ISLAMIC UNIVERSITY OF TECHNOLOGY(IUT)
ORGANISATION OF ISLAMIC COOPERATION(OIC)

APPLICATION OF RENEWABLE ENERGY TECHNOLOGIES IN MARINE VESSELS: STATE OF THE ART REVIEW

A Thesis by

OMAR MANNEH

MD SAYEDUL ISLAM

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Bachelor of Science in Technical Education with Specialization in Mechanical Engineering

DEPARTMENT OF MECHANICAL AND PRODUCTION ENGINEERING

ISLAMIC UNIVERSITY OF TECHNOLOGY

MAY 2022

Islamic University of Technology

Department of Technical and Vocational Education

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May (2022)

CERTIFICATE OF RESEARCH

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I hereby declare that this thesis entitled "Application of renewable technologies in marine vessels: state of the art review" is an authentic report of our study carried out as a requirement for the award of degree BSc.T. E (Mechanical Engineering) at the Islamic University of Technology, Gazipur, Dhaka, under the supervision of [Associate Professor Dr. Md. Mohammad Monjurul Ehsan], Supervisor designation, MPE, IUT in the year 2022

The matter embodied in this thesis has not been submitted in part or full to any other institute for the award of any degree.

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ACKNOWLEDGMENT

IN THE NAME OF ALL THE MOST GRACIOUS AND THE MERCIFUL.

We thank ALLAH SWT for the blessings he has poured upon us and for writing this thesis.

We would like to sincerely thank our supervisor MOHAMMAD MONJURUL EHSAN, ASSOCIATE PROFESSOR, and co-supervisor ASSISTANT PROFESSOR MR. SAYEDUS SALEHIN MPE, for their guidance, understanding, and patience. Most importantly, for his continuous positive encouragement throughout this work. It has indeed been an honor and pleasure to work with them.

Our sincere thanks also go to MR. HAMISI RAMADHAN MUBARAK, ASSISTANT PROFESSOR, TVE for his valuable contribution in teaching us report writing.

We will also equally thank our various families for all their support and encouragement throughout the course of this work. Their support both financially and morally has gone a long way towards the completion of this thesis and degree as well.

And also to our colleagues with whom we have worked together throughout the duration of the course. Their contribution to the completion of this thesis is well appreciated.

Finally, to the Islamic University of Technology (IUT) for giving us admission and the Organization of Islamic Corporation (OIC) for the scholarship to do this degree program. May Allah SWT continues to strengthen both institutions.

ABSTRACT

The constant push to reduce energy costs, combined with the growing urgency to address climate change and air quality degradation, has resulted in a significant shift in environmental awareness facilitated by the advent of tighter regulations and legislation. Energy conservation initiatives must be coordinated across all energy-intensive sectors, including industry and transportation (whether land, sea, or air modes are involved). Seaborne transport is generally recognized as a significant source of exhaust emissions, owing to the onboard combustion engines' primary fuel supply being heavy and light oil.

As a result, scientific research efforts are concentrated on developing and implementing various technical and operational solutions for reducing ship exhaust emissions. Among these, the shipboard renewable energy technology implementation may be a realistic alternative given the ship's technical and operational requirements.

Diverse emission control systems and procedures are required to rein in marine vessel greenhouse gas emissions. Renewable energy sources are now being investigated for their potential to reduce emissions from the maritime sector. Green energy options including renewable then alternative energy sources such as solar, wind power, supercharger capacitor, and energy storage system or battery integration of renewable systems can be implemented into current and new ships.

We would want to focus our discussion to review various papers that are related to the application of renewable in marine vessels. To study the need for renewable energy in marine vessels. To find out the type of RES applicable to marine vessels. To find out how renewable energy sources can be applied in marine vessels. And also to find out various problems and solutions to the application of renewable to marine vessels.

The introduction of some strong regulations against environmental pollution and its related issues in recent years has necessitated the need for renewable energy resources. Despite the heavy traffic of goods and services by the marine vessels, it has not been given the attention it deserved. The international maritime organization (IMO) is coming up with some measures to limit the amount of pollution caused by the use of fossil fuels in marine vessels. Solar PV and Wind energy are among the renewable energy source with a lot of potential for maritime vessels.

In this review, we examine some of the applications of renewable energy sources that can be applied to marine vessels to minimize pollution rates.

Keywords*;* *Marine vessels, renewable energy, solar energy, wind energy, hybrid energy system, propulsion system, clean energy, energy storage*

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NOMENCLATURE

Symbols	**Meaning of symbols**
IMO	International maritime organization
PV	Photovoltaic
CO_2	Carbon Dioxide
IP	Ingression protection
CENELEC	European Committee for Electro-technical Standardization
CIS	copper (C), indium (I,) and selenium (S)
MPPT	maximum power point tracking
GaAs	Gallium arsenide
CdTe	Cadmium telluride
CuInSe2	Copper indium selenide
Si	silicon
IC	integrated circuit
mc-Si	multi-crystalline silicon
c-Si	Crystalline silicon
CIGS	copper indium gallium selenide
A-Si	Amorphous Silicon
DC-DC	Direct Current to Direct Current
DC-AC	Direct Current to Alternate Current
MPPT	Maximum power point tracking
DG	Diesel Generator
M	Motor
I–V	Current-Voltage
CO_2	Carbon Dioxide
US	Unite States
DWT	Dead Weight Tonnage
CFD	Computational fluid dynamics
WAPS	Wind Assisted Propulsion System

Chapter 1

INTRODUCTION

Renewable power applications in ships of all sizes include options for primary, hybrid, and auxiliary propulsion, as well as on-board and shore-side energy use. Potential renewable energy sources for shipping applications include wind (soft sails, fixed wings, rotors, kites, and conventional wind turbines), solar photovoltaic, biofuels, wave energy, and the use of super-capacitors charged with renewable[1].

Of the many potential replacements for fossil-based fuels, solar energy is the most abundant energy source on the earth. It is globally available free of cost in its extraction as a primary source, unlike fossil-based products. The energy supply from the sun is so huge that on an hourly average the earth receives about 1.2 x 10^{17} W of solar power. Therefore, Sun provides a total global energy demand for just under an hour throughout the year. However, the major drawback of solar as a primary energy source is its unavailability at night and unpredictability during the day[2].

Solar PV applications use electricity generated by photovoltaic (PV) cells. All advances in this fast-evolving technology are available for maritime transport use. The primary limitations are the lack of sufficient deployment area for the PV panels and the energy storage required. Recent advances in energy storage technology offer higher potential and better prospects for solar PV- powered propulsion systems for ships in the short term, but full ship propulsion using solar PV requires further technical development and is likely to be confined to relatively small vessels[3][1].

To provide an alternative to fossil-fuel-powered vessels, researchers are developing solar and wind-powered marine vessels. Technological advancements and new materials are enabling the development of high-performance, lightweight composites. but environmentally friendly, naval vessels. Sailing vessels powered by fossil fuels are being phased out in favor of environmentally friendly watercraft with near-zero emissions, which are being produced in the tradition of pre-industrialized sailboats. The results of recent experimental initiatives and research have demonstrated that maritime design may incorporate more environmentally friendly modes of transportation. Volitant is a boat that is powered by solar and wind energy and incorporates composite materials to improve performance and efficiency. In addition to demonstrating the feasibility of alternative energy sources, the Volitant Project also showcases cutting-edge materials and technology for the construction of sailboats.[4].

Wind energy is another key renewable energy source with a lot of potential for maritime vessels. Wind energy for naval vessels is the second most significant source of propulsion after solar photovoltaic[5]. Wind energy, which is less expensive than heavy oil, appears to be the most cost-effective energy source for the high seas. A system for catching wind and converting it to electricity is what is meant by wind-assisted propulsion, regardless of whether the energy is utilized to power the primary machine or not. [6]. Depending on the wind conditions, the ship's cost savings might range from 10% to 35% in optimal conditions that savings reach almost 50% instantaneously. Kite systems are available for all cargo ships, including newly constructed ships. In this regard, binary propulsion systems offer a cost-effective alternative [7].

Wind propulsion is a well-known method of propulsion that has been used to drive ships for millennia. However, with the arrival of fossil-fuel-powered ships about a century ago, wind energy's usefulness for freight transport waned. The combination of rising fuel prices and a growing awareness of the repercussions of CO2 emissions has fueled the revival of this energy source, and a range of wind-assisted propulsion systems are now available[8]. The critical aspects that contribute to the effectiveness of wind-assisted propulsion are reviewed, along with a case study of a multipurpose vessel[9].

Chapter 2

LITERATURE REVIEW

A marine vessel is like a mobile power plant. It moves from one place to another under different environmental and weather conditions. This is among the challenges of the application of renewable in marine vessels[10]. Most of the renewable energy technology that is developed was mostly made for stationery applications. They are developed for deployment on the land and not for seagoing vessels. But when it comes to the applications RE does not have much attention as compared to the land[11][12].

Many of the RES that is applicable on land are also applicable to vessels too. Although their applications have some limitations as compared to land. The limitations that hindered the application of RES on the marine vessels are more due to the developing technology for their applications on the vessels.
This paper focuses on some of those applications and their limitations[13]. It will also look at some of the possible solutions that can be applied as well[14]l[15].

