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A Review on Ferry Electrification: A Path towards Sustainable Maritime Transport

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***Abstract:** This paper reviews research and development efforts for ferries' electrification, focusing on energy supply grids, communication networks, charging systems, and energy storage. It analyzes energy storage technologies, battery charging requirements, shore side infrastructure design, power system architecture, and alternative battery charging stations[1]. The study evaluates the effectiveness of using an electric/hybrid ferry boat for tourist transportation in a real case. The optimal system configuration depends on engine power, energy storage, photovoltaic system sizes, and percentage of hybrid or pure electric usage. The analysis can be replicated to other cases, showing the potential of new technologies for sustainable boating and improving passenger service, especially in terms of comfort[15]. One of the most important steps in lowering greenhouse gas emissions and the marine industry's reliance on fossil fuels is the electrification of ships. This analysis examines the technical developments, difficulties, and environmental effects of switching from conventional fossil fuel-powered ships to electric and hybrid ships. The future of fully electric ships, legislative efforts, and how these advancements relate to international sustainability goals are also covered in the study.*
***Keywords:** electrification; electric ferries; green transformation; maritime industry; fuel cell;*

I. INTRODUCTION

Water pollution is a significant environmental concern, particularly in lakes, which are vital for agriculture and civil use. Lake navigation affects water pollution levels, and reducing or prohibiting it is crucial. This paper proposes a lakeside transport system with zero environmental impact, using electric boats propelled by lithium-ion batteries and renewable energy sources like photovoltaic plants. This system minimizes drag and improves environmental sustainability[3].
The schematic diagram of the Eco friendly Electric Propulsion Boat is illustrated in Figure 1[3].

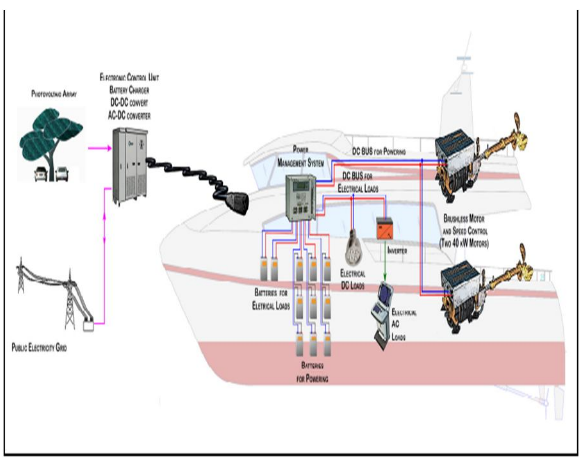

Figure 1.Eco friendly Electric Propulsion Boat

A boat uses rechargeable batteries powered by a photovoltaic array, which generates all its energy needs annually through photovoltaic electric field grid-connected systems. It proposes a boat with 10 kW propulsion and 10 kW on-board services, allowing 11 hours of navigation without recharging 226 kW batteries[3].One of the most important and essential steps in fulfilling the objectives of the Paris Agreement and preventing the worst effects of climate change, like the loss of ecosystem disturbance and environmental habitats.[1]

Maritime transportation is responsible for approximately 3% of global carbon dioxide (CO_2) emissions, primarily due to the widespread use of heavy fuel oil (HFO) and marine diesel oil (MDO). Electrification is seen as a promising approach to mitigate this impact. In recent years, increasing regulatory pressure and advances in battery and energy storage technology have made electric propulsion systems more viable for a variety of ship types. This review aims to explore the current state of ship electrification, its benefits, challenges, and future prospects.

II. EVOLUTION OF SHIP PROPULSION

In past years, ships have been propelled by the wind (sailing ships), coal-fired steam engines, and then diesel engines. Diesel engines' efficiency and great energy density have made them the cornerstone of maritime propulsion for more than a century. Electric propulsion is becoming more popular, though, as the maritime sector feels more and more pressure to reduce its carbon footprint. Some ships currently use totally electric or hybrid-electric systems. Maritime transport is a significant contributor to global greenhouse gas emissions, accounting for approximately 3% of global CO_2 emissions. Within the sector, ferries, especially those operating on short routes, have been early adopters of electrification. The development of electric ferries presents a solution to local pollution, reduced fuel consumption, and compliance with international regulations aimed at curbing maritime emissions.

