EXPERIMENTAL PERFORMANCE CHARACTERISTIC OF PEM FUEL CELL

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IN
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I, Shubhaditya Kumar, 2K20/THE/26 student of M. Tech. Thermal Engineering, hereby declare that the project Dissertation titled "Experimental Performance Characteristic of PEM fuel cell" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, carried out under the supervision of **Dr. Anil Kumar**, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled "Experimental Performance Characteristic of PEM fuel cell" which is submitted by Shubhaditya Kumar, 2K20/THE/26, Department Of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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Abstract

The motive of this paper work is to analyze the improvement of commercial fuel cell (rated capacity 1000W) with the help of resistive load and output power variation with change in H2 flow rate and calculate the maximum power point (MPP) of the proton exchange membrane (PEM) while changing AC and DC load respectively. The factors influencing the output power of a fuel cell are hydrogen flow rate, cell temperature, and membrane water content. The results show that when the H2 flow rate is changed from 11, 13, and 15 lpm, MPP is increased from lower to higher flow rate. The power of the fuel cell is increased at the rate of 29% by increasing the flow rate from 11 to 15 lpm. This study will allow small-scale industries and residential buildings (in remote or inaccessible areas) to characterize the performance of PEMFC. Furthermore, these cell helps in reducing the emission in the environment as fossil fuels produces a lot emission so to break this these fuels can be are of the best alternative for ecofriendly as well as cost effective these are renewable energy source which production increases day by day .

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CHAPTER 1

INTRODUCTION

A fuel cell (FC) is an electro-chemical energy conversion device that changes chemical energy from fuel into electrical energy directly. Many academics have been looking for new efficient energy conversion technologies due to rising energy consumption, pollution-free energy generation, and other environmental concerns [1]. Due to practical advantages such as high energy density, minimal environmental harm, good dynamic response, and lightweight, FC systems may be considered a feasible alternative. Polymer membrane, alkaline, phosphoric acid, molten carbonate, and solid oxide fuel cells are the several types of electrolyte materials utilized in FCs [2]. PEM fuel cells have unique characteristics such as a low functioning temperature (around 79.99^{o}C), high power density, rapid-start, quick-response, and high modularity, which make them the most capable system for power generation in applications such as automotive, distributed power generation, and portable electronic devices [3].

1.1 History of Fuel Cell

Sir William Grove presented the basic operating principle of FCs to the scientific community for the first time in 1839. Grove developed a 50-cell stack in 1842, which he dubbed the "gaseous voltaic battery." It took almost a century for the FCs to be reintroduced to the scientific world after Grove's conception. F.T. Bacon began working on practical FC in 1937, and by the end of the 1950s, he had produced a 6 kW output stack. Grubb and Niedrach developed a solid ion-exchange membrane electrolyte fuel cell in the early 1960s. Initially, sulfonated polystyrene-based membranes were used as electrolytes, and then Nafion membranes were used to replace the sulfonated polystyrene-based membranes. Despite the fact that the Nafion membrane has been shown to be superior in terms of performance and durability, it is still the most often used membrane. Polymer electrolyte membrane fuel cells or proton conversation membrane fuel cells are common names for this type of FC.

The PEM fuel cell (PEMFC) was originally utilized in the Gemini space programme in the early 1960s; the FC was built by General Electric based on Grubb and Niedrach's work. Following the

Gemini Program, the FC was utilized to provide electricity for life support and communications in the Apollo programme. Pratt & Whitney manufactured these FCs using Bacon's patents.

The majority of early research focused on alkaline and phosphoric acid fuel cells. Ballard Research started working on a Polymer Electrolyte Membrane fuel cell in 1983. Over the last two decades, Canadian companies have worked to commercialize fuel cells and associated goods, with some government assistance. The first fuel-cell bus was finished in 1992, and many fuel-cell cars are currently being manufactured in Europe and also in the United States. In 1997, Daimler Benz and Toyota introduced prototype fuel-cell vehicles. Several firms, including major automakers and federal organizations, have financed current research into the development of fuel cell technology for custom in fuel cell automobiles and other applications in recent years (1999-2004). In 2004, Honda began shipping hydrogen-powered fuel cell automobiles. Fuel cells are predicted to exchange outdated power sources in the next eight years, with micro fuel cells being used in cell phones and high-powered fuel cells being employed in stock car racing. In 2005, the British company Intelligent Energy released the ENV (Emission Neutral Vehicle), the world's first functional hydrogen motorcycle. With a top speed of 50 miles per hour, the motorcycle can run for 4hr. or cover 100-miles in an urban area.

