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Research Article

MODELLING THE FEASIBILITY OF USING FUEL CELLS IN MARINE APPLICATIONS

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Abstract

Fuel cells as clean power sources are very appealing to the maritime industry, which is committed to sustainability and reducing greenhouse gas and pollutant emissions from ships. Currently, power capacity, costs and lifetime of the fuel cell stack are the primary barriers. This report presents a mathematical model for optimizing the cost of gasoline with regard to hours from an hourly dispatch aboard a Marine Fuel Cell Power System (MFCPS) powered by hydrogen and gasoline. The model is based on a differential equation (DDP) that is used to determine the best energy the board procedure (EMS) for the typical power profile for each practical power source size mix Z. The proposed model is then used to calibrate the cost optimization findings for the constraint of hydrogen fuel (H2) tanks. The results show that there is no statistically significant difference between a non-hybrid energy system and a hybrid energy system that uses zero-emission hybrid energy systems. The suggested method's performance is demonstrated by examining hourly power dispatch statistics for the investigated ship over a one-year period.

Keywords: Fuel cells, Mathematical models, Maritime industry, Sustainable development.

INTRODUCTION

The marine sector is getting more attention on the international environmental issue. As shipping's contribution to air pollution rises, legislative pressure to reduce shipping emissions is steadily increasing due to consumer awareness. The International Maritime Organization is enforcing worldwide laws guiding the reduction of SOx and NOx emissions from shipping, and also intends to implement more regional restrictions to minimize emissions. Therefore, novel ideas for energy conversion that are both environmentally friendly and energy efficient are being discussed. Utilizing fuel cell technologies for auxiliary power or perhaps primary propulsion is one potential option. The legal history of global shipping in relation to the use of fuel cells and gas as fuelling ships is summarized in the paper. The early encounters with the usage of fuel cell technologies on marine applications will be the main topic of the paper (Sapra *et al.,* 2021). Several of the advantages that fuel cells might provide to the utility sector would also be applicable to the marine sector. Increased fuel cell effectiveness has potential to result in gasoline potential savings, which is very intriguing. Additionally, the performance of fuel cells remains largely consistent across a wide variety of power values. Such a feature indicates that fuel cells could be effectively used in vessels with regularly varying power requirements, including icebreakers, towboats, ferries, offshore supply boats, and ferry vehicles. Fuel cells have the ability to provide supplemental energy and other demands in addition to primary propulsion. Compared to ships that exclusively use batteries, the fuel cell system will enable quicker refuelling and greater ranges between refilling. Battery and fuel cell combination technology will provide a stable and effective power source for propulsion (Wu and Bucknall 2020).

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Research question

1. How a renewable energy systems are used to supply the electric power in remote?
2. How the fuel cells can be economically competitive for various system with the different batteries?

LITERATURE REVIEW

Potential Applications of Fuel Cells

Fuel cells with different power rates can be utilized in a broad range of applications in the marine sector. To date, though, the majority of fuel cell developmental initiatives made by companies and supported by governmental and commercial organizations have been linked to improving the state-of-the-art of fuel cell innovation for ground gas and electricity grid purposes. These areas could be used to categorize certain potential fuel cell applications in the marine environment (Li *et al.,* 2018).

Submarines and submersibles: The durability of submerged ships, including submarines and submersibles, is a significant limitation. Because they allow underwater vessels to stay below for longer than batteries, which are generally used to power small submersibles, fuel cells have been taken into consideration for submerged activities (Mashkour *et al.,* 2021).

Commercial transport ship propulsion: With such kinds of transport ships like tankers, bulk carries and cruise ships, the challenge from alternative technologies is going to be significantly tougher. This is so because the diesel engines now powering these ships which travel at steady speeds are highly efficient and low-rpm. Sector resistance to abandon a dependable and effective propulsion technology would restrict the utilization of fuel cells (Mashkour *et al.,* 2021). Generally, despite military uses, commercial fuel cell uses must demonstrate cost effectiveness. Fuel cells are not probably to be utilized until they offer distinct and substantial economic benefits.

Naval ship propulsion power: The primary consideration in the construction of naval combat ships is not always cost. If fuel cells turn out to be the most efficient device for a specific application, they will be employed. Despite significant statistical study, the Navy has not yet identified certain operations for which fuel cells are particularly well-suited. The major obstacles to creating fuel cells for naval ships are the restricted supply of fuel and the reduced power output. As was just mentioned, switching a fleet to a new fuel is not an easy operation (Chiche, 2022).