The size, purpose, and operating location of a particular vessel all play a role in determining how much of a role renewable energy technology plays in the maritime sector as well as the degree to which it is adopted. However, study and innovation efforts on the utilization of RE choices, as well as efficient design, are yielding substantial improvements in terms of immediate and near-term energy savings for a select number of applications[16]. This is according to those who supply the technology. The SolarSailor, developed by OCIUS Technology Ltd, is expected to save between 5% to 100% depending on the application. The SolarSailor claims a RE solution cost of 10% to 15% of the vessel's financial cost and a return on investment between the period of 2 and 4 years. For a predicted 60 percent decrease in fuel consumption, B9 Shipping carrier and Fair Transport BV estimated higher construction and repairs costs of 10 to 15 percent of total asset values. The company also expected major decreases in main engine and propeller wear.

Savings in fuel range from over 100% to nearly zero percent. [1]Brief designs, such as Greenheart, reduce the major energy reserves of NYK's solar array retrofitting vehicle carrier Auriga Leader to 0.05 percent and 1 percent, respectively, compared to the original design. The University of Tokyo has calculated that the 60 000 gross tons UT Wind Challenger might lower fuel expenses by as much as one-third compared to conventional ships. Shipping operators can expect 20% to 25% fuel savings on ships that sail across the equator and 30 to 40 percent fuel savings on ships that do not cross the equator that is, same-hemisphere shipping routes by retrofitting opening wing sails to a "motor-sail," without changing the main propulsion system of a new tanker, with a payback time of just 2 years, based on the normal fuel prices of 2013. This shows that assisted sails have a positive impact on the overall reduction of using fossil fuels and their negative effects. They increase savings on fuel costs and usage and thereby reducing the emission of CO_2 and other harmful gases.

Over the last several years, the growth of RE solutions for shipping has been hindered by an oversupply of fossil fuel-powered transportation, along with a reduced investment market as a result of this oversupply. Very little records and information is available on the actual implementation costs of the different renewable energy solutions that have been implemented in the maritime industry so far[17]. But what is evident is that there has not been sufficient demonstration of commercially practical answers for the industry to drive implementation and, as a result, reduce prices. Ultimately, the rate at which renewable energy technology solutions for shipping are adopted will be decided by market forces in an increasingly stringent regulatory environment. Nevertheless, the acceptance of new technologies will be limited by the infrastructure lock-in of current investments as well as other non-market considerations.

Despite recent advances in renewable energy technology, the total contribution of renewable energy technologies to international shipping is unlikely to become dominant or even significant in the near future. Nonetheless, it has a significant and increasingly shown ability to make a small contribution in a wide range of industries throughout the short- and medium-term periods. Renewable energy sources may play a major, if not dominating, role in a variety of applications. Advanced biofuels, among the several renewable energy solutions available, have the most potential to revolutionize the energy choices available to the maritime industry. It is important to note that the potential of biofuels will be determined by a variety of variables, including the worldwide supply of sustainably sourced feedstock for biofuel production. Hydrogen fuel cells as a source of energy for shipping have also shown great promise, but the long-term viability of the energy source used to generate the hydrogen, as well as the lack of cost-effective and reliable low-pressure storage options for the fuel, are still major concerns that must be addressed in the near future[15].

The main factors that are pushing the development and the implementation of renewable in shipping industries are; Environmental, Technical, Economic/Financial, and Policy and Regulations factors. Each of these factors has a significant impact on driving the need for renewable energy in marine vessels. One can consider them as the catalyst for driving the need for renewable for the vessels industry[18].

Finally, in this review paper, we have identified several prospects for the application of renewable energy in marine vessels. The driving forces behind them and some of the major obstacles that are acting as barriers to the application of renewable in the marine vessels. The use of renewable energy in marine boats will drastically cut the boats' emissions. Furthermore, it will reduce pollution caused by the use of conventional fuels in marine engines[19]. They will also significantly save fuel costs and provide economic benefits. When the ship is powered entirely by renewable energy sources such as solar or wind energy, some will eventually eliminate the need for gasoline.

Chapter 3

SOLAR-POWERED VESSELS

Even though solar-powered vessels first appeared on the scene in the 1970s, it took another couple of decades before they were commercially viable for public transportation. After several efforts by different initiatives, vessels utilizing solar energy were popularized, and the idea became more accessible via multiple solar-powered boats constructed, verified, then operated. The study by Gorter (2010), who looked at 105 photo voltaic-powered boats from around the world, found that they can be divided into three categories based on their intended use: 'people's transportation, “recreational boats,' and the third category for private or research boats.

Solar Craft 1, the first reported solar-powered watercraft, had its first trip in 1975. Solar-powered electric boats, on the other hand, were popular in the 1990s. Boats powered by solar energy for use on rivers and lakes were among the first commercially available solar boats. Fuel leakage on rivers and lakes is strictly prohibited. Solar Shuttle Boats by Solar Lab, built-in 1998, were among the first public transportation vessels powered entirely by solar energy. [20].

3.1 Methodological Provisions in-order-to Photovoltaic Systems in Marine Vessels

While building photovoltaic plants on the mainland is conventional and carefully reviewed, special considerations must be made when placing them aboard ships. The primary difference between terrestrial and maritime photovoltaic implementation is the climatic circumstances, which need photovoltaic organizations to occur more accepting of strong winds, more moisture, & salt [21].

Winds on a ship are characterized by their severe directional and speed unpredictability, which has a significant impact on the orientations of the photovoltaic panels that are affixed to the ship. The adoption of a stable bank provides the ship with an approachable and sturdy embracement. It is recommended to align the approach with the keel to aid the vessel's aerodynamics. However, the fixed-tilt configuration has a considerable disadvantage. Because of the diversity of vessel directions and continuously varying latitude, photovoltaic panels cannot completely harness solar energy. While photovoltaic plants with integrated tracking control systems are more efficient, they have a large number of mechanically movable components that are sensitive toward maritime tempests, are costlier, and requirement additional maintenance prices that are also greater than those for comparable on-land systems. The golden mean is tangentially mounted photovoltaic panels toward the vessel's shells. In strong winds, the air resistance of the photovoltaic panels becomes negligible, and the sailing routes have little effect on their incident solar radiation. However, this configuration optimizes the surface area of the installation and restricts airflow behind the panels, so lowering the likelihood of cooling. [21].

No research deals explicitly with PV development for marine applications. However, Glasner and Appelbaum present an efficiency test of the PV module under marine conditions. The PV module is installed on a ship, and then the data is collected during the voyage. Is there an age difference of 1 volt between the driving test and the stationary test due to the boat's movement? Hence, we can conclude that a researcher who wants to develop a solar-powered boat should consider that the PV performance may differ slightly from the rating as the rating is based on the stationary test. A better understanding of PV behavior undersea conditions can be achieved if more data such as temperature, humidity, solar radiation, and ship's course are obtained.[22].

Additionally, the water environment may be damaging to a photovoltaic system's electronics and panels. High levels of moisture in the air and salt might result in short circuits and corrosion of the mechanical components of the converters. The European Committee for Electrotechnical Standardization (CENELEC) developed an ingression protection rating to quantify the degree of protection provided to electronic circuits against entrance by solid objects, solids, and liquids. This means that converters used in maritime solar plants must be protected to an IP54 or higher level (especially for those positioned outside the ship's hull), resulting in inferior ventilation and higher total costs. [21].

The copper frames of photovoltaic panels must be properly designed to withstand corrosion. Each metal surface must be galvanized or protected from corrosion with a specific antirust coating. The metal of superior grade must be utilized, particularly at fastening places (e.g., aluminum). Additionally, because moisture penetration leads to cell degradation, extra attention must be paid to the encapsulating materials used in their construction. [21].

PV plants installed on a maritime vessel are likewise subject to area constraints. The systems must not interfere with the movement of cargo or people. Neither must they shelter areas through economic ramifications, for instance, the surface, storing great hall, and reservoirs. Additionally, they should be kept out of harm's way in the event of electrical shocks or damage to photovoltaic panels or converters, making maintenance simple for trained staff. Thus, the new roof and superstructure's facades, the funnel, the port, and the starboard, as well as the glazing and glass fronts, are all ideal installation locations.

An additional issue that photovoltaic schemes face is shading. It is less efficient and may even be harmful to the system when a solar cell or even an entire string grid is designed to block all or a portion of solar radiation. A hot spot arises when sheltered panels cease to function as producers and converted electrical burdens.

Shade is avoided in inland applications by selecting open installation sites. On the other hand, open areas are restricted in maritime applications, and shades are more difficult to forecast owing to the vessel's constant orientation changes. As a result, it is preferable to avoid using semiconductor diodes and to install solar systems on a smaller scale. Additionally, the lower size installations must adhere to two additional standards. To begin, photovoltaic (PV) systems aboard ships should be tightly coupled to critical loads to reduce distribution losses. They must generate distributed electric power to maintain the required reserve for photovoltaic power production [21].