1.2 Concept of fuel cell

During the electrochemical reaction that occurs between oxygen and hydrogen to make water, fuel cells generate energy and heat. Nowadays, Fuel cell systems are widely used in both minor and major-scale applications, together with combined heat and power (CHP) systems, Portable power systems, portable computers, and military communication equipment are all examples of mobile power systems [4]. It has been depicted as the substance designing strategy for delivering energy over electrochemical redox responses which happen at the cathode and anode of the cell. The power module offers the guarantee of a low polluting and exceptionally proficient energy source which can be intended to use a nearly boundless overflow of fuel.

Similar to the battery, it is intended for the constant recharging of the reactant consumed, and creates power from an outside supply of fuel and O_2 as displayed in Figure 1.1. Each energy component has two cathodes and an electrolyte.

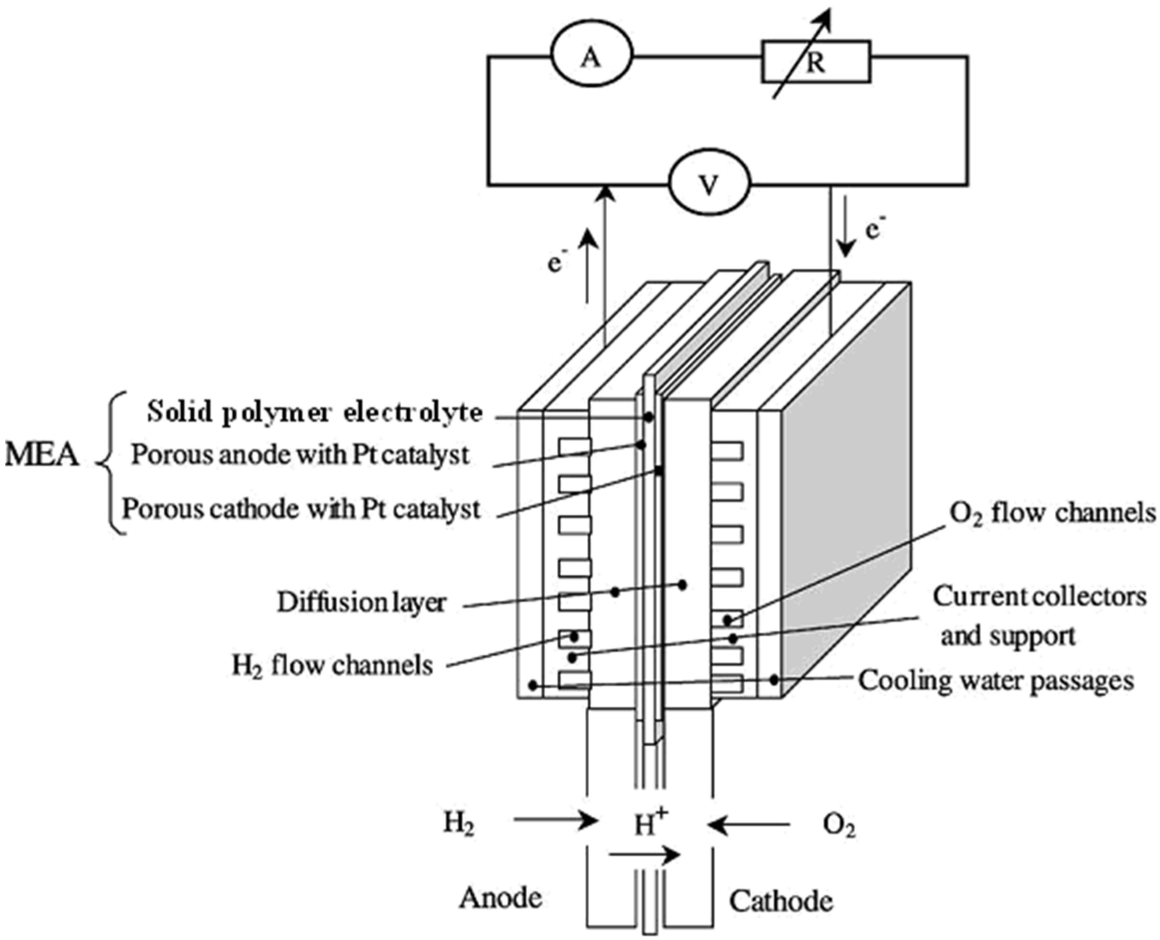

Figure 1.1: Basic Fuel Cell Components

The two terminals are +ve and -ve, called the cathode and anode individually. They permit the responses that power, while the electrolyte assumes a vital part of allowing just the suitable particles to pass between the anode and cathode. If free electrons or other things could get through the electrolyte, the synthetic response and the impetus work, which speeds up the responses at the cathodes, would be disrupted [5]. One extraordinary allure of energy components is that they develop power with next to no contamination; thus the energy unit has turn into the main possibility to supplant the gas powered motor and other lower energy thickness power capacity gadgets like batteries. A significant part of the H_2 from the fuel and O_2 utilized in producing power eventually joins to shape an innocuous result, specifically water. The motivation behind a power device is to develop an electrical flow that can be directed external the phone to take care of business, from driving an electric engine to enlightening a light. An energy unit produces power artificially, as opposed to by ignition, and is thus not expose to the thermodynamic regulations that limit an ordinary power plant. Along these lines, power modules are more proficient in extricating energy from a fuel. Squander heat from certain cells can likewise be bridled, helping framework effectiveness even further. In light of the manner in which power acts, the current produced by a power device gets back to the cell, finishing an electrical circuit. Accordingly, the compound responses that harvest this current are the way to how an energy component functions.

1.3 Types of fuel cells