III. ELECTRIFICATION TECHNOLOGIES

A. Battery Electric Ships (BES)

Ships powered by batteries only use onboard battery systems for propulsion. This market is dominated by lithium-ion batteries because of their scalability and high energy density. Short-haul ships, tugs, and small ferries are among the first to use this technology. The Ampere, the world's first fully electric auto ferry, made its debut in Norway in 2015 and proved that battery-powered boats could travel short distances.

Key advantages include:

- Zero emissions during operation.
- Quiet,vibration-free propulsion.
- Reduced maintenance costs compared to internal combustion engines (ICE).

Challenges include:

- Limited energy storage capacity, restricting the range and size of battery-electric ships.
- Long recharging times, particularly for larger vessels.
- The environmental impact of battery production and disposal.

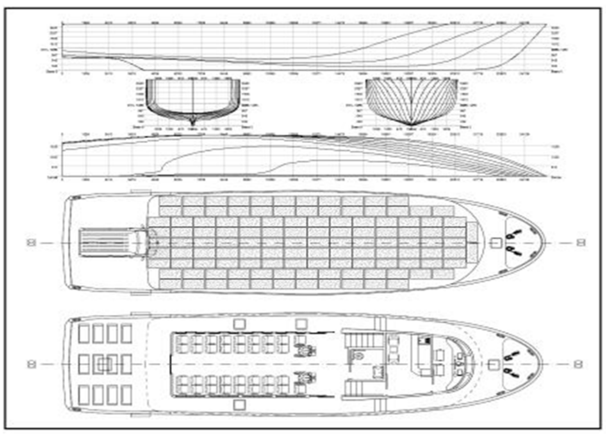

Figure 2. Battery Arrangement In Ferry[13]

B. Charging Infrastructure

For electric ferries to provide prompt and effective energy replenishment in between voyages, sophisticated charging infrastructure must be installed at ports. The size of the battery and the wattage of the charging stations affect how long it takes to charge; certain systems allow for quick charging in less than 30 minutes. Various techniques for charging consist of:

1) *Onshore Power Supply (OPS):* Plugs or automated docking systems are used by ferries to link to land-based electrical grids, allowing for quick recharge while loading and unloading cargo.
2) *Wireless Charging:* To improve efficiency and lower downtime, inductive charging technology is being investigated for use in ferry systems in the future.

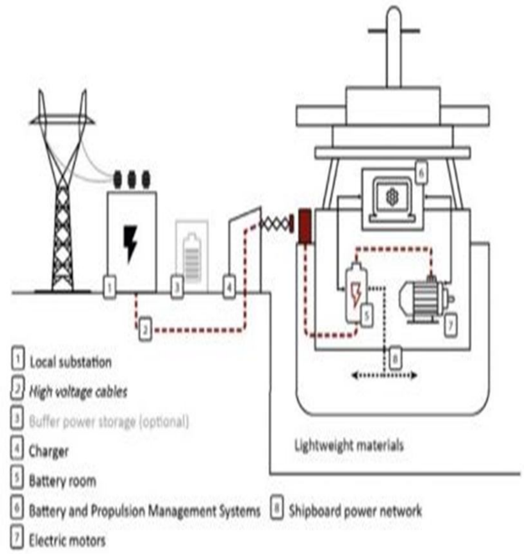

Figure 3. . Schematic of an electric ferry and onshore infrastructure [1]

A. *Electric-Hybrid Ships*

Conventional diesel engines are combined with electric propulsion systems and battery storage in hybrid-electric ships. This maximizes efficiency by enabling ships to switch between several power sources. The most popular setup employs diesel engines for long-distance cruises and batteries for propulsion at low speeds or in port (zero-emission operations).

Advantages of mixed systems:

- Higher fuel economy.
- Operational flexibility allowing adherence to more stringent port requirements.
- Lower emissions when running on electricity.

