CONCEPTS, CONCEPTS, CONCEPTS

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ABSTRACT

This article outlines the current state of the Surface Ship Full Electric Propulsion project managed by FP412 and indicates the opportunities offered by recent breakthroughs in electrical machines and power semiconductors.

Background

The Director of Future Projects (Naval), (DFP(N)), is charged with undertaking conceptual studies for ships and submarines prior to staff target/requirement. Accordingly, the main tasks these days tend to investigate various options and balance the required military capability against cost. For example, if the central or naval staffs believe a future frigate's ability to operate helicopters must be enhanced, DFP(N) might demonstrate that the required operating envelope can be achieved by adopting a catamaran design. DFP(N) would then compare this hull form with a monohull and trimaran and undertake studies to derive various detailed hull forms and powering requirements, potential machinery fits and cost.

DFP(N) has several assistant directors who, broadly, address relevant specializations:

- ADFP/D leads on naval architecture and acts as the design coordinator.
- ADFP/WE on weapon engineering.
- ADFP/ME on marine engineering.
- ADFP/DC on design computing. The Directorate uses extensive computing power, including the GODDESS suite.

Within ADFP/ME, the FP412 desk is responsible for surface ship marine engineering concepts. This article is one of a series that will describe some of the possible ways ahead for the marine engineering installation of future surface warships. Professional comment from readers is welcomed, particularly if based on practical experience, and anything addressed to FP412, DFP(N), Foxhill, Bath will find the author. FP412 terms of reference include 'Full Electric Propulsion project manager' and the status of that project is the subject of this article.

Full Electric Propulsion

The Combined Diesel Electric and Gas (CODLAG) Type 23 frigate has an electric propulsion cruise capability with a 1.5 MW motor on each shaft. The QE2 has Full Electric Propulsion (FEP) with 44 MW per shaft. Work to date by the FEP project has been assessing, by paper studies, the merits of FEP for future warships of frigate size and above. However, to keep things simple, this article is constrained to the requirements of frigates of around 4,000 tonnes with two shafts and some 20 MW per shaft.

So far the FEP project consists of some 70 studies, which have cost around £½M and been undertaken over the last five years. To summarize the findings, FEP is a low risk alternative transmission system that is available now. An FEP installation for a frigate would cost some 20% more than a mechanical system such as Combined Gas and Gas (COGAG), but improved efficiency pays back this excess after 1½ to 10 years in service by savings on fuel expenditure. The payback time spread varies due to differing operating profiles; the flexibility of FEP operation means that it is particularly efficient at low powers.

When looking at FEP equipments in isolation, they are typically double the weight and the volume of a COGAG installation with the excess weight being mainly attributable to the propulsion motors and the excess volume to the convertors required to control them.

Electrical machines

The propulsion motors selected by each contractor undertaking FEP studies, even though they had a free choice, were all Alternating Current (AC) synchronous machines. Direct Current (DC) machines were not selected because they are limited to about 10 MW; commutators limit voltage to around 1,000 volts to avoid flashover and current to about 10,000 amps due to brush problems. There are various reasons for choosing synchronous rather than induction motors which include shock withstand, efficiency, better speed control and easier control of regenerated power.

Having selected a synchronous motor, speed control necessarily requires variable frequency AC. This requirement has been met in various ways in the past including:

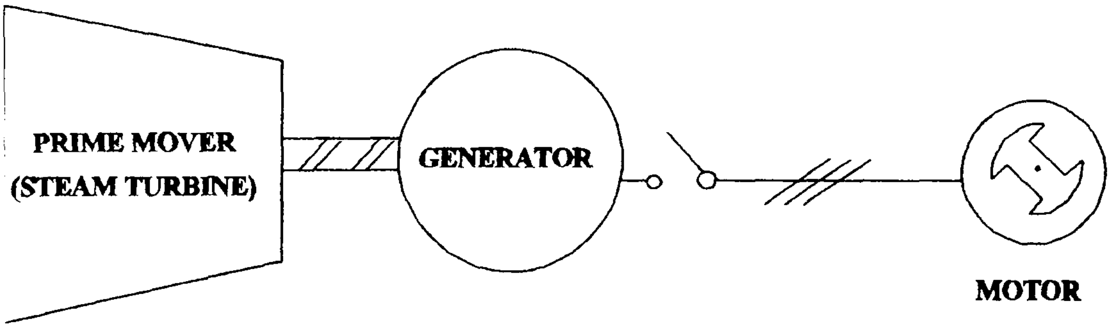

FIG. 1—VARIABLE SPEED GENERATOR SYSTEM

Variable Frequency Generator (VFG)

