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SOLAR AND WIND ENERGY FOR SHIP POWER SYSTEM, CURRENT STATUS AND FUTURE PROSPECT

Diah Zakiah[1*], Vidya Selasdini[1]

[1]STIP Jakarta, Jl Marunda Makmur Cilincing, Jakarta Utara 14150
*Email : diahz2018@gmail.com

ABSTRACT

The issue of climate change due to the greenhouse effect encourages various parties to try reducing emissions in energy fulfilment. In maritime sector, IMO has adopted mandatory measures to reduce emissions of greenhouse gases (GHG) from international shipping, under IMO's pollution prevention treaty (MARPOL). Besides Carbon Oxides (COX), statistics show that other exhaust emissions from ships, such as Sulfur Oxides(SOX), Nitrogen Oxides(NOX) and Particulate Matters(PM) have also increased significantly in the past years due to the rapid increase of the maritime transportation. It is necessary for the shipping industries to find out the available clear energy to reduce the emission of GHG. This paper will discuss application of solar and wind energy on ship power systems, current status and future prospect.

Keyword: solar, wind, energy, ship, zero emission

1. Introduction

The issue of climate change due to the greenhouse effect encourages various parties to try to reduce emissions in energy fulfillment. On the other hand, world oil reserves are running low, causing world oil prices to continue to rise. Renewable energy is an option to replace fossil energy sources and will continue to be developed.

In the maritime sector, IMO continues to contribute to the global fight against climate change, in support of the UN Sustainable Development, to take urgent action to combat climate change and its impacts. IMO has adopted mandatory measures to reduce emissions of greenhouse gases (GHG) from international shipping, under IMO's pollution prevention treaty (MARPOL) - the Energy Efficiency Design Index (EEDI) mandatory for new ships, and the Ship Energy Efficiency Management Plan (SEEMP).

The GHG emission has increased dramatically in the past years, especially after the industrial revolution. According to a research in the Journal of the U.S. National Academy of Sciences, it is estimated that global carbon dioxide emissions increased by 13% in the past 10 years. The GHG growth rate of the global transport sector was up to 25% during this period [4]. Seaborne trade is the cheapest and most cost-effective way of the international cargo transportation. Accounting for 90 percent of international cargo transportation, the seaborne trade only emits nearly 2 percent of the total carbon dioxide. Although the emission percentage of the seaborne trade is not huge, however, it is estimated that the emission of carbon dioxide from the seaborne trade will increase 5 percent annually.

Therefore, it is necessary for the shipping industries to find out the available clear energy to reduce the emission of GHG. Besides Carbon Oxides (COX), statistics show that other exhaust emissions from ships, such as Sulfur Oxides(SOX), Nitrogen Oxides(NOX) and Particulate Matters(PM) have also increased significantly in the past years due to the rapid increase of the maritime transportation. This encourages the shipping industries to develop the use of alternative energy to propel ships. Several renewable energies such as solar, wind, hydrogen and even nuclear are considered.

This paper will discuss application of solar and wind energy on ship power systems, current status and future prospect.

2. Literature Review

2.1 IMO Recommendations

The Energy Efficiency Design Index (EEDI) for new ships is the most important technical measure and aims at promoting the use of more energy efficient (less polluting) equipment and engines. The EEDI requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship type and size segments. EEDI is expected to stimulate continued innovation and technical development of all the components influencing the fuel efficiency of a ship from its design phase. The EEDI provides a specific figure for an individual ship design, expressed in grams of carbon dioxide (CO_2) per ship's capacity-mile (the smaller the EEDI the more energy efficient ship design) and is calculated by a formula based on the technical design parameters for a given ship.

The Ship Energy Efficiency Management Plan (SEEMP) is an operational measure that establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner. The SEEMP also provides an approach for shipping companies to manage ship and fleet efficiency performance over time using, for example, the Energy Efficiency Operational Indicator (EEOI) as a monitoring tool.

Under the amendments to MARPOL Annex VI, on or before 31 December 2018, in the case of a ship of 5,000 gross tonnage and above, the SEEMP shall include a description of the methodology that will be used to collect the data and the processes that will be used to report the data to the ship's flag State.

2.2 Solar Energy

Solar energy has been used as the vital power source for human society for many years. At present, solar energy has been widely applied in many fields such as the solar power generation, solar heating for the buildings and solar electricity for spacecrafts.

Solar energy provided by solar panels that convert light from the sun into electricity. Solar panels on ships are not very common at present, but some installations have been done over the last years [3]. Solar panels are applicable for all ages of vessels trading in areas with sunlight. Further, to produce electricity from solar panels a large area for installation is required and therefore only ships that are not dependent on deck space can utilize the system.