However, the majority of the functions of hybrid systems still rely on fossil fuels, which limits their long-term sustainability.

B. *Integration of Renewable Energy with FuelCells*

An further means of electricity is provided by fuel cells, particularly hydrogen fuel cells. Water is the only result of the electrochemical reaction that produces energy between hydrogen and oxygen. Fuel cell applications in the maritime industry are still in the experimental stage, but they have potential, especially for big ships where battery weight and capacity are constraints.

IV. ENVIRONMENTAL IMPACT OF SHIP ELECTRIFICATION

The main advantage of electric and hybrid-electric ships for the environment is the decrease in harmful pollutants, such as particulate matter, CO2, sulfur oxides (SOx), and nitrogen oxides (NOx). Additionally, electrification lowers noise pollution, which is good for marine life, especially in locations that are environmentally sensitive.

Nevertheless, electricity has a somewhat non-zero environmental impact. Significant environmental costs are associated with the production and disposal of batteries, including the extraction of raw minerals that have negative effects on the environment and human rights, such as nickel, cobalt, and lithium. Compared to conventional diesel-powered vessels, electric ferries have a number of advantages in terms of operational costs and environmental effect.

Direct emissions of CO2, sulfur oxides (SOx), and nitrogen oxides (NOx), which are frequently produced by diesel-powered ferries, are eliminated by electric ferries. The air quality is improved by these pollution reductions, especially in cities close to harbors. Additionally, there is a noticeable decrease in noise pollution, which is advantageous for both travelers and marinelife.

A. No Emissions

Because electric ferries don't use heavy fuel oils, they help to clean up the air and water.

B. Decrease in Water Contamination

Conventional ferries may spill fuel or oil, contaminating marine environments. This risk is removed with electric ferries.

C. Financial Aspects

Because batteries and charging infrastructure are more expensive than in the case of traditional ferries, the initial cost of electric ferries is higher. These initial expenditures, however, may be mitigated by operational savings from decreased fuel and maintenance costs. Compared to diesel-powered counterparts, electric ferries have a lower total cost of ownership over the long run. One major obstacle to the broad adoption of electric and hybrid-electric ships is their high upfront cost. Specifically, batteries are more costly and have a shorter lifespan than traditional propulsion systems. Long-term savings, however, come from decreased fuel expenses and less maintenance because there are fewer moving components. Short-sea transport is a good fit for electric ships because frequent port stops allow for recharging and battery range constraints are less of an issue. In the near future, hybrid systems and other fuels like hydrogen are more practical choices for long-distance shipping.

V. FUTURE PROSPECTS AND CHALLENGES

Ship electrification in the future is largely dependent on developments in energy storage, especially battery technology. Solid-state batteries are being developed and have the potential to completely change the architecture of electric ships since they offer increased safety and energy density. Although there are still issues with hydrogen generation, storage, and cost, hydrogen fuel cells are also a promising technology.

Development of the infrastructure is another important component. In order to handle the increasing number of electric ships, ports must make investments in grid upgrades and charging stations. To enable the broad use of new technologies, the regulatory environment must also change.

There are a number of technology developments that could help electric ferries overcome their existing problems. Solid-state batteries and other advancements in battery chemistry have the potential to greatly boost energy density and shorten charging times. Although still in its infancy, wireless charging technology has the potential to completely transform the efficiency of charging by allowing ferries to charge while docked without the need for human interaction.

VI. CONCLUSION

In especially for short-sea travel, electric ferries offer a practical way to cut emissions in marine transportation. The range of electric ferries is expected to increase as battery storage and charging infrastructure advance technologically. Nonetheless, issues such the high upfront price, restricted range, and limitations with the charging infrastructure need to be resolved. Environmental rules and the demand for sustainable mobility have prompted ferries to switch to all-electric operation, which is a crucial step in the decarbonisation of the maritime sector. An approach to go towards a more sustainable maritime sector is through electrification. The electrification of larger vessels and long-haul routes is anticipated to be made possible in the next decades by continued technology developments and regulatory assistance, even though the current focus is on hybrid systems and short-sea shipping. Although achieving universal electrification would need large expenditures in infrastructure, technology, and regulatory frameworks, the advantages to the environment and operations make the effort worthwhile.

