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Investigation of Solar-Fuel Cell Hybrid System Technology in Medium-Sized Electric Power Propelled Boat for Central East India

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Abstract
In the focus on green and clean transportation, for this exploration of different alternative energy sources in the domain of electrical drive systems, solar energy plays the most significant role. The massive solar PV panel with battery operation systems has an efficiency limit of 12 to 18 percent. In addition, electric grid power is required to run the entire system. The research study focuses on hybrid electric boats using the solar-fuel cell for sustainable design, construction, and system testing for water bodies present in the central-east India region. The newly developed hybrid power system is to be utilized to its maximum power extraction from solar energy. The overview results show that the optimized hybrid solar power system can reduce CO_2 emissions and save 3.84 per cent of the electricity for the ship grid on an average of 5.4 kWh per square meter per day of solar radiation.
Keywords: Electric Boat; Hybrid System; PV Module; Solar Power

1. Introduction

In recent years, scientists and researchers have already been attempting to develop alternative modes of transport systems that do not produce pollution and thus do not harm the Earth's ecosystem. Many initiatives have also been made to use clean and sustainable energy sources, but they are inefficient in meeting the power needs of today's busy and fast-paced world. Since the Sun is the ultimate source of energy that nature has bestowed upon the Earth [1], we must maximize its use and eliminate the use of fossil fuels to generate energy [2]. With the focus on the reduction of carbon footprint and carbon emission, the green energy generation system is highly impactful [3].

Green energy is critical for reducing carbon emissions; nevertheless, a handful of analyses have examined the overall influence of sustainable power on carbon emissions [4]. These studies have primarily focused on two issues: the influence of renewable energy consumption and the impact of renewable energy regulations on carbon footprints. The novelty of the present study in the solar-fuel cell hybrid system of an electric propulsion boat is its high energy efficiency and optimization by design and construction. And fewer carbon emissions in terms of carbon footprints.

2. Literature Review & Objective

Researchers explain the latest trend of electrification for boat propulsion using photovoltaic systems and wind power [5]. Those cruising vessels use hybrid power (battery and generator) or battery with any one of the LNG, diesel, wind, or PV as another source of energy. The challenge for battery technology improvement is to tackle limiting battery mileage, as well as battery recharge options. Other researchers [6] have developed hybrid fuel-cell, diesel, and PV power systems to handle the primary and secondary power requirements of Dubai tourists. It's also demonstrated that their suggested design regarding dual power system is the most environmentally beneficial. However, the power acclimatization method cannot be explained.

A hybrid renewable energy source for an electric powered boat contains photovoltaic solar panels with Maximum Power Point Tracking technology, a hydrogen storage vessel, a diesel engine connected with a synchronous machine [7] [8] and a polymer electrolyte membrane (PEM) fuel cell which has a water electrolyzers to make hydrogen. A battery management system (BMS) regulates the flow of fuel in a fuel cell based on charge state of the battery. It was reported that the tests were conducted in different weather conditions while maintaining the boat speed constant. The effect of fluctuating speed has not been considered.

A significant amount of research is required in this area, with a reliance on making the best use of natural sources for energy solutions. The imbalance among the supply and demand of electrical power in India is deepening day by day [9]. As a result, load shedding has become the last resort for maintaining the stability of the power system. In the Indian scenario, focused research is required to develop a hybrid power system using fuel cells and PV cells. In the present work, proton exchange membrane fuel cells (PEMFC), photovoltaic cells (PV), and power acclimatizing units (PAU) are combined to create diverse system architectures. Since it tries to maximize the use of a renewable energy source, the system is aimed to be an eco-friendly approach.

Auxiliary electricity is required during periods of low solar radiation. A fuel cell is used to keep the precision at the same level as the conventional system while reducing the overall system's environmental impact. When the PV energy is insufficient, the fuel cell consumes gases produced by an electrolyzer to fit specific load requirements, acting as an emergency backup powering unit.

In the present investigation, the solar fuel-cell hybrid system has been tested and the key objectives are to design and develop the hybrid system for water bodies of central-east India.

3. Solar Radiation

The direction of the sun's beams varies due to scattering interaction [10]. As a result, dispersed radiation is redistributed in all directions at random. Diffuse radiation is the term for dispersed radiation [11].