Finally, photovoltaic systems work the same way on land and sea. High efficiency, power factor, maximum power point tracking (MPPT), and anti-islanding management are required to match the output characteristics to the grid's installation sites [21].

Boats are available in a variety of sizes, ranging in length from 14 to 27 meters and carrying between 40 and 120 people. For example, the Hamburg Solar Shuttle was completed in 2000 and has a length of 27 meters, a top speed of 15 kilometers per hour, and a capacity of 120 passengers. Comparatively, other specialized shuttles, such as the Constance Solar Shuttle, have a body that is 20 meters long and can accommodate 60 passengers. Solar Shuttle Boats use solar panels on their roofs to provide a translucent design that is conducive to tourism [4].

3.2 Construction of Solar Cell

Solar cells are essentially junction diodes; however, their construction is somewhat different from that of standard p-n intersection diodes. A tinny coating of p-type semiconducting material is produced on top of an n-type semiconducting material that is much thicker than the original. Following that, we'll place a few more suitable electrodes on top of the p-type semiconductor layer to finish the circuit's final configuration. In addition, these electrodes do not impede the flow of light via the thin p-type layer. A p-n junction is found immediately under the p-type layer, and it is responsible for conduction. On the lowest of the n-type coating, additionally include a current-collecting electrode to help in the current collection. A thin coating of glass is applied to the whole system to protect the solar cell from mechanical damage [23], [24].

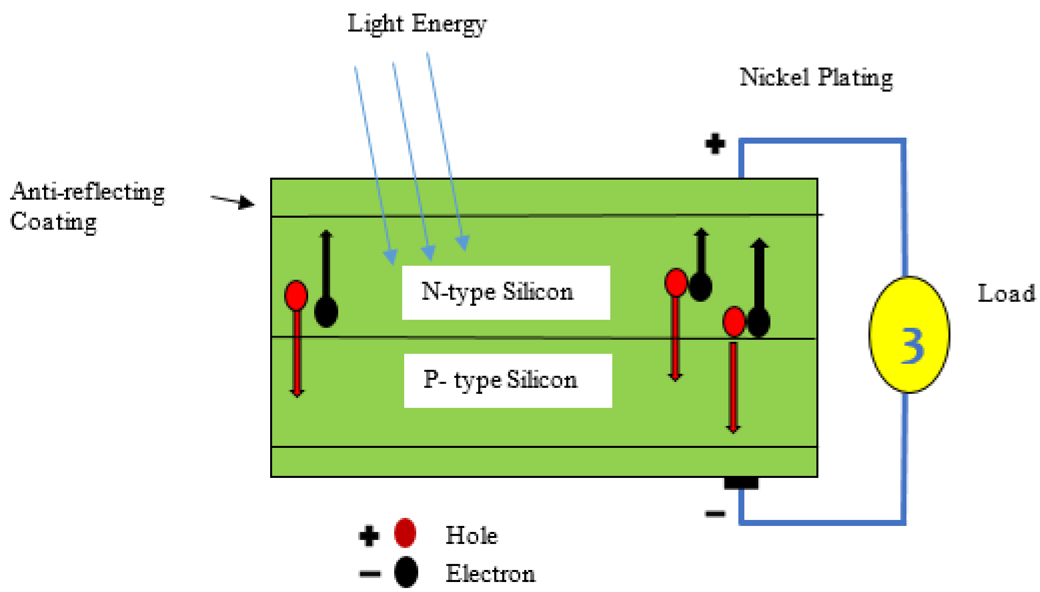

Figure 1. The structure of solar cell

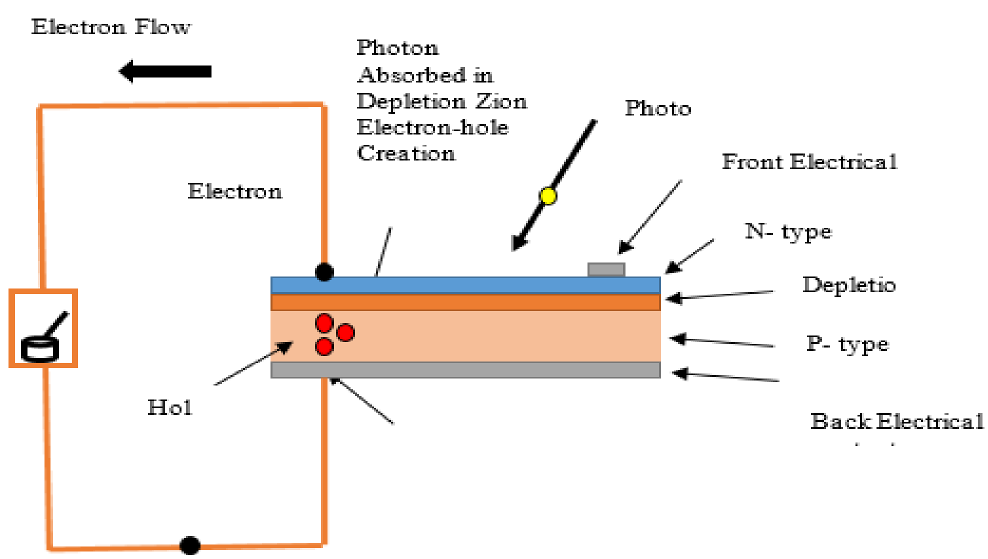

Figure 2. The working principle of solar

A single photovoltaic cell is typically made in square shapes of 12.5 cm and 15 cm and produces just 1 or 2 watts of electricity. Solar photovoltaic modules are used voltaic cells together to increase their output. When photovoltaic cells (included in solar modules) absorb solar energy, the energy contained in photons of light is transferred to the semiconductor material. Electric current is created by causing electrons to pass through the semiconductor material. [25].

3.3 Materials Used in Solar Cells

The bandgap of the materials utilized aimed at this determination compulsion be close to 1.5eV. The most often seen materials are as follows [26];

Silicon.

Gallium arsenide (GaAs).

Cadmium telluride (CdTe).

Copper indium selenide (CuInSe2)

Materials to be used in solar cells must meet certain requirements. The bandgap should be between 1ev and 1.8ev.

It must have a significant level of optical absorption to be effective.

It must have a strong electrical conductivity to function properly.

The raw material must be easily available in big numbers, and the cost of the raw material must be competitive in the market.

3.4 Merit of Solar Energy System

- There is no environmental impact linked with it.
- It has to be durable for a lengthy period.
- There are no ongoing maintenance expenses.

3.5 Demerit of Solar Cell

- It takes a significant installation price. The issue is not recommended.
- It has a poor level of efficiency.
- It is impossible to generate energy on a cloudy day, and it is also impossible to generate solar electricity at night.
- Solar energy systems have a variety of applications.
- It has the potential to be utilized to charge batteries.
- This is a term that is used in light meters.
- Calculators and wristwatches run on this kind of battery.
- It has the potential to be employed in spacecraft to generate electrical energy.

3.6 Solar Cell Types

Solar cells may be classed into two fundamental varieties based on their structure: crystalline cells and thin films. The primary material for crystalline cells is silicon (Si), which is structured in crystalline grids. The direction of the grid determines the crystallinity of the cell.

The kind of cells used in marine photovoltaic applications is determined by the overall price also the kind of fixing outward. For flat surfaces, crystal-like solar panela remains preferable. They are inexpensive, efficient, and have a high power density, enabling them to use tiny installation spaces fully. The overall budget and available space dictate the choice of monocrystalline or polycrystalline crystals. Window and glass facades, curves, and dark areas are all suitable for thin-film modules. [21].

3.7 Solar Cells and Their Operational Principle

When light hits the p-n junction, the photons of light may swiftly pass through the extremely thin p-type layer and into the semiconductor. During the collision of photons, the light energy provides enough energy to the junction to result in the formation of multiple electron-hole pairs. When incoming light is present, the thermal equilibrium state of the link is disrupted. As long as the depletion zone is sufficiently thick, the free electrons in it have the potential to travel very quickly to the n-type side of the junction. [27], [28].

Furthermore, holes in the depletion may quickly migrate to the p-type side of the junction in the same manner as holes in the depletion did previously. Once the freshly formed free electrons reach the n-type side of the junction, they are unable to cross across to the other side due to the barrier potential of the intersection.

Similarly, once the freshly generated holes reach the p-type side of the junction, they are unable to cross the junction because they have the same barrier potential. As the concentration of electrons on one side of the intersection increases, i.e. In this case, because the concentration of holes grows on one side of the junction, namely on the n-type side of the intersection, and decreases on the other side of the intersection, namely on the type of intersection, the p-n corner behaves similarly to that of a small battery cell. Photovoltaic voltage is the voltage generated as a result of the solar energy being converted into electricity. In the case of a minor load connected across the junction, a very modest current will pass through it[29], [30].

