Advanced Ship Propulsion Technology: A Review

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ABSTRACT— ***Ships need drive in order to move from one place to another. Propulsion has been known since 40,000 BC and continues to grow. In the development of increasingly complex use of the vessel so that it will directly affect the ability of propulsion to move the ship. Taking into account the purpose and use of the design of the ship, then the designer will consider in the choice of the type of propulsion that will be used so that the ship and propulsion really matching at the time of operation. Selection of the right will ensure the vessel's ability to maneuver in the conditions and situations that will be encountered by the ship itself. With the technological revolution, especially in the field of marine have impacted very significant in the development of marine transportation and water in particular ships, which have given rise to other types of ships along with other types of propulsion are more trusted and considered to ensure the vessel's ability to operate in accordance with current needs. Each type of propulsion have advantages and disadvantages of each, but in spite of that each type of propulsion has been tested capacity and feasibility in each era. This paper review, put forward the types of propulsion and development since it was first discovered up to now, with the development of technology in the field of marine then there are several types of propulsion used as ship propulsion. Researchers are still conducting research to choose the suitable type of propulsion that can address global issues concerning environmental pollution.***

Keywords — Advanced ship propulsion, propulsion technology, types of propulsion

1. INTRODUCTION

Even 40,000 years before Christ, man built boats and paddled through the waters with them. And, they paddled and paddled and paddled for 35,000 years until a major discovery revolutionized ship propulsion for the first time. For a long time, the seaman couldn't give up using the oar and combined the oar with the sail. Here, for the first time, we hit head-on the practice typical over a long period of time in seafaring: trust the tried and true and only replace it step-by-step with something new. This is a practice, which at its time certainly saved the lives of many seamen, and, in modern times, the abrogation thereof has cost the insurers a lot of money. Then once again for a long time, very little happened, at least in the realm of ship propulsion[1].

Both Archimedes (c.250 BC) and Leonardo da Vinci (c.1500) can be credited with having considered designs and ideas which would subsequently be explored by ship propulsion engineers many years later. In the case of Archimedes, his thinking centered on the application of the screw pump which bears his name and this provided considerable inspiration to the nineteenth century engineers involved in marine propulsion. Unfortunately, however, it also gave rise to several subsequent misconceptions about the basis of propeller action by comparing it to that of a screw thread. In contrast Leonardo da Vinci, in his sketchbooks which were produced some 1700 years after Archimedes, shows an alternative form of screw propulsion based on the idea of using fan blades having a similar appearance to those used for cooling purposes today[2].

A propulsion system consists of three parts: an energy source (carried aboard as animal or fuel energy, or collected from outside as wind or solar power), an engine that transforms it to a mechanical form, and the propulsor or thruster (that pushes the surrounding water backwards). Without propulsion, a surface ship cannot steer (all rudders work only dynamically), the boat being dangerously rolled by waves; and underwater, without propulsion it is almost impossible to keep a fixed depth of immersion simply by buoyancy. Of course, crawling propulsion can be used to move along the sea floor, but this is a rarity because of the muddy bottom[3].

Propulsion is making a body to move (against natural forces), i.e. fighting against the natural tendency of relative-motion to decay. Motion is relative to an environment. Sometimes, propulsion is identified with thrust, the force pushing a body to move against natural forces, and one might say that propulsion is thrust (but thrust not necessary implies motion, as when pushing against a wall; on the other hand, propulsion implies thrust). Sometimes a distinction is made from propulsion (pushing) to traction (pulling), but, leaving aside internal stresses in the system (compression in the first case and tension in the latter), push and pull motions produces the same effect: making a body to move against natural forces. In other occasions 'traction' is restricted to propulsion by shear forces on solid surfaces[4].

Today, the primary source of propeller power is the diesel engine, and the power requirement and rate of revolution very much depend on the ship's hull form and the propeller design. Therefore, in order to arrive at a solution that is as optimal as possible, some general knowledge is essential as to the principal ship and diesel engine parameters that influence the propulsion system[5].

The propulsion system consists typically of prime movers as diesel engines, generators, transmissions and thrusters. A thruster is here defined as the general expression for a propeller unit. A ship can be equipped with several types of thrusters. Conventional ships typically have a main propulsion unit located aft. Traditionally, shaft line propulsion with controllable pitch or fixed pitch propellers is applied, with rudders to direct the thrust. Another common type is the tunnel thruster which is a propeller inside a tunnel that goes through the hull and produces a fixed-direction transverse force. A third type is the azimuth (rotatable) thruster, which can produce thrust in any direction[6].

One of the greatest contributors to increasing the useable space in a ship, most notably a warship or a cruise liner where the premium on space is greatest, is the concept of the Electric Ship. Integrated Full Electric Propulsion, IFEP, lies at the heart of the Electric Ship. IFEP also offers valuable running cost advantages, combined, in some cases, with purchase cost savings. In an IFEP system, the ship's propulsors are driven by electric motors alone, and the power for the electric motors is drawn from a unified electrical power system that also provides all of the ship's electrical services. The power and propulsion systems are therefore integrated, because there is only one electrical power system where more conventionally there might have been two. One of the key technologies enabling the realisation of the benefits of IFEP, particularly in naval vessels, is the compact electric motor. Over the past ten years there have been significant improvements in the torque density of electric motors, moving from conventional motors to advanced induction motors and permanent magnet propulsion motors[7].

