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Study of Green Shipping Technologies - Harnessing Wind, Waves and Solar Power in New Generation Marine Propulsion Systems

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ABSTRACT: The purpose and scope of this paper is to describe the complexity of the new generation marine propulsion technologies implemented in the shipping industry to promote green ships concept and change the view of sea transportation to a more ecological and environment-friendly. Harnessing wind, waves and solar power in shipping industry can help the ship's owners reduce the operational costs. Reducing fuel consumption results in producing less emissions and provides a clean source of renewable energy. Green shipping technologies can also effectively increase the operating range of vessels and help drive sea transportation towards a greener future and contribute to the global reduction of harmful gas emissions from the world's shipping fleets.

1 INTRODUCTION

Nowadays, early in the 21st century around 90% of world trade (by volume) is carried by the international shipping and constitutes an essential part of the modern world economy. Nowadays we have an access to the high technology as well as the adequate knowledge, skills, attitude and behavior. These elements give us good opportunities and adequate competences to lead the shipping industry to a more ecological and environment-friendly sea transportation system.

Unfortunately, if we look deeper in the shipping industry development observed since the 19th century, it may appear to the public and the media that the growth in the marine propulsion technologies is not adequate to our ability and, what is more, that the sea transportation has not done much to reduce the environmental impacts such as emissions of toxic gases or pollution at sea [3], [4].

Figure 1. Comparison of the environmental impacts brought by shipping observed in the last 200 years of sea transportation related activities. Source: Teekay Environmental program, Nov.2016.

Figure 2. Complexity of Marine Propulsion Technologies. Source: Inerjy website [7].

Keep in mind that around 200 years ago ocean going sailing ships were already reaching speeds of 16 knots or more and carrying goods across the globe without using a drop of oil. Best of all, they also released no harmful emissions or pollution, being always a part of very ecological and environment-friendly sea transportation system (see Figure 1) [4].

But since then, the world shipping industry has strayed off the green path and the benefits of using wind power on-board large ships was forgotten. In such case, we must draw the following conclusion: nowadays there is no adequate progress in green shipping industry and we must concentrate how to move our fleet again to a green path and change the view of the sea transportation to a more ecological and environment-friendly system.

It is crucial that currently we have a wide range of modern marine green technologies available on the market, used to enhance the performance and sustainability for the oceangoing vessels (see Figure 2). These technologies range from simple with low capability such as traditional sails or small scale renewables wind power plants or solar modules to very capable and highly complex systems such as LNG & dual fuel power plants. In this article we are going to concentrate on a few modern marine green shipping technologies which harness wind, waves and solar power to support marine propulsion system of new generation.

2 HARNESSING WIND, WAVES AND SOLAR POWER

Whenever we are talking about harnessing wind power in modern marine propulsion system we must keep in mind, that whether using flexible or rigid sails, the aerodynamic efficiencies on the vessels are limited by the tip speed ratio, or the ratio of the air foil's speed through the air to the wind speed. Taking all of this into consideration, foiling catamarans, like the America's Cup race boats, in specific situation are able to sail faster than the wind, and therefore achieve tip speed ratios well above one. This allows their air foils (sails) to obtain a higher propulsion efficiency. Unfortunately, this works great only on a racing boat, but when loaded down to the cargo ships with all the needs of a ship serving a purpose other than racing, the efficiency is reduced by the lack of ability to achieve the same tip speed ratios. Also, when the vessel is intentionally moving more slowly than optimal, e.g. when limited by a comfort in a seaway, performing mission objectives not involving transit, or sailing in a non-optimal direction, the wind energy is wasted. However, even in such specific scenarios we still can take into consideration harnessing wind power to the new generation wind sails, Flettner rotors or a power generation plant which can support, but not necessary replace, traditional marine propulsion systems reducing shipping operational cost and emissions.

With SkySails the worldwide patented propulsion system [9] the modern cargo ships can use the wind as a source of power to support the main marine propulsion system and not only to lower fuel costs, but also significantly reduce emission levels. SkySails system consists of three main components: a towing kite with a rope, a launch and recovery system, and a control system for an automated operation. The system can be installed effortlessly as an auxiliary propulsion system on both newly built and existing vessels harnessing the wind as a cheapest, most powerful, and greenest source of energy on the high seas. The SkySails propulsion system is efficient, safe, and easy to use – and the fact that wind is cheaper than oil makes SkySails one of world's most attractive technologies for reducing the operating costs and emissions.