The output frequency of a generator is related to the speed at which it rotates, thus a typical VFG, as fitted to the SS *Canberra*, is driven by a steam turbine and the electrical power generated is connected directly to the propulsion motor (FIG. 1). The shaft speed range thus reflects the prime mover speed range, or turn down. However, as few prime movers have such a turn down characteristic, VFG tends only to be adopted when payload space is not at a premium and a large volume steam plant can be installed.

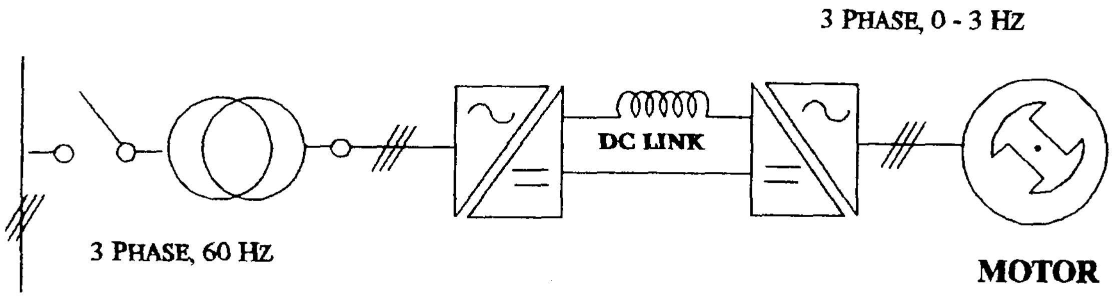

FIG. 2—SYNCHRO CONVERTOR SYSTEM

Synchro convertors

Synchro convertors take the AC input, rectify it onto a DC link and then invert to reconstitute an AC waveform with controlled and continuously variable frequency (FIG. 2). The processes of rectification and inversion 'chop' the AC

