Fuel Cell Based Future Power Supply for Remote Locations

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Abstract - This paper presents an analysis of a fuel cell-based hybrid power supply system. The primary objective of this research is to evaluate the feasibility of utilizing a fuel cell as a primary power source, which will be augmented by secondary sources such as batteries and solar panels for remote locations. The study investigates the technical and economic viability of the proposed hybrid system by considering various factors such as system efficiency, operating costs, and environmental impact. The report also discusses the design, implementation, and testing of a prototype hybrid power supply system, which utilizes a proton exchange membrane fuel cell (PEMFC) as the primary power source, and secondary sources include batteries and solar panels. In this report, we present a detailed analysis of fuel cell-based hybrid power supply system, including its working principle, components, and design considerations. We also discuss the potential advantages of fuel cell-based hybrid power supply system, such as high efficiency, zero emissions, and reliability.

***Key Words*:** Fuel cell, Hybrid power, Primary power source, Environmental impact, Zero emission, Reliability, Control Strategies

1. INTRODUCTION

The increasing demand for energy and the need for clean and sustainable power sources have led to the development of alternative energy technologies such as fuel cells. Fuel cells offer several advantages over traditional power generation systems, including high efficiency, low emissions, and quiet operation. The use of fuel cells as a primary power source for various applications has gained significant attention in recent years. However, fuel cells have limitations such as high cost, low durability, and the need for a continuous supply of fuel. These limitations can be addressed by using a hybrid power supply system that combines fuel cells with other power sources. Power supply systems are critical components of modern society, providing energy for various applications, from homes and offices to transportation and communication networks. Traditionally, these systems have relied on fossil fuels, such as coal and oil, which have significant environmental impacts, including greenhouse gas emissions and air pollution. Moreover, these fuels are finite resources, and their prices are subject to fluctuations and geopolitical tensions. To address these issues, alternative power sources have been developed, such as renewable energy technologies, including solar, wind, and hydroelectric power, and energy storage systems, such as batteries and capacitors.

2. HYBRID POWER SYSTEM

A hybrid power supply system is a type of power system that uses multiple sources of energy to generate electricity. The system combines renewable energy sources, such as solar and wind power, with traditional energy sources, such as fossil fuels or a fuel cell, to provide a reliable and sustainable source of power. The system typically includes a combination of energy storage devices, such as batteries or a fuel cell, and a power conditioning unit, such as an inverter or DC-DC converter, to ensure that the electricity generated is stable and compatible with the needs of the load. Due to fluctuation and interruption in power generated from renewable sources like wind, solar and hydro energy, considering a form of energy storage to backup power fluctuation is very important. Therefore, short-term and/or long-term energy storage, such as batteries or supercapacitors and/or hydrogen storage tanks, must be used to achieve a reliable and safe operation and to maintain the required power supply during power fluctuation, failure or high-power peak conditions. To achieve this, system components should be selected carefully and the control system must ensure that HPS components are well managed and monitored properly. This chapter will cover a brief description of the important hybrid system components used in this work:

- PV System.
- Fuel cell System.
- Batteries (or Ultra-capacitor)
- Power management system

A. PV System

A photovoltaic panel is an assembly of PV cells which are semi-conductor materials generating electricity from electro-magnetic radiation. When the source of radiation is the Sun, the PV cells are called solar cells. Most of the commercial solar panels are produced from silicon based solar cells. According to the quality of the cell, the energy conversion efficiency of the devices from solar power into direct current can be in the range of 5% to 20%. Because of the low energy conversion efficiencies and high cost of the solar panels, practical use of these devices are mostly limited to electricity generation in rural and remote areas, to telecommunication stations and to spacecrafts. In the following sub-sections, a mathematical model of solar panels will be introduced.

B. Fuel cell System

A fuel cell is an electrochemical device that converts the chemical energy of the fuel (hydrogen) into electrical energy. It is centred on a chemical reaction between the fuel and the oxidant (generally oxygen) to produce electricity where water and heat are by products. This conversion of the fuel into energy takes place without combustion. Generally, efficiency of the fuel cells ranges from 40-60% and can be improved to 80-90% in cogeneration applications. The waste heat produced by the lower temperature cells is undesirable since it

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cannot be used for any application and thus limits the efficiency of the system. The higher temperature fuel cells have higher efficiency since the heat produced can be used for heating purposes. The structure and the functioning of a fuel cell is similar to that of a battery except that the fuel can be continuously fed into the cell. The cell consists of two electrodes, anode (negative electrode) and cathode (positive electrode) separated by an electrolyte. Fuel is fed into the anode where electrochemical oxidation takes place and the oxidant is fed into the cathode where electrochemical reduction takes place to produce electric current and water is the primary product of the cell reaction.

