Are trends electric? New naval power and propulsion generations emerge

The United Kingdom and the United States are leading the field in the adoption of integrated electric power generation and propulsion for surface ships. However, not all shipbuilders or navies may follow this lead. Andrew Tate considers trends and developments in diesel, gas turbine, and hybrid electric propulsion systems.

Much attention has been drawn to the adoption of integrated electric propulsion (IEP) by the UK Royal Navy (RN) for its Type 45 anti-air warfare destroyers and the forthcoming Queen Elizabeth-class aircraft carriers, and by the US Navy (USN) for the DDG 1000 Zumwalt-class destroyers, the first of which currently is in its pre-commissioning phase. While there is no doubt that IEP is a major development in naval ship propulsion, is it going to rule the waves? A survey of both recently built ships and those in design suggests that instead of IEP becoming the dominant configuration, designers are adopting a diverse range of propulsion options incorporating diesels, gas turbines, and electric motors in various combinations.

The goal of reducing operating costs led to the demise of steam propulsion systems in ships (with the exception of those driven by nuclear power), as such propulsion systems required a high number of people for operation and maintenance and, as developed, arguably could not match the fuel efficiency of other technologies. Consequently, most ships built since the 1970s are powered by a combination of diesel or gas turbine engines, giving rise to familiar acronyms such as CODAD (combined diesel and diesel), CODOG (combined diesel or gas), CODAG (combined diesel and gas), and COGAG (combined gas and gas). However, several factors are driving further change in propulsion systems, particularly the perpetual requirement to reduce acquisition and through-life operating and maintenance costs.

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Integrated electric propulsion
The US Navy’s first-in-class DDG 1000 destroyer. Integrated Electric Propulsion (IEP) has been adopted for the Zumwalt class. (US Navy)

While the integrated power systems (IPSs) on board lead DDG 1000 ship USS Zumwalt and the future HMS Queen Elizabeth have drawn attention to electric propulsion in recent months, development and refinement of IEP in naval service has been progressing for more than two decades.

In the United Kingdom, the first IEP warships were the two 18,000-tonne Albion-class landing platform dock (LPD) vessels, the first of which was commissioned in 2003; these ships have four Wärtsilä diesel generators, two producing 12.5 MW and two 3.1 MW, driving an electric motor on each shaft, capable of propelling the ship at 18 kt. Electrical power is generated at 6.6 kV and then distributed at high voltage to the propulsion motors and at 440 V to the ship and weapon systems. In the 7,500-tonne Type 45, the total installed power is significantly greater in order to support a more extensive weapon system fit, particularly the high-power radars, and also to propel the ship at up to 31 kt. Two Rolls-Royce WR-21 gas turbine generators rated at 25 MW are installed, and two Wärtsilä diesel generators can provide a further 2 MW each. Power is supplied at 7.2 kV to the two 20 MW GE Power Conversion/Converteam electric motors and the ship’s electrical distribution system.
A Converteam Advanced Induction Motor (AIM). GE Power Conversion/Converteam AIMS are installed in the US Navy’s DDG 1000 destroyer to help meet the 30 kt top speed requirement. (Converteam)

To meet designed speed and current weapon system requirements, as well as providing expansion potential for directed energy/laser weapons and an electro-magnetic railgun, the installed power in the 15,600-tonne DDG 1000 totals 80 MW, delivered by two 36 MW Rolls-Royce MT30 and two 3.9 MW Rolls-Royce RR4500 gas turbine generator units. While the original design was to adopt Finmeccanica/DRS Technologies’ permanent magnet motors (PMM) for propulsion, which offer very high torque and power density in a relatively compact unit, although ultimately GE Power Conversion/Converteam Advanced Induction Motors (AIM) were introduced instead to generate the maximum speed of 30 kt.

A schematic showing the principal components of the integrated electric propulsion system on the UK Royal Navy’s Type 45 destroyer. (Converteam)
With a design displacement of around 65,500 tonnes and required top speed of over 25 kt, the UK’s Queen Elizabeth-class carriers require more power again. A total generating capacity of 110 MW will be derived from two 36 MW Rolls-Royce MT30s and four Wärtsilä diesel generators (two 9 MW and two 11 MW). These will supply electrical power for ship and weapon systems and for the four 20 MW GE Power Conversion AIM induction motors, installed in tandem on both shafts.