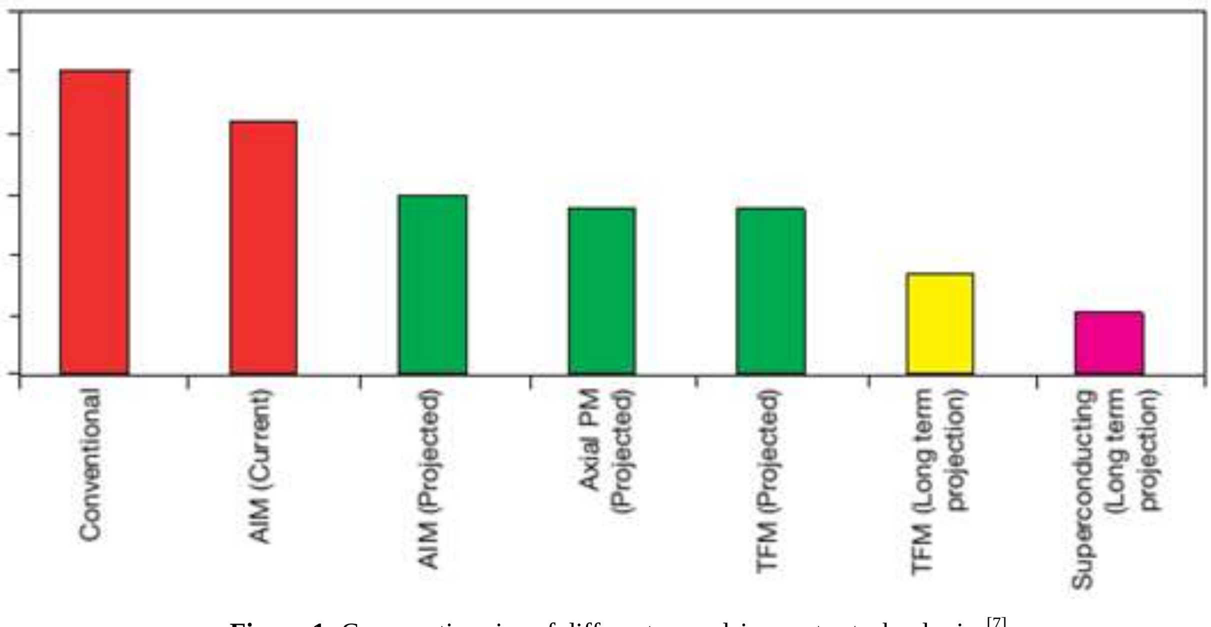

Figure 1: Comparative size of different propulsion motor technologies[7].

AIM : Advanced Induction Motor
PM : Permanent Magnet
TFM : Transverse Flux Motor

2. DIESEL ENGINE PROPULSION

The first decade of the 1900s proved to be a time of experimentation and success in the area of diesel engine design and manufacture. The installation of diesel engines into river and coastal craft was eagerly anticipated, however, there still remained some scepticism in the performance abilities of the combustion engines on long, seafaring journeys. Rudolf Diesel patented his engine in Germany, on February 28, 1892 and he later obtained patent rights in most industrialised countries. In 1894, Diesel contacted David Halley, the managing director of Burmeister and Wain (B&W), requesting the company experiment with his design, which eventually laid the ground for a most successful career in the design and manufacture of diesel engines. While the Selandia, built 1912, remains heralded as the first seagoing diesel engined vessel, in 1905, the 125 ton vessel, Venoga, built by Sulzer, became the worlds first recorded diesel engine vessel and was used on Lake Geneva. Further diesel experiments were occurring in Rochefort, France, where Sautter-Harle and Cie designed an engine similar to that of Dyckhoff's. It ran at 120 HP and was tested in the French naval submarine, Z. In Russia, Rudolf Diesel's patent was taken over by the engine works of Ludwig Nobel of St. Petersburg on February 16th, 1889. In 1899, Noble began building a 20 HP diesel engine of cross head type. Some changes were made to Rudolf Diesel's original design in an attempt to facilitate the manufacture and operation of the engine as well as the accessibility to the engine parts for inspection. The utilisation of the diesel engine was not solely used on marine vessels. In a rush to exploit the petroleum oil fields throughout Russia, the government installed a pipeline from Baku at the Caspian Sea to Batum at the Black Sea. The two vessels, Vandal and Sarmat were in use throughout 1904/1905. They became models for the design and the building of a series of ships for the Imperial Russian Navy as they proved that: a) it was possible to use diesel for the propulsion of ships and; b) ship design could be easily adapted to fit a diesel engine. Russia had a favourable situation because of the petroleum fields and because of their geographical location; the Russian diesel powered vessels were set upon inland waters, they had yet to conquer the open seas. The Russo-Japanese war of 1904 impacted the pace of development, however their innovations did not falter. Research began into the design of ocean-going diesel vessels with the sole purpose of developing a liner that could travel from Kronstadt to the Yellow Sea and back again without needing to stop for fuel. Because of the war, Russia did not build such a vessel, and instead, concentrated upon increasing the naval fleet. They became the first to develop a light, fast burning diesel powered vessel. The military diesel vessels had reversible engines and were modelled after the gunboat of the Kars class[8].

