic filter and supply transformers for the Services, mud pump and drilling switchboards.

In this paper we shall be looking in more detail at the propulsion system for the vessel, i.e. the six azimuthing thrusters fitted to the hull.

Thruster Drive Systems

The vessel is fitted with 6 identically rated azimuthing thrusters.

Thruster Specifications:

- Fixed Pitch
- 5.2MW
- Variable Speed 0-790 RPM
- Azimuthing
- Reversing

These thrusters were driven by Cegelec's Synchronous Load Commutated Inverter (LCI) or

Introduction to Synchrodrive

The Synchrodrive system is an A.C. Variable Speed drive system, comprising of input transformers, a synchroconvertor (including a DC Link Reactor), and a synchronous a.c. motor.

The drive can operate in all four quadrants, i.e. motoring in both directions, or regenerating in both directions. Therefore, as well as powering, the drive can be used to remove kinetic energy from a system, convert it back into electrical energy and feed it back into the mains supply.

The power source for the Synchroconvertor is a fixed frequency mains supply, usually at a high voltage.

In this application, the power source is the six main diesel generators generating at 11kV, 60Hz.

Transformers are required to reduce this high supply voltage down to a level suitable for the synchroconvertor input.

In this application there are two supply transformers per thruster drive which reduce the input voltage of 12kV to a supply bridge input voltage of 1266V a.c..

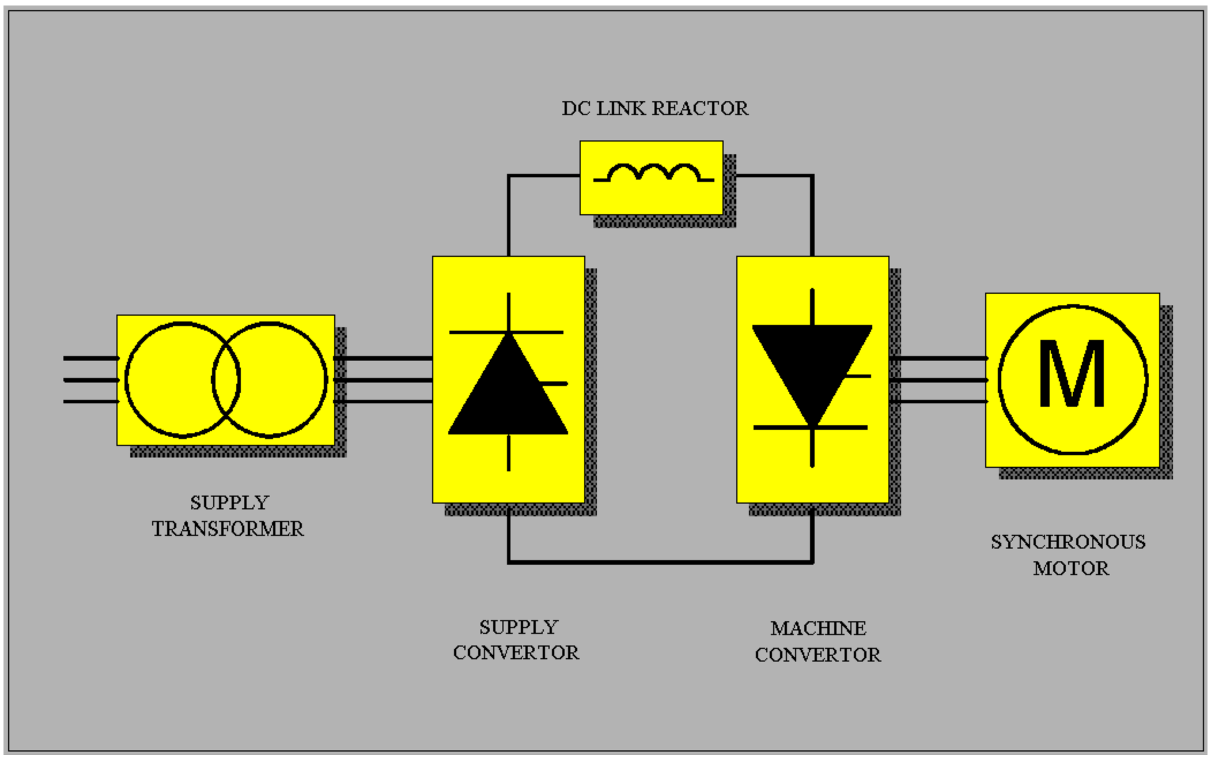
The output from the synchroconvertor is variable frequency a.c. that is input directly to a synchronous motor. As the output frequency of the synchroconvertor is varied to match the speed demand, the speed of the synchronous motor on the output varies, since the speed of the motor is directly proportional to the frequency applied to it.

