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Fuel Cell-Based Hybrid Ship Design

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Abstract

Considering the pollution-related challenges and fuel supplement constraints, all-electric ships with clean energy resources are being developed. On the other hand, due to the prominent features of hydrogen and the possibility of achieving zero-pollution hydrogen production, hydrogen has received much more attention in recent years as the main fuel of the future. Hydrogen usage growth in the electric transportation industry has also been significant, and in the shipping industry, the use of hydrogen fuel and the development of fuel cell technology have been significantly developed. This paper proposes a conceptual design process for the all-electric fuel cell ship. To create a comprehensive and systematic approach to the proposed design process, by investigating the phases of internationally recognized projects in the field of design, construction, and operation of fuel cell ships, a conceptual design flowchart has been presented. By using this flowchart and having the ship's input parameters such as power capacity, the energy required for each trip, load change rates, ship's dimensions, fuel tank capacity, available space, and by considering available technologies including fuel cell modules, hydrogen supplement, and storage methods, it is possible to design a basic power system of all-electric hybrid ship based on fuel cell.

Keywords: Fuel Cell, All-Electric Ship, Hydrogen, Design Flowchart

1. Introduction

Surface vessels are generally vessels with a complex and dense power system and with high-power engines and advanced technologies. These types of vessels are equipped with complex sensors, equipment, and telecommunication systems and require an integrated power system with high reliability and redundancy.

From the point of view of owners and operators of surface vessels, fuel cost is a big concern, because most of them still use diesel systems. The energy efficiency of the diesel system at the low load level decreases, and in order to solve this problem, some diesel generators can be turned off, in which case the cost of turning off and restarting should be considered. An effective solution is to replace their fuel with hydrogen fuel and develop clean fuel cell technology.

The use of hydrogen energy in various areas of transportation, especially electric vehicles equipped with fuel cells, has developed significantly in recent years, and the continuation of this increasing trend is largely dependent on the decreasing cost of hydrogen production from renewable energy sources.

The first use of a fuel cell in the air-independent propulsion system was in the submarine U1 class 205 of Germany in 1980, in which an alkaline fuel cell was used [1].

In 2009, a combined system of 330 kWh fuel cell and 450 kWh battery was installed on the Viking Lady to power the propulsion system. This surface float is actually the first fuel cell-based surface float in the world. In 2015, an all-electric passenger ship was launched in Norway. This ship was equipped with a 1 MW battery bank, which is capable of carrying 120 cars and 360 passengers in a half-hour trip.

The first use of fuel cells in passenger vessels was used as a power supply for the propulsion system in the Alsterwasser vessel. The most important challenge in the development of fuel cells in surface vessels is hydrogen storage and its distribution.

Among the different types of fuel cells, PEM fuel cells are more popular due to their high power density, system simplicity, and technology maturity.

Various methods of hydrogen production from renewable energy sources are presented [2].

In this article, a conceptual design process of an all-electric hybrid surface float based on a PEMFC is proposed. All design factors of a hybrid energy system based on a PEMFC are presented. A case study of a conceptual design of a surface floating fuel cell, to show the practical aspects of the proposed design process, has been carried out and its results have been analyzed.

2. Feasibility studies of using an FC in an AES

To design the vessels, the following requirements must be met at a higher level [3]:

• Performance with proper energy efficiency
• Low noise
• Low infrared effect
• Uninterrupted supply of goods
• Low pollution

The advantages of using a fuel cell and attracting global attention in its use in various applications have caused various companies to be active in the design and development of its construction. The most important of these companies are Hyundai, Doosan, Nedstack Fuel Cell, Ballard, Horizon, Nuvera, Hydrogenics, Power Cell, etc.

The purchase and availability of fuel for all energy sources and converters is a very important category that requires strategic management. In the field of fuel supply, higher efficiency will be achieved when high-purity hydrogen is used. Hydrogen can be stored in two forms: compressed gaseous hydrogen and liquid hydrogen in cryogenic tanks. Hydrogen has a density of 0.09 kg/m3 at a pressure of one bar and a temperature of 0 degrees Celsius.

Hydrogen charging pressure in the world is usually done at a pressure of 350 to 700 bar. Cryogenic storage is one of the advanced methods for storing hydrogen in liquid form, which has the ability to store more hydrogen than in gaseous form. One of the hydrogen storage methods is the use of metal materials and powders that have the ability to store and release hydrogen. Some of these metallic items are $LiBH_4$, $NaAlH_4$, $LiAH_4$, etc. Hydrogen tanks with this storage technology are called metal hydride tanks.

3. Designing an AES based on PEMFC

To determine the appropriate power system of an AES based on a PEMFC, the proposed flowchart, which is shown in Figure 1, can be used. First of all, the technical and operational information of the vessel should be specified.