The solar panels on vessels are installed to produce electricity and will be used to supplement the diesel generators and thus reduce the power required from these units. The solar power units can produce energy both at sea and in port, but only during daylight. Moreover, solar panels produce power also in cloud cover though not at full capacity.

Because of the round shape of the Earth, the sunlight strikes the Earth's surface at different angles, ranging from 00 (just above the horizon) to 900 (directly overhead). If the sunlight is vertical, more energy can be captured. Otherwise, less energy can be absorbed. The reason is that the energy of the radiation is scattered and dispersed more when the sunlight is slanted resulting in the longer distance of the sunlight passing though the atmosphere. Secondly, the earth's revolution also influences the absorb of solar energy. In the summer, the earth is closer to the sun than the winter. In the tropics the intensity of sunlight is more intense than in the subtropics, where the sun shines throughout the year.

Thirdly, the earth's rotation also contributes to the light length of the sunlight. Obviously, in the morning or afternoon, the sunlight is weaker than the noon.

There are advantages of using solar energy. Firstly, solar energy is nearly free except for initial capital expenses, unlike the conventional energy sources, solar energy does not need the continuous investment to fuel oil, coal or gas. It is attractive for the shipping industry, especially under the high oil price circumstance. Secondly, the solar energy is one kind of renewable energy, compared with the conventional energy such as the fossil energy, solar energy is never going to run out.

Thirdly, solar energy is more environmentally friendly than the fossil energy. As we know, fossil energy has adverse impact on the environment, where does the most contribution to the greenhouse effect. By contrast, solar energy is one kind of "zero emission" energy hence it causes less pollution to the vulnerable environment.

Although there are many advantages of the solar energy, however, some shortcomings are also attached to the solar energy. Firstly, the solar energy is un stable. It varies according to several factors and fluctuates dramatically even one day. Secondly, its energy density is very low. Thirdly, due to different geographic environments, weather condition, season as well as day and night alternation, the radiation of sunlight fluctuates every time, which results in the difficulty of the utilization of the solar energy [4].

Solar panels that were originally only used on land have begun to be applied in shipping, especially those that require small power like fishing boats. For example, a Belgium engineer, has transforming traditional fishing boats to run on solar power. They embraced that old boat building tradition and merge it with the highest renewable energy technology. Their first boat has sailed over 2,000 km around Indonesia without using a single drop of gas [5].

Figure 1. "Surya Namaskar", the first solar-powered "jukung" or traditional boat. Source: https://www.eco-business.com/news/bali-trials-solar-powered-boat/

2.3 Wind Energy

Another promised renewable energy source is wind energy. Wind is moving air, wind blows from high pressure to low pressure. The difference in air pressure in the atmosphere makes the wind a potential energy source. Wind power has been used since the 18th century for grinding wheat and irrigation purposes. In 1887 for the first time the wind turbine was transferred into electrical energy and continues to grow until now.

The principle of wind powered electric is the wind energy that rotates the windmill is forwarded to rotate the propellers on the generator at the back of the windmill, thus producing electrical energy

Wind is used to produce electricity by converting the kinetic energy of air in motion into electricity. In modern wind turbines, wind rotates the rotor blades, which convert kinetic energy into rotational energy. This rotational energy is transferred by a shaft which to the generator, thereby producing electrical energy.

The two main types of turbines are Horizontal-axis Turbines (HAWT) and Vertical-axis turbines (VAWT). HAWT have the rotating axis oriented horizontally. They typically feature 3-blades and are designed to face to the wind. VAWT have the rotating axis aligned vertically and are designed to harnesses kinetic energy in the opposite direction. Apart from HAWT and VAWT there are other iterations of the turbine that are worth exploring.

Harnessing wind to generate energy has its advantages and is an efficient option for many different parts of the world since it doesn't depend on direct sunlight exposure like solar energy. There are many advantages in wind energy application.

Firstly, free fuel, since wind turbines themselves run strictly on the power of wind generated, there is no need for fuel. Once the turbine is complete and installed, it doesn't need to be fueled or connected to power to continue working. This also reduces the overall cost to continue to run large-scale wind farms in comparison to other forms renewable energies, which require may require some energy investment.

Secondly, wind energy is one of the cleanest forms of energy, since wind energy doesn't rely on fossil fuels to power the turbines, wind energy does not contribute to climate change by emitting greenhouse gases during energy production. Thirdly, advances in technology. The latest advances in technology have transformed preliminary wind turbine designs into extremely efficient energy harvesters. Turbines are available in a wide range of sizes, increasing the market to many different types businesses and by individuals for use at home on larger lots and plots of land. As technology improves, so do the functionalities of the structure itself, creating designs that will generate even more electricity, require less maintenance, and run more quietly and safely.

