(1) PULSE WIDTH MODULATION – AC to DC to AC

This type of converter is used for induction motor drives and uses transistors as the switching devices. Unlike thyristors, a transistor can be turned on and off by a control signal and at a high switching rate.

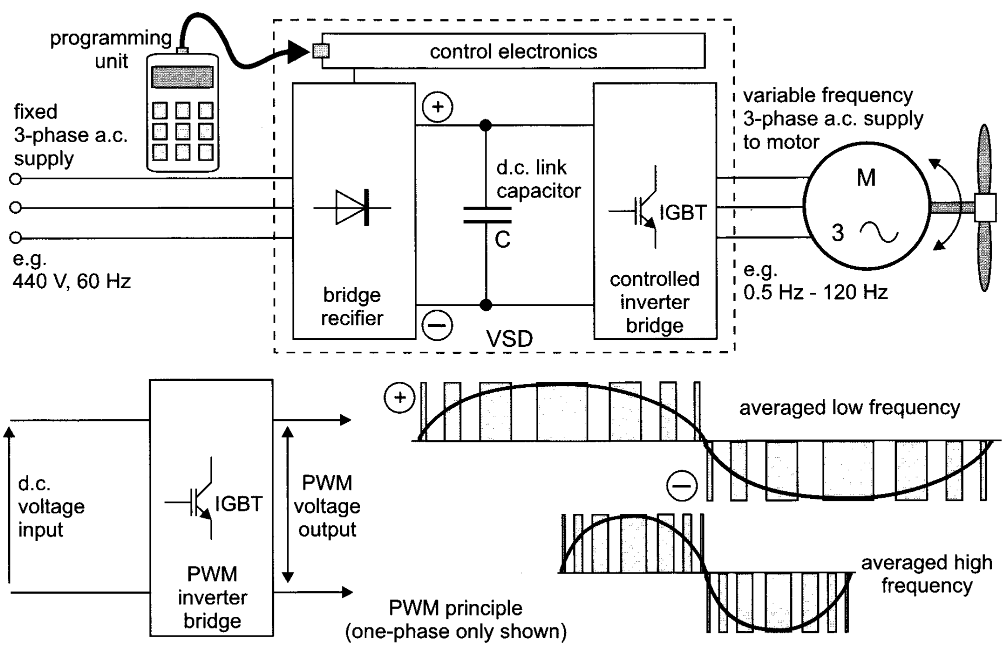
The input rectifier stage is not controlled so is simpler and cheaper but the converter will not be able to allow power from the motor load to be regenerated back into the mains supply during a braking operation.

From a 440 V a.c. supply, the rectified d.c. (link) voltage will be smoothed by the capacitor to approximately 600V. The d.c. voltage is chopped into variable width, but constant level, voltage pulses in the computer controlled inverter section using IGBTs (insulated gate bipolar transistors). This process is called pulse width modulation or PWM. By varying the pulse widths and polarity of the d.c. voltage it is possible to generate an averaged sinusoidal a.c. output over a wide range of frequencies typically 0.5-120 Hz.

Due to the smoothing effect of the motor inductance, the motor currents appear to be nearly sinusoidal in shape. By sequentially directing the currents into the three stator windings, a reversible rotating magnetic field is produced with its speed set by the output frequency of the PWM converter.

Accurate control of shaft torque, acceleration time and resistive braking are a few of the many operational parameters that can be programmed into the VSD, usually via a hand-held unit. The VSD can be closely tuned to the connected motor drive to achieve optimum control and protection limits for the overall drive.

Speed regulation against load changes is very good and can be made very precise by the addition of feedback from a shaft speed encoder. VSDs, being digitally controlled, can be easily networked to other computer devices e.g. programmable logic controllers (PLCs) for overall control of a complex process



(2) CURRENT SOURCE INVERTER (SYNCHROCONVERTER) – AC to DC to AC

An inverter is an electronic circuit that converts direct current (DC) to alternating current (AC).

A current source inverter accepts input from a power supply that acts as a current source rather than a voltage source. Within some limits, a DC current source delivers a set current to a load without regard to the impedance of the load or the voltage required. Most DC power sources, such as generators and batteries, are voltage sources that deliver a set voltage to the load regardless of the current drawn by the load within some limits.

While a voltage source inverter produces an AC voltage by switching the input voltage to provide positive and negative voltage pulses, a current source inverter produces an AC current by switching or steering the input current to divide the current into positive and negative current pulses.

A synchroconverter has controlled rectifier and inverter stages which both rely on natural turn-off (line commutation) for the thyristors by the three-phase a.c. voltages at either end of the converter. Between the rectification and inversion stages is a current-smoothing reactor coil forming the d.c. link. An operational similarity exists between a synchro-drive and a d.c. motor drive.

This view considers the rectifier stage as a controlled d.c. supply, and the inverter / synchronous motor combination as a d.c. motor. The switching inverter acts as a static commutator. The combination of controlled rectifier and d.c. link is considered to be a current source for the inverter whose task is then to sequentially direct blocks of the current into the motor windings.

The size of the d.c. current is set by the controlled switching of the rectifier thyristors. Motor supply frequency (and hence its speed) is set by the rate of inverter switching. The six inverter thyristors provide six current pulses per cycle (known as a six-pulse converter).

A simplified understanding of synchroconverter control is that the current source (controlled rectification stage) provides the required motor torque and the inverter stage controls the required speed.