Potential Marine Fuels

Although the majority of fuel cell systems are more power efficient than dual-fuel or conventional marine diesel systems, the benefits are not particularly significant while considering costs and level of technological sophistication. The concept of fuel cell deployments in the marine sector is predicated on the use of zero carbon or carbon-neutral fuels, taking lower carbon or no carbon potential transport into consideration. In other words, the research makes the fundamental premise that carbon capture and storage (CCS) is not possible on board ships (Chiche, 2022). Hence, synthesized natural gas (SNG, primarily methane), hydrogen, ammonia, and methanol via sustainable origins are recognised as fuel oil with lengthy prospective and would be explored in this study. Traditional marine hydrocarbon fuels are omitted due to their weak long-term prospective. Short-term uses of hydrocarbon raw substances utilized as feedstock for hydrogen, ammonia, SNG, and methanol are deemed appropriate as a transition (Gadducci *et al.,* 2022).

Fundamentals of safeness regarding fuel cell technology use on Marine sector

A few safety guidelines must be observed when using fuel cell systems on ships to assure that the technology offers the same degree of protection as traditional systems. The following illustrates some key protection ideas and how they can be used in real-world situations (Vogler and Würsig, 2023).

Single failure criterion: Generally, the solitary failure criteria is used. It indicates that the fuel cell technology must be built such that zero solitary failure can result in an unsafe circumstance. Additionally, all safety-related equipment must be certified for their intended use (Vogler and Würsig, 2023).

Two-Barrier-Principle for gas supply: According to the two-barrier-principle of gas delivery, every gas is encircled by two separate barriers. In the event that one barrier fails, the second barrier will guarantee the gases secure confinement. The two-barrier concept can be fulfilled in a variety of ways. The approach can be implemented utilizing gastight enclosures, double-wall pipes (Figure 1), or a gas pipe contained within a ventilation duct (Figure 2). A sensing element placed in-between the pipes can track the failure of a double-walled pipe obstacle. As a result, the pressure level between the pipes must be greater than high pressures and less than the inner pipe's pressure. In that situation, an internal and external barrier collapse can be identified. A sensor module at the head of the ventilator duct will normally identify a gas pipe collapse inside the ventilator duct.

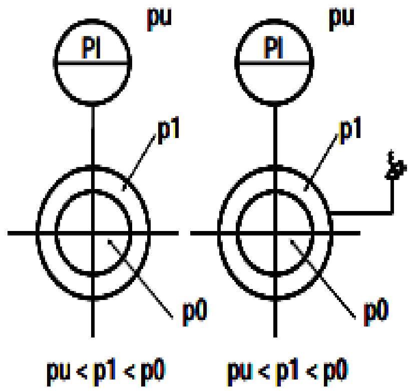

Figure 1. Sketches of Double-Walled-Pipes (Gadducci *et al.,* 2022)

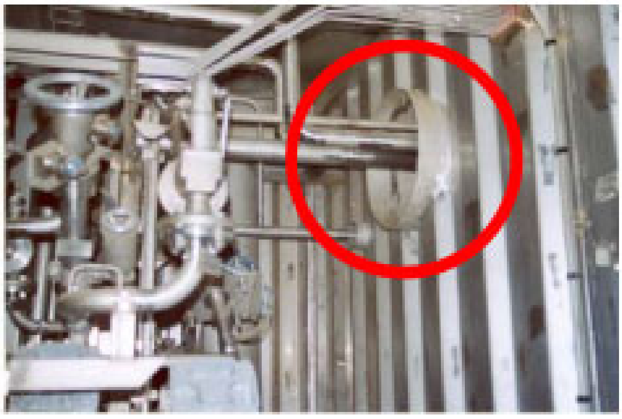

Figure 2. Gas Pipe in Ventilation Duct (Vogler and Würsig, 2023).

METHODOLOGY

A Marine Fuel Cell Power System (MFCPS) is a hybrid electric propulsion system that utilizes a membrane process unit (MPU) to generate power and hydrogen fuel (H2) while moving at a slow pace or operating on land. It is comparable to a gas/diesel hybrid, except that there is no separate combustion chamber; instead, it blends burning and electricity conversion operations into a single unit. Stacked fuel cells serve as generators in conjunction with batteries and/or solar cells for storage and/or distribution (Mashkour *et al.,* 2021). The necessity for rapid and dependable start-up times drove the creation of the small 'battery-agnostic' design required for maritime applications. The ability to keep up with significant developments in battery technology that allow improved use of solar energy from thin film technology will be a critical issue for maritime fuel cell producers. Contingent upon the temperature of the fuel, hydrogen can be stored in two ways. The first method is to compress gas pressure and store it at 350 or 700 bar. The second method is to liquefy gas pressure and store it below 253 C. We have separated hydrogen storage tanks into two categories of studies based on this two-way - one is a liquidized country under 253 C, stores media with 7% H2, and so on. The other is a compressed state at 350 or 700 bar, which inundated medium with 1% H2, and so on. For long-term storage in naval fuel cell power systems, a hydrogen storage tank with low density and good temperature tolerance is extremely desirable (Xing *et al.,* 2021).