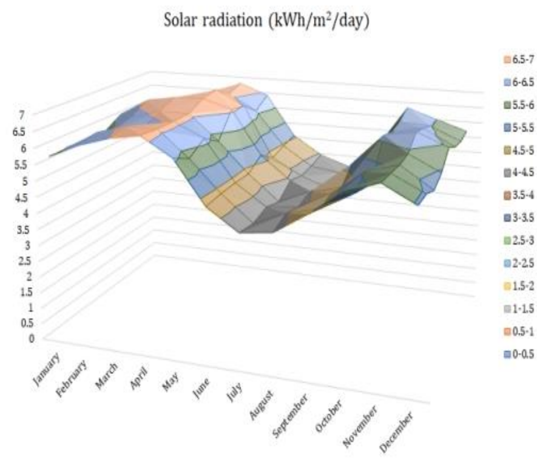

FIGURE 1. Measured solar radiation level of central-east India

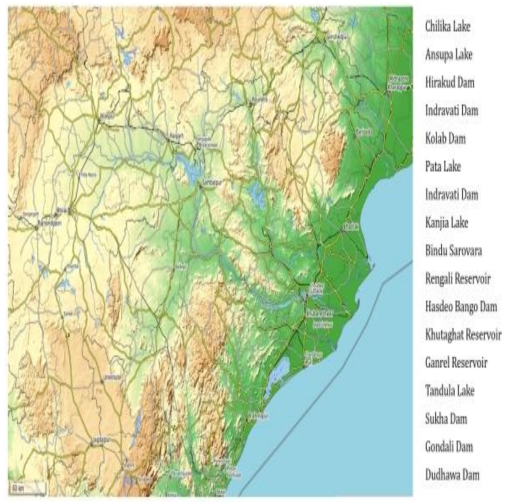

FIGURE 2.Geographical Map Location With Water Bodies In Central-East India (Source: Google Earth Software)

Direct radiation, also known as beam radiation, is radiation that is not affected by absorption or scattering but instead hits the earth's surface directly. When radiation reaches the Earth's surface, part of it is reflected by the ground and other things on the ground (direct or diffuse). Albedo radiation is the name given to this reflected component [12]. As a result, the total radiation reaching a particular place on the earth's surface is equal to the sum of diffuse, direct, and albedo radiation. Solar radiation in kWh per square meter per day measured in central-east India (Odisha and Chhattisgarh) is shown in figure 1. The geographical location of huge water bodies in Odisha and Chhattisgarh is shown in Figure 2.

4. System Design

4.1. Design

The boat was developed and produced using modern composite process techniques and Fibre-reinforced plastic (FRP) composite materials. For inland water operations, it is both safe and effective. The hull structure is built of FRP and has appropriate stringers. All of the components, including glass fiber, polyester resin, and wood, are of the highest grade. The craftsmanship and finish are of the highest quality and meet the customer's expectations. The deck is constructed of FRP.

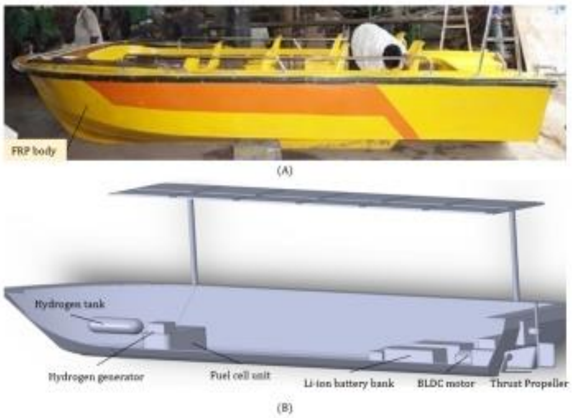

FIGURE 3. (A) FRP Boat bodies (B) CAD layout of inner components

To produce the desired impact, proper supports, stiffeners, and other materials are given. The steel fittings (including fasteners) wherever necessary, are galvanized iron or powder-coated steel with nice flat surfaces. As needed, buoyancy bricks are mounted at the bottom of the vessel. The boat is an open boat with benches made of FRP. An insulated fish hold has been placed before the entry of water into the propeller. The boat's flooring is composed of plywood sandwiched between two layers of FRP. The length and width of the boat are 5.84 m and 4.28 m respectively. It is of 12-seat capacity having a gross weight of 1200 kg. The depth of the boat is 0.4 m and its draft height is 0.038 m. In figure 3(A) FRP body of the boat and in figure 3 (B), the inner key components of the subsystem are shown.