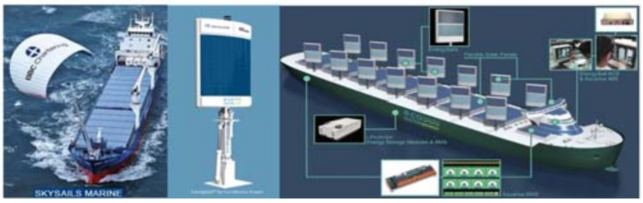

Figure 3. Comparison the SkySails Marine system with EMP's Energy Sail technology installed on Aquarius Eco Ship. Sources: SkySails [9] and EcoMarine Power [6] websites. Nov.2016.

Eco Marine Power (EMP) Co. Ltd. [6] decided to go one step ahead offering to green shipping industry their unique design concept and the innovative technology well known on market as Aquarius MRE System with revolutionary EMP designed Energy-Sails (see Figure 3) as a renewable energy collectors. Their vision is to create a sustainable future for shipping where our trade and transport routes will once again see ships utilize wind power but also harness the power of the sun via solar modules, which can reduce emissions, but also save ship owners and shipping companies money by reducing fuel costs even when a ship is in port or at anchor.

Solar PV is an excellent technology and should augment power supplies whenever possible. Planet Solar even made their MS 'Turanor' recognizable by making it sail around the world on PV power alone. The trouble is that it requires a great deal of area to obtain enough power to propel a ship. As with the 'Turanor', much of the functionality was sacrificed to maximize unshaded module area. This isn't practical on a typical cargo ships and scale doesn't alter these dynamics. However, using the solar PV technology, we still can support traditional marine power plant and by reducing fuel consumption significantly reduce emission levels.

The EMP's Energy Sail technology [6] allows the ship to harness the power via a computer controlled rigid sail or rigid sail array. Typically, an Energy Sail array would be incorporated into an Aquaris MRE solution but the installation of an Energy Sail as a standalone device is also possible. The Aquarius MRE System is an advanced integrated system of rigid sails, solar panels, energy storage modules that will enable ships to tap into the renewable energy by harnessing the power provided by the wind and sun. The array of rigid sails will be automatically positioned to best suit the prevailing weather conditions and can be lowered and stored when not in use or in bad weather. The array of rigid sails is based on EMP's Energy Sail technology (patent pending) and can even be used when a ship is at anchor or in harbor. Clearly the Energy Sail is unlike any other sail. All EMP's hybrid marine power and marine renewable energy solution incorporate the Aquarius Management and Automation System or Aquarius MAS. The Aquarius MAS is a cost effective, alarm handling, performance monitoring and data logging platform suitable for a wide range of ships. Using the Aquarius MAS system CO2, NOx & SOx emissions can be monitored or calculated. The system is based upon the type approved KEI 3240 Data Logger which is already in use on hundreds of vessels [6].

An Energy Sail can include marine grade solar panels either on the sail itself or located near the sail. The flexible nature of the Energy Sail design will also allow for it to be upgraded during the life-cycle of the ship it is fitted to so that newer technologies can be incorporated as they become available such as more efficient solar modules or panels. Other technologies can also be fitted to the Energy Sail including wind power generating devices. In addition to being suitable for ocean-going ships including RoRo vessels, cruise ships and large passenger ferries, several variations of the Energy Sail are being developed [6] which will be suitable for smaller vessels including Unmanned Surface Vessels (USV's) and autonomous ships and vessels.

Technologies associated with the Energy Sail are also suitable for the offshore renewable energy projects and land-based renewable energy projects. An example of how the Energy Sail could be incorporated into a modern ship design is the Aquarius Eco Ship. This low emission - sustainable ship design concept includes an Energy Sail array and other technologies so that solar & wind power can be used to reduce fuel consumption and lower noxious gas emissions.

EMP's Hybrid Power or Hybrid Marine Power (HMP) systems [6] are another example of low emission, cost effective an attractive return on investment solutions for the vessel owners and operators. EMP is currently developing a range of cutting edge solar-electric hybrid powered ferries, workboats and other vessel concepts. These designs will incorporate a range of technologies including computer systems, flexible marine grade solar panels, energy storage modules, power management and hybrid propulsion with highly efficient electric motors, generators and lithium batteries. Eco Marine Power's vision is to provide a clean, cost-effective, low pollution and efficient form of water transport on urban waterways across the globe that will not only benefit the environment but also reduce their operating costs.