In the next step, the voltage level of the float power system is determined. If the power change rate is high, it is recommended to use hybrid sources. The combination of fuel cell with battery and combination of FC/battery/renewable/diesel generator provides various options.

A common storage device used in FC-based hybrid energy systems is a battery. Different types of batteries are used in hybrid fuel cell systems, which, of course, due to technological progress and the premium features of the lithium battery family, in recent years, hybrid PEMFC/Li BES have developed significantly in various applications. In PEMFC/Li BES hybrid systems, the PEMFC may be the main power source and the battery may be the auxiliary source or vice versa. In electric transportation applications, the auxiliary source is usually considered a range extender. The ratio of participation of fuel cell and battery in providing the load is also calculated by the degree of hybridization of the system [4].

In the conditions where the fuel reforming technology is available, depending on the capacity and flow of hydrogen produced by the reformer system and the characteristics of the floating fuel storage tanks, the maximum capacity of the FC can be easily calculated. The pressure of hydrogen produced by the reformer is generally in the working pressure range of the FC or higher. A common fuel reformer that is used in surface vessels is a steam reformer. One of the important challenges related to the reformer is the purity level of the hydrogen. The standard for the purity of hydrogen gas is the ISO14687 standard.

Hydrogen fuel stored in tanks is used when reforming technology is not available. Depending on the type of hydrogen, gaseous or liquid, and the working pressure and temperature, a specific mass of hydrogen can be stored in a known dimension. The more the hydrogen fuel storage source has the ability to operate at higher pressure and lower temperature, the more mass of hydrogen can be stored. Therefore, according to the available space in the vessel and the temperature and pressure levels of hydrogen fuel, the obtained energy from hydrogen can be determined.

In the next step, it is necessary to determine the proportion of other energy sources. Depending on the percentage of the FC capacity to the total power capacity of the vessel, the rest of the power must be provided by other sources. The rate of changes in the power consumption of loads and available dimensions are two important factors in determining the capacity of hybrid resources. After extracting the appropriate combination of hybrid energy sources, the appropriate topology of the elements of the vessel power system should be determined.

In the final step, technical studies should be carried out to ensure the performance of the surface floating power system in different surface floating maneuvering scenarios.

4. A case study: 200 kW PEMFC in a surface vessel

According to the approach of designing the hybrid FC power system and based on available commercial models, a 200 kW PEMFC module from PowerCell company (PowerCellution Marine System 200) is selected to equip surface vessels.

In addition to the FC power density, the load factor of the surface vessel power system should be considered. The energy consumption of a vessel depends on the mission of the vessel.

The load factor for vessels varies between 0.45 and 0.6 depending on their dimensions and mission. The required electricity energy for this case study with a maximum power of 200 kW and load factor of 0.6 and a round trip of 15 hours, is calculated to 1800 kWh.

One of the most important challenges in this field is the high cost of FC. Due to the volume of production and the improvement of technology, the cost of the FC is decreasing.

The total cost of an FC depends on the type and mechanism of the FC, power level, working environmental conditions, reliability level, and the purity level of required hydrogen. In general, the total

