

A novel stand-alone proton battery-based power supply system for marine ships

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The extensive use of fossil fuels have resulted in the extinction of the world fossil reservoirs, and brought tremendous change in earth's environment. One such activity is powering marine ships from conventional fossil fuels that contribute towards pollution. Solar energy has potential to address this concern. However, solar energy being intermittent in nature is storage dependant. Presently, lithium-based batteries are fulfilling the global need of energy storage which is self-discharging, highly expensive to recycle and emit fumes. To overcome such challenges, a novel proton-battery which works on the principle of unitized regenerative fuel cell is proposed in this paper along with conventional photovoltaic system suitable for marine ship power supply. The fabrication of an experimental set-up is disclosed. The obtained experimental results revealed the technical feasibility of the proposed system. The proposed system for marine ships could play a vital role catering this industry to contribute towards a sustainable future.

[Keywords: Fossil fuels, Green house gases, Lithium batteries, Marine ships, Photovoltaic system, Proton battery]

Introduction

The extensive use of fossil-based energy sources have not only pushed the world fossil reservoirs to near extinction but also brought tremendous and rapid change in earth's environment. Most of the human activities are fossil-fuel dependent which liberate green house gases (GHGs) when burnt. GHGs have led to drastic change in the environment like acid rain, global warming, depletion of ozone and climate change^{1,2}. Owing to the liberation of harmful green-house gases, mankind is left with no other choice but shift to renewable energy sources. Marine industry has been a major consumer of fossil fuel since its origin thereby, contributing directly/in-directly towards deterioration of global weather conditions³. Average total power requirement of a marine engine depends on the total resistance and usually fall in the range of 450-500 kW which is equivalent to 650 BHP. However, the brake power per engine for an average marine ship is 240-250 kW which is equivalent to 325 BHP. The specific fuel oil consumption (SFOC) of the marine ships range from 50-350 tons/day at corresponding speed ranging from 17-25 knots, respectively³⁻⁶. Burning of fossil-based fuel oil at such high rate contribute to environmental pollution to a great extend.

Solar energy and related conversion technologies being easily available are being exploited globally for electricity generation and meeting world energy

demands including marine industry^{7,8}. However, solar energy being not available round-the-clock is incapable of meeting the continuous supply demand of power and hence, is storage dependant. Till date lithium-based batteries are fulfilling the global need of energy storage which is self-discharging, highly expensive to recycle and also emit fumes. Apart from this, the earth is eventually being converted into a lithium dump due to zero recycling of lithium owing to the corresponding high cost⁹⁻¹². To overcome such challenges, a novel proton-battery is proposed in this paper along with conventional photovoltaic system suitable for marine power applications. An experimental stand-alone power supply system for marine ships is designed, fabricated and tested at laboratory level.

The proposed system consists of an ion-exchange battery which works on the principle of unitized regenerative fuel cell and an array of best available 3rd generation flexible solar cells and could be installed at nose of the ship as shown in Figure 1. The charging and discharging cycles were performed and reported in this work. The design of proton-battery is discussed and its feasible working with solar photovoltaic system is exploited and presented.

Materials and methods

The experimental set-up comprised of a proton battery, gas-collection cylinders, water reservoir, DC

power supply of 5 Amperes, and an electrical load. A proton battery is a single unit that could run as electrolyser to split water into H_2 and O_2 , and fuel cell to give electricity and water. It works on the principle of a reversible unitized regenerative fuel cell (URFC) which consists of various parts as shown in the exploded view in Figure 2. Figure 3 shows the actual picture of the experimental setup.

The bi-polar end plates of the proton battery were fabricated from SS316 to avoid any reaction with the dilute sulphuric acid that act as a proton conductor within the activated carbon electrode. These plates are engraved with flow channels of serpentine design to accommodate the gas flow in/out from the cell. The H_2O , H_2 , and O_2 inlet/outlet connections are connected to the respective collection cylinders as shown in Figure 1. Gas diffusion layers (GDL) were employed to arrest moisture/impurities from the gas flows through the flow channels before entering the collection cylinders. A membrane-electrode-assembly (MEA) forms a heart of the cell that regulates the entire performance of the cell. MEA is made by hot-pressing two separate catalyst loadings on each side of a Nafion-117 membrane



Fig. 1 — A typical marine ship equipped with a novel stand-alone proton battery-based power supply system