In theory, the synchroconvertor could produce an output frequency from zero to several times the supply frequency. However, the Synchroconvertor normally produces output frequencies between zero and the supply frequency. In practice, the Synchroconvertor output frequency is chosen in conjunction with the number of poles on the motor to achieve the required speed at a reasonable frequency. For some marine applications, this output frequency can be lower than the mains frequency, due to the relatively low rev/min. of some large marine propellers.

For this application, the maximum speed of the propulsion motor is 790 rev/min. which corresponds to a synchroconvertor output frequency of 52.7Hz (8 Pole machine). The motor can however produce its maximum power output of 5.22MW, at any speed between 720-790 RPM.

The Basic Synchrodrive Power Circuit

The Synchrodrive has a d.c. link arrangement with one or more input convertors to rectify the a.c. into d.c., and one or more machine convertors to invert that d.c. back into variable frequency a.c..



Basic Synchrodrive Circuit Diagram

Each of the convertors is a three phase fully controlled thyristor bridge, and may consist of single devices in each arm, or combinations of series and parallel devices to achieve the desired current or voltage rating for a particular application.

The diagram above illustrates the basic elements of the Synchroconvertor, this diagram shows the Synchroconvertor in its simplest form. Although this configuration is used for some applications, in most cases more than this minimum arrangement is used, for harmonic and power level reasons.

This diagram is useful for initial understanding of the drive elements and basic operation.

Major Synchrodrive Components

Supply Transformer

On the left of the basic synchrodrive circuit is the supply transformer. This is used to reduce the level of the generated supply to a suitable level for the synchroconvertor.

Supply Convertor

The supply transformer secondary is connected into a fully controlled three phase thyristor converter. The devices within this ‘supply’ convertor are switched on in a carefully controlled manner to create d.c. on the link. The devices switch off naturally, as the current on a particular phase reduces to zero, they are not forced to turn off.

Machine Convertor

The d.c. on the link is inverted back to a.c. using the machine convertor, which once again, is carefully controlled to allow variable frequency a.c. to be produced on the a.c. output lines of the ‘Machine’ convertor.

D.C.Link

The d.c. link is the connection between the supply and the machine convertors, it is because of this link that the drive is able to operate at frequencies completely independent of the supply frequency.

The d.c. link reactor is included in the circuit to smooth out the d.c. current flowing in the link, and to limit the rate of rise of current should a fault occur. This allows fast acting electronic protection, and the supply circuit breaker to be employed in place of fuses and motor circuit breakers.

Synchronous Motor

The motor is constructed similarly to a normal fixed frequency motor, however, it may have adesigned top speed that does not relate to the usual 50 or 60 Hz, but a lower frequency, especially for some marine applications. With large diameter marine machines, it is usually mechanical considerations that impose a maximum speed on a particular low frequency machine.

The excitation required by the propulsion motor field is also supplied from the Synchroconvertor. This is supplied through a small dedicated power controller within the Synchroconvertor cubicles. This excitation can either be transmitted to the rotor by means of slip rings, or by means of a rotating brushless exciter, where there is no direct connection to the shaft, with the d.c. excitation being derived from rotating diodes on the motor shaft.

PRINCIPLES OF OPERATION

Normal Speed Range (MODE 2)

This speed range is defined as when the motor is operating from approximately 10% to 100% of rated frequency/speed in either direction, and is referred to as operation in MODE 2.

The Supply Convertor is used to control the level of d.c. current to that appropriate to the requirements of the motor and the motor convertor thyristors are switched to ensure that this current passes through the correct phase windings of the motor to obtain the motor torque. The Supply Convertor is therefore acting as a controlled rectifier and the Motor Convertor as an inverter passing power from the d.c. link to the motor windings.

The switching points of the Motor Convertor have to be chosen to allow inversion to occur and to make use of the motor voltages to effect the transfer of current from one phase to another by natural commutation. The switching of the machine bridge thyristors must be determined by the rotational position of the motor, i.e. the relationship between the stator and rotor windings.