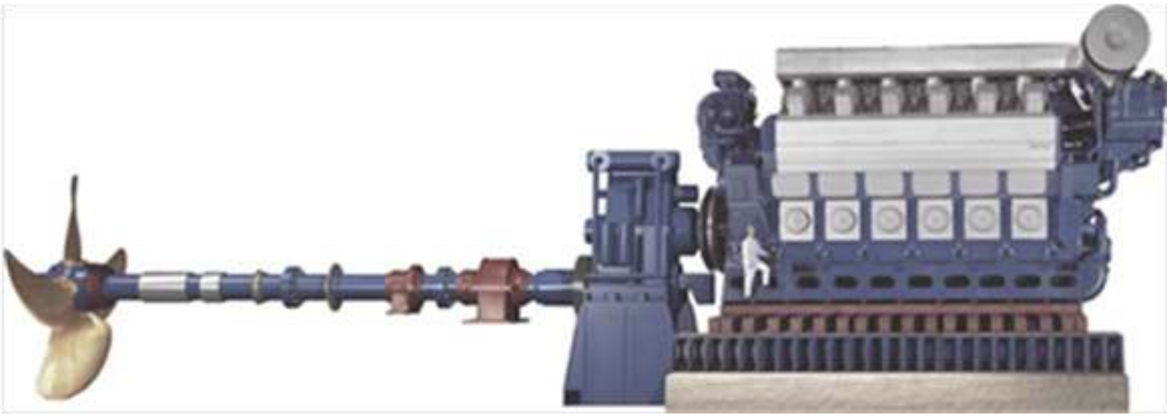

Figure 2: Diesel Engine Propulsion

3. STEAM TURBINE PROPULSION

Steam turbines have had a long and eventful life since their initial practical development in the late 19th century due primarily to efforts led by C. A. Parsons and G. deLaval.Significant developments came quite rapidly in those early days in the fields of ship propulsion and later in the power-generation industry. Steam conditions at the throttle progressively climbed, contributing to increases in power production and thermal efficiency. The recent advent of nuclear energy as a heat source for power production had an opposite effect in the late 1950s. Steam conditions tumbled to accommodate reactor designs, and unit heat rates underwent a step change increase. By this time, fossil unit throttle steam conditions had essentially settled out at 2400 psi and 1000F with single reheat to 1000F. Further advances in steam power plants were achieved by the use of once-through boilers delivering supercritical pressure steam at 3500-4500 psi. A unique steam plant utilizing advanced steam conditions is Eddystone No. 1, designed to deliver steam at 5000 psi and 1200F to the throttle, with reheat to 1050F and second reheat also to 1050F. Unit sizes increased rapidly in the period from 1950 to 1970; the maximum unit size increased from 200 to 1200 mW (a sixfold increase) in this span of 20 years. In the 1970s, unit sizes stabilized, with new units generally rated at substantially less than the maximum size. At the present time, however, the expected size of new units is considerably less, appearing to be in the range of 350–500 mW. In terms of heat rate (or thermal efficiency), the changes have not been so dramatic. The advent of regenerative feedwater heating in the 1920s brought about a step change reduction in heat rate. A further reduction was brought about by the introduction of steam reheating. Gradual improvements continued in steam systems and were recently supplemented by the technology of the combined cycle, the gas turbine/steam turbine system (see Fig. 2). In the same period of time that unit sizes changed by a factor of six (1950 to 1970), heat rate diminished by less than 20%, a change that includes the combined cycle. In reality, the improvement is even less, as environmental regulations and the energy required to satisfy them can consume up to 6% or so of a unit's generated power. The rate of improvement of turbine cycle heat rate is obviously decreasing. Power plant and machinery designers are working hard to achieve small improvements both in new designs and in retrofit and repowering programs tailored to existing units[9].

The steam turbine has until recently been the first choice for very large power main propulsion units. Its advantages of little or no vibration, low weight, minimum space requirements and low maintenance costs are considerable. In steam turbines high pressure steam is directed into a series of blades or vanes attached to a shaft, causing it to rotate. This rotary motion is transferred to the propeller shaft by gears. Steam is produced by boiling water in a boiler, which is fired by oil. Recent developments in steam turbines which have reduced fuel consumption and raised power output have made them more attractive as an alternative to diesel power in ships. They are 50% lighter and on very large tankers some of the steam can be used to drive the large cargo oil pumps. Turbines are often used in container ships, which travel at high speeds. The mechanism for conversion of thermal energy is the heat engine, a thermodynamic concept, defined and sketched out by Carnot and applied by many, the power generation industry in particular. The heat engine is a device that accepts thermal energy (heat) as input and converts this energy to useful work[10].