3.8 Opportunities and Challenges in Current PV Manufacturing Technologies:

3.8.1 Crystalline silicon:

Silicon is a specially developed and highly well semiconductor, according to decades of study and development by the integrated circuit IC sector. Its properties may be regulated and altered using well-established procedures. Silicon is the most common semiconductor globally and has exhibited field stability. Although its market share has decreased from as high as 65percentt earlier in the decade, multi-crystalline silicon (mc-Si) remains the most common PV material. Wafer diameters have been reduced, and single-crystal (c-Si) silicon has remained competitive due to a combination of improved efficiency, lower poly-silicon pricing, and developments in wire cutting technology. The challenges that now limit (c-Si) technology are relatively similar[31]; the price of silicon feedstock continues to be the most significant factor influencing the cost of production. Improvements in feedstock, the manufacturing of kerfless wafers, the creation of ultrathin silicon, and the utilization of bifacial cells are all being explored to decrease the cost of silicon[25].

3.9 Types of Solar Cells and Application

Solar cells are often referred to by the semiconducting substance from which they are constructed. These materials must have a certain ability to absorb sunlight. Certain cells are designed to endure the amount of sunlight that strikes the Earth's surface, while others are designed for usage in space. Solar cells may be constructed with a single layer of light-absorbing material (single-junction) or with various physical topologies (multi-junction) to use various absorption and charge extraction processes. Solar cells are classified into three generations: first generation, second generation, and third generation[27], [29], [30]. The first-generation cells, also known as classic or wafer-based cells, are made of crystalline silicon and are the most extensively used photovoltaic technology. They are composed of materials such as polycrystalline silicon and monocrystalline silicon. In the second generation, thin-film solar cells such as amorphous silicon (CdTe) and copper indium gallium selenide (CIGS) are employed in utility-scale photovoltaic power plants, building-integrated photovoltaics, and small standalone power systems. Solar cells of the third generation are composed of the following components[32].

3.10 Amorphous Silicon Solar Cell (A-Si):

Silicon that is not crystalline is called amorphous silicon (a-Si). It is a well-established thin-film technology that has been in use for more than 15 years. Although it is often found in pocket calculators, it also powers several private dwellings, structures, and distant locations. Sharp, Sanyo, and United Solar Systems Corp (UniSolar) were the first companies to produce amorphous silicon solar cells. Amorphous silicon panels are made via vapor deposition of a thin layer of silicon material (about 1-millimeter-thick) over a glass or metal substrate. Amorphous silicon may be formed on plastic at very low temperatures, as low as 75 degrees Celsius. The cell structure is composed of a single series of pin layers in its simplest form. When exposed to the environment, single-layer cells, on the other hand, face a considerable loss in power generation (between 15% and 35%) [33][34].

3.11 Hybrid Solar Cell:

In composite Solar Cells in hybrid solar cells, several chemical semiconductors are blended to provide the best of both worlds. In hybrid photovoltaics, organic molecules composed of conjugated polymers absorb light as the donor and transport holes [35]. In hybrid cells, inorganic materials act as both the acceptor and carrier of electrons. Hybrid photovoltaic systems can provide large-scale solar energy conversion while also enabling low-cost roll-to-roll manufacturing. In hybrid solar cells, organic material is mixed with a chemical with a high electron-transport capacity to create the photoactive surface [36].

3.12 Flexible Solar Panels with Mounting Frames for Ships & Marine Applications

Marine solar panels are designed for use on a range of boats, from tiny pleasure craft to ocean-going passenger ferries and cargo ships.

Sustainable Maritime Power works with leading manufacturers of marine-grade solar panels to select the optimal photovoltaic module and installation strategy for each project [37].The use of lightweight polymer films rather than standard glass allows for crystalline silicon cell technology[38].

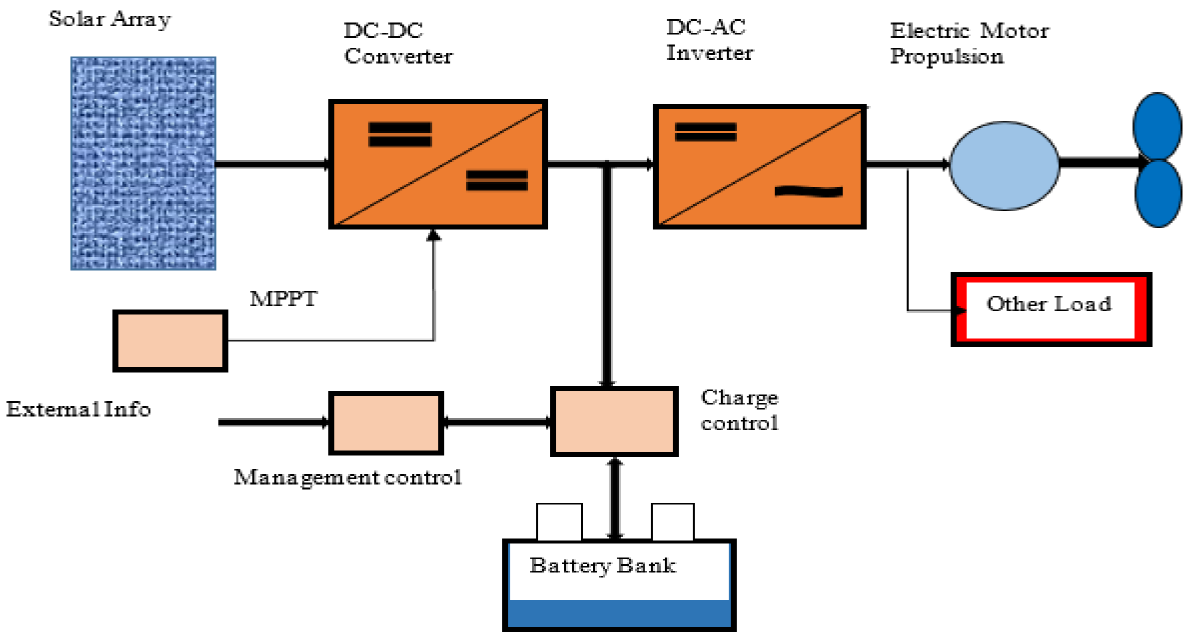

Figure 3. illustrates a typical PV diagram on a ship[39]**.**

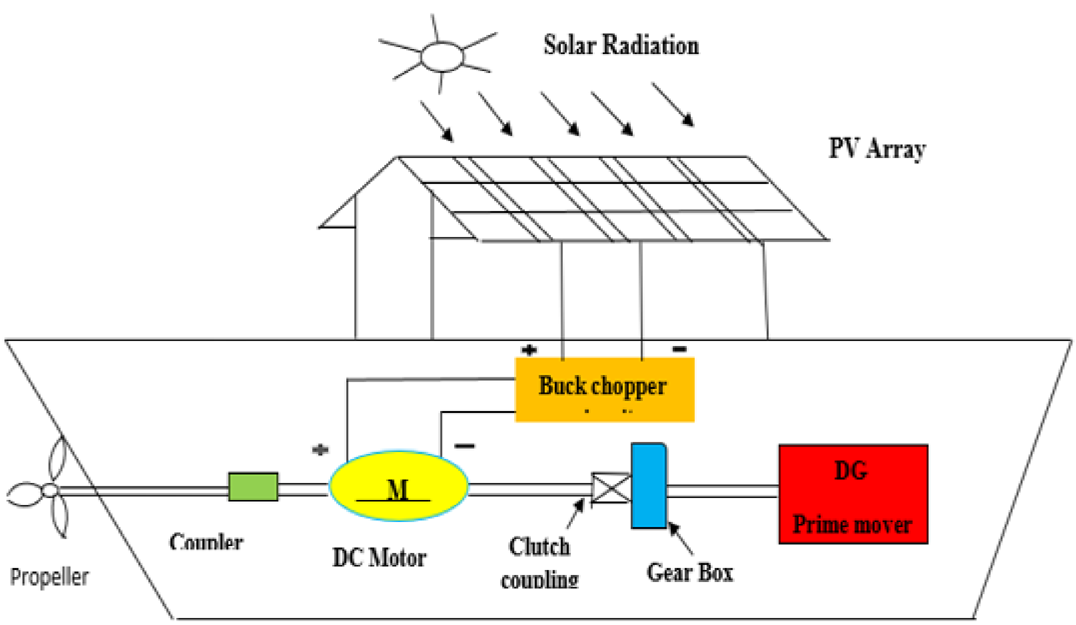

Figure 4. A solar-powered boat model.

In recent years, several boats and yachts worldwide have been operating with renewable energy sources for propulsion through electric motors or charging batteries. This is particularly true for photovoltaic systems due to their simplicity, lack of effect on the boat's stability, and low maintenance requirements. Nowadays, an increasing number of fishing boats and short-distance leisure vehicles are powered by photovoltaics. These boats are all similar in size, operate without rolling, and have a low sailing speed, related to the shallow requirement for propulsion power [40]. Figure 2.1 is a model of a solar powerboat. This can be used for transporting a small number of passengers' goods. In the above, the PV array can either be arranged horizontally or shown in the picture. They both have their own merits and demerits. The size and the capacity of the boat or ship determine the size of the solar array together with its auxiliaries.

The diagram below in figure 3 is another possible arrangement of a PV and diesel generator on a ship, due to fluctuating nature of the PV system, especially at night and under unfavorable weather conditions[11].