The most accurate way to determine the point at which to switch the thyristors is to use the sinusoidal voltages generated by the machine as it rotates. From this voltage signal, the precise points of thyristor operation can be determined. The Synchrodrive therefore does not require the use of a shaft encoder during the normal (MODE 2) operating speed range. The point of operation of devices is determined from the stator voltage feedback signal, and the devices are naturally commutated by the load (motor). The drive is therefore referred to as an LCI Drive, a Load Commutated Inverter Drive.

Cegelec refer to the above operation, using the voltage generated by the motor for commutation and thyristor control as MODE 2 Operation.

The other mode of operation is used for low speeds and is referred to as MODE 1 Operation.

Low Speed Operation, 0-10% Rated Frequency/Speed (MODE 1)

Since the motor generated voltages are proportional to speed if excitation remains constant, as the machine slows down, these voltages are not sufficient to allow switching to take place reliably, therefore a different method is employed for low speed operation.

In general, it is possible to use the motor generated voltages to obtain operation down to speeds of around 10% of rated speed, however at speeds lower than this, including starting, the drive requires a shaft encoder to determine rotor position in relation to the stator.

The shaft encoder on the motor is a simple robust construction of one proximity detector per phase. As a lobed wheel passes this detector, the SIGMA Controller detects that the rotor is in the correct angular position for current to be switched to the next motor phase.

The point at which the next phase is energised is therefore decided by the shaft position encoder which indicates the physical position of the rotor field poles with respect to the stator.

This control method is used for starting and low speeds only, and is referred to as MODE 1 Operation.

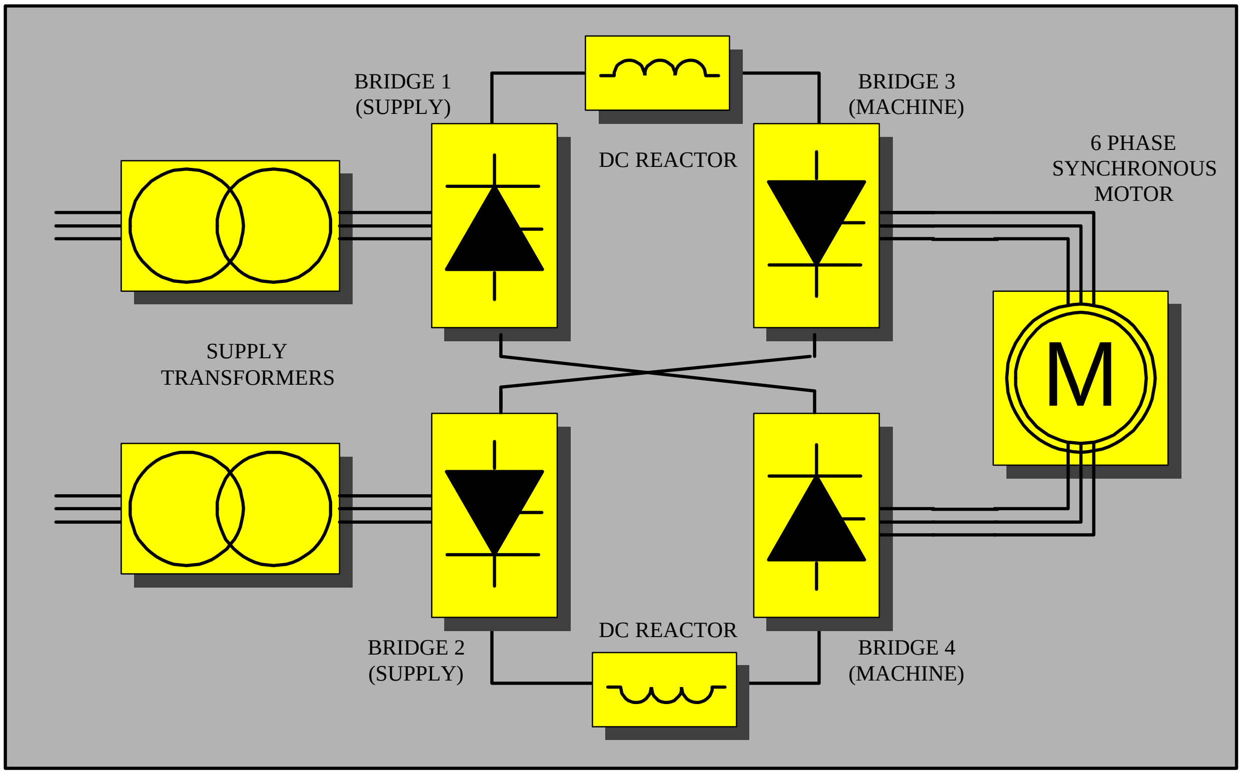
The Synchrodrive therefore only requires its shaft encoder for low speed operation and starting.