4.2. Hybrid and Drive System

The brushless DC (BLDC) motor has been chosen as the main drive propulsion for the boat. It is more efficient, easily speed controlled, and requires less maintenance than respect to conventional AC or DC permanent magnet motors [13].

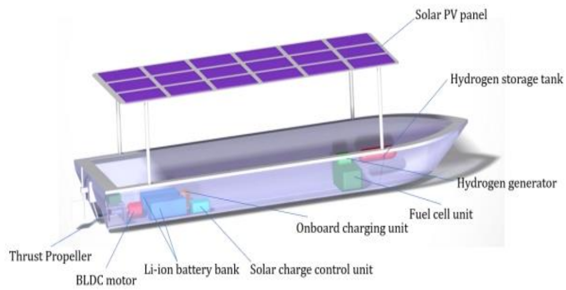

Figure 4. 3d Cad Schematic Diagram Of Solar-Fuel Cell Hybrid Boat

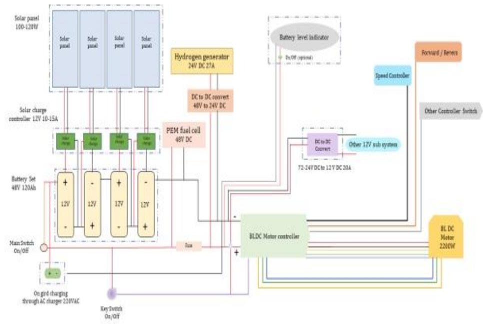

FIGURE 5. 3D CAD schematic diagram of solar-fuel cell hybrid boat

The 3-D schematic diagram is shown in figure 4. The solar photovoltaic panel on the top of the roof supplies DC electricity to the charge controller to charge the Li-ion battery bank with a maximum power point tracking (MPPT) system. The hydrogen storage gas tank with a hydrogen generator is shown with the PEM fuel cell system. The water in the reserve distilled water tank is used for the generation of hydrogen gas. This gas is stored in the hydrogen tank which is used for the generation of DC electricity during an overloaded condition or power shortage of lithium-ion battery bank or low solar radiation. The electrical layout diagram is shown in Figure 5.

4.3. Specification of a hydrogen generator

As a hydrogen producer, electrolyzers of the Polymer Electrolyte Membrane (PEM) type are used. The electrolyte is taken as a solid specialty plastic material. The hydrogen generator sub-components are depicted in figure 6. At the anode, the electrochemical reaction of water produces oxygen and hydrogen ions (positive). These hydrogen ions pass through the membrane and produce hydrogen gas on the cathode side.

Experimental hydrogen flux of a maximum of 3.4 grams per square meter per hour is found during the test and the result is shown in Figure 7. The variation of conversion coefficient with time is shown in figure 8. The maximum value of the conversion coefficient percentage is observed to be 16.2.

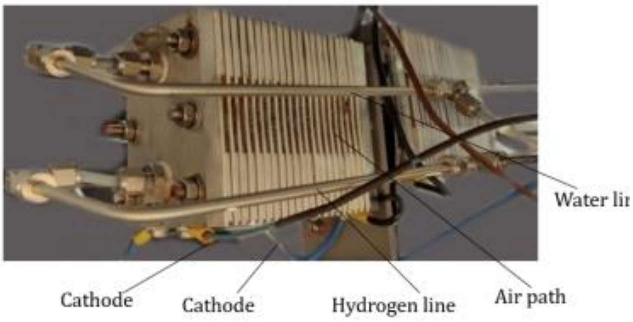

FIGURE 6. Hydrogen generator

The hydrogen ions preferentially migrate across the PEM to the cathode as electrons flow through an external connection. Hydrogen ions combine with electrons from the external circuit at the cathode to generate hydrogen gas.

$$Anode\ Reaction:\ 2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$
$$Cathode\ Reaction:\ 4H^+ + 4e^- \rightarrow 2H_2$$