It's worth noting that the diesel generator serves just as a backup; the boat's primary energy source is the photovoltaic system. It has been determined that this design results in a significant decrease in pollution-causing gases and other detrimental effects caused by the combustion of fossil fuels. [41].

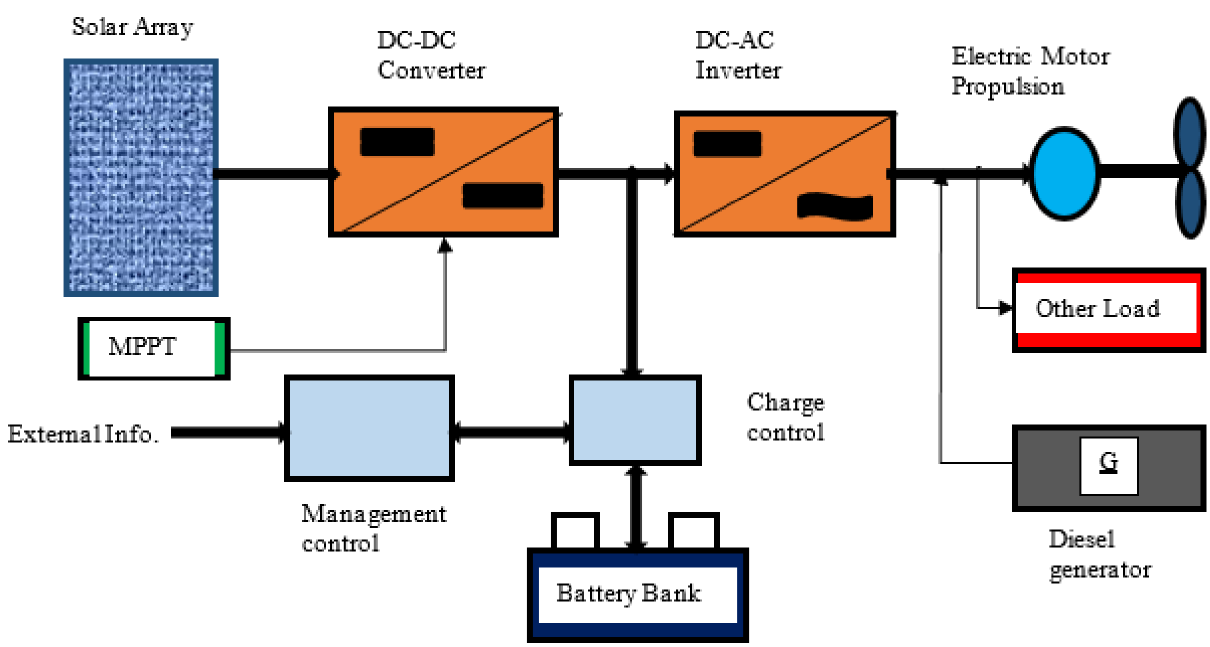

Figure 5. A photovoltaic system coupled to a diesel generator aboard a ship[39]**.**

3.13 The issue of solar PV system

Renewable energy sources such as solar photovoltaic (PV) systems create energy by converting solar radiation into direct current electricity via the use of semiconductors that take advantage of the photovoltaic effect. A terrestrial photovoltaic system may use one of two sun-tracking technologies (single or dual-axis tracking) to achieve high energy conversion efficiency. By contrast, various novel constructions are employed to put the photovoltaic system on solar ships. Significantly, the "Solar Sailor" design has gained widespread acceptance and has been used on several catamarans. For small boats and marine vessels, on the other hand, the horizontal placement of solar panels is the most effective configuration. [42]. Two reasons to consider are:

(1) Maximizing solar radiation collection while keeping the deck surface as little as feasible;

(2) A decrease in metacentric height is caused by the additional weight of the solar panels, mounting bracket, and batteries (if any) when the vessel is powered by solar energy. It is possible that the design of the solar sailor would aggravate this situation[43].

3.13.1 Friction and wear

Meteorological factors such as solar radiation, temperature, and wind directly affect the I–V characteristic of a solar cell. Other elements, such as gaseous pollutants, air dust (including smoke and dust particles, salt particles), and rainfall, on the other hand, all have a varied influence on the dependability of the PV cell. A large number of studies have shown that saltwater leads to electrochemical corrosion on the cell's outer surface. It is possible that salt particles released during the evaporation of saltwater will affect the surface morphology of the solar cell's cover glass as a result of friction and wear. Seawater experiments were carried out using synthetic seawater at four different concentrations, which were then analyzed. Additionally, additional research demonstrates the appearance of certain black spots on the top surface of the cover glasses, resulting in a decrease in spectrum transmittance. [43].

3.13.2 Vibration and fretting wear

In electrical engineering, a converter is a device that transforms direct current (DC) into alternating current (AC) (AC). Hull vibrations and low-frequency vibrations generated by waves and moving equipment are the principal drivers of inverter vibration and fretting wear on the mechanical connection components, which are responsible for the majority of the wear. Furthermore, the performance characteristics of electronic components and switch devices functioning in a multifactor environment, such as acidic spray and oil mist suffusing at high temperatures, must be extensively investigated.

3.14 Summary of PV technology for marine vessels

This innovative photovoltaic technology is suitable for big and medium-sized seagoing vessels. Marine grid-connected photovoltaic research will result in significant energy savings and decrease ship emissions. Photovoltaic technology has the potential to be a viable energy source for ships. It serves as a complement to the ship's traditional energy sources. [24].

The cost of a photovoltaic system, the availability of space, and, of course, the availability of solar energy are the primary issues to consider when designing a solar energy system for use aboard a ship. Using photovoltaic technology to power a portion of the vessel reduces fuel consumption and ship emissions. It may also be employed as the ship's primary propulsion system or both. A photovoltaic solar system put aboard a vessel may affect the ship's stability, particularly if the location of the storage batteries is not taken into account appropriately.

Photovoltaic (PV) technology might be regarded as a potential energy source for ships. It is a viable alternative to traditional shipboard energy producers.

Chapter 4

WIND ENERGY FOR MARINE VESSELS

Wind energy is another key renewable energy source with a lot of potential for maritime vessels. Wind energy for naval vessels is the second most significant source of propulsion after solar photovoltaic[5]. Wind energy, which is less costly than heavy oil, looks to be the most cost-effective source of energy for the high seas, according to the International Energy Agency. Wind-assisted propulsion systems may be characterized as arrangements that capture wind and change it to electricity, regardless of whether the energy is utilized to power the primary machine or is used for other purposes. Depending on the wind conditions, the ship's cost savings might range from 10% to 35%. At optimal conditions, the cost savings reach almost 50% instantaneously. Kite systems are available for all cargo ships, including newly constructed ships. In this regard, binary propulsion systems offer a cost-effective alternative [7].

Wind propulsion is a well-known method of propulsion that has been used to drive ships for millennia. However, with the arrival of fossil-fuel-powered ships about a century ago, wind energy's usefulness for freight transport waned. The combination of rising fuel prices and a growing awareness of the repercussions of CO_2 emissions has fueled the revival of this energy source, and a range of wind-assisted propulsion systems are now available. The critical aspects that contribute to the effectiveness of wind-assisted propulsion are reviewed, along with a case study of a multipurpose vessel[44][9].

Some of the reasons for the stopped or the decline of sailing after centuries of years are as follows;

- It is challenging to be 'on time.
- Due to a big crew size.
- Due to Low-cost fuel.
- Because of no environmental concerns.
- Because of Improved engines.

To move at a specific speed, a ship must overcome the resistance force created by both surroundings. This is accomplished through the ship's propulsion system's lift force.

Although propellers are still the most frequent propulsion technology, alternative propulsion technologies have gained popularity. Increasing energy prices and environmental concerns are the most crucial causes of this. To fulfill changing market conditions and economic requirements, superior propulsion systems must be developed in energy efficiency and lifespan.

Operating costs must be kept low to compete in today's industry. Many wind energy technology is traditionally made for land use. Some of these techniques need some significant improvement before they can be comfortably used for marine vessels[45], [46].

Wind-based propulsion systems are being touted as a viable option for reducing fuel use and avoiding harmful environmental consequences from ships. According to previous studies, wind-based propulsion systems can save between 10% and 30% of annual fuel. This paper, it is described how to get the daily energy requirements for boats that employ wind-based propulsion systems such as kite systems, Flatter rotors, and wind turbines[9][7].

4.1 Configurations

The methods of transforming wind moving energy into a push for a ship have recently received much attention. Whereas early sailing ships were constructed around their sails, contemporary commercial ships are constructed about the cargo they transport, needing a big clean level and little above machinery to enable cargo management. The other factor to consider when developing a sail propulsion assembly used for a saleable transport vessel remains that it must not require a considerably bigger crew to operate and must not jeopardize the ship's stability to be economically viable[47]. Three primary ideas have arisen as the dominant configurations for wind-assisted propulsion, based on these design criteria: "Wing Sail," "Kite sail," and "Flettner Rotor."