Marine steam turbine engines have largely been replaced by the more economical marine two stroke diesel engine, mainly for commercial reasons as the diesel engine is much more economical. Notwithstanding this there are still a few about, running like clockwork- their one big selling point along with reliability, little maintenance, and high speed pushing large cruisers and battleships along at forty knots, but they are very thirsty. Let's find out how steam turbines work in the context of marine turbine engines. For marine applications, the cross compound double reduction steam turbine was a popular choice because it was more compact, taking up less space in the ships engine-room. It also had the advantage of a built-in astern turbine giving easier astern movement, with up to 50% astern output power as that of the ahead turbine. This was a big advantage when the first oil super tankers were built – they took half a mile to stop from full ahead. In operation, the steam is supplied from the ship's boiler as high pressure, high temperature superheated steam and passes into the high pressure turbine, (HP) expanding through the blades and exiting into the low pressure turbine through a large bore insulated pipe[11].

Figure 3: Steam Turbine Propulsion[11]

4. WIND PROPULSION SYSTEM

Wind is a mechanical fluid flow energy, which is already transformed from solar radiation by the global weather machine. This offers the unique chance of a short-cut to direct propulsion, without further transformation, by flow forces acting straight on air-foils to push the ship through the water - without ‘slip’. This has been practiced, on an artisanal level, in shipping for at least 5000 years, until 100 years ago coal and oil burning engines driving propellers took over the role of propulsion. And this is just that period of 100 years, where our technical know-how developed explosively, in structural and mechanical engineering, in fluid-flow, control and information technology. We now understand, how wind-propulsion works and we could apply it much more efficiently, but we have used this new knowledge so far only for sports and recreation. Air-Foils for Wind-Propulsion may be traditional soft Sails, advanced soft Sail-Wings and rigid Wing-Sails. All of them have their special features and fields of application. Normal Sails are simple and well-known, Sail-Wings are soft, variable-area and variable–camber air-foils with improved lift-to-drag, and Wing-Sails are hard wings with flaps and even higher lift-to-drag[12].

Wind propulsion, as obvious a solution it may appear in the context of maritime transportation, is only one among many options to mitigate the GHG emissions of the sector. Fuel substitutions (from natural gas to hydrogen), speed reduction, waste heat reduction, weather routing or water flow optimization are among the list of other ways to reduce the ships' GHG emissions. But for obvious historical reasons, wind propulsion is a technique that has been particularly documented and made great progress in the past decades (mainly thanks to sport-oriented innovations). Physical reasons should also be mentioned here: indeed, the wind power is directly delivered to the hull, without losses from the propeller (usually about 50%) that make the wind propulsion system twice as powerful as a thermic propulsion[13].

The wind has been the major source of ship propulsion for thousands of years, until the advent of fossil fuels. Recently, with the rising prices of oil and the urgent need to reduce CO2 production, the use of wind for ship propulsion has been regaining a growing attention. Some new concepts have been proposed for harvesting wind energy and some companies are already delivering products for new or existing vessels[14].

The innovative wind propulsion technology, that was developed with the WINTECC project, achieved 5% fuel savings-corresponding to 165 tonnes/year of fuel and correspondingly 530 tonnes of CO2 per year for the vessel Beluga Skysails on an average route mix, and10-12% savings on North Atlantic and North Pacific routes. Larger 'kites', which will be available soon, will provide higher savings. For fish trawlers also higher yields are expected due to lower ship speed[15].

`` **Figure 4:** Wind Propulsion System

5. NUCLEAR PROPULSION SYSTEM

Rising tensions between the United States and the Soviet Union caused the United States to bulk up its military resources. The nation needed bigger and better planes and ships, and in the wake of the destruction caused by "Little Boy" and "Fat Man" over Hiroshima and Nagasaki, respectively, the focus was on the atom. The United States managed to show that nuclear fission could indeed power a jet engine, but the project was cancelled in 1955 and an operational aircraft was never developed. Research into nuclear fission for the seas was more fruitful, and models today continue to use a system used by many nuclear land reactors. The United States Navy beat the Soviet Union to the nuclear powered ship. The development of a nuclear propulsion plant was authorized by Congress in July 1951. Captain Hyman G. Rickover led the Naval Reactors Branch of the Atomic Energy Commission and would go on to be known as the father of the nuclear submarine[16].

The cost of nuclear fuel is low and stable, which means speed is not an economic limitation for nuclear powered ships. While slow-steaming for fossil-fueled ships can reduce costs for the ship owners through lower fuel consumption, the benefits are not necessarily felt by cargo owners unless those lower fuel costs translate into lower freight rates. While time sensitive cargo does not go on ships, there is a certain benefit to getting cargo to the buyers as quickly as possible. Nuclear power can achieve these higher speeds for much lower costs than fossil-fueled powered vessels. Based on the low cost of fuel, the economics of nuclear powered ships will tend towards higher speeds such as 20 knots for bulk carriers, or 30 knots for container ships. Slow steaming is a strategy that evolved relatively recently to lower fuel costs and absorb excess capacity by reducing the number of vessels available at any given time as they are locked up in longer transit times. It is not necessarily ideal for the containerized cargo market[17].