Another quite interesting solution for green shipping concept has been implemented by Germany's Enercon [2], the third-largest wind turbine manufacturer and owner of 'E-Ship 1'. The 'E-Ship 1' was built by German shipbuilder Lindenau Werft in Kiel as RoLo (Roll-on/Roll-off) cargo ship used to transport wind turbine components. The ship is equipped with four large rotor-sails (well known as Flettner rotors), which are rotating at variable speed to create lift on the cylinder body, supporting the ship-like sails by means of the Magnus effect (the perpendicular force that is exerted on a spinning body moving through a fluid stream).

The fundamental configuration of the rotor propulsion system has been initially created already in the 1920s by German engineer Anton Flettner. In October 1924, the Germaniawerft finished construction of a large two-rotor ship named ‘Buckau’. The vessel was a refitted schooner which carried two cylinders (rotors) approximately 15 metres high and 3 metres in diameter, driven by an electric propulsion system of 50 HP (37 kW) power. The ‘Buckau’ set out on her first voyage, from Danzig to Scotland across the North Sea, in February 1925. The rotor ship could tack (sail into the wind) at 20-30 degrees, while a vessel with a typical sail rig, cannot tack closer than 45 degrees to the wind, hence, the rotors did not give cause for concern in stormy weather. Next year in 1926, ‘Buckau’, now renamed as ‘Baden Baden’ sailed to New York via South America and despite having completed trouble free crossings of the North Sea and Atlantic the power consumed by spinning 15m tall drums was vastly disproportionate to the propulsive effect when compared with conventional screws (propellers). As the Flettner system could not compete economically Flettner turned his attention to other projects, such as his rotor aircraft.

The innovation used on ‘E-Ship 1’ is the propulsion system [2], which contains four modern Flettner rotors working together with two traditional propellers propulsion system. The ‘E-Ship1’ bridge is located at the bow, and has three decks and two port-related long-boom cranes with payload capabilities of 80 and 120 tonnes. The ship has a rear ramp, and can function as a RoLo cargo ship. The vessel is 130 meters in length and 22.5 meters wide, 6 to 9 m draught, with tonnage 10500 DWT and maximum speed 17.5 knots (32.4 km/h). It is equipped with fore and aft maneuvering thrusters and has an ice class GL E3 hull rating. The ‘E-Ship 1’ is equipped with nine Mitsubishi marine diesel engines with a total output of 3.5 MW. The ship's exhaust gas boilers are connected to a Siemens downstream steam turbine, which in turn drives four Enercon-developed Flettner rotors. These rotors, resembling four large cylinders mounted on the ship's deck, are 27 meters tall and 4 meters in diameter. The ship made its first voyage with cargo in August 2010, carrying nine turbines for Castledockrell Wind Farm from Emden to Dublin, Ireland. On 29 July 2013, Enercon provided a press release claiming a potential for ‘operational fuel savings of up to 25% compared to same-sized conventional freight vessels’ after 170000 sea miles, actual performance figures were not provided. [2]

In 2009 similar concept that would utilize Flettner rotors as means of reducing fuel consumption has been developed by Finland-based maritime engineering company Wärtsilä in association with the Finnish ferry operator Viking Line. Because of researching and testing different green shipping technologies Wärtsilä, in September 2016 during SMM conference in Hamburg, has set out her visions for the future of the shipping industry which include rotor ships concept as a very effective and environmental friendly solution. The work on future visions [5] has been prompted by the inevitable effect that growing global energy demand and increasingly stringent environmental legislation to combat climate change will have on the shipping sector. Additionally, Wärtsilä assesses various emerging trends, such as sharing economies, new business models enabled by the new digital universe, the huge growth in energy storage capacity, and new affordable 'green' energy sources, since they represent both challenges and opportunities for the future of shipping (see Figure 4).

The concept of rotor ships is not new, but up to now, the main idea has been to have the rotors create additional propulsion from the wind, thereby producing fuel consumption. But German researchers [8] are further developing the concept to create synthetic gas (power to gas or P2G). The rotating turbine kept in motion by the ship's kinetic energy is used to generate electricity, which then creates synthetic gas by means of electrolysis. The gas can then be used as a fuel and to generate electricity as need be.