Changeover between MODE 1 and MODE 2 is automatic, and invisible to the operator.

Discoverer Enterprise Equipment

Synchrodrive Circuit Used on 'Discoverer Enterprise'

There are a total of 6 propulsion Synchrodrives used on Discoverer Enterprise, one per Thruster.



Synchroconvertor Circuit Used in this Application

In the arrangement for this vessel each Synchrodrive consists of:

- Two Supply Transformers (in a common enclosure)
- Two Supply Convertors
- Two DC Link Reactors
- Two Machine Convertors
- One Six phase Thruster Motor.

Supply Transformers

There are two 3187 kVA transformers supplying each Synchroconvertor, these are switched from a common HV circuit breaker.

The two transformers are electrically phase displaced by 30 degrees, by having different secondary windings, to reduce the harmonics on the supply by acting as a 12 pulse system.

Each supply transformer feeds one supply convertor, transforming the generated supply voltage at the HV switchboard down to 1266V at the supply bridge input terminals.

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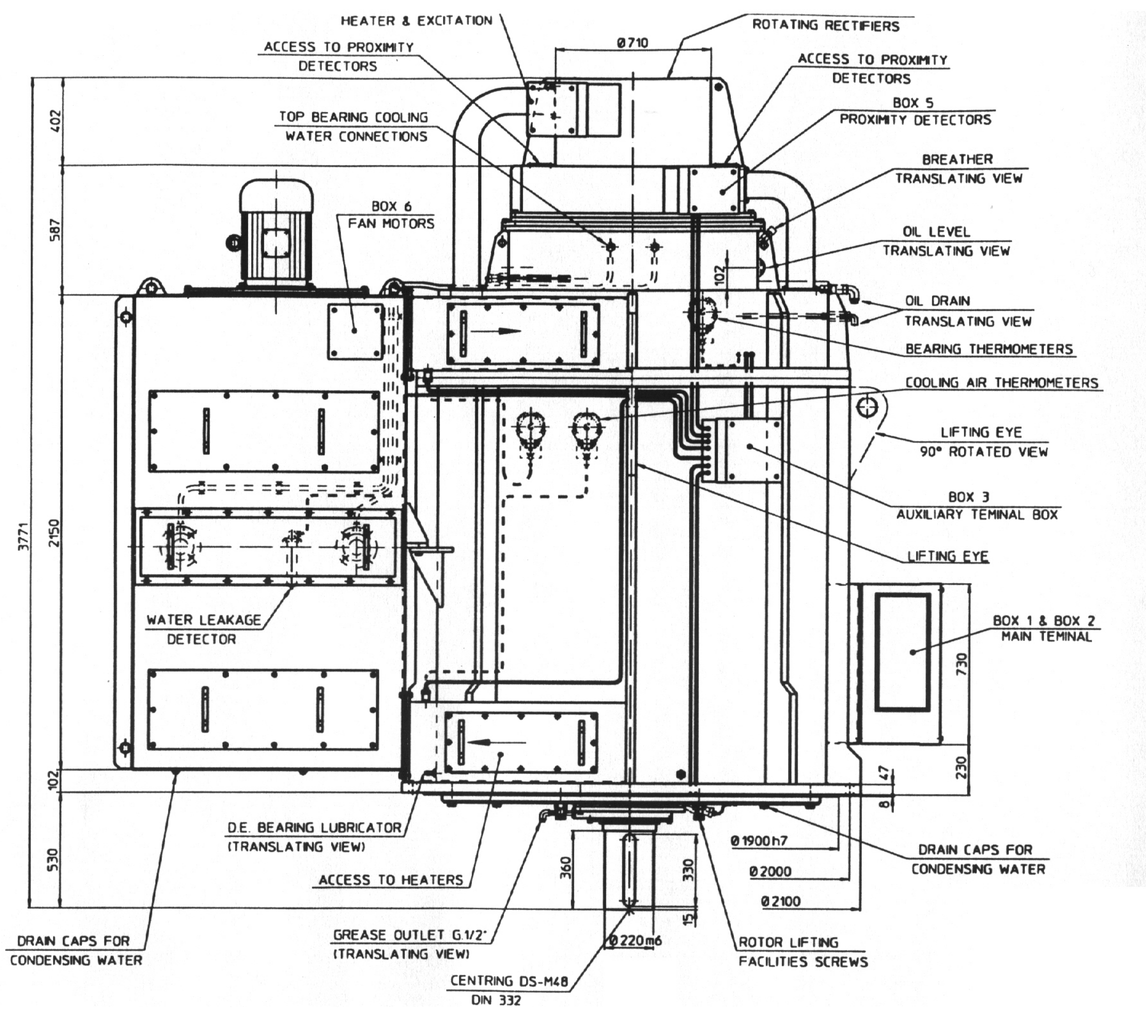
Synchronous Thruster Motor