Proton trade film, strong oxide, salt, liquid carbonate and phosphoric corrosive power modules are the five sorts of energy components presently accessible on the lookout. The initial two are strong electrolyte whereas the last 3 are fluid electrolyte. The sort of electrolyte in each energy unit decides the sort of fuel utilized in each. Some of them require unadulterated H_2 and subsequently need reformer to purge the fuel, while some can endure pollutants, despite the fact that they require a high temperature to really work. Every one of the five kinds of power modules have their benefits and downsides; but none is economically accessible at a less expensive cost to contend with the current energy source. The following are the portrayals of various sorts of energy units, characterized by kind of electrolyte utilized in creating power. Each works somewhat in an unexpected way, as displayed in Table 1.1 [4]. In general, H_2 iotas enter a power module at the anode, where they are stripped of their electrons by a substance response. The H_2 molecules have been ionized and are now carrying a positive electrical charge. The adversely charged electrons give the current through wires to take care of business. If Rotating Current (AC) is required, the Direct Current (DC) result of the energy component should be steered over a transformation gadget called an inverter.

Table 1.1: Overview of Fuel Cells

Fuel cell type	Common electrolyte	Operating Temperature	Typical Stack size	Electrical efficiency(LHV)	Applications	Advantages	Challenges
Polymer Electrolyte Membrane (PEM)	Perfluoro sulfonic acid	<120°C	<1 kW - 100 kW	60% direct H2;i 40% reformed fuel	• Backup power • Portable power • Distributed generation • Transportation • Specialty vehicles	• Solid electrolyte reduces corrosion & electrolyte management problems • Low temperature • Quick start-up and load following	• Expensive catalysts • Sensitive to fuel impurities
Alkaline (AFC)	Aqueous potassium hydroxide soaked in a porous matrix, or alkaline polymer membrane	<100°C	1 - 100 kW	60%	• Military • Space • Backup power • Transportation	• Wider range of stable materials allows lower cost components • Low temperature • Quick start-up	• Sensitive to CO2 in fuel and air • Electrolyte management (aqueous) • Electrolyte conductivity (polymer)
Phosphoric acid (PAFC).	Phosphoric acid soaked in a porous matrix or imbibed in a polymer	150 - 200°C	5 - 400 kW, 100 kW module (liquid PAFC); <10 kW	40%	• Distributed generation	• Suitable for CHP • Increased tolerance to fuel impurities	• Expensive catalysts • Long start-up time • Sulfur sensitivity

	membrane		(polymer membrane)				
Molten Carbonate (MCFC)	Molten lithium, sodium, and/ or potassium carbonates, soaked in a porous matrix	600 - 700°C	300 kW - 3 MW, 300 kW module	50%	• Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Suitable for CHP • Hybrid/gas turbine cycle	• High temperature corrosion and breakdown of cell components • Long start-up time • Low power density
Solid Oxide (SOFC)	Yttria stabilized zirconia	500 - 1000°C	1 kW - 2 MW	60%	• Auxiliary power • Electric utility • Distributed generation	• High efficiency • Fuel flexibility • Solid electrolyte • Suitable for CHP • Hybrid/gas turbine cycle	• High temperature corrosion and breakdown of cell components • Long start-up time • Limited number of shutdowns

1.3.1 Alkali fuel cell

Alkaline fuel cells (AFC) are fascinating options in contrast to polymer electrolyte layer power modules. They work on packed H_2 and O_2. They by and large utilize an answer of KOH in water as their electrolyte. The -OH particle (goodness) from potassium KOH moves from the cathode to the anode [6].