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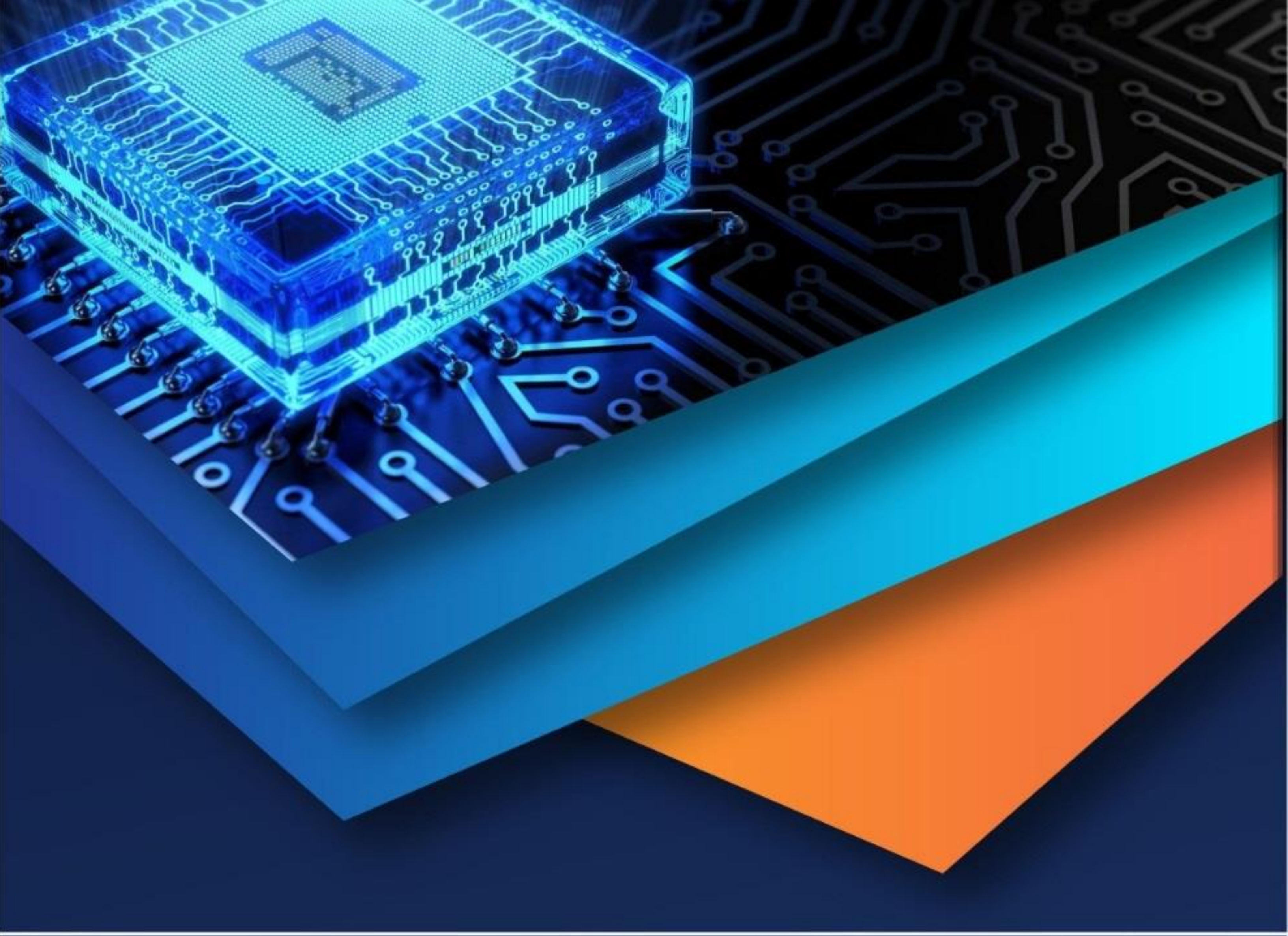

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