The 5.22MW synchronous motor on each thruster has two sets of three phase windings, displaced by 30 Degrees.

The motor is a vertically mounted machine with self contained bearings.

The motor is Closed Air/Closed water cooled with the heat transferred to the ships water via a tube cooler. Air is circulated around the machine and through the heat exchanger by means of two electrically powered fans on the top of the motor cooler.



5.22 MW Vertical Synchronous Thruster Motor

The machine stator is supplied from the synchroconvertor at 0-1250V a.c. depending upon the motor speed, and at a maximum frequency of 52.7Hz.

The machine excitation is produced by a rotating exciter on the motor shaft, the a.c. supply to this exciter is from a power controller within the drive cubicle.

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The Synchroconvertor

Supply Convertors

There are two supply convertors, each fed by a separate transformer, this enables the d.c. link current to have less a.c. ripple imposed on it. The supply convertors act as controlled rectifiers to vary the voltage on the D.C. Link as required. They are also used in mode 1 to commutate the machine bridge thyristors by shutting down the dc link to take the current in the machine bridges to zero.

Machine Convertors

There are two machine convertors, each machine convertor supplies one set of three phases of the propulsion motor stator. In Mode 1 the bridges are force commutated by the supply bridges switching the DC link on and off. In Mode 2, the devices commutate naturally using the generated voltage of the machine.

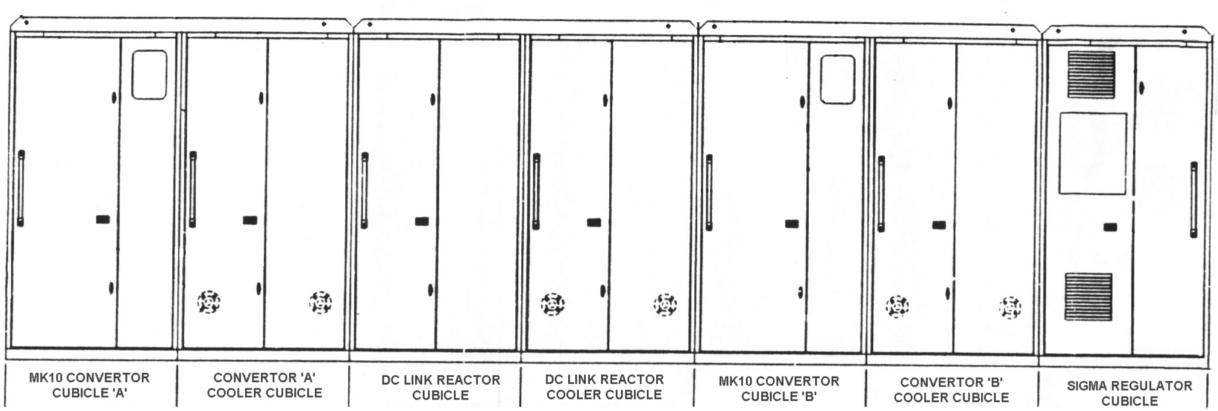
DC Link

There are two reactors in the d.c. link. The Link carries the total current flowing through the two supply convertors, so there is only one d.c. current path.