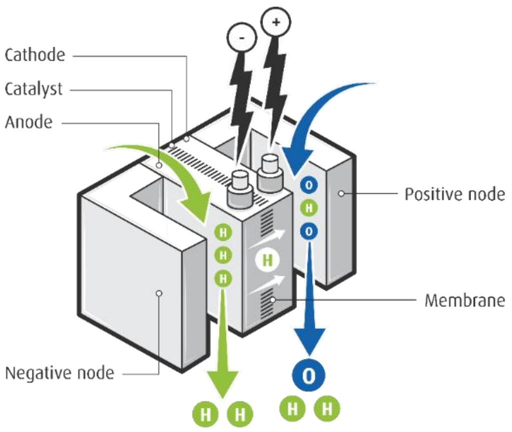

Fig -1: Electrolysis of Hydrogen molecules

Fig-1 shows the flows of reactants in a simplified fuel cell. The hydrogen which enters the anode side is broken into hydrogen ions and electrons with the help of the catalyst. In case of lower temperature cells like the PEMFC and the PAFC, the hydrogen ions move through the electrolyte and the electrons flow through the external circuit. The oxygen which enters through the cathode side combines with these hydrogen ions and electrons to form water as shown in the above figure. As this water is removed, more ions are passed through the electrolyte to continue the reaction which results in further power production.

C. Battery Energy Storage System

The battery energy storage system (BESS) comprises mainly of batteries, control and power conditioning system (C-PCS) and rest of plant. The rest of the plant is designed to provide good protection for batteries and C-PCS. The battery and C-PCS technologies are the major BESS components and each of these technologies is rapidly developing. The batteries are made of stacked cells where-in chemical energy is converted to electrical energy and vice versa. The desired battery voltage as well as current levels are obtained by electrically connecting the cells in series and parallel. The batteries are rated in terms of their energy and power capacities. Foremost of the battery types, the power and energy capacities are not independent and are fixed during the battery design.

D. Power management system

Power management is an important aspect of any hybrid power supply system, and this is especially true for fuel cell-based hybrid systems. Here are some key considerations for power management in such a system:

1) Optimization of power flow: A fuel cell-based hybrid power supply system typically consists of multiple power sources, such as fuel cells, batteries, and supercapacitors. To optimize the system's performance, power flow must be managed efficiently, with the power sources used in the most optimal manner to minimize energy waste.
2) Monitoring and control of fuel cell stack: The fuel cell stack is the heart of the fuel cell-based hybrid power supply system. It is crucial to monitor and control the stack to ensure optimal performance and longevity. This involves monitoring parameters such as temperature, humidity, pressure, and gas flow rates.
3) Battery management: In a fuel cell-based hybrid power supply system, batteries play a critical role in providing power during peak loads and in supporting the fuel cell during transient events. Battery management involves monitoring battery health, ensuring proper charging, and discharging to maximize battery life.
4) System-level control: A fuel cell-based hybrid power supply system consists of multiple components, including the fuel cell stack, batteries, and power electronics. System-level control involves coordinating these components to ensure that the system operates optimally and efficiently.
5) Fault detection and diagnostics: In any power supply system, faults can occur. It is essential to have a fault detection and diagnostic system in place to quickly identify and isolate faults, minimizing downtime and maximizing system reliability.

3. SYSTEM LAYOUT FC-FPS

The system layout for a fuel cell-based hybrid power supply system will depend on the specific requirements of the application. However, a general system layout could include the following components:

- **Fuel cell stack:** The fuel cell stack is the main component of the system that converts hydrogen and oxygen into electricity.
- **Battery pack:** The battery pack serves as a backup power source and provides additional power when needed. It also stores excess power generated by the fuel cell for later use.
- **Power conditioning unit:** The power conditioning unit is responsible for regulating the power output of the fuel cell and battery to meet the electrical requirements of the application.
- **DC-DC converter:** The DC-DC converter is used to step up or step down the voltage output of the system to match the requirements of the application.
- **Cooling system:** The cooling system is used to dissipate heat generated by the fuel cell and other components to prevent overheating and ensure optimal performance.
- **Control system:** The control system is responsible for monitoring and controlling the operation of the fuel cell and other components to ensure safe and efficient operation.
- **Hydrogen storage tank:** The hydrogen storage tank stores hydrogen fuel for use by the fuel cell.
- **Other components:** Depending on the specific requirements of the application, additional components

such as sensors, filters, and power management systems may be required.