Forthly, Wind energy application Doesn't Disrupt Farmland Operations. Energy suppliers can build their wind turbines on pre-existing farmland and pay the farm owners to build on their property in the form of contracts or leases.

This is a great boon to farmers who can use some extra income, and it wind turbine footprints take up very little space at the ground level, so it doesn't disrupt their farm's production.

Although wind energy is a renewable, greener option of energy, it still has its disadvantages and limitations. Firstly, It is dangerous to some wildlife. Wind turbines are known to pose a threat to the wildlife. Flying birds and bats whose habitats or migratory paths could be injured or killed if they run into the blades that turn on the fanlike structure of wind turbines when they are spinning. The deaths of birds and bats are a controversial subject at wind farm sites, which has raised concerns by fish and wildlife conservation groups. Secondly, wind turbines can be quite noisy, which is why they're mostly found in very rural areas where most people don't live. Depending on the location of the turbine, such as offshore, noise isn't an issue. With advancements in technology, newer designs have been shown to reduce the noise complaints and have a much quieter presence.

Thirdly it is Expensive Upfront Cost, since these massive structures are often hundreds of feet tall and require substantial upfront investment. The placement of wind turbines in rural areas requires further investment in underground lines to send power to more populated areas like towns.

and cities where it's needed. The majority of the cost is the initial installation and building stage, but after that, wind energy produces an endless supply of energy as long as there is wind. Forthly, wind energy suffers from what is called intermittency, which is a disruption caused by the inconsistency of the wind itself. Since wind can blow at various speeds, it's hard to predict the amount of energy it can collect at a given time. This means suppliers and cities need to have an energy reserve or alternative sources of power in case the winds die down for longer lengths of time [7].

After wind energy was applied as a source of electrical energy on land and even offshore, the shipping industry began to implement the use of wind energy on ships. They developed various types of wind turbines to suit the conditions of the ship and its aerodynamics.

3. Today Implementations

Today, solar and wind energy has been applied on several ships, and more are still under development. Below are some examples of implementation solar and wind energy on ship or boat power systems

3.1 PlanetSolar

MS Tûranor PlanetSolar, known under the project name PlanetSolar, founded by the Swiss explorer Raphaël Domjan, is the largest solar-powered boat in the world and launched on 31 March 2010.

In May 2012, it became the first solar electric vehicle ever to circumnavigate the globe taking 584 days between 2010 and 2012.

The boat was renamed Race for Water in 2015, after the name of the foundation which then operated it. It was dedicated to water conservation missions and to prevent the oceans from plastic pollution. In 2021, new owners Porrima projects renamed the ship Porrima.

The 31-metre boat is covered by 537 m2 of solar panels rated at 93 kW, which in turn connect to two electric motors, one in each hull. There are 8.5 tons of lithium-ion batteries in the ship's two hulls. The boat's shape allows it to reach speeds of up to 10 knots (19 km/h). The hull was model tested in wind tunnels and was tank tested to determine its hydrodynamics and aerodynamics. The boat was designed to be used as a luxury yacht after the record attempt was finished.

It is currently being used as an ambassador for the project Race for Water [9].

Figure 2. Planet Solar Source: https://www.designboom.com/technology/planetsolar-the-first-solar-powered-boat-around-the-world/

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3.2 Silent 55

Silent 55 launched in 2018, but the team has continued to improve and upgrade its drivetrain. The hull I sea trialed in late 2019 was powered by twin 250-kW e-motors, giving it a solid cruising speed of 10 to 12 knots. Among the many things that make the Silent 55 unique are the 30 solar panels arrayed on its coach roof. The roof incorporates a hydraulic hardtop that “pops up” to provide access to the flybridge helm and seating area. Deploying the hardtop shades the remaining solar panels, however, so when the boat is not in operation, it’s more efficient to keep the top closed.

Solar energy charges the Silent 55’s lithium-ion batteries, which have a capacity of 210 kWh—the equivalent of three Teslas, although the propulsion system is quite different from a car’s.

The batteries are housed in an easily accessible hatch on the bridge deck. They provide power for the Silent 55’s twin 250-kW “synchronous permanent magnet” e-motors, which were built in Quebec. The motors are designed for buses [8].