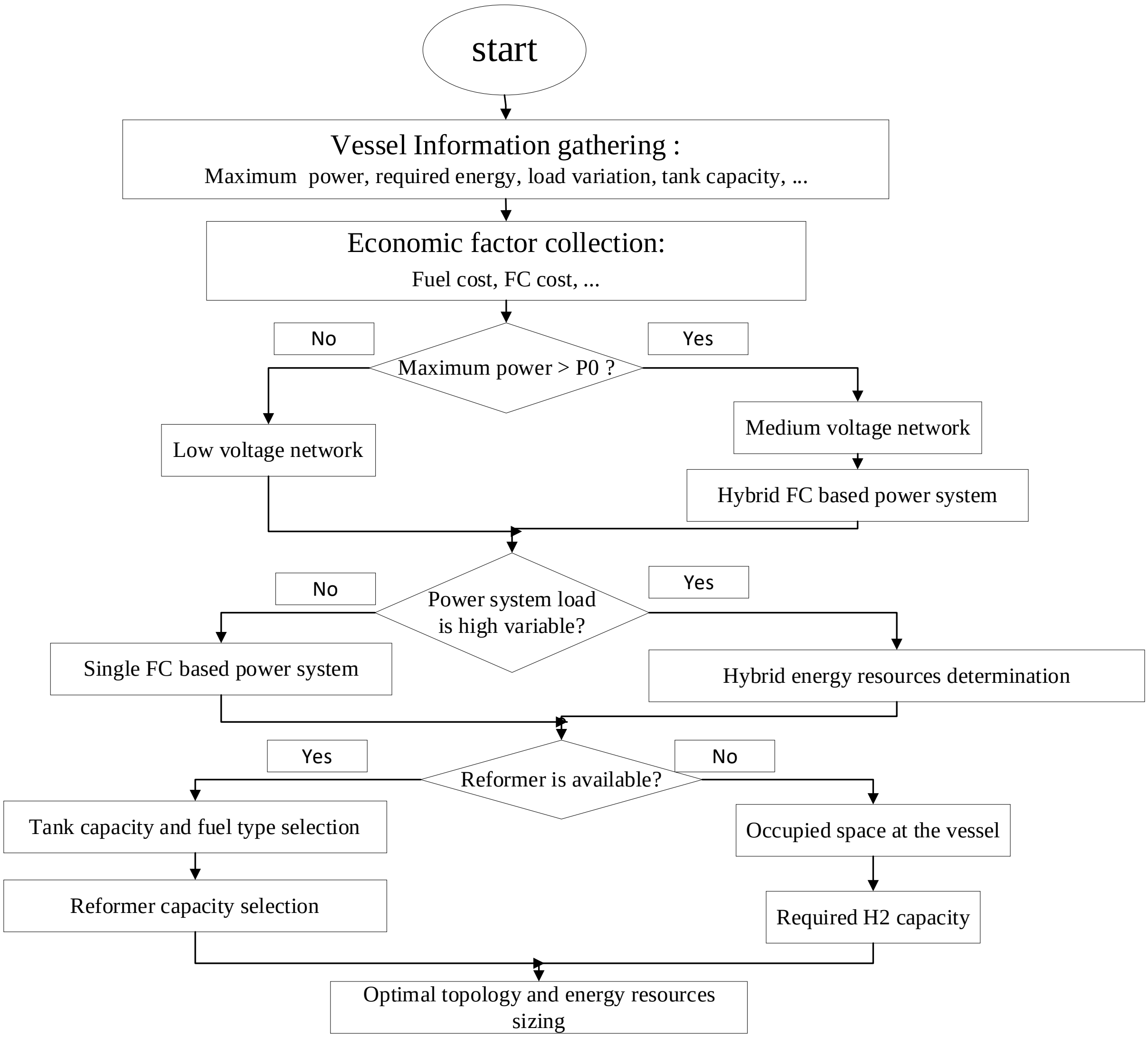

Figure 1. The basic proposed design flowchart

Table 1. Technology Comparison

Technology	Output energy (kWh)	Efficiency (%)	Required fuel (Mj)	Fuel (kg)	Fuel cost ($/kg)	Total cost ($)	Sea endurance (hr)	Noise level (db)
HyPM HD 180	2400	55	15709	130 H_2	2.12 based on china fuel production	39.5	2.15	40
					16 based on USA fuel production	52		
					32 based on 40 Lit cyl.	104		
Diesel generator		40	21600	517	0.925	14.3	1.1	90

cost of providing a fuel cell is between 120 and 800 dollars per kilowatt [5]. The fuel cells used in surface vessels usually have higher power and special operating conditions and are designed and produced in a customized manner. So, for a 200 kW PEM FC, we expect a cost of around $160,000.

According to the hydrogen storage pressure of 300 bar about 6.4 m^3 of hydrogen gas is needed for this case study.

To investigate and compare two different technologies, FC and diesel generators, the energy efficiency, fuel cost, duration of staying in water, and noise level are considered. According to Table 1, the PEMFC will consume the fuel for a longer time due to its higher efficiency, and as a result, it will remain at sea for a longer period.

It can be seen that the noise produced by the FC is much lower than that of the diesel generator and within the permissible range of sound noise.

5. Conclusion

One of the most important technical and economic challenges of FC development is the high cost of FC and its accessories and hydrogen fuel. The price of an FC varies depending on the type of capacity and input fuel. Another technical limitation in providing hydrogen fuel is its distribution and storage. If the number of refueling and charging stations in the distribution network increases, it is expected that the process of equipping surface vessels with fuel cells will increase. Hydrogen fuel storage is usually done in high-pressure and low-temperature or cryogenic tanks.

The power level for FC application depends on the combination and presence of other electric power resources, available FC technology hydrogen storage tank technology, and its charging. In countries that have cryogenic technology, it is possible to develop surface vessels equipped with FCs with higher power capacity.

In Iran, due to the high cost of hydrogen fuel, the lack of hydrogen fuel distribution infrastructure, and the limitation in the capacity of storage tanks and charging process at low pressure, hydrogen fuel has a lower position than diesel generators. Considering the advanced FC technology and related processes on the one hand and the existence of research potentials in the country and the abundance of hydrocarbon fuels as the main source of hydrogen fuel on the other hand, it is necessary to conduct extensive research in this field at first.

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