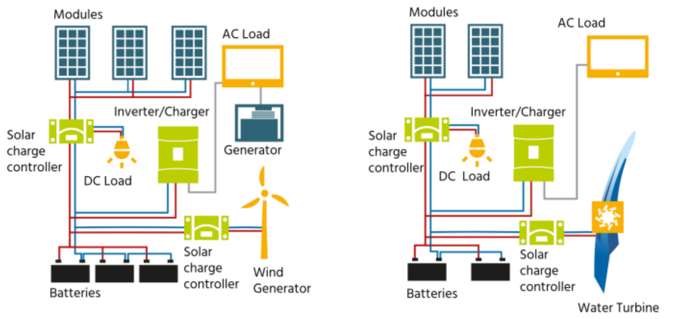

Fig -2: System Layout of FC-FPS

The layout of these components will depend on factors such as the size of the system, the power requirements of the application, and the specific components used. However, a typical layout may involve integrating the fuel cell stack, battery pack, and power conditioning unit into a single housing, with the other components located separately as needed.

3.1 Component Selection

When designing a fuel cell-based hybrid power supply system, selecting the right mechanical and electronic components is crucial to ensure safe, reliable, and efficient operation. A fuel cell-based system typically includes a fuel cell stack, fuel processor, battery pack, heat exchanger, mechanical supports and enclosures, cooling system, control and monitoring sensors, wiring, and cables. In this context, it is essential to carefully consider various factors such as power output, efficiency, durability, reliability, safety, and cost when selecting mechanical and electronic components. In this answer, we will delve deeper into the process of selecting mechanical and electronic components for a fuel cell-based hybrid power supply system.

3.1.1 Electronic Components

Selecting the right electronic components is a critical step in the design of a fuel cell-based hybrid power supply system. Designing a fuel cell-based hybrid power supply system requires careful consideration of both electronic component and cooling system selection. The electronic components used in such a system must be carefully chosen to ensure optimal performance, while the cooling system must be designed to manage the heat generated by these components. This is particularly important for fuel cell systems, which generate significant amounts of heat during operation. In this response, we will explore some of the key factors to consider when selecting electronic components and cooling systems for a fuel cell-based hybrid power supply system. The components used in such a system must be carefully chosen to ensure optimal performance, reliability, and efficiency. From power electronics to sensors and control systems, every component plays a crucial role in the system's overall performance.

The selection of electronic components for a fuel cell-based hybrid power supply system will depend on the specific requirements of the application. Here are some key factors to consider when selecting electronic components:

Sr. No.	ELECTRONIC UNITS	
1	DC-DC Converters (For FC)	Inverter Power Module Supply Unit (IPMS)
2	DC-DC Converter (For Solar)	IPMS Controller
3	DC-DC Converter (For Wind)	Selection and Manual Control Unit (SMCU)
4	Wind Charge Controller	AC Distribution Unit (ACDU)
5	Transformer	Display Unit (Remote + Local)
6	Inverter (DC-AC Converter)	
7	Power Supply Unit (PSU)	
8	Ethernet	

Sr. No.	COOLING UNITS	
1	Auxillary Tank	Battery Bank
2	Air filter	Ultracapacitor
3	Radiator units	Solar Controller Box
4	Condenser	Fuel cell Junction Box (FCJB)
5	Inlet Manifold	Fuel Cell
6	Outlet Manifold	Whether station
7		Lightning arrester
8		Display Units (Remote + Local)

Table -1: List of Electronic & Cooling system units

3.1.2 Mechanical Components

Mechanical component selection is a critical aspect of designing a fuel cell-based hybrid power supply system that is efficient, reliable, and safe. The mechanical components of a fuel cell-based system include the Solar frames, Mechanical lifting frame, Gas spring, Telescopic guide rail, Linear Mechanism Guide Rail, Mechanical Winch, Telescopic support and other components. When selecting mechanical components for a fuel cell-based system, it is essential to consider various factors such as material, strength, durability, weight, and cost to ensure the system performs optimally and meets the specific requirements of the application. In this answer, we will explore the process of selecting mechanical components for a fuel cell-based hybrid power supply system in more detail.