Figure 3. Silent 55 Source: https://www.powerandmotoryacht.com/boats/sea-trial-and-review-of-the-silent-55-solar-electric-power-catamaran

3.3 Aditya

Aditya a solar-powered ferry operating in the Indian state of Kerala, was inaugurated on 12 January 2017. It is India's first solar-powered ferry and the largest solar-powered boat in India. The vessel was designed and built by NavAlt Solar and Electric Boats in Kochi, India. NavAlt is a joint venture firm between Navgathi Marine Design and Constructions, Alternative Energies (France) and EVE Systems (France).

In August 2020, MarineLink reported that by the end of the year the Kerala state would replace the three diesel ferries operating the same route with solar ones, mentioning that Aditya costs about US$79 per month compared to US$2867 for diesel-powered ones. In three years the Aditya has saved more than 100,000 liters of diesel. The State Water Transport Department of the Government of Kerala also decided to replace all of its 48 diesel ferries with solar ones.

The 20-metre-long and 7-metre-wide boat is covered by 140 square metres (1,500 sq ft) of solar panels rated at 20 kW, which in turn connect to two electric motors of 20 kW, one in each hull. There are 700 kg of lithium-ion batteries in the ship's two hulls with a total capacity of 50 kWh. The catamaran hull and its shape allow it to reach speeds of up to 7.5 knots. The boat is designed to be used as a passenger ferry to operate between Vaikom and Thavanakadavu.

Figure 4. Aditya Source: https://ewnsnews.com/did-you-hear-about-indias-aditya-worlds-best-electric-boat/

3.4. E-Ship 1

The E-Ship 1 is a RoRo cargo ship that made its first voyage with cargo in August 2010. The ship is owned by the third-largest wind turbine manufacturer, Germany's Enercon GmbH. It is used to transport wind turbine components. The E-Ship 1 is a Flettner ship: four large rotorsails that rise from its deck are rotated via a mechanical linkage to the ship's propellers. The sails, or Flettner rotors, aid the ship's propulsion by means of the Magnus effect – the perpendicular force

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that is exerted on a spinning body moving through a fluid stream.

The ship made its first voyage with cargo in August 2010, carrying nine turbines for Castledockrell Wind Farm from Emden to Dublin, Ireland.

The ship's bridge is located at the bow, and it 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, with a gross tonnage of 12,968 and a deadweight tonnage of 10,000. It is equipped with fore and aft maneuvering thrusters and has an Ice class GL E3 hull rating.

The E-Ship 1 was 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 speed and direction of rotation varies up to 300RPM depending on the prevailing wind speed and direction relative to the ship. Due to technical problems the Mitsubishi diesel generators were replaced by Caterpillar diesel generators in 2013. The new Caterpillar generators generate a total power of 6.3 MW [12].

Figure 5. E-Ship 1 Source: https://www.vesselfinder.com/vessels/details/9417141

3.5. Wind Challenger

TOKYO-Mitsui O.S.K. Lines, Ltd. and Oshima Shipbuilding Co., Ltd. announced the completion of the hard sail system jointly developed under the "Wind Challenger" project at the Oshima shipyard.

MOL have been promoting the Wind Challenger Project to harness wind as a propulsive force for merchant ships. The additional propulsion power from wind can reduce a vessel's greenhouse gas (GHG) emissions by an estimated 5% to 8% compared to conventional ships of the same class.

Installed on a bulk carrier currently under construction at Oshima Shipbuilding after shoreside tests. The vessel is slated for delivery after sea trials and engaged in the transport of cargoes for Tohoku Electric Power Co., Inc.

The Wind Challenger is a system, developed mainly by MOL and Oshima Shipbuilding, which uses a telescoping hard sail that harnesses wind power to propel the vessel. By installing the system, it is possible to reduce the amount of fuel used for operation, which is expected to reduce environmental impact and improve economic efficiency.

Wind Challenger applied on the 100,422 dwt vessel was named Shofu Maru. 235-metre-long Shofu Maru will transport coal mainly from Australia, Indonesia, and North America as a dedicated vessel for Tohoku Electric Power [13].

Figure 6. Wind Challenger Source https://www.mol-service.com/case/windchallenger01

4. Discussion and Future Prospect

4.1. Solar Power Prospect

A PV plant's energy density and relatively low energy conversion efficiency will produce power of only a few hundred watts to a few kilowatts.

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Therefore, this feature decided that solar energy is usually used as the main power source in small-scale ships and an auxiliary power source in largescale ships. However, for large power requirements and long operating times, a storage system or battery is needed. Medium and small scale ships using solar PV as ship propulsion need a power system configuration using batteries for energy storage.

It is known that the ship's area is limited for the placement of a large number of solar panels, so the energy obtained is limited. In the future, if solar panels' density can be increased where more electrical energy is generated, then solar energy can be applied to drive larger ships.