4.1.1 Wing sail

The United State administration commissioned a study in the 1980s in response to rising oil prices to determine the economic viability of employing wind-assisted propulsion to cut ships' fuel use in the country. A wing sail was found to be the most successful among the designs studied in this study. An automatic system of big rectangular sails reinforced by cylindrical masts was considered for the wing sail alternative under consideration[48]. These would be symmetrical sails, which would require slight control to maintain sail orientation at various wind angles; nonetheless, this design was inefficient. This device was installed on a small freighter to assess actual fuel savings, and it was projected to save about 15% to 25% of the marine vessel's fuel[49].

Illustrations

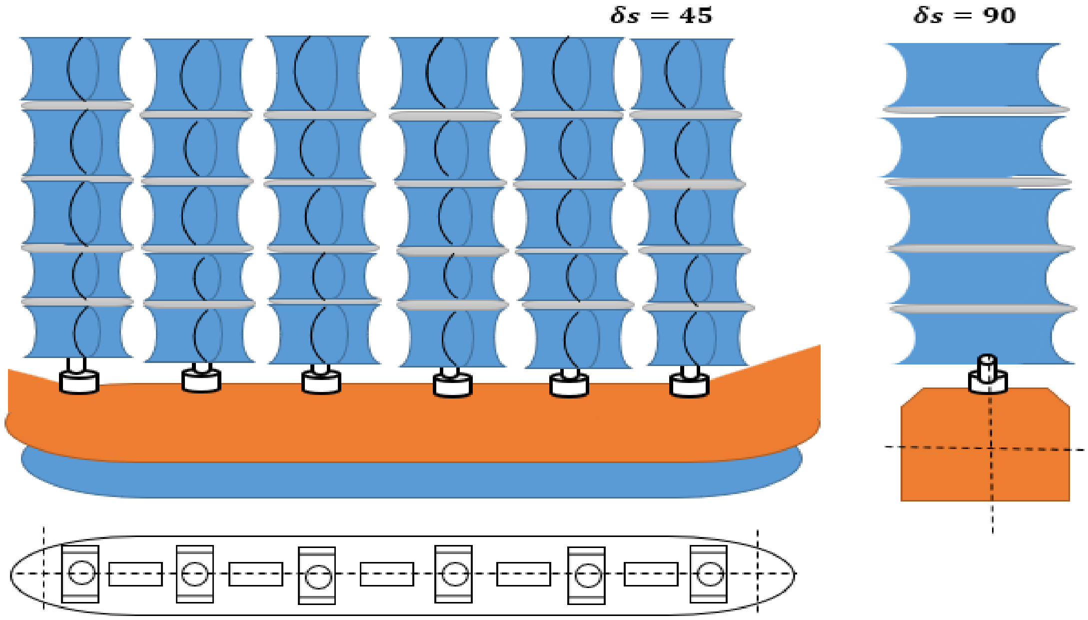

Figure 6. The wing sail system

4.1.2 Kite

The concept of a kite sail propulsion has lately sparked many interests. This outfit involves hovering a massive kite from the bow of a vessel and using the kite's power to help drag the vessel through the water. Other ideas have included having the kite outfit also jerk out and withdraw on a roll, which would drive a producer. This arrangement uses a kite comparable to what recreational kiteboarders use but on a much greater size. This design also permits users to increase the number of kites by stacking many kites[49].

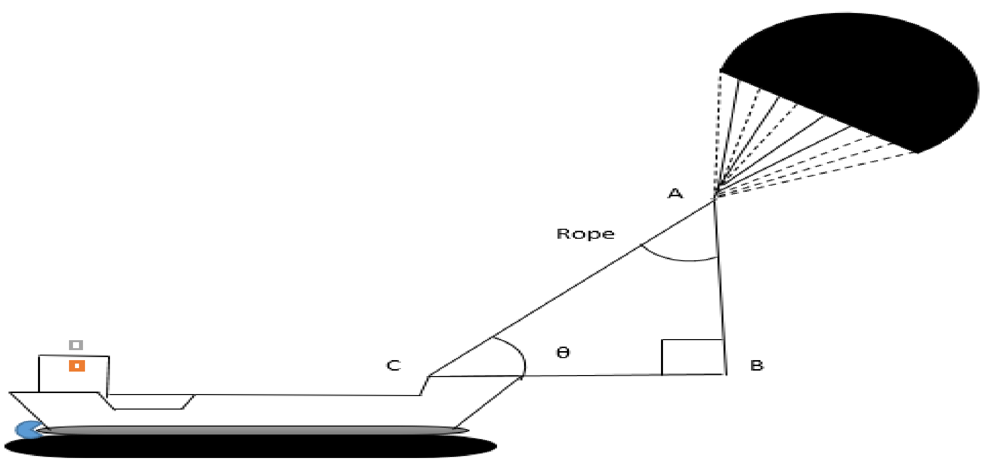

Figure 7. The kite system.

Kites were the most common kind of wind-assisted impulsion on marketable vessels in 2012, owing to the small budget and concerns about adapting the method to current vessels by negligible structural change[50]. This technique also provides calculates the best kite angle and position. Kites allow you to capture wind at a higher height above sea level, where the wind speed is higher and steady[8]. The MS Beluga Skysails, a commercial ship rented by the United State Army Expertise in 2009 to assess the request of effectiveness and possibility of installing this structure on additional vessels, was the most noteworthy ship to use this system in 2009.

4.1.3 Flettner rotor

The Flettner rotor is the third design under consideration. This enormous cylinder is mechanically spun and positioned vertically on a ship's deck. A spinning zone in interaction by wind flowing from one place to another generates a driving force i.e., propels the vessel forward. Since their invention in the 1920s, Flettner Rotors have seen limited use[9][51]. In 2010, four Flettner Rotors were installed on a Ten thousand -Deadweight tonnage cargo vessel to see how effectively they increased fuel effectiveness. Subsequently, at that time, more than a few cargo vessels are fitted with this technology.

Flettner Rotor's only controllable factor is the rotor's rotational speed, implying that this wind propulsion requires minimal human input[6]. Whenever the kite is compared to the size of the propeller and the principal wind situations, Flettner Rotors consistently provide greater efficiency benefits than kite sails [52].

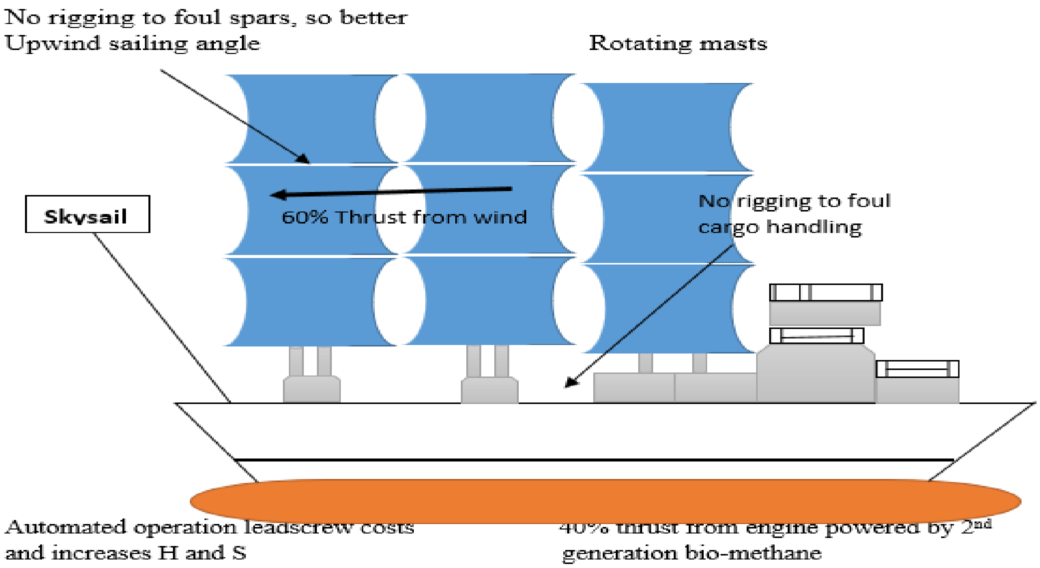

Figure 8. The Flettner rotor system

4.2 Rising trends

Depending on the scale of the system, the efficiency benefits of these three propulsion aid techniques are approximately 15–20 percent. The primary reason why these approaches are not more commonly employed is that transportation corporations are cautious to invest in new technology that has not been tested in previous operations. Government initiatives to limit carbon emissions, along with increasing gasoline and diesel prices, appeared to indicate that these power systems will become more commonly employed in the next years. [53].

Table 1 Fuel consumption comparison for the route between Cape Lopez (Gabon) and Point Tupper (Canada)[52]

Sail Technology	**Time (h)**	**TFC (t)**	**Saving (Compared to no sail)**	**Remark**
No sail	313	966.7	0.0%	No savings
Dyna-Rig	313	912.6	0.60%	Small savings
Wing sail	313	881.5	0.80%	More savings
Flettner rotor	313	80.6	0.90%	Most savings

The above table shows the different types of wind sail propulsion applications and their impact on fuel consumption between Gabon and Canada. As can be seen from the above table, the Flettner rotor is the most efficient type of all of them. It should be noted that these are just auxiliary propulsion system that helps the main propulsion thereby reducing the fuel consumption which has further economic and environmental benefits.