- **Solar Panel frame Structure & Lifting Frame:** When selecting components for solar panel frames made of AL 6061 extrusion, several key factors need to be considered to ensure that the frames are strong, durable, and efficient. Here are some important considerations: Aluminum Alloy: AL 6061 is a popular choice for solar panel frames due to its high strength-to-weight ratio, good corrosion resistance, and ability to be extruded into complex shapes. Other aluminum alloys may also be suitable, depending on the specific requirements of the application. The cross-sectional shape of the extrusion will determine the strength and rigidity of the frame. Common shapes include square, rectangular, and T-shaped profiles. The wall thickness of the extrusion will affect the strength and weight of the frame. Thicker walls will provide greater strength but will also be heavier. The surface of the extrusion can be treated to improve its corrosion resistance and durability. Common treatments include anodizing and powder coating. The frame must be compatible with the solar panels being used, as well as any mounting hardware or racking systems. It is important to check the specifications of the solar panels and mounting hardware to ensure compatibility. The cost of the extruded aluminum frame is an important consideration, as it will affect the overall cost of the solar installation. It is important to balance cost with the necessary strength and durability requirements.

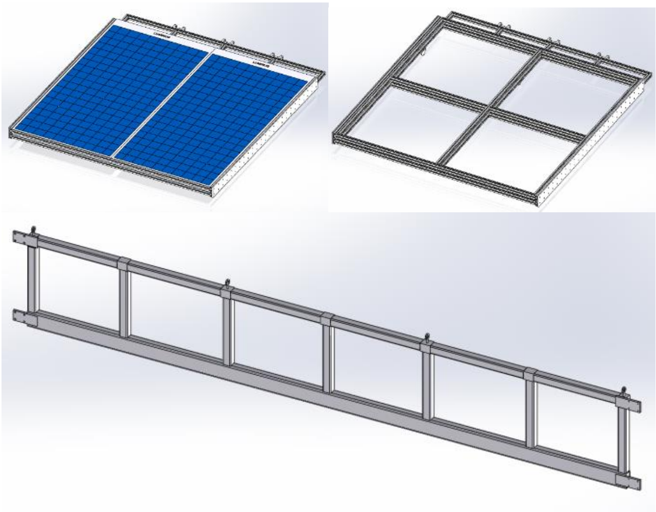

Fig -3: Solar Panel frame & Lifting frame Structure

- **Gas Spring:** A gas spring is a self-contained, hermetically sealed hydropneumatic linear actuator containing pressurized nitrogen gas, which provides an output force. Gas springs offer a unique alternative to conventional mechanical or coil sprig lifting or counterbalancing devices. The advantages of these springs involve a combination of a relatively flat force curve, controlled forces, and extension speed, and damping at the end of the stroke. The spring rate for a gas cylinder, as the illustration (below) shows, is far less than for any mechanical spring. Each gas spring also contains a specific amount of oil, which lubricates the seal, piston, and piston rod. The oil and gas within the cylinder move from one side of the piston head to the other when compressed or extended, providing a damping effect. This flow can be controlled either on extension, compression, or both. In its "unloaded" static state, the piston rod within the cylinder extends outside of the gas-pressurized tube. The extended output force (P1) is a result of the difference between the internal gas pressure and the outside atmospheric pressure. As the piston rod is compressed, the internal pressure and output force increase according to the rod volume displaced. During rod extension, the internal pressure and output force decrease according to the reduced internal rod volume.

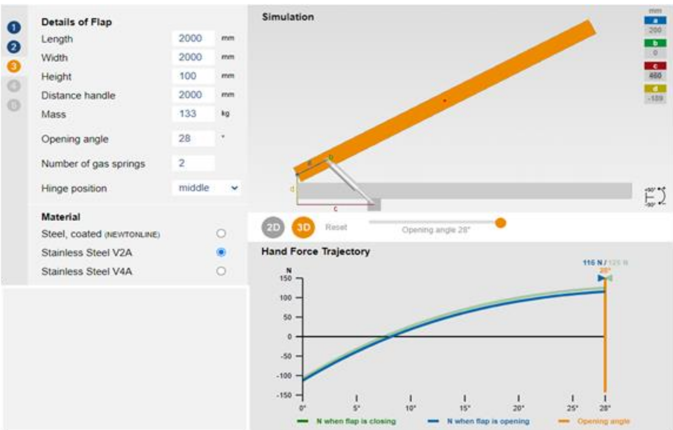

Fig -4: Gas spring selection simulation

- **Telescopic/linear Guide Rail**

  Telescopic slides are special ball bearing guides for high load rating. Two or more ball bearing mounted guide rails which can be drawn telescopic-wise guarantee a high reliability. According to the requirements a combination of different manufactured parts is used (rolled parts, cold-rolled steel, and machined parts). Load and extension proportions are the basic characteristics of the telescopic slides. This type of part extension type guide rails will be used on solar frame for the sliding movement of primary & secondary solar frame.