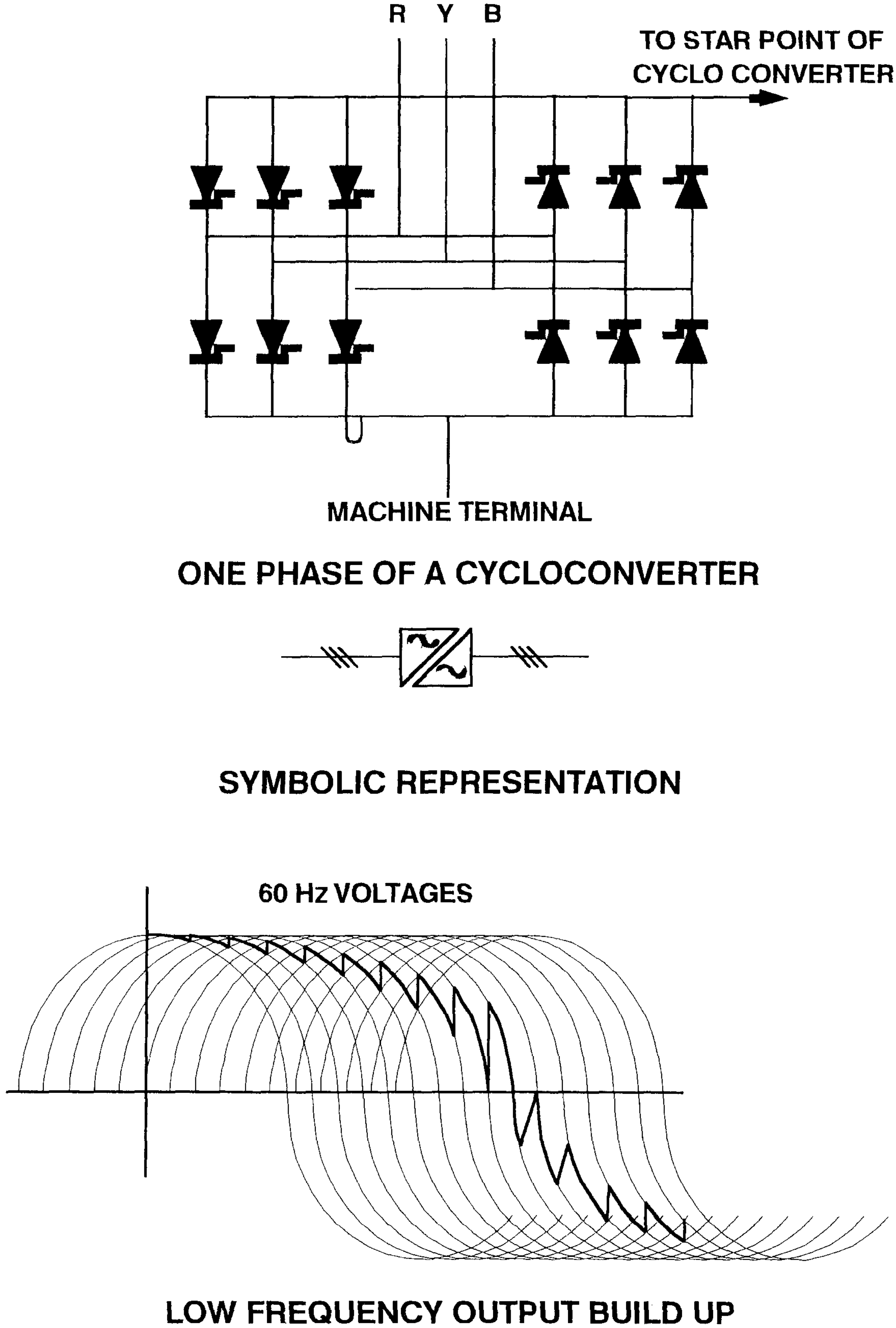

FIG. 3—THE CYCLO CONVERTOR

waveform and create harmonic distortion of both the power supply to and the output from the convertor. Ship and weapon supplies must be isolated from this distortion which can be transmitted either along the power supply conductors or as Electro Magnetic Interference (EMI), due to the high frequency components of the distortion. Distortion caused by the Type 23 AC to DC convertor, despite large filtering and smoothing circuit components, still requires isolation by motor generators and by ship layout for EMI.

Cyclo convertors

Cyclo convertors take the AC input and, by intelligent selection of various sections of phase shifted waveforms, can generate an AC output without requiring a DC link (FIGS. 3&4). They tend to be smaller and can produce less distortion than synchro convertors, but do not have the same turn down.

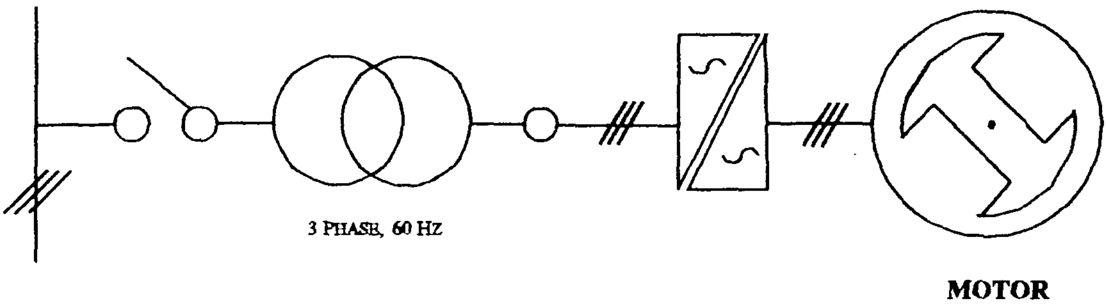

FIG. 4—CYCLO CONVERTOR SYSTEM

Power electronics

Most of the convertors at sea and all of those assessed in the Phase 1 studies used the Silicon Controlled Rectifier (SCR) thyristor as the active power electronics device. The SCR is capable of high power switching but suffers from several disadvantages, one of which is being relatively slow. As such the switching frequency is only an order or two faster than the waveform it is trying to generate and distortion caused is relatively low frequency, typical waveform is at (FIG. 5). This makes smoothing or filtering difficult and leads to the need to isolate ship and weapon supplies and protect against EMI.