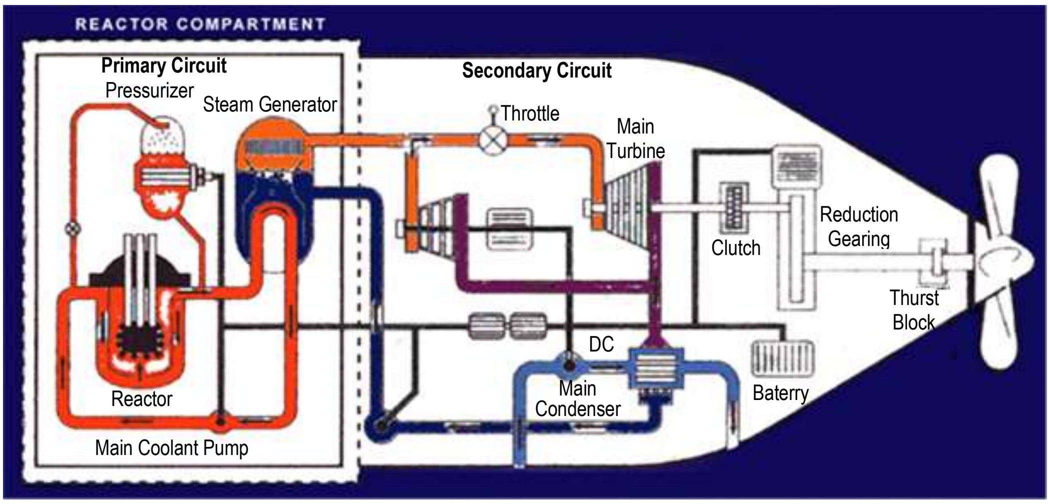

Figure 5: Nuclear submarine layout[29]

The Naval Nuclear Propulsion Program comprises the military and civilian personnel who design, build, operate, maintain, and manage the nuclear-powered ships and the many facilities that support the U.S. nuclear-powered naval fleet. The Program has cradle-to-grave responsibility for all naval nuclear propulsion matters[18].

Nuclear-powered ships have a proven record of safety, cost-effectiveness, and strategic value. With the industrial capacity already in place, Congress must seriously consider the unique benefits of providing and maintaining a larger nuclear navy. But nuclear reactors are already expensive. Just being "cheaper" than current costs, which are already high, is not enough. In order to make these passively safe marine nuclear reactors cheaper, let alone get them developed at all, certain economic strategies must be employed[17].

6. ELECTRIC PROPULSION SYSTEM

Electric propulsion systems, regard to the method of applying force to the propulsion systems are generally divided to electric propulsion systems using electric motors and electric propulsion systems using electromagnetic propulsion. The first part of this article is paid to different kind of electric motors that can be used in vessel propulsion and their speed control systems (drives), and simulation of one type of these systems. Noble type of electric motors that is used in propulsion systems because of using superconductors in their structure is named high temperature superconducting motors (HTS motors)[19].

Electric propulsion is an emerging area where various competence areas meet. Successful solutions for vessels with electric propulsion are found in environments where naval architects, hydrodynamic and propulsion engineers, and electrical engineering expertise cooperate under constructional, operational, and economical considerations. Optimized design and compromises can only be achieved with a common concept language and mutual understanding of the different subjects[20].

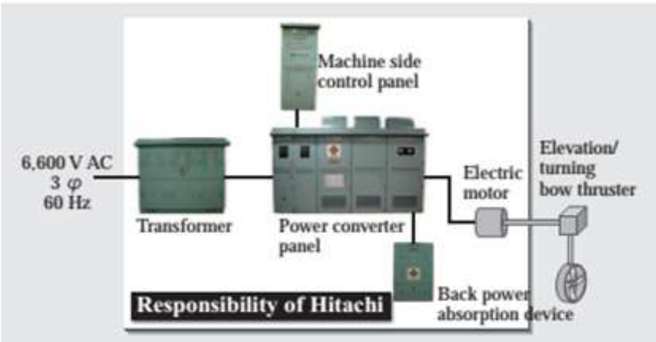

Figure 6: Electric Propulsion[22]

Marine electric propulsion describes the practice of employing prime movers to generate electricity to drive electric propulsion motors in contrast to the prime mover driving the propeller, either directly or through a gearbox. The past twenty years have seen a dramatic growth of vessels being configured in this manner and electric propulsion now dominates certain sectors of the maritime industry, such as cruise ships. Conceived in the early 1900s to facilitate the reversal of ship propellers at a time of limited gearbox manufacturing capability, and to meet the high torque demanded by ice breakers, early electric propulsion systems were based either upon the Emmet steam-turbo AC system or the low powereddiesel-electric DC system. The former used variable speed AC generators and motors and the latter constant speed DC generators and mechanically commutated DC motors. In both systems the equipment tended to be large and heavy, difficult to control and inefficient. A critical part of an electric propulsion system is the propulsion converter, required to control the speed of the propulsion motor. Early propulsion converters, such as cycloconverters and load commutated inverters (LCI) suffered intrinsic limitations. The LCI is smaller only requiring a third of the components of a cycloconverter and has a more favourable kVA (Simon & Duriaud, 1998), however it is difficult to control at low powers and also introduces relatively high levels of supply waveform distortion. Both the cycloconverter and LCI are used in ships today butare being superseded by voltage source inverters in new ships having electrical propulsion[21]. Electric ship propulsion is an effective means of helping to achieve the low-carbon society required by global societal needs[22].