In adopting IEP, designers are aiming to maximise the efficient use of primary power generation machinery by using the same source to deliver power for propulsion and for weapon systems, as well as for the auxiliary electrical load. Fuel savings can be made in operating single or multiple power generators at full load where they are most efficient, rather than running multiple machines at partial load, supplying power to unconnected systems. Furthermore, in conventional power generation and propulsion configurations, around 80% of the total installed power is dedicated to the propulsion system to deliver the maximum speed required. For most ships, with the possible exception of surface ships used to escort carriers, this maximum speed is infrequently used, as fuel consumption cost rises dramatically at high speed and range falls as a consequence. By using a common source for electrical load and propulsion, the total installed generating capacity required can be optimised to meet the requirements of the propulsion and weapon systems, as the peak demands of each rarely coincide.

In a conventional propulsion configuration where the diesel or gas turbine prime movers drive the shaft mechanically, these must be installed in line with the shaft low down in the ship. However, when the generated power is distributed by electrical cables, there are fewer physical constraints on where to position the principal power generator. This gives ship designers greater flexibility in where to locate components of the power generation and propulsion systems.

Choices

The choice of diesel generators is an interesting one. In an amphibious assault ship class like the Mistral, the pressure on space to accommodate propulsion machinery is slightly less onerous than in a destroyer or frigate, so the lower power density associated with diesel engines when compared with gas turbines can be accepted. Another significant difference is that the maximum speed of an amphibious assault ship is typically in the region of 20 kt. If these ships needed to achieve a maximum speed of around 30 kt, the power requirements would increase dramatically and would dictate a much larger installation if only diesel generators were used. This increased power would also have to be handled by the podded motors and though Rolls-Royce offers a range of Mermaid pods up to 27 MW, these pods are fitted with propellers up to 8 m in diameter. This would potentially give a ship fitted with very large pods a draught of 10 m or more, which may be acceptable for a carrier but is unlikely to meet the requirements for a destroyer or frigate.

Another amphibious ship design which adopted both IEP and podded propulsion motors is Navantia's LHD, the first of which, Juan Carlos I, was commissioned into the Spanish Navy in 2010; the design was subsequently adopted by the Royal Australian Navy for its Canberra class. At 27,000 tonnes, these LHDs are larger than the French Mistral class and consequently require more installed power; thus, a combined diesel and gas turbine configuration has been adopted. Two 8 MW MAN diesel generators, together with a single GE LM2500 gas turbine-powered generator rated at 19.1 MW, deliver power to ship systems and to two 11 MW Siemens-Schottel azimuth thrusters which propel the ship at a maximum speed of 21 kt.
The Indian Navy’s first indigenous aircraft carrier Vikrant, seen here being launched at Cochin Shipyard Ltd’s Kochi facility, will be propelled by four GE LM2500+ gas turbines in a conventional COGAG configuration. (Press Association Images)

Not all large-deck vessels under construction are adopting integrated or hybrid power generation and propulsion systems. India’s first indigenous carrier, the 40,000-tonne INS Vikrant, will be propelled by four GE LM2500+ gas turbines in a conventional COGAG configuration, providing 90 MW of power to two shafts through gearboxes supplied by Elecon Engineering, with electrical power for ship and weapon systems provided by diesel generators. The same COGAG configuration has been adopted for the Japanese 24,000-tonne helicopter-carrying Izumo-class destroyer, the first of which should commission early in 2015, and is capable of speeds of up to 30 kt. Similarly, the 27,500-tonne Italian Navy carrier ITS Cavour employs four GE LM2500+ gas turbines in a COGAG configuration, but also has two Ansaldo Sistemi Industriali shaft generators so that the number of diesel generators running for electrical power generation can be reduced while underway.

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In diesel

While for a given volume and weight, diesel engines produce less power than gas turbines, there remain attractions to adopting diesel engines for propulsion; a number of newbuild and recently completed ships have a CODAD configuration. The Royal Danish Navy’s Iver Huitfeldt-class frigates are powered by four MTU diesel engines, producing 33 MW, giving the 6,600-tonne ships a top speed of 28 kt and an estimated 9,000 n mile unfuelled range at 15 kt. The 19,300-tonne RoKN Dokdo class is powered by four SEMT Pielstick diesel engines, providing total power of 24 MW to the two shafts to drive the ship at up to 22 kt. The 4,000-tonne PLAN Type 054A Jiangkai II frigate, first commissioned in 2008 and now a class of 22 and rising, is thought to be powered by four Shaanxi (SEMT Pielstick) diesels, producing 20.7 MW of power for propulsion. Ships that the Chinese are building for export, such as the F22P Sword-class built for the Pakistan Navy, the Type 056 corvettes fitting out for the Bangladesh Navy, the C28A frigates under
construction for the Algerian Navy, and the P-18N offshore patrol vessels (OPVs) for the Nigerian Navy, are all propelled solely by diesel engines.