4.3 Auxiliary energy sources

These are only a few energy sources used in ship wind propulsion. The following are a few key players[5]:

- **Energy from waves**; Although theoretically viable and demonstrated on a small scale, huge ships are not practical.
- **The sun's power Large-scale demonstration;** The amount of propulsive power saved is minimal (about 2 percent). Installation is costly. Instead of using wind, it generates power.
- **Wind energy;** Several alternatives are available for producing thrust: Textile: Kites (SkySails) and textile sails (Dyna-Rig)? Non-textile sails: Suction sails (Turbosail), flap sails, fixed sails (EffSail)? Rotor.

4.4 Wind turbine for propulsion

Even though the installation of wind turbines on some vessels such as yachts is more difficult than the installation of photovoltaics, the main requirements for both are almost identical. For boaters that are away from the dock for at least half of the year and sail in more wind areas, wind energy may be a feasible source of electricity. There is no point in spending money on a yacht that would only be utilized for a month out of the year.

The vast majority of maritime wind turbines have a horizontal axis, and the vast majority of them are installed aboard yachts. They are frequently altered for vessel mounting and the marine environment from onshore featured designs. The boat's electricity needs are partially met by these wind turbines, which have a power range of 400 W to 1kW.

As a consequence, in maritime applications, the capacity of the vessel and the location of the wind turbines are two of the most important elements to take into consideration. To maximize the efficiency of wind turbines, they should be installed on the deck of a ship where they will not interfere with vessel operation or crew comfort. Integration of wind turbines on massive warships, on the other hand, would necessitate giant turbines and substantial mounting and energy storage areas.

Unfortunately, this portion is still up in the air, but it must be considered. The ideal site or place for the wind turbine to be installed on the ship is at the mask, where it would be quickly assessed without negatively influencing the ship geometry[7].

4.5 Flattener rotor for ship propulsion

Another technique for harnessing wind energy for ship propulsion is the Flettner rotor. In 1924, the Magnus effect was used to spin a ship's rotor for the first time. They reappeared in 2008 when Lindenau shipyards delivered an Enercon-owned GL-class cargo equipped with Flettner rotors. These four 25-meter-tall and 4-meter-diameter cylinders are expected to save the ship around half of its current fuel use [49]. The Flettner rotor is a vertically rotating cylindrical structure powered by electricity that revolves vertically on the deck[54], [55]. The Magnus effect produces a forward push as the cylinder rotates against the wind. Some researchers also used computational fluid dynamics (CFD) models to evaluate the aerodynamic performance of the Flettner rotor. A performance model based on CFD simulation results to simulate the energy savings provided by Flettner rotors[56].

The following are the advantages of Rotor Sail systems for cargo ships:

- As with all WAPS, fuel savings result in decreased operational costs. • Simple handling requires no additional installation and maintenance costs per thrust force are lower than for other WAPS (Borg, 1985).
- The ship is highly maneuverable. • Passive load limitation: because all rotating cylinders have a maximum operating speed when exposed to high wind speeds, their velocity ratio decreases, and, as a result, their aerodynamic loads decrease.

Thus, Rotor Sails' self-power, making them hurricane-proof, is an advantage not found in other types of WAPS.

Rotor sails have the following disadvantages:

- Vibrations generated by the rotor may cause discomfort to the crew or perhaps structural damage.
- Rotor Sails are active rotating devices that require some form of electricity to rotate.
- Because rotor sails have a low lift-to-drag ratio, they are less effective on fast vessels with lower apparent wind angles.

Chapter 5

THE HYBRID PROPULSION SYSTEM

Because most renewable energy systems are unreliable owing to environmental and other meteorological factors, combined energy systems are gaining popularity. This is the most commonly anticipated scenario for renewable energy usage in marine vessel propulsion. The combination of solar and wind energy sources is the most prevalent hybrid system for maritime vessels[57]. This is especially true for small and medium-sized ships. Alternating generators combined with renewable energy sources such as solar and wind are becoming more attractive for large vessels such as cruise ships and oil tankers. This is owing to tougher rules against greenhouse gases that are damaging to the environment, such as CO2 produced by the use of conventional fuels[50].

The objective of designing any hybrid-electric system is to maximize power generation while adhering to cost and other restrictions such as system reliability, low fuel consumption, and environmental circumstances, as well as ensuring system dependability[58].

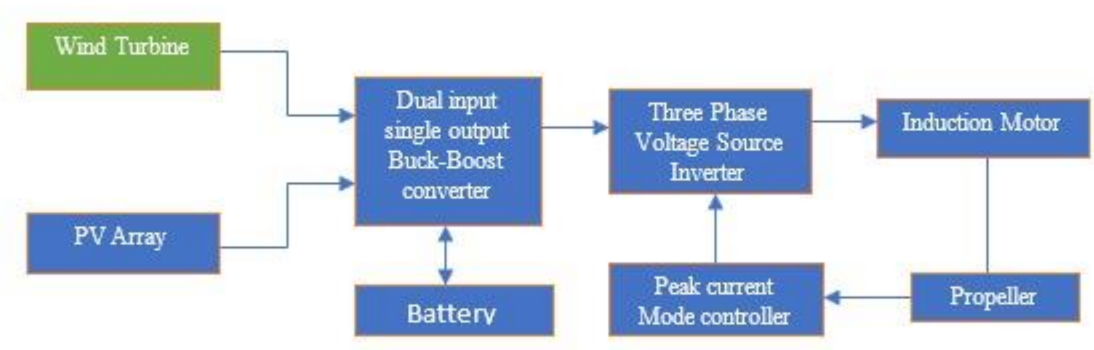

Figure 9. Wind and solar hybrid system

The illustration above illustrates a typical solar and wind hybrid system for a maritime vehicle. It should be noted that this system will also need energy storage, such as a battery, to serve as a complement or backup system, as shown[59] [60]. This is because renewable systems are not reliable in certain weather conditions.

While extreme climatic conditions, such as the sail's durability in stormy weather, are the primary impediments to wind power, dust and aerosols are the primary impediments to solar power[61].

This barrier must be addressed if future renewable energy applications for vessels are to be safeguarded.

Table 2 Hybrid RE system components [54].

System Component	Description	Remark
Solar photovoltaic	polycrystalline; maximum panel power = 330 W; operating voltage Vmp = 37.5 V, current operating Imp = 8.80 A, Open Circuit Voltage VOC = 45.9 V, Open circuit Current ISC = 9.31 A, Efficiency = 16.97%, Operating Temperature 45 °C, and Derating factor fPV = 90% PV panels are equipped with 2-axis tracking system, Capital cost $1200/kW, replacement = $1200/kW, O&M = $3/year/kW and lifetime duration = 25 yrs.	Solar parameters
Generator	Generic Generator; Fuel: Capital cost of fuel $300/kW, replacement = $300/kW, O&M = $0.01/hour, lifetime duration = 15,000 h.	Diesel generator parameters
PEM Fuel Cell	Type: Proton Exchange Membrane fuel cell (DC power) with electrical efficiency ηFC = 70%, Fuel: H2 Capital cost $400/kW, Replacement = $400/kW, O&M = $0.01/hour, lifetime duration = 50,000 h.	Fuel cell parameters
Electrolyzer	Electrolyzer (DC power) with efficiency ηEZ = 90% Capital cost $100/kW, Replacement = $100/kW, O&M = $8/year/kW, lifetime = 15 yrs.	Electrolyzer parameters
Hydrogen Tank	H2 fuel cost = $1/kg, and lifetime duration = 25 years	H_2O parameters
Converter: Inverter	Leonics MTP-4117H 300 kW, Voltage = 480 VDC, efficiency = 94% Capital cost = $40/kW, Replacement = 40$/kW, O&M = 10$/year/kW, Lifetime duration = 25 yrs.	Converter parameters

The table above compares the different energy resources of a typical marine vessel. The hybrid energy system of the ship is analyzed. The initial cost, power output, efficiency, operation, maintenance cost, and durability of each particular component have been examined. And also their replacement cost in case they are no more working. Despite their high initial price, Renewable energy systems are more environmentally friendly, and their long-term benefits are numerous[58][62].

Renewable energy cannot be used to power naval ships' propulsion systems, but it can be used as an emergency power source to ensure crew safety in a life-threatening situation or on specific military operations. All navy ships should use renewable energy to conserve fuel, reduce hazardous emissions, and so help rescue the world[58].

5.1 *Optimization of the hybrid energy system.*

For effective utilization of hybrid energy systems, the software called HOMER is an acronym for hybrid optimization of multiple energy resources. This is a software for finding out which of the energy sources is most suitable at a particular moment in time among all the energy resources that are joint together

The HOMER software is capable of simulating all possible energy resource system configurations that meet the demand load with the required power under the specified conditions of solar radiation data and diesel generator installed size. It performed energy balance computations in ascending order for each conceivable system configuration according to cost of energy and net present cost. The software is capable of simulating all possible system configurations that meet the load demand with the required power under the specified conditions of solar radiation data, wind data, and diesel generator installed size. It performed energy balance computations in ascending order for each conceivable system configuration according to COE and NPC[39], [63], [64]. It will show the real-life performance of the system under different conditions. The best for the system according to the load demand will the used considering the most economical terms in terms of cost of energy and net present cost. The key to cost optimization is the control strategy for switching between existing sources and integrating these sources[65].