7. GAS TURBINE PROPULSION

Using a GTE to propel a ship goes back to 1937 when a Pescara free piston gas engine was used experimentally with a GTE. The free piston engine, or gasifier, is a form of diesel engine. It uses air cushions instead of a crankshaft to return the pistons. It was an effective producer of pressurized gases. The German navy used it in their submarines during World War II as an air compressor. In 1953 the French placed in service two small vessels powered by a free piston engine/GTE combination. In 1957 the liberty ship William Patterson went into service on a transatlantic run. It had six free piston engines driving two turbines[23].

Gas turbines differ from steam turbines in that gas rather than steam is used to turn a shaft. These have also become more suitable for use inships. Many naval vessels are powered by gas turbines and several container ships are fitted with them. A gas turbine engine is very light and easily removed for maintenance. It is also suitable for complete automation. The gas turbine efficiency being low, its main advantage is its small weight and size which makes a gas turbine installation very attractive for naval applications. Most of modern warships of about to 5,000 tonne displacement are powered with gas turbines usually combined with diesel engines. Gas turbines are easier to start and reliable in operation. However, the use of astern gas turbines is a rather complex problem therefore ships powered with main gas turbine units are equipped with either controllable pitch propellers (CPP) or other reversing gears[24].

Figure 7: Gas Turbine Engine

The GTE, when compared to other types of engines, offers many advantages. Its greatest asset is its high power-to-weight ratio. This has made it, in the forms of turboprop or turbojet engines, the preferred engine for aircraft. Compared to the gasoline piston engine, the GTE operates on cheaper and safer fuels. The relatively vibrationfree operation of the GTE, compared with reciprocating engines, has made it even more desirable in aircraft. Less vibration reduces strain on the airframe. In a warship, the lack of lowfrequency vibration of GTEs makes them preferable to diesel engines because there is less noise for a submarine to pick up at long range. Modern production techniques have made GTEs more economical in terms of horsepower-perdollar on initial installation. Their increasing reliability makes them a cost-effective alternative to steam turbine or diesel engine installation. In terms of fuel economy, modern marine GTEs can compete with diesel engines and they may even be superior to boiler/steam turbine plants that are operating on distillate fuel. Most GTE propulsion control systems are very complex and require the monitoring of numerous operating conditions and parameters. The control systems must react quickly to turbine operating conditions to avoid casualties to the equipment. In shipboard installations special soundproofing is necessary because GTEs produce high-pitched noises that can damage the human ear. The turbine takes in large quantities of air that may contain substances or objects that can harm it. Also, the large amount of air used by a GTE requires large intake and exhaust ducting, which takes up much valuable space on a small ship. This adds to the complexity of the installation and makes access for maintenance more difficult[23].

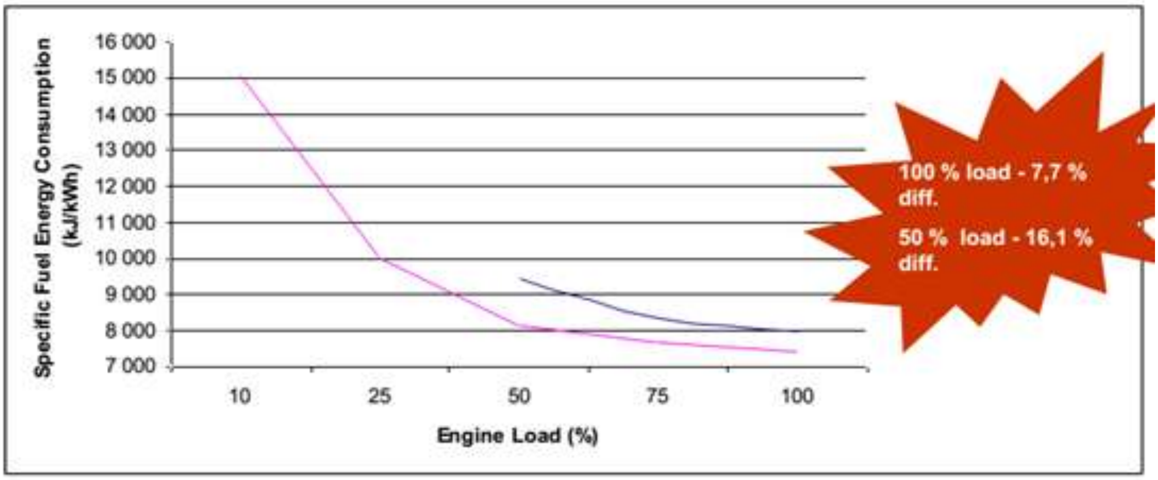

Figure 8: Gas consumption comparison-Generators-constant speed: Single fuel vs Dual fuel[24].