The advantages of adopting diesels are found in lower initial procurement costs; more simple and rugged technology, which may enable local build under licence and will certainly be more compatible with indigenous maintenance facilities; extended periods between maintenance routines; and a less-demanding level of required maintenance skill. The trade-off is against maximum power delivered, and hence likely maximum speed. However, the wider band in which the diesels can be run efficiently has the potential to give greater operating range. Against this, two or more diesel engines mechanically coupled through a gearbox to the shafts are inherently noisy and therefore not well-suited to tasks such as ASW.

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**Hybrid propulsion**

An alternative hybrid propulsion system that is becoming prevalent in ships built in Europe is to use a hybrid electric system, most commonly in combined diesel electric and gas (CODLAG) configuration. This uses diesel generators to supply power to ship and weapon systems, as well as an electric motor for slow or passage speed, with gas turbines mechanically connected to the shafts for high speed. This has been utilised in the RN's Type 23 frigates since 1990, and offers a number of the advantages of IEP; these include high fuel efficiency when propelled in diesel-electric mode, and very low acoustic signature at patrol speeds (provided that the diesel generators are installed on acoustically isolating mounts). Diesel-electric drive is typically used at speeds up to 12-14 kt, requiring electric motors around 3 MW, which are considerably smaller than those required to handle 20 MW. However, a mechanically coupled gas turbine for high-speed propulsion reintroduces the requirement for a gearbox.
The General Electric LM2500+ G4 gas turbine, rated at 35.3 MW at 3600 rpm, is fitted to the French Navy's FREMM frigates, along with four 2.1 MW MTU diesel generators. (General Electric Aircraft Engines)

The 6,000-tonne Franco-Italian FREMM frigates employ a hybrid diesel-electric drive, with a 2.2 MW electric motor on each shaft. The Italian variant, the Bergamini class, has four 2.1 MW Isotta Fraschini diesel generators and one LM2500+ gas turbine, while the French Aquitaine class has four 2.1 MW MTU diesel generators and one GE LM2500+ G4 gas turbine. Curiously, the former are reported to operate in a CODLAG configuration, whereas the latter are operated in a combined diesel electric or gas (CODLOG) mode.

The configuration of two electric propulsion motors supplemented by a single gas turbine has also been adopted for the 7,300-tonne F 125 Baden-Württemberg frigate class, currently under construction by Thyssen-Krupp Marine Systems and Lürssen for the German Navy. These ships have a 4.7 MW electric motor on each shaft, and a single GE LM2500 20 MW gas turbine. The gearbox arrangement allows the engine to drive both shafts, using a CODLAG configuration.

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Smaller vessels
The lead ship of the Irish Navy's Samuel Beckett-class offshore patrol vessels (OPVs) being floated out at Babcock Marine's Appledore yard in November 2013. Using CODLOD configuration, the class is fitted with two 5.4 MW Wärtsilä diesel engines, a PTI motor, and three diesel generators. (Babcock Marine)

While destroyers and frigates that adopt a combined diesel-electric and mechanical propulsion configuration may require a gas turbine for high speed, smaller vessels such as patrol boats are less demanding. The Royal Netherlands Navy's 3,800-tonne Holland-class OPVs are equipped with two 5.4 MW MAN diesels, each of which can drive the two shafts through Renk gearboxes to a maximum speed of around 22 kt. The two gearboxes can also each be driven by a 400 kW Power Take In (PTI) electric motor, which draws power from the ship's electrical distribution system, provided by three 1 MW Caterpillar diesel generators, two of which can propel the ships at speeds up to 10 kt. This CODLOD configuration was chosen because the efficiency provided by the diesel-electric drive matched the required operating profile well. The Irish Navy's Samuel Beckett-class OPVs are configured in the same way as the Holland class, but with two 5.4 MW Wärtsilä diesel engines with a PTI motor drawing its power from three 630 kW diesel generators.

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Conclusion

As shown by this review, while integrated full electrical propulsion has been highlighted as the direction of future naval propulsion, the reality is that, instead of converging on a common configuration, ship designers are adopting an increasing range of propulsion system combinations. However, there is much scope for confusion, as the terminology used to describe combinations of diesel and gas turbine propulsion has not been adapted to provide a consistent and reliable set of descriptors for this wider range of propulsion systems. Consequently, shipbuilders, designers, and commentators are referring to configurations such as CODAGE, CODOE, and COGES, and applying the terminology IPS or IEP, without identifying the primary power source.

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