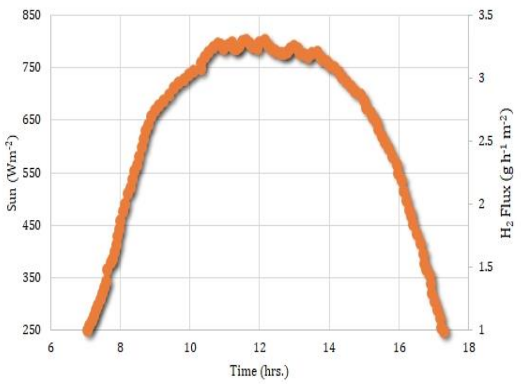

FIGURE 7. Variation of hydrogen flux with time

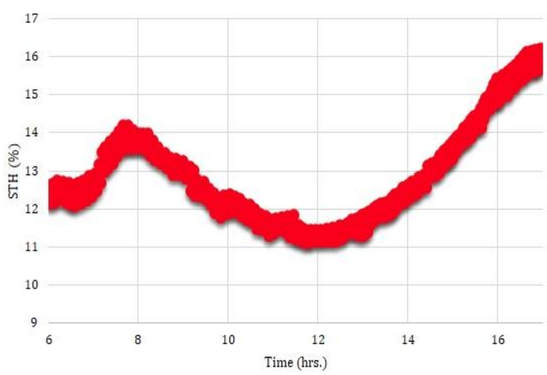

FIGURE 8. Variation of conversion coefficient with time

4.4. Technical Details of the solar fuel-cell Hybrid Boat

Motor specification:
Model: M2200 (Brushless Motor)
Max. output: 2200W/ 8.0 hp at 3000 rpm
Input voltage (48 V) with 50AH
Start system: On/off knob switch with BLDC motor controller
Power budget/Electrical power specification:
Motor controller: 2200 W, 48 V, 50A
Battery: 120 AH
Charging system: Solar & electric with PEM fuel cell (dual charging system)
Hydrogen generator: Voltage: 24 V, Wattage: 670, Current: 27 A
Solar panel unit specification: Voltage: 12 V, Wattage: 100, Current: 6 A
PEM fuel cell unit specification: Voltage: 48 V, Wattage: 400, Hydrogen flow: 400 L/hr.

5. Results And Discussion

Testing of solar fuel cell hybrid boat was carried out near Kalinga Institute of Social Sciences Deemed to be University still water pond (location: 20°21'53.0" N 85°48'51.2" E). Testing of vessels was done with battery operating mode at 10 per cent discharge of the battery. The graphical results obtained are shown in Figure 9. The overlapping of the speed of vessels with propeller speed indicates the slip of vessels due to acceleration or moment of inertia [14].

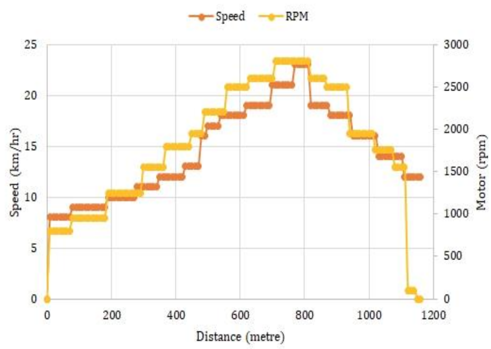

FIGURE 9. Test run with only battery power at fully loaded condition

In this mode battery is in fully charged condition, the solar PV module is in an active state, the hydrogen generator is active and the

PEM fuel cell powering system is active. Testing time is fixed at 10 minutes of running the system. The graphical results obtained are shown in figure 10. The obtained result indicates the improvement in drive pattern concerning single powering mode.