Fig -5: Part Extension type - Telescopic Guide Rail

- **LM Guide Rail (Linear Motion Guide Rail)**

  Linear guides play the role of easily and smoothly guiding linear motion while bearing loads in order for machines to operate precisely and efficiently. They are an indispensable part of linear components in devices such as machine tools and semiconductor manufacturing equipment. Recently, they have also been used in railway vehicles, buses, automatic doors, seismic isolation systems, and other consumer fields. The linear guide largely comprises three components: a mobile carriage, a rail that supports the movements of the carriage, and balls. Linear motion is enabled by attaching a mechanism for recirculating the balls. Linear guide mechanisms (linear motion systems) are used to move or position objects along a straight line with precision. Their main functions are split between guiding and driving elements. In particular, they refer to a system made up of machine elements that utilize rolling technology to move objects accurately in a straight line. The linear guide is one machine component that can be used for the guiding element.

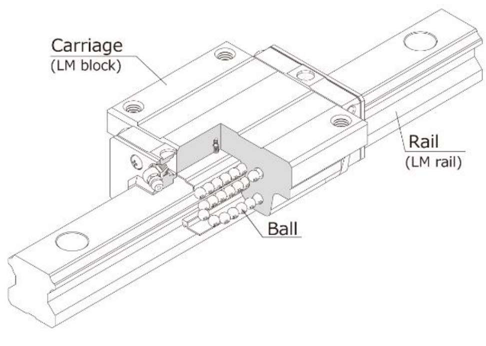

Fig -6: LM Guide Rail

- **Manual Winch**

  A winch is a mechanical device to lift or move heavy objects. It winds wire around a drum (or a spool) while holding the wire rope steady until it needs to be adjusted. Winches are used for backstage mechanics in the film and live event industries. There is a myth that hand winches are for pulling and not recommended for lifting. As there are multiple types of winches available, they are fitted with different brakes that determine if the device is safe for lifting. For example, non-brake and ratchet hand-operated winches are designed for pulling instead of lifting. If they are used in vertical lifting applications and you lose control of the lever, the load and winch will be left in a precarious situation - the lever will violently spin to causes to load to freefall to the ground. If yours is a brake winch or gear worm winch, their specific brakes are designed with vertical lifting applications in mind.

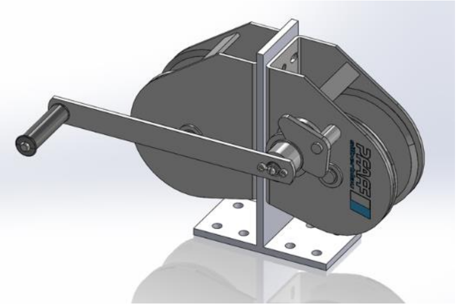

Fig -6: Wire rope winch

4. RESEARCH METHODOLOGY

The research methodology for this project will include the following steps:

4.1 Literature review

A thorough review of the literature related to fuel cell technology, hybrid power supply systems, and related research will be conducted to understand the current state of the art and identify research gaps.

4.2 System design

The hybrid power supply system will be designed based on the requirements of different applications, incorporating a fuel cell, battery, and other power sources as needed.

4.3 Simulation and analysis

The performance of the designed system will be simulated and analysed under different operating conditions to evaluate its efficiency, reliability, and environmental impact.

4.4 Optimization

The system design will be optimized based on the simulation results to achieve the best performance for different applications.

4.5 Economic analysis

The economic feasibility of the proposed system will be evaluated based on the cost of materials, manufacturing, and maintenance. A comparison with other power supply systems will also be made to assess the economic viability of the proposed system.