Another important component that is normally part of the hybrid system is the energy storage system (ESS). The energy storage system can provide good stability to the hybrid system as a whole. This is particularly important given the fact that most renewable energy sources have some stability issues in certain environmental conditions. For example, solar energy sources cannot work when there is no sunshine and wind energy source which is dependent on the wind cannot be gotten when there is no wind blowing. Due to these unreliability issues, ESS steps in and fills this gap[66][11]. It is the stabilizing factor in the whole hybrid system. There are different kinds of ESS. Among them, the most common is the battery system. Although there are several types of ESS. Physical energy storage, electromagnetic energy storage, phase change energy storage, and electrochemical energy storage are the four types of energy storage technologies.

5.2 *Hybrid systems challenges*

Renewable energy systems have some major environmental challenges. This is more so when it comes to marine vessel application. It is the major setback that leads to the unpopularity of renewable energy applications for marine vessels. Wind and solar are affected the most by these challenges. The main challenges of renewable energy are the cost-effectiveness and availability of these energy sources[67].

While conventional energy is constantly accessible, the output power of renewable energy changes daily and seasonally, as well as depending on the ship's location and environmental circumstances, and must be carefully assessed and managed[58].

However, some of these challenges are being minimized in hybrid energy systems. That is the essence of having multiple sources of energy. Since it is unavoidable when it comes intermittence nature of renewable, there are multiple sources to choose from.

5.3 Hybrid Prospects for future

By 2050, some creative proposals aim for almost zero-emission ships. However, given the vast quantity of energy consumed by a ship, it is evident that the shipping industry's environmental effect can be decreased only through the construction of hybrid systems based on alternative energy sources.

Aquarius MRE will utilize a combination of rigid sails and solar modules to create a ship-based renewable energy system. The system is predicted to lower a vessel's yearly fuel usage by up to 20% depending on the number, size, form, and arrangement of the rigid sails.

Solar-powered eco-friendly watercraft intended for use as a commuter ferry in metropolitan areas. Solar modules put on the roof will be able to be lifted and lowered. Additionally, it may be modified to run on several power sources, including LNG or biofuel.

Solar Sailor has been selected to install solar and wind energy systems aboard a huge dry cargo ship capable of transporting iron ore from Australia to China. Solar Albatross is a 24-meter-long catamaran ferry capable of transporting 100 passengers, equipped with stowable Solar Sails.

The E/S Orcelle will have an optimal cargo capacity of 85,000 m2, about the equivalent of 14 football fields, of cargo deck stowage area. Solar, wind, and wave energy are the primary sources of energy. This is a 50% increase in space over today's car carriers, which are capable of hauling 6,500 automobiles.

The primary design considerations are as follows: a) Using the sun, wind, and waves to power multiple energy generators, including fuel cells; b) Optimizing cargo capacity and lowering energy consumption per transported unit; and c) Addressing additional environmental concerns, such as eliminating ballast water problems due to the new hull design.

Solar energy will be utilized to create power that may be used immediately or stored. The Solar Impulse is propelled forward by solar modules embedded in the sails. When not in use for wind propulsion, the sails can be angled, laid down, or directed to capture the maximum amount of solar energy [68].

5.4 The distinction between the HRES on land and vessel.

There is, without a doubt, a significant gap between the HRES on land and the one on a ship. This is because there is a constant burden on land that is located in an unchanging location. The load on a ship, on the other hand, can be moved about where the vessel is.[69][70]. On a sailing ship, the solar radiation statistics for the photovoltaic array on the ship's latitude and longitude, as well as the angle at which the sun's rays shine on the photovoltaic array, change all the time. Besides that, it is built on the land. [19][71]. Additionally, the effectiveness of the photovoltaic system is impacted by the ocean water smashing against the vessel's surface. Additionally, the overall load carried by the ship fluctuates depending on the load circumstances. To be safe, it must be verified that the ship's systems are 100 percent reliable[72][73].On the contrary, it is preferable to have a system on land that is completely reliable, but not as mandatory as the system on a ship[74][75]. Another distinction is that the penetration of a photovoltaic system on a vessel is restricted by the vessel's allowed zone. The variations of the utilized oil tanker vessel and the slamming of water into the vessel's surface will not be taken into account while simplifying the suggested research. Additionally, HOMER software is based on a near-ideal scenario that ignores shifting weather patterns or navigational challenges encountered by the ship.

5.4.1 solar radiation

Solar radiation changes not only with the ship's route from Dalian in China to Aden in Yemen, but also with elevation, time of day, day of the month, and month of the year. Six stopping places were chosen for the ship's route, as shown in Table 3. Fig. 10 shows the tanker ship's route from Dalian, China, to Aden, Yemen. During the 22 years from July 1983 to June 2005, the National Aeronautics and Space Administration (NASA) kept track of the average monthly solar radiation. [76]. Fig. 10 shows the average monthly solar radiation measurements for each of the ship's six ports of call. Additionally, the same graphic includes statistics on the average monthly sun radiation for all six cities.

Table 3 The navigation route of the oil tanker ship[63]**.**

The city	The coordinates	Annual average solar radiation	Remark
Dalian (China)	38° 54.80 N, 121° 36.90 E	4.56 (kWh/m2 /day)	Main port
Shanghai (China)	31° 13.80 N, 121° 28.40 E	3.81 (kWh/m2 /day)	Aux. port
Hong Kong (China)	22° 23.80 N, 114° 6.600 E	3.91 (kWh/m2 /day)	Aux. port
Singapore	1° 21.100 N, 103° 49.20 E	4.56 (kWh/m2 /day)	Aux. port
Matara (Sri Lanka)	5° 57.300 N, 80° 33.300 E	5.56 (kWh/m2 /day)	Aux. port
Aden (Yemen)	12° 47.10 N, 45° 1.100 E	6.49 (kWh/m2 /day)	Main port

Figure 10. The journey from Dalian to Aden in Yemen via oil tanker [63]

5.4.2 Technical inputs

Table 3 outlines the technical specifications of the photovoltaic system installed aboard the oil tanker ship. The various expenses were derived from ref. It should be mentioned that the ship's photovoltaic system has a limited capacity. For HRES that are installed on land, there are no limits placed on the capacity of the PV system as long as there is adequate room for installation. The oil tanker ship's intended system contains 2MW diesel generator sets to meet the ship's peak load. The diesel generators installed cost $280,000 new and $260,000 replaced. while petrol is $0.86/L. This experiment uses LiFePO4 batteries. These batteries have a capital cost of $50/kWh, a replacement cost of $45/kWh, and a charging efficiency of 80%. The power converter used in this research has a 15-year life and a capital cost of $600 per kW. [63].

Table 4 The technical specifications for the photovoltaic system installed on the oil ship [63]

The PV system		Remark
Total allowable area	2000 m^2	Properties of the PV system installed on a ship
Maximum capacity	300 kW	
PV panel rated power	250 W	
PV panel area	1.66 m × 0.99 m	
Total no. of PV panels	1217 panels	
Capital cost	$1600/kw	
Replacement cost	$1400/kw	
Lifetime	20 years	
Efficiency	15%	

The above table shows an example of a ship’s photovoltaic specifications and parameters. It shows how PV has been installed capacity, the available area, and also the associated costs. It is an extract from a research paper that compares the application of PV on the vessel and land.

Chapter 6

CONCLUSION

The introduction of renewable energy applications in marine vessels has some significant benefits. From both the economic and environmental point of view. The maritime industry is undergoing some significant transformations. Some of these include some stricter regulations for the emission of carbon dioxide (CO2) and other greenhouse gas (GHG) emissions that are causing global warming thereby changing the nature of our climate for the worst. Although the use of renewable +++energy in marine boats is not a new concept, it has not received the attention it deserves, despite the industry's high volume of traffic. Which is on the rise every day. As a result, we must learn more about how these ecologically friendly energy sources are evaluated. As previously stated in this analysis, renewable energy may be used in a variety of ways in maritime boats. The key issues causing the majority of these applications, however, are economic benefits considerations and underdeveloped technology as compared to the land.

Solar PV and Wind energy are one of the most favorable renewable energies that we can in marine vessels. They have some quite significant advantages from zero CO_2 emission to zero noise and its overall green energy nature benefits. With the advancement of both technology and the discovery of new materials, their applications are expected to grow. With many renewable energy sources costs are reducing day by day.

It is important to note that this review also serves as a reminder that there is some huge potential for applications of renewable energy resources in marine vessels. As discovered from numerous papers that have been reviewed. They will contribute significantly to the reduction of fuel consumption and greenhouse gas emission. Furthermore, they will help in the conservation of the maritime sector to help in meeting the enforce a strong environmental policy against pollution and also obtain higher fuel savings.

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