As alternative, solar energy can be combined with another green energy like wind or wave. For example Black Magic is a 4.000 ton Solar Hybrid Vessel from Sauter Design Circa 2010 that reduces GHG emissions by 75 to 100% by harnessing energy from the Sun, Wind & Waves.

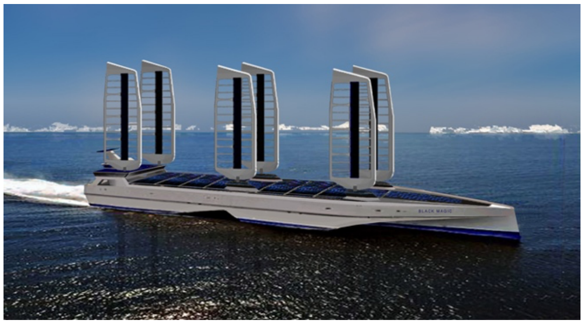

Figure 7. Black Magic Source: http://www.change-climate.com/Transport_Land_Sea_Sustainable/Assisted_Ships_Sails_Solar_Projects_Marine_Pollution/Black_Magic_Rigid_Wing_Sails_Solar_Assisted_Cargo_Ships.htm

4.2 Wind Energy Prospect

When solar energy is converted into electrical energy, on ship, wind is used more to help propulsion ships. The use of wind has been shown to reduce fuel use and emissions.

The two main ways to apply wind energy in the shipping industry today are Wind Assisted Ship Propulsion (WASP) and Wind Power Generation. There are two types of WASP of equipment used to capture wind energy for ship propulsion, namely wind power ships: traditional and modern. Examples of traditional WASPs are rectangular sail ships, and triangular sail ships. Modern WASP is Walker Wingsail ships, Flettner rotor sail ships and skysail ships

The main component of the walker wing sailing ship is to use a multielement three-plane sail in the form of symmetrical foil, and there is a flap to adjust the angle of attack of the sail.

The Flettner rotor works to rotate the cylinder exposed to the wind and generate a Magnus force that converts wind energy into thrust. A 10,000 DWT cargo ship "E-Ship I" with Flettner rotor sails can increase the ship's energy efficiency by 30% under favourable working conditions, with four Flettner rotor sails 27 m high and 4 m in diameter on deck. Another Flettner rotor sailing vessel, "M/V Estraden" built-in 2015, is equipped with two Flettner rotor sails 18 m high and 3 m in diameter, producing a main engine equivalent of 2 MW for propulsion.

Principle work skysail ship converts wind power to drag a ship with a rope connected to a kite flying in front of the ship attached to a high altitude. The propulsion system with skysail requires several components to control the skysail, the launch or release method, roll the skysail and optimization setting wind route. This propulsion system does not reduce deck space or change the ship's main dimensions. Another advantage of this system is that it can reduce the wave factor that causes slamming forces and torque on the ship so that it will increase performance and increase ship safety. The challenge for this system is implementing automatic control to manage kite flight, manage launch and recovery operations and keep the kite flying in an efficient position that is most important. Skysail ship was first implemented and successfully reduced engine load by 20% and saving $1000 in fuel was the "Beluga skysail" ship in 2007 with its maiden voyage from Hamburg to Houston using a skysail area of 160 m2.

Figure 8. Sky sail ship; source https://gcaptain.com/ocean-kites-top-10-green-ship-designs/

So far wind has been applied as Wind Assisted Ship Propulsion (WASP). Energy efficiency is a consideration, when the wind itself can assist ship propulsion, it no longer needs to be converted into electrical energy and then converted again into thrust.

It may be like going to the past, before the invention of steamships, when wind energy is used to propel the ship. But it is a little bit different, with advanced technology, wind energy is synergized with machines with accurate control to produce efficient shipping.

Wind power generation for electrical purposes so far applied on boats or yachts. Implementation of wind power generation on larger ships is still under development.

Figure 9. Wind power on yacht Source https://www.pinterest.com/pin/wind-powered-ships-marine-renewable-energy-research-rotary-sails--147985537734404540/

5. Conclusion

The issue of global warming will encourage the utilization of green energy, which is emission free, and saves operations because it does not require fuel.

Solar and wind are green energy sources that are widely considered because they are everywhere, free of charge, safe, and relatively easy to use

So far, solar and wind energy which has been used on board ships for electrical energy has only been used for small and medium-sized ships. For larger ships, more energy requirements, so limited solar and wind energy must be combined with other energies.

Wind energy is mostly used as Wind Assisted Ship Propulsion (WASP) which is proven to save fuel use and reduce emissions by more than 20%.

In the future solar and wind energy will play an important role in realizing zero emission shipping.

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