At the anode, H_2 gas responds with the Goodness particles to create water and delivery electrons. Electrons produced at the anode supply electrical capacity to an outer circuit, then, at that point, coming back to the cathode. There the electrons(e^-) respond with O_2 and water to deliver high quantity of -OH particles that diffuse into the electrolyte. Its proficiency is around 70%, furthermore, the working temperature is 90 to 100^oC. The cell result of AFCs goes from 0.3kW to 5kW and like other energy components, makes close to nothing contamination [7]. Since they produce consumable water notwithstanding power, they have been an intelligent decision for rocket. A significant disadvantage, nonetheless, is that antacid cells need extremely unadulterated hydrogen; in any case, an undesirable substance response frames a strong carbonate that impedes the other compound responses inside the cell. Since most strategies for creating H_2 from different powers create some CO_2, the requirement for unadulterated H_2 has eased back work on antacid power devices in later years [7]. Additional downside is the requirement for huge measures of an exorbitant platinum impetus to accelerate the reaction. NASA chose antacid power modules for the Space Transport armada, as well as the Apollo program, principally as a result of force creating efficiencies that approach 70%. Salt cells likewise give drinking water to the space travelers.

The cells are costly: the platinum terminal impetus maybe makes this fuel type as well costly for business application and, similar to some other compartment loaded up with fluid, these energy units can spill. A few organizations are in any case looking at ways of diminishing costs and work on the cells' flexibility. The majority of the soluble base power devices are being intended for transport applications.

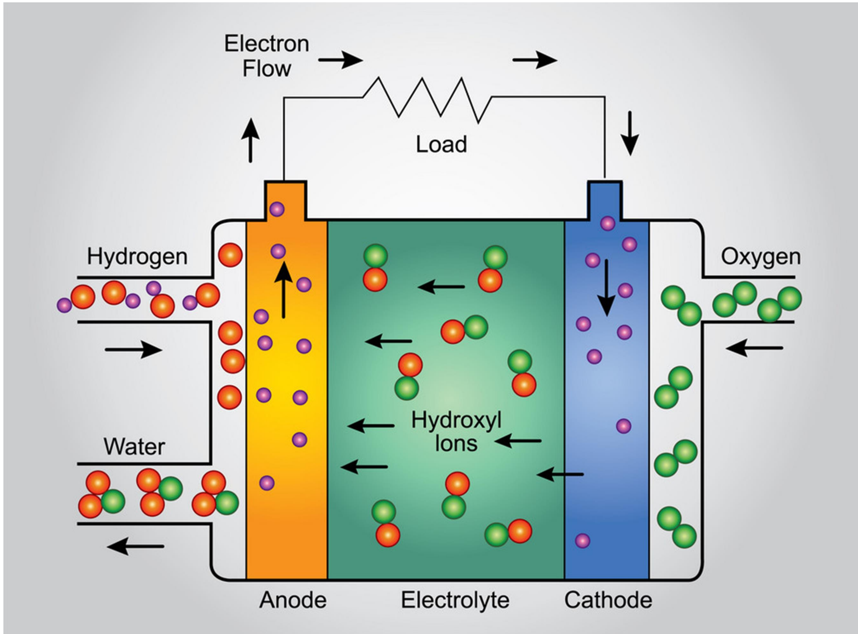

Figure 1.2: Alkali fuel cell (AFC)