New power electronic devices such as the Insulated Gate Bipolar Transistor (IGBT) and the Metal oxide silicon Controlled Thyristor (MCT) can switch at much higher frequency than the SCR as well as being capable of turning off at other than zero volts, another of the SCR's disadvantages. IGBTs and MCTs are now becoming available at the power levels required for FEP and their high switching frequency enables pulse width modulation when forming the AC waveform. This technique in turn reduces harmonic distortion and minimizes that generated at low frequencies; smoothing and filtering is thus relatively straightforward and only requires small components.

Increasing FEP power density

As stated earlier, the excess weight of FEP equipments is mainly attributable to the propulsion motors and the excess volume to the convertors. Immediate work for the FEP project is thus to reduce volume, weight and cost of motors and convertors such that FEP more closely aligns with mechanical transmission, yet remains a low risk to any future project when assessing machinery fits.

It is likely that IGBTs and MCTs will reduce the size of convertors by an order of magnitude or more and prediction are that cost will fall pro-rata. There is much commercial pressure to reduce the cost of convertors for both shore and marine installations and it is likely that this will happen without active MoD sponsored development.

What about motors? Over the last twenty years or so the magnetic field strength of permanent magnets has increased dramatically and they are now capable of providing sufficient flux density to excite electrical machines in the 20 MW range. The flexibility that comes with not requiring wound field coils on the rotor has led to the development of various new machine topologies. One of these, the Transverse Flux Motor (TFM) has been described in the *Journal.*[1] Suffice it to say that TFM sketch designs indicate a six or eightfold increase in power density against a synchronous motor; for example, an 18 MW TFM is about the same size as a Type 23 1.5 MW motor and weighs significantly less.

Another advantage of permanent magnet excitation is that there are no electrical losses from the excitation system thus the machine is up to 2% more efficient than an equivalent machine with a wound excitation system. This drives down the fuel bill.

The permanent magnet materials that enable such a power density increase are expensive. However, with the decreased size of the machine the amount of copper reduces pro-rata, thus driving the price down. The best current estimate is that a TFM will be some 80% of the price of a similar rating wound rotor synchronous machines. Unfortunately, with this relatively small cost saving, there is not the commercial pressure to develop permanent magnet motors suitable for FEP. Shore installations are not constrained by weight or volume. Commercial marine markets will generally accept the bigger and heavier synchronous motor, as they do not have the extreme payload pressures of a warship, where cubic metres mean weapons.

It is thus the permanent magnet propulsion motor where MoD sponsored development is required and that has been accepted as the next stage of the FEP project. All FP412 has to do now is to get the funding released to enable the development to continue!

Summary

The project has shown that FEP is a viable and economic transmission system for warships and it is a low technical risk. In most applications the additional cost of the marine engineering equipments required for FEP is paid back in around 5 years from fuel economy due to the high part load efficiency.

The next stage of the project is now starting with the intention of developing a permanent magnet excited propulsion motor which will be more efficient and about one eighth the size of an equivalent synchronous motor.

The future

The combination of the new generation of power electronics with high power density generators driven by fuel efficient, low emission gas turbines on an integrated electrical ship service and propulsion power system, has the potential to open up completely new horizons for future warships.

At Foxhill the electrical and mechanical engineering fraternity are beginning to visualise possible marine engineering fits for electric ships of the future. Once an agreed vision is established, trade off studies will be undertaken to assess the most cost effective installation whilst at least retaining the current military capability. Programmes will then need to be initiated to develop the required equipments where they are not available off the shelf.

The vision of the electric ship will be reported in a later article. If the reader wishes to contribute to the debate, see above, and remember 'Times are exciting'.