Physical Arrangement of Synchrodrive on Discoverer Enterprise

Each thruster drive suite consists of 8 cubicles, from left to right:

- Convertor Cubicle A (Containing one supply bridge and one machine bridge)
- Cooler Cubicle for Converter Cubicle A (Containing Air to Water Heat Exchanger and Fan)
- DC Link Reactor Cubicle (Containing a double Unit, Air Cooled DC Link Reactor)
- Cooler Cubicle for DC Link Reactor Cubicle.
- Convertor Cubicle B (Containing one supply bridge and one machine bridge)
- Cooler Cubicle for Converter Cubicle.
- Regulator Cubicle (Containing the Sigma Drive Controller and all of the control electronics)

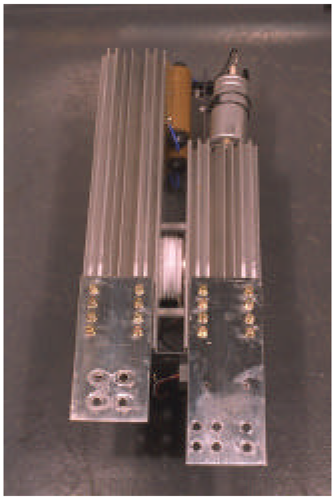


5.22MW CACW Synchroconvertor Cubicle Arrangement on Discoverer Enterprise

Convertor Cubicle Hardware

The Mk10 Convertor Cubicles contain the thyristors (or SCR's).

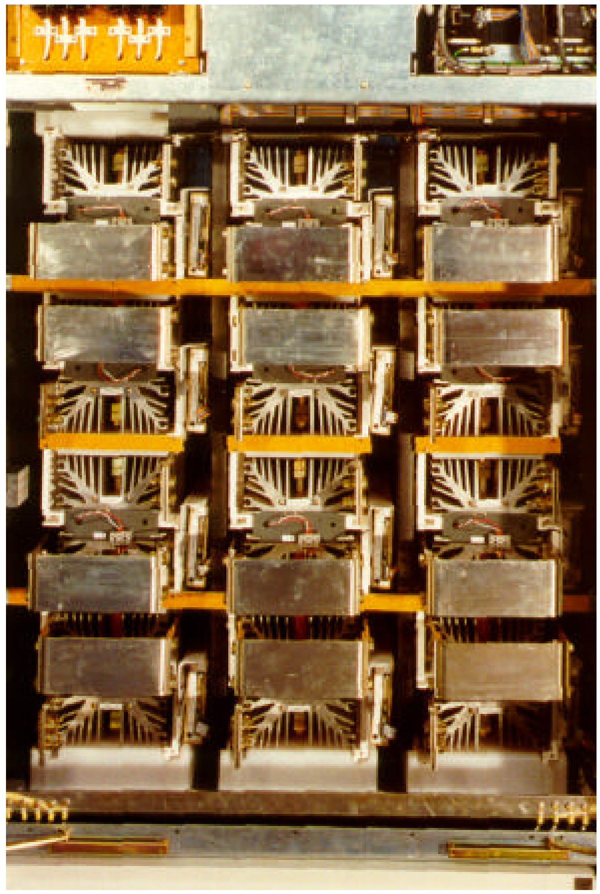
The design of the convertor bridges is modular and very easy to maintain.



Mk10 Thyristor Module

Each of the thyristors is mounted, with its associated snubber circuits, on a removable module. The thyristor device itself is sandwiched between two air cooled heatsinks.

These modules are standard units, and can be built up into convertors in may different configurations, the configuration for one of the convertors in the Discoverer Enterprise Drive can be seen on the right.



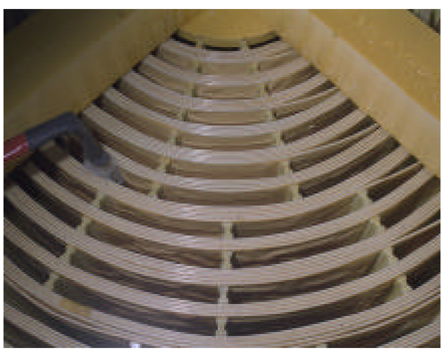
Thryristor Convertor
(Supply and Machine Bridge)
Using Mk10 Modules

The modules are removed from the front of the convertor and can be replaced in a matter of minutes.