1.3.2 Molten carbonate fuel cell

The electrolyte of a molten carbonate fuel cell (MCFC), as shown in Fig. 1.3, is a high-temperature salt compound such as sodium or magnesium carbonates (Brouawer et al, 2005; Alkanar and Zhoau, 2006). Its effectiveness goes from 56 to 78 percent, and the working temperature is around 652^{o}C. The power yield from MCFC depends on 2MW. The high working temperature of the cell limits damage from the CO harming of the cell and waste intensity can likewise be recycled to make extra power [8]. Their nickel terminal impetuses are cheap related with the platinum used in different cells however, the high working temperature additionally confines the materials and wellbeing uses of MCFCs, making it excessively hot for home use. A significant trouble with liquid carbonate innovation is the intricacy of working with a fluid electrolyte instead of a strong. One more comes from the substance response inside a liquid carbonate cell. Carbonate particles from the electrolyte are spent in the responses at the anode, making it important to repay by infusing carbon dioxide at the cathode. In a MCFC, the electrolytes (salt of sodium or magnesium carbonate) are warmed to 652^{o}C, and the salts dissolve and lead carbonate particles (CO_{32}) from the cathode to the anode. At the anode, hydrogen responds with the particles to create water, carbon dioxide, and electrons[8]. The electrons travel through an outer circuit, giving electrical power along the manner in which They then, at that point, coming back to the cathode, where the O_2 from the air and CO_2 reused from the anode respond with the electrons to shape CO_{32} that recharges the electrolyte and moves current through the power module. Requests for MCFC are restricted to enormous fixed power plants as a result of its high working temperature. The high working temperature of the cells permits the open door of utilizing its side-effect squander intensity to make steam for space warming, modern handling furthermore, a steam turbine equipped for creating higher power.

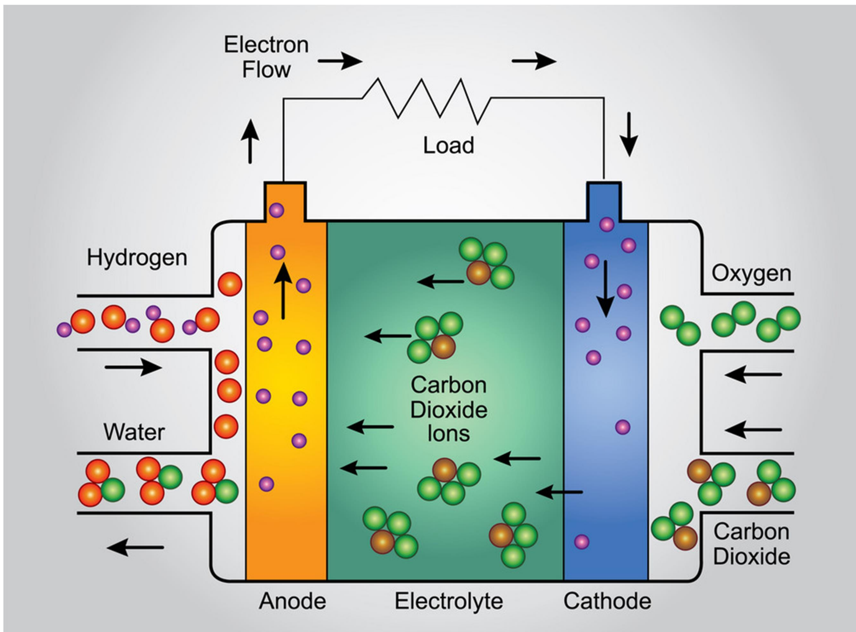

Figure 1.3: Molten Carbonate Fuel Cell (MCFC)

1.3.3 Phosphoric acid fuel cell

The energy emergencies of the 1971s enlivened specialists at Lose Alaamos Public Research center to start concentrating on power devices. Their goal being to create electric vehicles, they had the option to plan a golf truck controlled by a phosphoric corrosive fuel cell. Phosphoric acid fuel cell (PAFCs) as of now accessible need a preparation time, a reality that has restricted their utilization in private vehicles.

The effectiveness pace of Phosphoric acid fuel cell (PAFCs) midpoints between 40% to 50%, yet assuming the waste intensity is reprocessed in a cogeneration framework its productivity can ascend to 80percent [9]. Existing PAFCs of up to 200 kW limits are in business activity, and units of 11 MW limits have been tried. Phosphoric acid fuel cell (PAFCs) work at temperatures around 149.9°C to 200°C, and utilize phosphoric corrosive as the electrolyte, while a platinum impetus at the anodes speeds the responses [4]. Emphatically charged hydrogen particles move by the electrolyte from the anode to the cathode. Electrons produced at the anode travel through an outside circuit, giving electric power en route, and getting back to the cathode. At the cathode, the e^-, H_2 particles and O_2 structure water. PAFCs endure a carbon monoxide centralization of around 1.50 percent, which widens the selection of energizes they can utilize. Assuming gas is utilized, the sulfur should be eliminated. Platinum anode impetuses are required, and interior parts should have the option to endure the destructive corrosive.