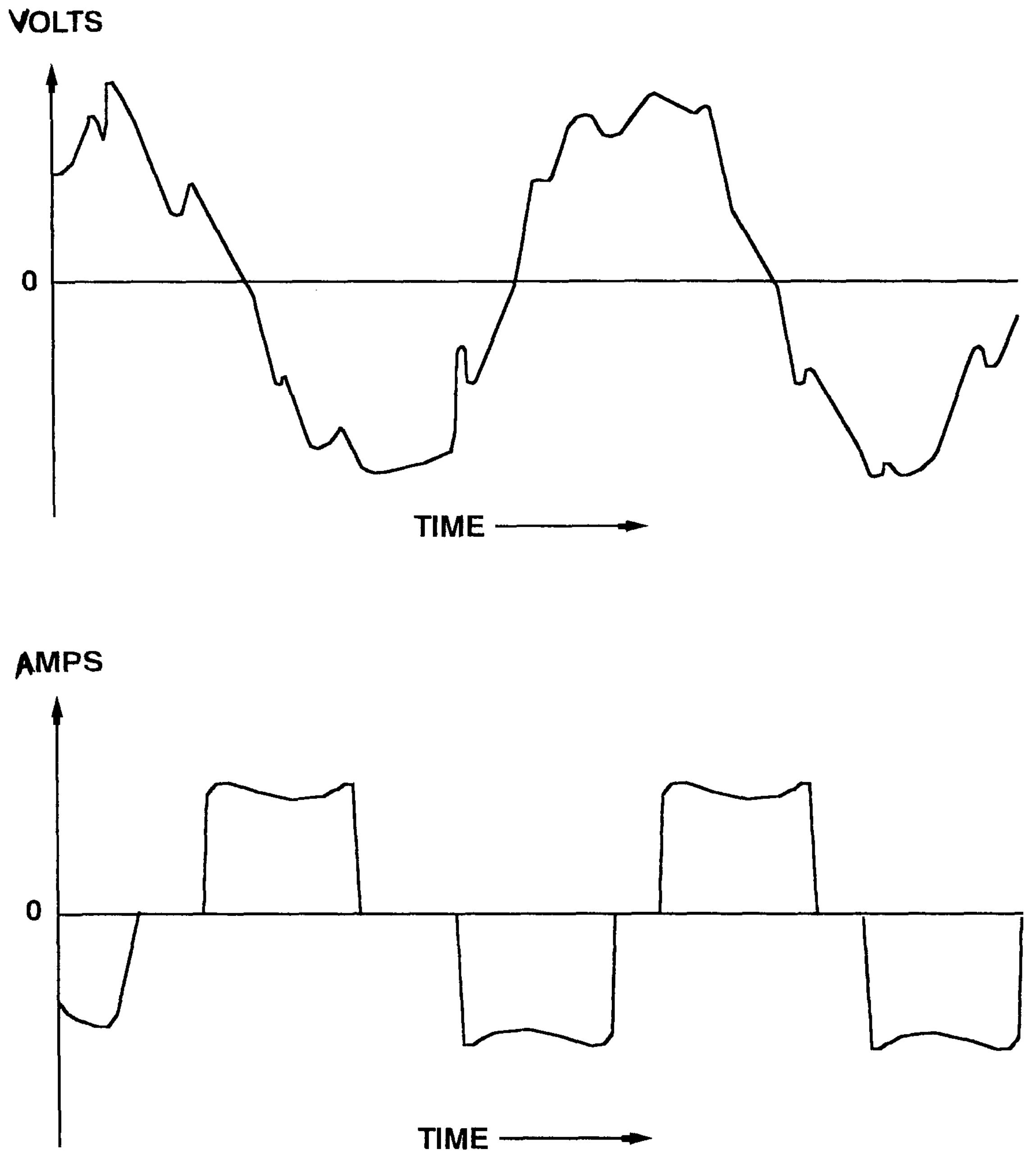

FIG. 5—TYPICAL DISTORTED WAVEFORM FROM USE OF SCR

References

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