8. WATER JET PROPULSION SYSTEM

Water Jet Propulsion system is an application similar to that of a water pump. A waterjet system generates its propulsive force or thrust from the reaction that is created when the stream of water is forced out through the rear side of the ship. It works on the principle of the Newtons third Law of motion-i.e "every action has an equal and opposite reaction". A water jet unit is mounted in the aft section of the ships hull. Water enters the jet unit through the intake grid at the bottom of the boat, drawn through the inlet duct by the impeller which in turn increases the pressure or "Head" of the water flow. This high pressure water flow is then discharged through the nozzle with high velocity jet stream. Water-jet systems finds a wide application in search and rescue patrol boats of the Navy and Coast Guards, Commercial car and passenger ferries, and also in a number of yachts. Speeds achieved by ships using a water jet is usually within a range of 35 to 40 knots. However, recently Australian shipyard Incat has built a High-speed dual fuel ship to be used for vehicle and passenger ferrying named Francisco, and is powered by two air craft engine-based GE gas turbines which drive a pair of water jets. The ship achieves maximum speeds up to 58.1 knots (67 miles per hour). Interestingly, apart from being the word's fastest ferry, Francisco is also the first ship to use liquefied natural gas as its primary fuel[25].

A stern-mounted waterjet installation as used in commercial applications, can be divided into four components: the inlet, the pump, the nozzle and the steering device. The main component is the pump, which delivers the head to produce the jet at the nozzle exit. In general the stator bowl and the nozzle are integrated in one part. In the remainder of the thesis, the combination of the pump unit and the nozzle is regarded as the waterjet pump[26].

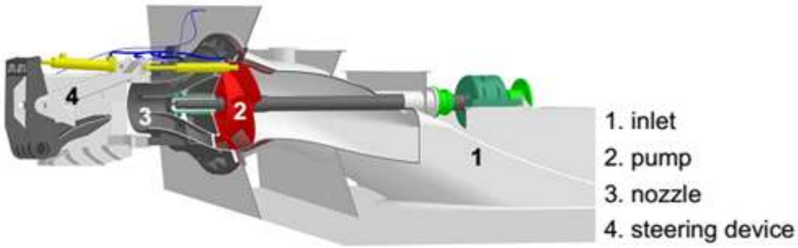

Figure 9: Three-dimensional view of a waterjet installation[26]

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Waterjet propulsion has many advantages over other forms of marine propulsion, such as stern drives, outboard motors, shafted propellers and surface drives. These advantages include: Reliability, Excellent Manoeuver ability, Speed, High Efficiency, Low Drag and Shallow Draught, Low Maintenance, Smooth and Quiet, Total Safety, Maximum Engine Life, Simplicity and Easy Installation[27].

9. SOLAR PROPULSION SYSTEM

With the increasing population of the world, researchers should think about alternate sources of energy because primary sources of fuel are limited in stock. So the scientists are looking for sustainable energy sources like sun, wind, water and tidal flow. Of them solar energy is the prime source of renewable energy as it can get easily from nature. The country which has enormous solar energy potentiality can think to use it in diversified sectors. Specially, the developing and least developed country can think solar energy as a cardinal source of energy to meet energy scarcity. Alike the household solar cell and solar car, solar energy also can be a smart choice to drive the boat. Some lowland countries like Bangladesh, Indonesia and Maldives can use this kind of solar boat for its inland navigations. The fabrication and installation of this solar boat is very simple and reliable. Considering the economy, fuel consumption, capacity, complexity and reliability solar energy driven boat is an innovative invention. This paper tries to find a noble approach to design and fabricate a solar powered boat that can satisfy the requirements of short transportation. The boat has a navigation capacity of 25km/Day with maximum total weight of the unit of 200kg. The proposed solar boat has two batteries which can provide power in short cloudy periods as if it can be a reliable source of transportation[28].

Figure 10: Solar Propulsion

10. DIESEL-ELECTRIC PROPULSION SYSTEM

Diesel-electrical propulsion is a collective noun for all propulsion systems in which, as the name says, combines a diesel engine with an electrical propulsion system. The previously mentioned azimuth thrusters are also an example of diesel-electrical propulsion, but they are mentioned separately because they are quite commonly known, and more developed than different systems in this same category. The diesel-electrical propulsion system is commonly used in non-nuclear submarines. Early diesel-electric submarines had to switch between electrical and diesel propulsion. Nowadays they are usually electrical powered. The switch is now to switch the source were the power comes from, direct from engine or from batteries. The diesel-electrical propulsion system is usually combined with Azimuth thrusters. One of the advantages is that the screw propeller can turn very slowly, without the diesel-electrical propulsion system this wouldn't be possible. Because of this the vessel can sail slower what sometimes can be useful. For example when the vessel would arrive through circumstances too early it can now sail slower so that it will arrive at the planned ETA what saves money for too early berthing[30].