Nowadays, the THiiiNK Holding organization describes an improved version of the Flettner Rotor that is retractable and supplemented by an additional control surface. The page [1] claims that ‘The system has been developed and tested both in tank tests and in full-scale sea trials. The design improvement claims include improved rotor performance (by 50% or more), and an improved internal rate of return (IRR) compared to a standard rotor (up to 55%)’.

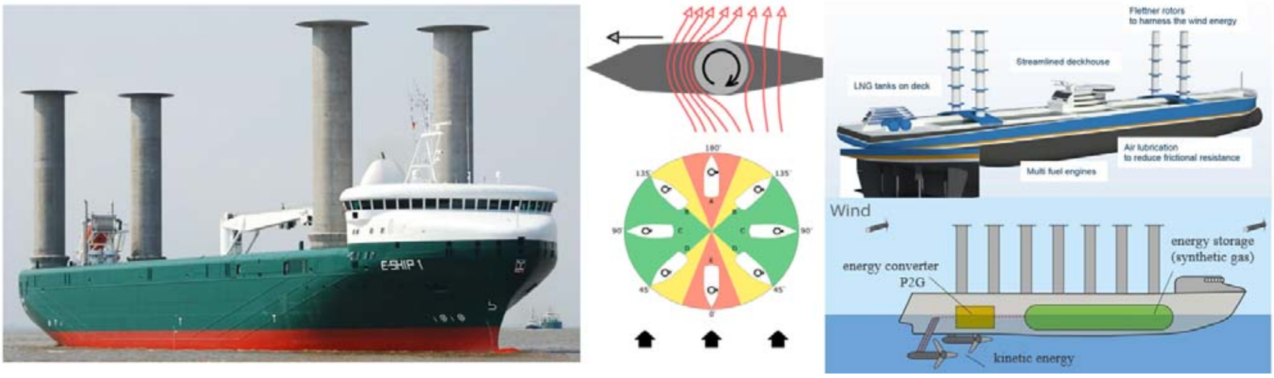

Figure 4. Comparison E-Ship 1 rotor ship by Enercon (on the left) with Wärtsilä 'Visions of Future Shipping' (on the right top) and Segelenergie project (on the right bottow corner). Sources: Enercon [2], Wartsila [5] and Segelenergie [8] websites. Nov.2016.

There is also another quite interesting green technology proposed by Wallenius Wilhelmsen [10] for zero-emission car carrier (see figure 5) with length overall 250 m, height 30 to 40 m, beam moulded 50 m, design draught 9 m, design speed 20 knots (maximum) and 15 knots (in service), vehicle capacity 10000 cars (based on today's standard units) with design cargo deck area 85000 m² and eight cargo decks, of which three are adjustable in order to accommodate high and heavy vehicles and equipment.

Figure 5. Comparison zero-emission car carrier proposed by Wallenius Wilhelmsen (on the left) with zero-emission Aeromancer system proposed by Inerjy (on the right). Sources: Wallenius Wilhemsen [10] and Inerjy [7] websites. Nov. 2016.

The hull design is pentamaran with design materials aluminium and thermoplastic composites. Ship will be equipped with solar panels (3 x 800 m²) which should generate 2500 kW output energy, wind sails (3 x 1400 m²), fins (12 x 210 m²), fuel cells energy output 10000 kW, pod propulsion system 2 x 4000 kW. As per plan ship will take advantage of solar energy, wind energy and waves energy and utilize such energy for manoeuvring, sailing and all on-board systems. For energy carriers system will use hydrogen, electricity, fuel cells and hydraulic energy.

Another very interesting zero-emission an innovative propulsion-scale wind power system for long range high endurance ships has been presented by ‘Aeromancer’ Inerjy [7]. The solution enhances system capabilities by providing indefinitely sustainable electrical and propulsion energy without fuel. It accelerates development cycles by providing a scalable technology platform that can modularize vessel design, eliminating the need for holistic designs for every vessel purpose as well as offering a simpler alternative to the complex state of the art hybrid energy systems. This simplification allows a framework suitable for streamlined procurement strategies, allowing ‘building blocks’ to be defined and sourced from different vendors. It reduces sustainment costs through drastic crew reduction plus elimination of fuelling infrastructure. Finally, it mitigates technical risks through modularization and simplified systems architecture.

The goal of ‘Aeromancer’ [7] is to have high capability in a very simple to design, implement, and maintain platform. This is accomplished with a wind turbine as the primary power source combined with a large battery buffer using an all-electric DC bus architecture.