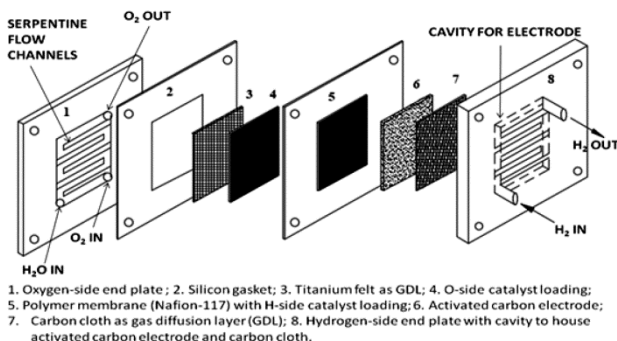


Fig. 2 — Exploded view of a novel proton battery with an integrated activated carbon electrode for hydrogen storage.

(chemically known as Perfluorosulfonic Acid), which is a polymer that could conduct protons but, not electrons through it and that is why the name, Polymer Electrolyte Membrane Fuel Cell (PEMFC).

Unlike, a normal PEMFC that works on the supply of O_2 and H_2 , the presented modified URFC that is named as proton battery in this manuscript is a combination of both electrolyser and fuel cell. This single unit could be charged with hydrogen protons that are stored in an integrated porous electrode, and later come out to combine with O_2 to form pure water (De-mineralized water). Water is fed continuously in electrolyser mode (E-mode shown in Figure 4) to the cell and water dissociation initiates under the influence

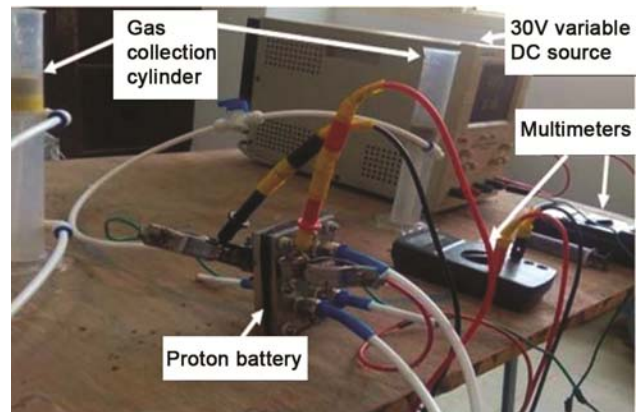


Fig. 3 — Actual picture of the experimental set-up

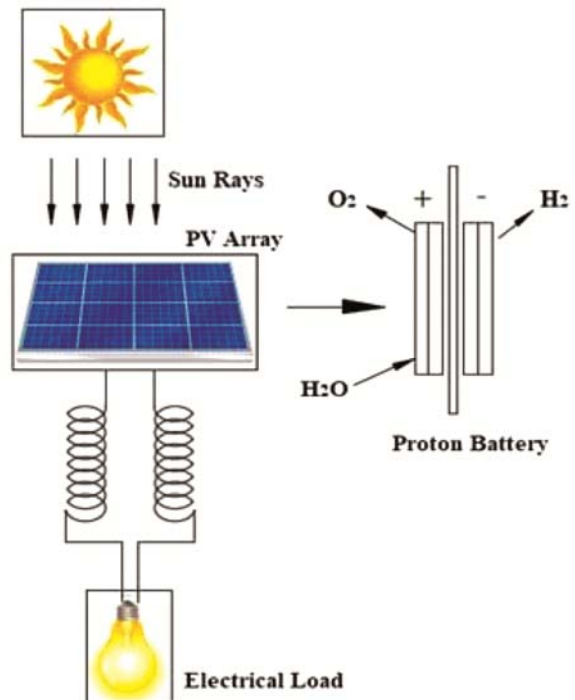


Fig. 4 — Charging circuit of a proton battery

of the applied electric potential across the cell and the catalysts (Iridium Ruthenium Oxide and Platinum). The produced components of water dissociation reaction are O_2 , H^+ (protons) and e^- (electrons). The produced O_2 is allowed to move out of the cell and is collected in the designated collection cylinder, H^+ passes through the polymer membrane and move towards cathode, and e^- travels through the external electric circuit where they form weak chemical bond with the storage material (activated carbon in this case) or get adsorbed physically under the action of Van-der-Walls forces. Excess ions form H_2 that move out of the cell from the hydrogen (cathode) side and collected. The rapid increase in H_2 liberation indicates that the charging is complete and hydrogen storage is full and operation is stopped thereafter. The hydrogen production rate would entirely depend upon the catalyst loading density and voltage applied across the cell to dissociate water.