11. FUEL-CELL PROPULSION SYSTEM

Basically, a fuel cell is a device that converts directly the chemical energy stored in gaseous molecules of fuel and oxidant into electrical energy. When the fuel is hydrogen the only by-products are pure water and heat. The overall process is the reverse of water electrolysis. In electrolysis, an electric current applied to water produces hydrogen and oxygen; by reversing the process, hydrogen and oxygen are combined to produce electricity and water (and heat). A fuel cell can be seen with profit as a "chemical factory" that continuously transforms fuel energy into electricity as long as fuel is supplied. However, unlike internal combustion engines that can be regarded as factories as well, fuel cells rely on a chemical reaction involving the fuel, and not on its combustion. During combustion, molecular hydrogen and oxygen bonds are broken and electrons reconfigure into molecular water bonds at a picosecond length scale. There is no possible way to "catch up" these free electrons and the net energy difference between molecular bonds in products vs. reactants can only be recovered in the most degraded form of energy, i.e. heat. A Carnot cycle involving the transformation of heat into mechanical and electrical energy is then involved in conventional methods for generating electricity: these successive steps of transformation of energy severely limit the overall efficiency of the process (which is by definition the product of the efficiency of the different steps[31].

Table 1: Type of Fuel Cell[33]

TYPE OF FUEL CELL	PEMFC (Proton Excange membrane Fuel Cell)	AFC (Alkaline Fuel Cell)	PAFC (Phosphoric acid fuel cells)	MCFC (Molten Carbonate Fuel Cell)	SOFC (Solid Oxide Fuel Cell)	DMFC (Direct Methanol Fuel Cell)
ELECTROLYTE	Polymer Membrane	KOH	H_3PO_4	$(LiK)2CO_3$	nonporous metal oxide ZrO_2	Polymer membrane
CHARGE CARRIER	H^+	OH^-	H^+	CO_3^{2-}	O^{2-}	H^+
ANODE	Pt/C	Pt/C	Pt/C	Ni+10 wt%Cr	N_i+(Zr,Y)O_2	R_u/C
CATHODE	Pt/C	C	C	NiO	(La,Sr)M_nO_3, $LaCoO_3$	Pt/C
OPERATION TEMPERATURE (^{0}C)	30-100	200	150-200	600-700	600-1000	20-80
SYSTEM OUTPUT	1-200 kW	10-100 kW	200 kW	500 kW	100 kW	0,1-10 W
USABLE FUELS	H_2; natural gas; methano	Pure hydrogen	natural gas; methanol naphtha	natural gas; hydrogen; carbon monoxide	natural gas; Coal methanol petroleum	Methanol

In the marine sector, legislation is likely to act as a key driver for the adoption of fuel cells. New restricting policies requiring low or zero emission for vessels in certain rivers, lakes and inland waterways in China and Europe, as well as growing pressure on regulating pollutant emissions in harbours, in coastal waters and on the high seas, are a favorable ground for the uptake of fuel cells as APUs on board vessels to reduce overall emissions and also for development of fuel cells as main means of propulsion[31].

At this moment fuel cells are not yet existing and proven technology, in the respect that they are not widely (commercially) applied, especially not on board of ships. The main reason for that is that the costs for the technology are still too high, because no series or mass production has been started. The technology is in the research and development phase. Although the working principle of fuel cells is demonstrated for hydrogen applications (PEMFC, AFC) and natural gas applications (PAFC, MCFC, SOFC), the application for logistic liquid fuels (sulphur containing diesel and marine oils) is still in the very early stages. A lot of research is currently aimed at more efficient, reliable and cost efficient conversion to hydrogen (for example the DESIRE project at ECN). See also the hydrogen production technique chapter[32].

There are many different types of fuel cells, characterized by the type of the electrolyte and/or catalyst used. The electrolyte used determines different operating conditions required such as heat and pressure. The difference in electrolyte leads to some fuel cells being more suited to distributed generation applications than the others. While there are many variants, there are five different types of fuel cells considered as potential for DG applications. Polymer electrolyte membrane (PEM), alkaline (AFC), and phosphoric acid fuel cell (PAFC) technologies are considered low temperature fuel cells and operate at about 80oC. While low temperature fuel cells are suitable in some applications where heat is undesirable, there is no option for co-generation. Co-generation requires high-grade heat that molten carbonate (MCFC) and solid oxide fuel cell (SOFC). These different types of fuel cells operate at a different temperature[33].

There are other types of fuel cells that are relatively newer to the family of fuel cells. The Direct Methanol Fuel Cell (DMFC) is very similar to the PEMFC, but it is able to directly utilize liquid methanol at the anode. There is also a Regenerative Fuel Cell, which contains a membrane that can both electrolyze water into hydrogen and oxygen and, with the flick of a switch, recombine the two elements, producing electricity and water. In a Metal Air Fuel Cell, zinc pellets and an alkaline electrolyte are circulated through the fuel cell stack and are combined with oxygen from air to create electricity, heat and zinc oxide (in a solution of potassium zincate). The zincate can be regenerated in a separate process into fresh zinc pellets[33].

Figure 11: Fuel-Cell Propulsion

12. CONCLUSION

Marine propulsion has been known since 40,000 years ago and is growing in line with technological advances. There are several types of propulsion and of these types are the advantages and disadvantages between propulsion with each other. Its use in ship propulsion types depending on the type, size, use and operation area of the vessel, so the use of propulsion on ships not observe the advantages and disadvantages of each propulsion.

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