The modules are also light enough to be removed without any special apparatus, and can easily be carried by one person.

DC Reactor Cubicle

The middle cubicle in the suite contains the DC Reactor, this is a dual unit with one reactor on top of the other.



DC Reactor Construction

The reactor is air cooled, and made up from concentrically wound insulation and metallic foil. The air passes through spaces between the winding before being circulated through the adjacent cooler cubicle.

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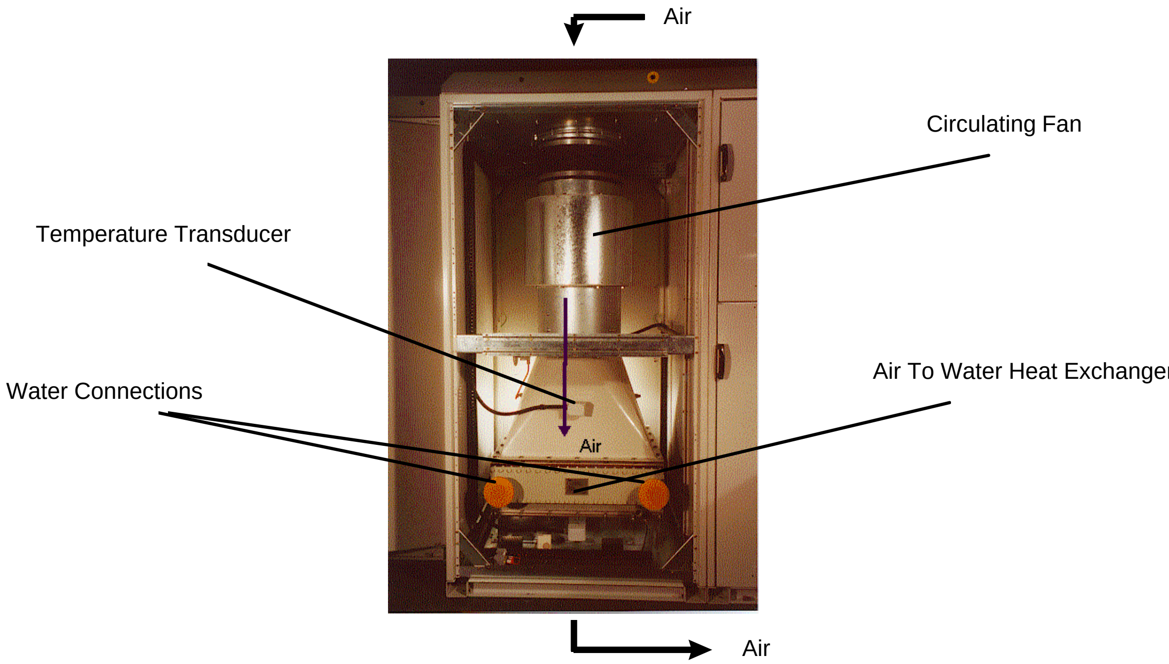
Cooler Cubicles

Each of the Reactor and Convertor cubicles has an adjacent cooler cubicle to remove the heat from the cooling air and transfer it to the vessels cooling water system.



Cooler Cubicle Arrangement

Hot air flows out of the top of the convertor/reactor cubicles, along an air channel on the top of the cubicles, and down through a air to water heat exchanger.

In the air path is a circulating fan, and a silencer.

Control System (Regulator Cubicle)

The regulator houses all of the light electronics and associated equipment required to control the drive, and to interface with the other ship systems for operation and monitoring.