For discharging, the cell is subjected to an electrical load and H_2 cylinder is cut-off from the system thereby leaving only the stored hydrogen in activated carbon electrode to be the powering source. The polarities are reversed in this case, as shown in Figure 5, so that the stored hydrogen atoms could come out of the storage under the influence of the established potential difference. The hydrogen catalyst layer made from Platinum black initiates the hydrogen reduction reaction (HRR) and splits hydrogen atom back into H^+ and e^- . The hydrogen protons passes back through the

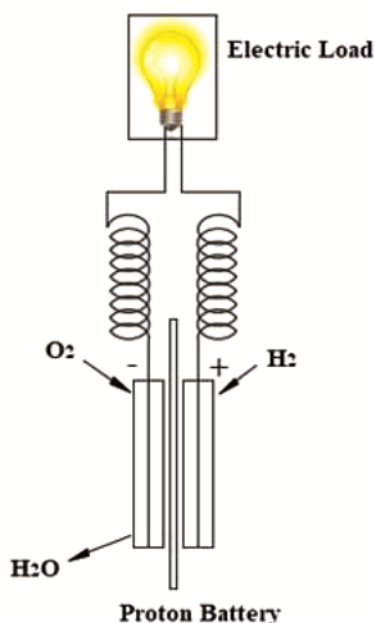


Fig. 5 — Discharging circuit of a proton battery

polymer membrane towards cathode (oxygen side in this case) and e^- follows the external circuit fulfilling the requirement of the applied electrical load before reaching to the cathode where the produced O_2 is fed back to reform pure water, that is collected.

It is an attempt to check the technical feasibility of a proton battery-based stand alone system; the objective was to demonstrate that hydrogen ions could go in and out of the storage electrode. The fabricated setup has an active area of 6.25 cm^2 with bi-polar end plates of 25 cm^2 capable of generating 0.7 W power. The entire setup payload is around 1.2 kg . This dead-weight could be brought down by replacing SS316 end plates. The voltage and power level of the setup can be increased by connecting various units of single cell in series/parallel configuration.

Results and Discussions

The developed experimental set-up was used in testing the proposed system which could easily be implemented by scaling-up for specific marine ships. The primary powering source for marine ships could be array(s) of typical solar photo-voltaic cells capable of generating electricity directly from sunlight. Simultaneously the same PVs could use the excess electricity (when demand is less than production) to charge proton battery which later could meet the supply demand during shading period. The testing of a prototype at lab scale was performed and charging-discharging cycles are shown graphically in Figures 6, 7 and 8, respectively.

In the E-mode or during charging cycle of the proton battery the cut-in-voltage was observed to be 1.5 V which is an acceptable figure when compared to a typical PEM electrolyser. The current was increased

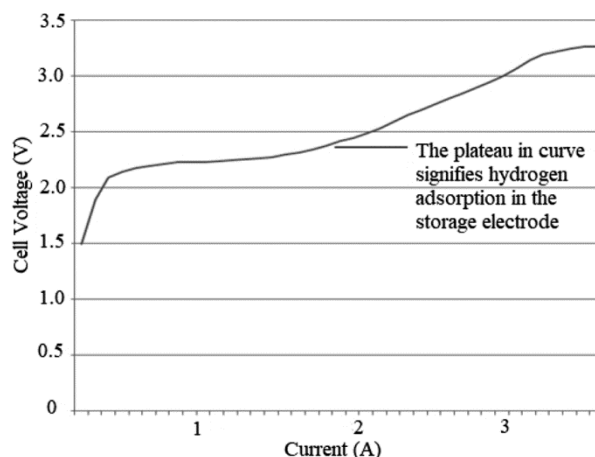


Fig. 6 — Voltage vs Current curve of charging cycle of the proton battery

linearly in equal increments and the corresponding voltage was recorded. The voltage behavior was observed to be fairly linear as shown in Figure 6 until 2.2 V where it remained stable for few current increments followed by a slight drop across 1.2 A to 2.5 A and resuming the linear behavior thereafter resulting in formation of a plateau in the V-I curve. This plateau indicated the adsorption of hydrogen in activated carbon electrode¹³. The charging was performed for around 4 hours before a rapid liberation of H₂ was observed indicating that the storage is full and the charging operation was stopped thereafter.