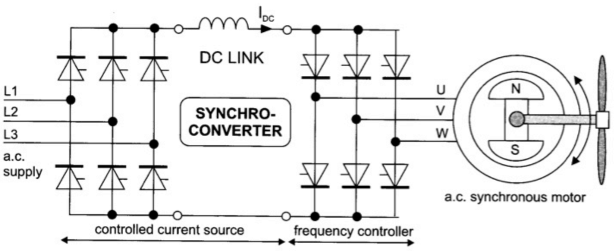
As the supply (network) and machine bridges are identical and are both connected to a three-phase a.c. voltage source, their roles can be switched into reverse. This is useful to allow the regeneration of motor power back into the mains power supply which provides an electric braking torque during a crash stop of the ship.

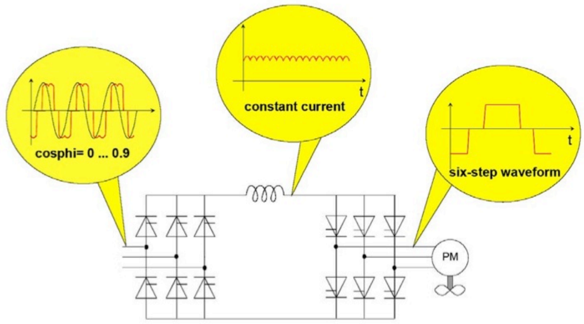
The thyristors of the input bridge (line converter) are fired using natural commutation and are controlled to keep the current at the required level in the DC link reactor.

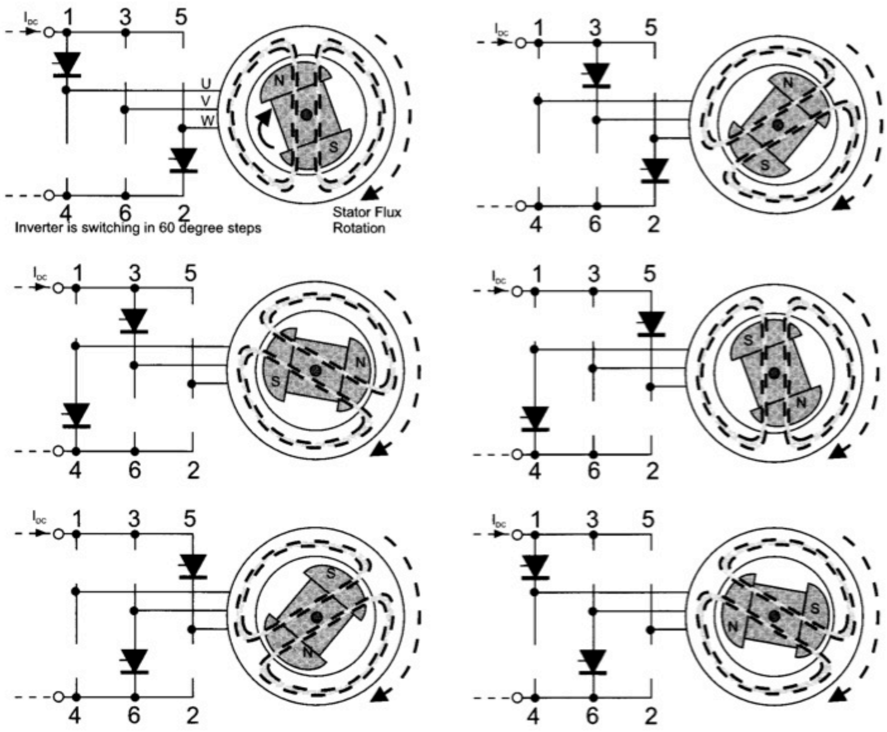
- The thyristors of the output bridge (load converter) are fired in step with the rotation of the motor and act as an electronic commutator. This works by using the back emf of the motor to also give natural load commutation of these thyristors.

- CSIs, also called current-fed inverters, behave like a constant current generator, producing an almost square-wave of current. This gives 6 steps of stator current per motor cycle, see figure for six-step waveform.

Sometimes the required range of control of thrust can be accomplished by controlling the pitch of a controllable pitch propeller (CPP) in conjunction with the (limited) speed control of the synchronous propulsion motors.







(3) VOLTAGE SOURCE INVERTER (CYCLOCONVERTER) - AC to AC

While a synchroconverter is able to provide an output frequency range typically up to twice that of the mains input (e.g. up to 120Hz), a cycloconverter is restricted to a much lower range.

This is limited to less than one third of the supply frequency (e.g. up to 20 Hz) which is due to the way in which this type of converter produces the a.c. output voltage waveform. Ship propulsion shaft speeds are typically in the range of 0-145 rev/min which can easily be achieved by the low frequency output range of a cycloconverter to a multi-pole synchronous motor. Power regeneration from the motor back into the main power supply is available.

A conventional three phase converter from a.c.to d.c. can be controlled so that the average output voltage can be increased and decreased from zero to maximum within a half-cycle period of the sinusoidal a.c. input. By connecting two similar converters back-to-back in each line art a.c. output frequency is obtained. The switching pattern for the thyristors varies over the frequency range which requires a complex computer program for converter control.

The output voltage has a significant ripple content which gets larger (worse) as the output frequency is raised and it is this feature that limits the maximum useful frequency.

There is no connection between the three motor windings because the line converters have to be isolated from each other to operate correctly to obtain line commutation (natural) switching of the thyristors.

The converters may be directly supplied from the HV line but it is more usual to interpose step-down transformers. This reduces the motor voltage and its required insulation level while also providing additional line impedance to limit the size of prospective fault current and harmonic voltage distortion at the main supply bus-bar