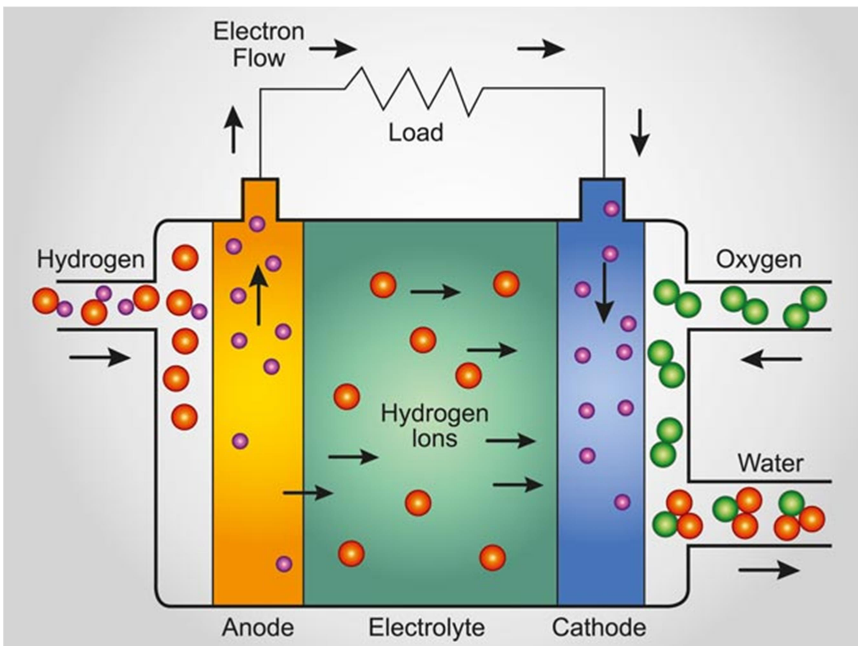

Figure 1.4: Phosphoric Acid Fuel Cell (PAFC)

1.3.4 Solid oxide fuel cell

Solid oxide fuel cells (SOFCs) are the most appropriate for enormous scope fixed power generators that can give power to processing plants and towns. SOFCs displayed in Figure 1.5 utilize a hard ceramic compound of metal, for example, CAO or ZrO_2 as the electrolyte, however other oxide mixes have likewise been utilized as electrolytes. The strong electrolyte is covered on the two sides with particular permeable anode materials. The cell proficiency is around 60 %, furthermore, it are around 1000^{o}C to work temperatures. The high working temperatures permit the SOFCs to co-produce squander heat and to create steam for space warming, modern handling, or in a steam turbine, to make greater power [10]. Oxygen particles (with a negative charge) pass through the gem cross section at extremely high temperatures. Whenever a fuel gas containing H_2 is ignored the anode, a progression of adversely charged O_2 particles moves across the electrolyte to oxidize the fuel. The O_2 is provided, generally from air, at the cathode. Electrons produced at the anode travel through an outer burden to the cathode, finishing the circuit and providing electric power en route. SOFCs yield ultimately depends on 100 kW and as a result of the high working temperatures a reformer isn't expected to remove hydrogen from the fuel, and waste intensity can be reused to make extra power. Not withstanding, the high temperature limits uses of SOFCs units and they will quite often be maybe huge; while strong electrolytes can't spill, they can break.