External layer

Taking into account the cost, energy, and carbon footprint of both battery and fuel cell modules, this study discovered that a hybrid propulsion system utilizing both technologies can result in a greater total cost than one utilizing simply one. However, while fuel cells are less expensive at every level of performance, they have much poorer energy and power density when compared to traditional diesel engines. Thus, at this time, it may be more practicable to combine both batteries and fuel cells for best performance than focusing on a single technology for whole system design. To discover the optimal power source for a ship, a multi-objective optimization model is designed [10].

Inner layer

When contrasted with stochastic powerful programming, the calculation time is greatly lowered. Using DDP, reverse iteration is utilized to determine the best energy the board procedure (EMS) for the typical power profile for each practical power source size mix Z. The movement from one state to the next in DDP is deterministic as a specific example of reverse iteration; hence, the computing time of NDC is greatly decreased when contrasted with stochastic powerful programming in terms of both hardware complexity and memory needs (Wu and Bucknall, 2020).

RESULT AND ANALYSIS

The chemical and pharmaceutical companies existing competitive advantage is maintained via increasingly efficient manufacturing technology. Chemicals and materials are increasingly being produced using renewable raw resources and purpose-built chemical production facilities that can compete with traditional chemical plants in terms of cost. The modelling indicates that chemical producers will continue to expand their share of global primary energy consumption in OECD nations between 2040 and 2060, despite significant rise in electricity demand, which we estimate to be approximately to 8–300%. The findings are consistent with McKinsey studies on the rise of energy-intensive industries in Europe between 2020 and 2050. According to the findings, the business case for a regenerative ammonia-based electrolyze is viable. Environmentally friendly power sources, like breeze or sun based power, should be utilized to produce power (Hansson *et al.,* 2020). Rising fumes gas from the SOFC stack can be utilized to pre-heat the fuel, air, and transforming unit. Rankine cycles might be used to create steam when the operating temperature of the SOFC stack is lower. A ST might create extra electrical energy, increasing the total efficiency of the system to more than 80%. Water is the most prevalent working fluid in the Rankine cycle. However, because of their low critical temperature, organic fluids are commonly used to replace water at the point when the temperature of the intensity source is lower. A SOFC stack, a fuel supply unit, an air supply unit, a transforming unit, and an after-synergist combustor contain a circuitous half breed SOFC-ST framework. The SOFC stack's elevated exhaust air may be used to pre-heat the fuel, air, and reforming unit. Rankine cycles might be utilized to create steam while the working temperature of the SOFC stack is lower. Thus, the ORC/SOFR technology in conjunction with SOFC might be studied further in order to boost electrical production by matching Rankine cycle in conjunction with the Exergy system (Xing *et al.,* 2021a).

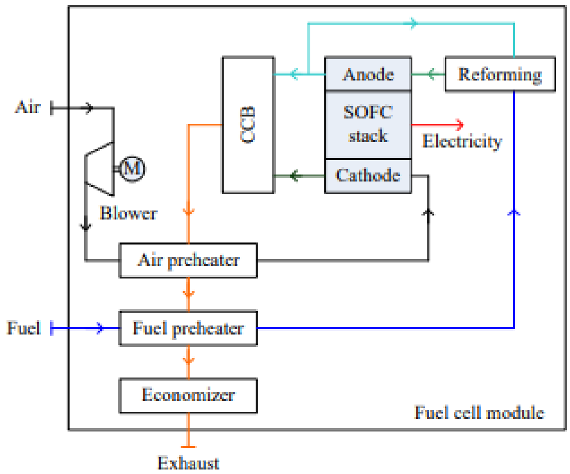

Figure 3. Schematic diagram of SOFC (Wu and Bucknall, 2020)

The inside of the vehicle can be regarded as a somewhat restricted and complicated atmosphere that is not favourable to hydrogen dissipation. A considerable amount of hydrogen will gather in the lodge following a hole, which could bring about a blast out of the blue. Subsequently, perhaps the most critical variable influencing the wellbeing of a hydrogen energy unit boat would be the ventilation states of the lodges. According to the original ventilation design. The results shows that the natural ventilation condition for LNG-S2H2 fuel cells has a natural ventilation capability of 37.5% and an optimal yet another rate of hydrogen leakage of 100%, with two ventilators in the stern cabin and four in the controlling cabin. It has a perfect one-way hydrogen leak rate of 88.6%, while Condition 3 with two vents in each cabin achieves 90%, which is higher than Condition 1 with just four vents in the control lodge and adding two regular vents with a breadth of 1.2 m in the traveller lodge, one on the left and one on the right; Condition 3: holding the extraordinary normal vents [4].