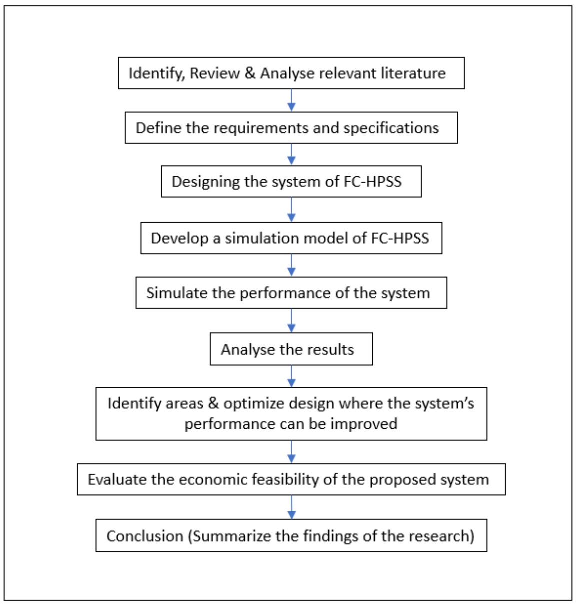

Fig -7: Flowchart of Research methodology chronological order

5. PROPOSED SYSTEM

When designing a fuel cell-based hybrid power supply system, selecting the right mechanical and electronic components is crucial to ensure safe, reliable, and efficient operation. A fuel cell-based system typically includes a fuel cell stack, fuel processor, battery pack, heat exchanger, mechanical supports and enclosures, cooling system, control and monitoring sensors, wiring, and cables. In this context, it is essential to carefully consider various factors such as power output, efficiency, durability, reliability, safety, and cost when selecting mechanical and electronic components. In this answer, we will delve deeper into the process of selecting mechanical and electronic components for a fuel cell-based hybrid power supply system.

In a proposed system we have developed a system having 28 solar panels arrangement on a 20 ft container. Arranged in a way that no components will come out of shelter & flushed completely inside shelter. It will cover 18 deg angle with surface and able to cover plus minus 10 deg angle with normal. For 20 solar panels arrangement on roadside, each solar panel frame will be having primary & secondary solar panels frame which will get expanded with the help of telescopic sliders. For lifting of a solar panel frame have designed a wire rope pulley mechanism with the help of manually operated winch, lifting frame & mechanical struts connected to eyelets. While vertical movement will be carried out by LM guide rail mounted on side wall of 20 ft ISO container.

On top roof side of 20 ft container for 8 solar panels arrangement will be having primary & secondary frame getting lifted with the help of Gas spring, while closing of secondary frame on primary will be carried by mechanical hinge. For locking of solar panel frames on top side mechanical locks arrangement will be provided.

All this hybrid system of Fuel cell, solar panels & wind turbine are connected together with the help of electronic units, ultracapacitor & battery bank for the power generation & storage. Which can be reutilized by DC-AC conversion with the help of Transformer & Inverter unit, whenever required at terrain or remote places.

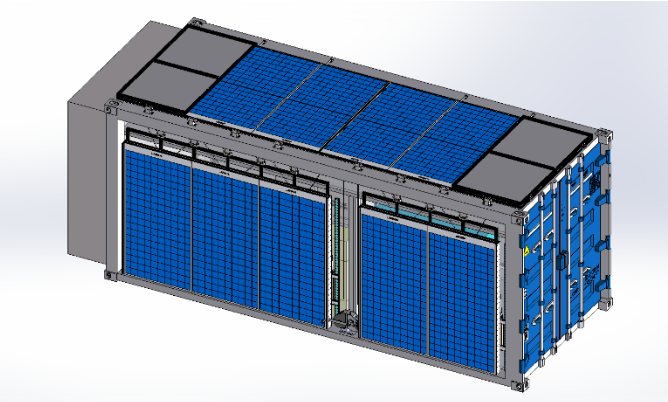

Fig -8: Proposed Fuel cell based Future Power Supply

This proposed system can be easily mounted on Truck or vehicle and can deployed at remote locations wherever required. This proposed system can be used as a DG set for places where power is not available.

6. CONCLUSIONS

In this way we concluded a Fuel cell based Future Power Supply system is a viable and efficient alternative to conventional power supply systems. The prominent applications of hybrid fuel cell power systems were reviewed. Hybrid fuel cells are a potential replacement for IC engines, electric batteries and fuel cell batteries used in mobile applications of some of the hybrid fuel-cell systems were discussed. These systems can be used for stationary power generation or for transportation applications. In addition to the systems described in this paper, hybrid power systems could also be configured by combining a fuel cell with other power sources.Hybrid fuel cell power systems are environmentally viable and sustainable. With greater research being carried out on hybrid fuel cells, they are being gradually accepted as a replacement to conventional power sources.

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