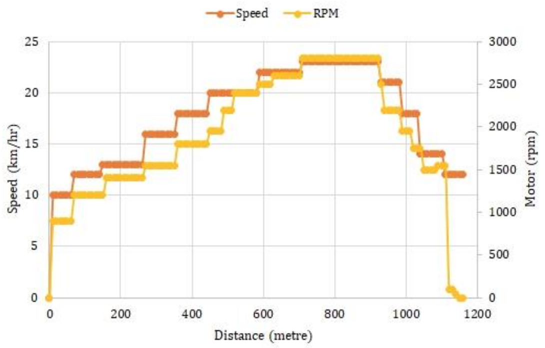

FIGURE 10. Test run on hybrid mode at fully loaded condition

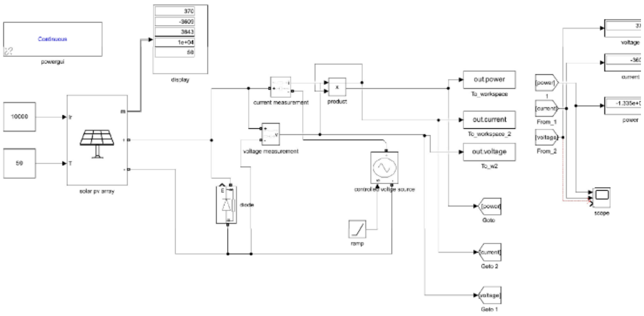

FIGURE 11. Electrical Layout of the system

This electrical layout diagram in Fig 11 shows the physical connections within our system. The key components here include solar PV array, diode, voltage measurement, current measurement, display, ramp and current voltage source. Understanding this circuit will help us understand the experimental setup. A solar array is a series of solar panels which are interconnected and it functions by converting solar energy into electricity. Current and voltage measurement systems are used for ensuring the safety of electrical circuits whereas diodes are used for rectification.

In simulating this layout, we obtained the following graph depicting the product, current measurement and voltage measurement as show in Figure 12.

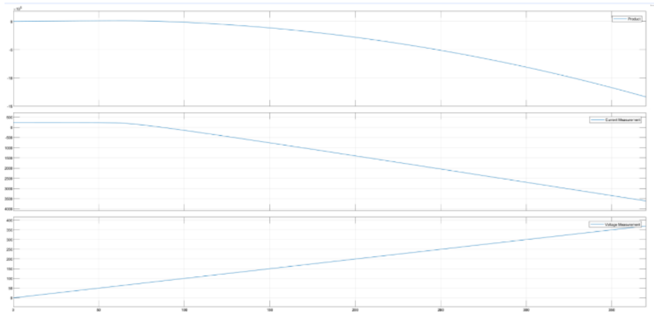

Figure 12. Simulation Graph Of The Electrical Layout

The graph includes ports for three inputs with a sample time of –1 initially. The input processing has been taken as columns as channels (frame-based). The voltage measurement graph goes from 0 to the range of 350-400. The current measurement graph depicts a fall to the range of –3500 to – 4000. At last, the product graph shows a fall to the range of –10 to –15. representing the voltage across a component in an electrical circuit. There is a sharp increase in voltage at the beginning which shows a rapid change in the system. The voltage shown in Figure 13 fluctuation till 0.8 seconds and then gradually rises.

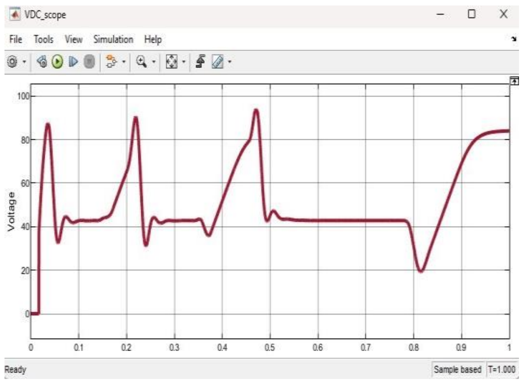

FIGURE 13. VDC scope

The mentioned graph has four input points. Starting from the top, the first graph represents a voltage signal that is subjected to sudden changes or steps. The fluctuations indicate noise or disturbances. Shown in Figure 14

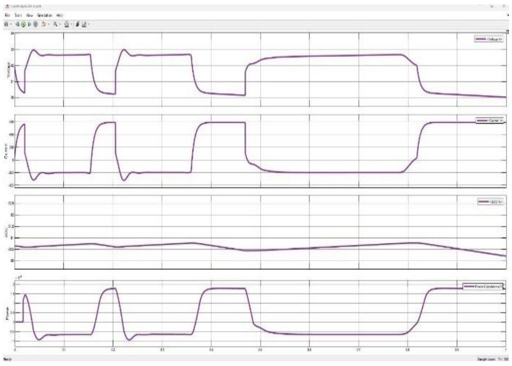

FIGURE 14. Supercapacitor Simulation graph

The second represents the current corresponding to the voltage in Graph 1. The peaks and troughs indicate a reactive component or a non-linear relationship between voltage and current. The third graph represents the state of charge of a battery. The gradual decrease shows that the system is being discharged, and the fluctuations indicate variations in load or charging/discharging conditions. The fourth graph represents the calculated power based on the voltage and current data. The peaks and troughs suggest variations in power consumption or generation.