The wind turbine and battery technologies are the two primary enablers, and are enhanced by high efficiency sub systems. The Turbine EcoVert75™ was designed for distributed generation applications, like powering schools, retail stores, etc. The key requirements focused on people living and interacting near the machine. It is technically called a pitch-controlled H-VAWT, a design originally modelled, prototyped, and tested by McDonnell Aircraft Corporation (now Boeing) in the early 80’s. It produces a healthy 70kW in a 21 knot (10.8 m/s) wind at 32 rpm. With a few hardware and software modifications it is an excellent machine for use aboard a vessel. The EcoVert75™ has less than ¼ the head mass and a third the storm wind loads compared to other similarly sized turbines and less than ½ the operational blade speeds of conventional turbines at similar power outputs, very low noise & safe blade path for vessel occupants, high power efficiency (Cp > 0.5 at some wind speeds) and the ability to produce propulsion thrust directly with the turbine instead of converting all the wind power into electricity (saving conversion losses).

Propulsion scale wind turbine power is the heart of the ‘Aeromancer’ concept. A common metric used to describe a sailing vessel is the sail area displacement ratio (SA/D). This basically allows vessels to be compared to each other in terms of a power to weight ratio. The highest SA/D ratio tested with a turbine thus far has been <5. Aeromancer’s target SA/D is 11. Given that ocean going sailing vessels are commonly around 15, and racing vessels above 20, there is opportunity for advancement in power to weight ratio metrics.

‘Aeromancer’s main hull is dedicated to little more than housing crew and mission spaces. In normal conditions the hull is jacked up clear of the water so it has no main running surfaces. Given the absence of diesels or related systems, all spaces within the main hull can be environmentally controlled, and relatively little mechanical space is necessary. A large enclosed garage is provided for storage of a RHIB (rigid-hulled inflatable boat**)** and unmanned systems.

In green shipping industry, the battery performance is advancing at a rapid pace, and is now providing critical energy supply on modern ships regularly. From work vessels like the impressive ‘Edda Freya’ to pure battery electric ferries like the ro-ro ‘Ampere’, and many more, Li-chemistry batteries are developing a maritime propulsion legacy. Numerous battery cell manufacturers are promoting solutions for marine applications. Traditional classification societies are also developing standards for large scale on-board Li based energy storage.

On ‘Aeromancer’ the 2500 kWh energy storage system will be divided into the two outrigger hulls, along with the DC-AC converters, the propulsion motors and drives, and H-VAWT equipment. Cooling requirements are suppressed by the highly paralleled architecture.

However, not all purposes are suitable for wind powered battery electric ship technology. As of now the batteries will hold far less energy than large fuel tanks, but most regions of the world’s oceans have abundant wind energy available on a regular basis so that there isn’t a need to carry weeks or months of energy on board. For instance, using solar PV technology, the ‘Aeromancer’, would require more than 10000 SQFT (≈929 m²) of unshaded module area to derive equivalent power production to the EcoVert, in a Caribbean type environment. EcoVert can maintain tip wind speed ratio and optimal angle of attack independently of vessel course and speed. The batteries allow the extra energy to get stored for later use.

Additionally, solar-electric commuter ferries will fulfil an important role in energy-efficient cities near harbors, bays and waterways in the years ahead. Not only will these vessels reduce fuel costs but also help reduce air and noise pollution thus improving the quality of life in these cities.

3 CONCLUSION

The innovative in green shipping industry including hybrid marine concepts which give us possibility to harness wind, waves and solar power and support ship's propulsion systems and power generation plants will not only reduce fuel costs, but will also play an important role in assisting ship owners/operators meet the requirements of operating in Emission Control Areas (ECA), marine parks and nature reserves etc. Marine wind, waves and solar power systems can be installed on large ships such as car carriers, bulkers, passenger ferries and oil tankers plus on smaller ships such as commuter ferries, river boats and recreational vessels. From the small powered pleasure craft and ferries to large super-tankers, the limitless energy of the wind, waves and sun can be used to help power ships thereby reducing fuel consumption, the emission of greenhouse gases (GHGs) and noxious exhaust emissions. Green shipping can also effectively increase the operating range of vessels and help drive sea transportation towards a greener future and contribute to the global reduction of harmful gas emissions from the world's shipping fleets.

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