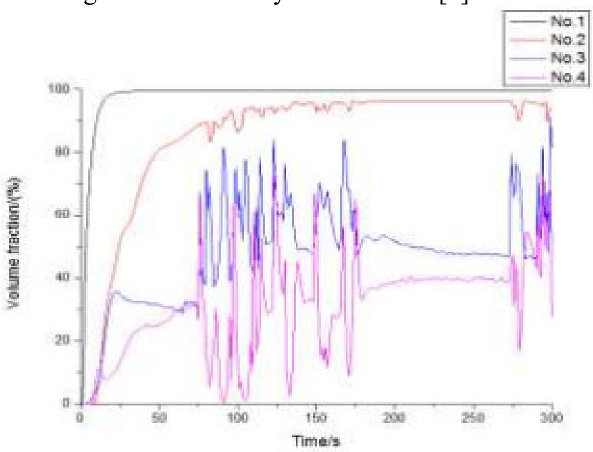

Figure 4. Hydrogen concentration at the detection points). [4]

Increase the volume and/or diluting rate of the chemical bonding to provide artificial ventilation of hydrogen in a fuel cell cabin. Mechanical vents are used in lieu of natural vents (pipes) to provide ventilation. When this is done, the centralization of hydrogen entering the control lodge drops to under 4% and arrives at nothing in the traveller region. Under Condition 4, hydrogen can be removed directly from the energy unit lodges to a detachable region, with practically zero hydrogen entering the control or traveller lodges. Because of limiting fuel cell fire threats caused by chemical explosions under these conditions, ship safety is considerably enhanced. Replacing the natural venting inside the fuel cell rooms with artificial vents can greatly reduce the concentration of hydrogen entering the control lodge and traveller room thus improving the safety of this fuel cell powered ship. As a result, with no hydrogen diffusion in between, a steady state may be established.

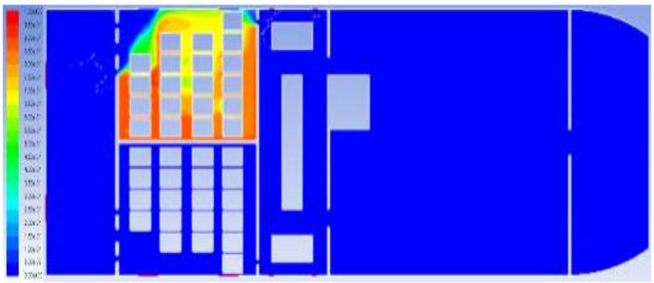

Figure 5. Concentration distribution of hydrogen (Li *et al.*, 2018)

The suggested method's performance is demonstrated by examining hourly power dispatch statistics for the investigated ship over a one-year period. The findings reveal that there is no statistically significant difference between a non-hybrid energy system and a hybrid energy system that uses a zero-emission hybrid energy system. As a result, it is reasonable to suppose that the suggested approach is relevant to the industrial ship industry. Optimization of power loads in hybrid energy systems fuelled by hydrogen and gasoline. The model is used to calibrate the cost optimization findings for the constraint of H2 tanks. In this paper, a mathematical model is constructed for characterizing and optimizing the cost of gasoline with regard to hours from an hourly dispatch aboard (Rafiei *et al.,* 2020).

Conclusion

When compared to stochastic dynamic programming, the calculation time is greatly lowered. The movement from one state to the next in DDP is deterministic as a specific example of reverse iteration; hence, the computing time of NDC is greatly decreased when compared to that of stochastic dynamic programming in terms of both hardware complexity and memory needs. The pharmaceutical company's existing competitive advantage is maintained via increasingly efficient manufacturing technology. According to the findings, the business case for a regenerative ammonia-based electrolyze is viable. Rising fumes gas from the SOFC stack can be utilized to pre-heat the fuel, air, and improving unit. Rankine cycles may be utilized to make steam while the working temperature of the SOFC stack is lower. The inside of the vehicle can be regarded as a somewhat restricted and complicated atmosphere that is not favourable to hydrogen dissipation. When this is done, the centralization of hydrogen entering the control lodge drops to under 4% and arrives at nothing in the traveller region. Under Condition 4, hydrogen can be removed directly from the energy unit lodges to a detachable region, with next to zero hydrogen entering the control or traveller cabins. The suggested method's performance is demonstrated by examining hourly power dispatch statistics for the investigated ship over a one-year period. As a result, it is reasonable to suppose that the suggested approach is relevant to the industrial ship industry.

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