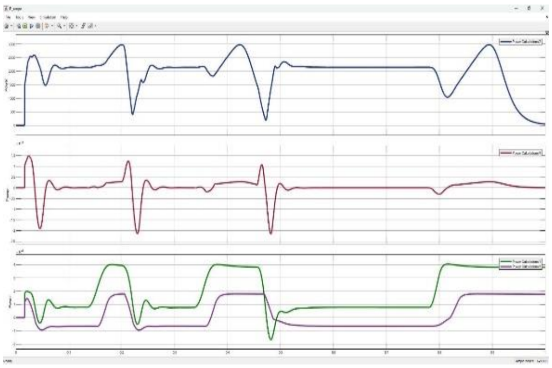

FIGURE 15. Power output recorded scope data

The above-mentioned graph in Figure 15 (top) represents the power demand or load on a system concerning time. The deviations from this graph indicate inefficiencies or losses in the power delivery process the following graph represents the power delivered to the system or load. The fluctuations and spikes indicate variations in consumption or disturbances. There are less fluctuations after 0.5 seconds. The last graph compares the actual power delivered to the system with a calculated or estimated value. The close match suggests that the calculation method is accurate.

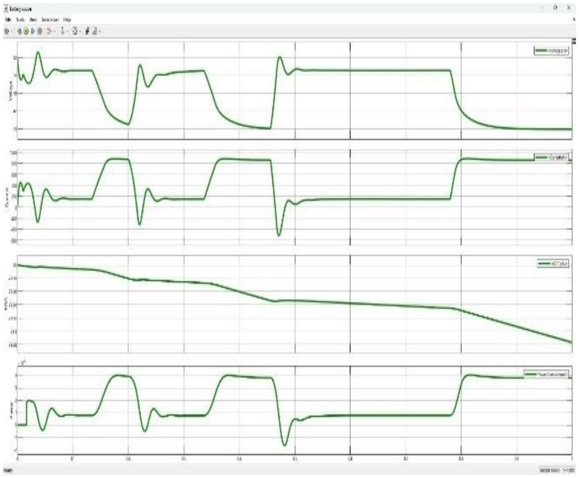

Figure 16. Battery Scope Output Data

Figure 16 represents a voltage signal that is subjected to sudden changes or steps. The fluctuations indicate noise or disturbances. There is a sudden decrease in the graph after reaching 0.8 seconds.

The following graph represents the current corresponding to the voltage in the first graph. The peaks and troughs indicate a reactive component or a non-linear relationship between voltage and current. The graph remains constant between the range of 0.6 and 0.8 seconds and then increases. The next graph represents the state of charge of a battery or energy storage system. The gradual decrease shows that the system is being discharged. There is a constant decrease in the graph. It touches the lowest point at 1 second. The last graph represents the calculated power based on the voltage and current data. The peaks and troughs depict variations in power consumption or generation. It remains constant between 0.5 to 0.8 seconds and then increases.

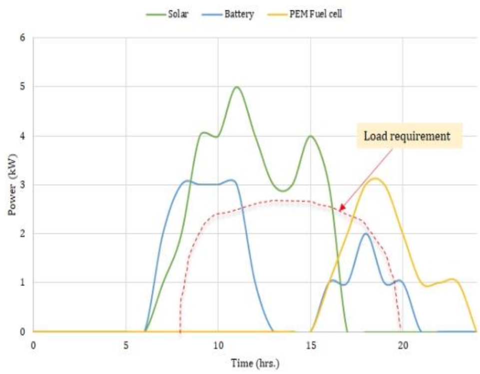

FIGURE 17. Power system performance curve

in hybrid mode

The overlapping of the speed of vessels with propeller speed indicates the slip due to acceleration or moment of inertia [14]. Figure 17 shows that source power is available for the whole day during the operation of a solar-fuel cell hybrid boat at full load conditions. These test results are generated by the vessel system control unit, which is connected to the battery management system (BMS) and motor controller. From the results, it is evident that the load requirement is less than the power source available during running conditions.

Conclusion

In the field of power through natural and renewable sources of energy, the development of a solar-fuel cell hybrid boat is a huge success. The boat is extremely quiet and has no negative impact on the environment. The trial of the boat went well and it was put to the test in front of the public. This boat has the potential to revolutionize the modes of transportation, fishing, tourism, and leisure activities. The designed vessel is most suitable for electric power-propelled boats for central-east India. Further studies for improving the efficiency of solar generating units utilizing an electric double-layer capacitor are going on.

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