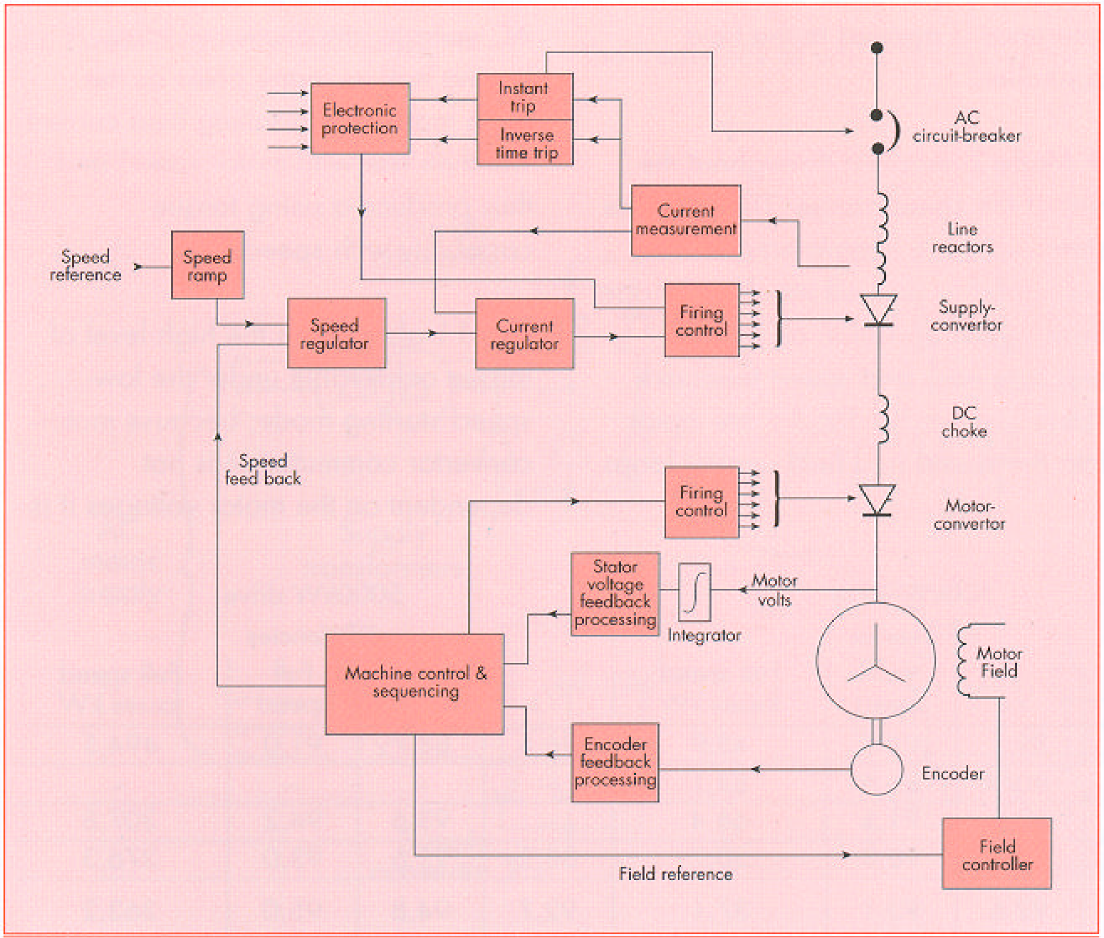
At the heart of the regulator cubicle is the Sigma Drive Controller.

Sigma Drive Controller

The SIGMA Drive Controller is a microprocessor-based programmable controller which performs two basic functions:

Sigma Drive Controller

- Fast control and electronic protection of the supply, machine and excitation convertors.
- General Role as a programmable logic controller (PLC) for operation of all of the Synchroconvertor auxiliaries and external interfaces.



Sigma Control System Block Diagram

In its first role, the SIGMA runs extremely fast software control loops to co-ordinate the accurate firing of all of the thyristors in the drive convertor bridges to enable the drive to exhibit good speed and current control.

In its second role, the SIGMA runs a less fast software program, more like a normal PLC, to enable it to communicate with other plant, for general I/O and for control of Synchrodrive auxiliary fans/pumps etc.

The diagram above shows the basic block diagram for the Synchrodrive control system. Most of the functions above are undertaken in software within the Sigma Controller, and are therefore repeatable, drift free and accurate, from first commissioning and throughout the life of the vessel.

Conclusion

Discoverer Enterprise is fitted with a proven, very capable, simple and robust drive system for each of its thrusters.

The Synchroconvertor is well suited for many marine applications, and this variant, the Mk10, has been used for many years in applications on and offshore.

It is both reliable and easy to maintain and incorporates all of the diagnostic advantages of the Sigma Controller and its associated hardware.

The 12 pulse configuration, easily achievable using the modular Mk10 convertors provides a powerful drive whilst imposing lower harmonic distortion onto the 11kV system.

The distortion that is imposed on the system is also at fixed frequencies, so can easily be filtered out using simple passive filters.

Why opt for something more complicated unnecessarily?