The discharging was performed by connecting the cell to an electric load with variable resistance and drawing current from the cell. It is to be noted that the H₂ collection cylinder was disconnected from the cell leaving the stored hydrogen in activated carbon electrode as the only powering source. In FC-mode or discharging mode, the polarities across the cell were reversed i.e. oxygen side as cathode and hydrogen

side as anode. The proton battery managed to deliver 45 mA of current as shown in a current vs time graph in Figure 6. The battery managed to maintain the current in the range of 35 mA to 40 mA for the period of 1.6 hours. When most of the stored hydrogen got used up, the cell failed to maintain the desired current to meet the demand and hence the current dropped to 0.35 mA and ceased thereafter. When no current and voltage was observed the operation was stopped.

In FC-mode or discharging of the battery, voltage curve also showed the linear behavior and dropped gradually across 1.75 hours as shown in the Figure 7 below. The maximum voltage recorded was 2.5 V that dropped suddenly to 1.7 V when electrical load was applied. A slow and gradual drop in voltage was observed thereafter for 1.3 hours indicating that the generated power from the stored hydrogen and supplied oxygen is driving the electrical load. When the power was not enough or when the stored energy in the form of hydrogen was fully consumed, the cell failed to maintain the desired current and voltage leading to an open-cell voltage of 0.1 V as shown in Figure 7.

Conclusion and recommendations

The proposed novel stand-alone power system was designed, fabricated and tested at lab scale with applications in the marine industry. The fabricated proton battery with an integrated activated-carbon electrode for hydrogen storage was tested by charging and discharging. The charging curves revealed that the battery was able to split water into H₂ and O₂, whereas, the discharging showed that the battery was able to store energy in form of hydrogen and generate electricity by combining with O₂ to reform water. It is clearly visible from the obtained results that hydrogen ions were able to flow across the cell and move in-out from the activated carbon storage electrode. The achieved results have clearly proven the technical feasibility of an experimental proton battery that could be implemented on marine ships in conjunction to solar PV arrays for power needs and energy storage. The overall system results have shown the superiority in renewable energy harnessing when compared to the conventional systems with lithium battery that is toxic, emit fumes, and is hazardous to the environment. The presented new concept would also discourage the use of hazardous lithium that currently not being recycled due to high cost and eventually would save the planet from being converted into a lithium dump. This would definitely

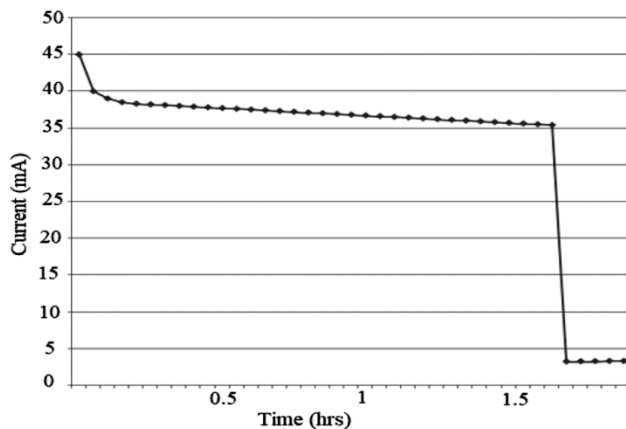


Fig. 7 — Current vs Time curve of discharging cycle of the proton battery

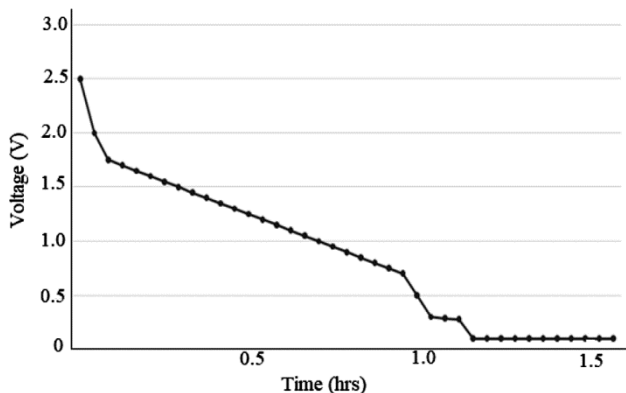


Fig. 8 — Voltage vs Time curve of discharging cycle of the Proton Battery

be a big leap forward towards conversion of marine industry in a sustainable industry and ultimate establishment of a sustainable environment.

Conflict of the interest

All the authors of the presented manuscript have contributed originally and equally in the presented research work and therefore, declare no conflict of the interest.

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