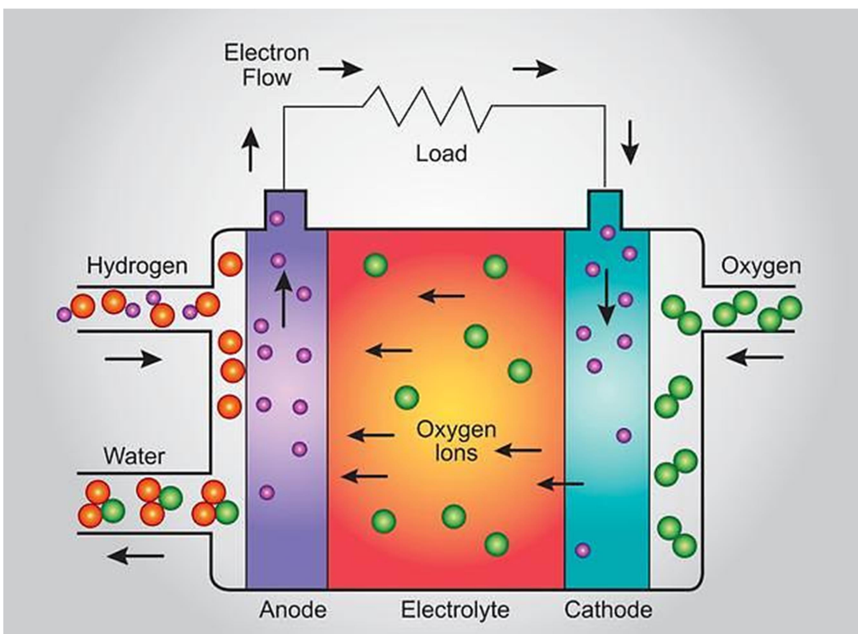

Figure 1.5: Solid Oxide Fuel Cell (SOFC)

1.3.5 Proton exchange membrane fuel cell

Since the mid-1980s, Polymer Electrolyte Membrane Fuel Cells' (PEMFCs) advancement has included fixed power applications. In 1989, Ballard Systems presented a 5 kW hydrogen and air PEM stack. After two years, GPU and Ballard presented a 250 kW plant at Crane Maritime Air Station in Indiana. 5kW Plug Power's PEM unit in Albany, New York, planned for home use and showed in June 1998, was the most advanced of PEMFCs accessible. The 5kW power plant assisted the organization to make huge associations with both GE and Detroit Edison. These associations had would have liked to showcase a private energy unit during 2002; but those plans have been delayed.

PEMFCs are one of the most encouraging energy unit types for broad use. They are especially receptive to differing loads and progressively modest to make. The PEM energy unit utilizes an high level plastic electrolyte as slim penetrable sheet to trade protons from the anode to the cathode [11]. The PEMFCs strong electrolyte is a lot more straightforward to deal with and use than a fluid partner, and its low working temperature permits a speedy beginning up. To speed the response, a platinum impetus is utilized on the two sides of the layer. PEMFCs productivity is around 40 to 50 percent, and the working temperature is around 80^{o}C [12]. Cell yields for the most part range from 50 to 250 kW. The strong, adaptable electrolyte won't hole or break and these cells work at a sufficiently low temperature to make them reasonable for homes and vehicles. In PEMFCs, hydrogen particles from the fuel sources are deprived of their electrons at the anode, and the emphatically charged protons diffuse through one side of the permeable layer and relocate toward the cathode. The electrons pass from the anode to the cathode through an outside circuit also, give electric power en route. At the cathode, the electrons, hydrogen protons and oxygen from the air consolidate to shape water. For this energy component to work, the proton trade layer electrolyte should permit hydrogen protons to go through, yet restrict the section of electrons and heavier gases.

There are two sorts of proton trade layer energy components, i.e., Hydrogen Fuel Cells also, Direct Methanol Fuel Cells (DMFC), the two of which use Proton Exchange Layer (PEM) to moves protons [4]. High power energy component and elite execution favor the decision of Hydrogen Fuel. Likewise, hydrogen controlled power devices are the greenest energy units, creating as it were water as a side-effect. Nonetheless, absence of capacity and conveyance foundations militate against the utilization of hydrogen thus, regulation and dispersion issues should be addressed before hydrogen fuel can be utilized for a huge scope for business purposes. The primary benefit of hydrogen is that it is effectively catalyzed under gentle circumstances; at the anode, hydrogen is oxidized to free two electrons and two protons as displayed in equation 1.1.

$$H_2 \rightarrow 2H^+ + 2e^- \quad (1.1)$$

The protons are directed from the impetus layer through the proton trade layer and the electrons travel through the electronic circuits. At the cathode, oxygen is diminished as introduced in equation 1.2.

$$\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O \quad (1.2)$$

Joining equation s 1.1 and 1.2 gives equation 1.3, which is the general cell response:

$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O \quad (1.3)$$

Responses displayed in equations 1.1 and 1.2 can be catalyzed by platinum or ruthenium on carbon dark help, to limit the carbon monoxide harming at the cathode, while the carbon dark help builds the surface region of the heterogeneous impetus region to increment utilization.

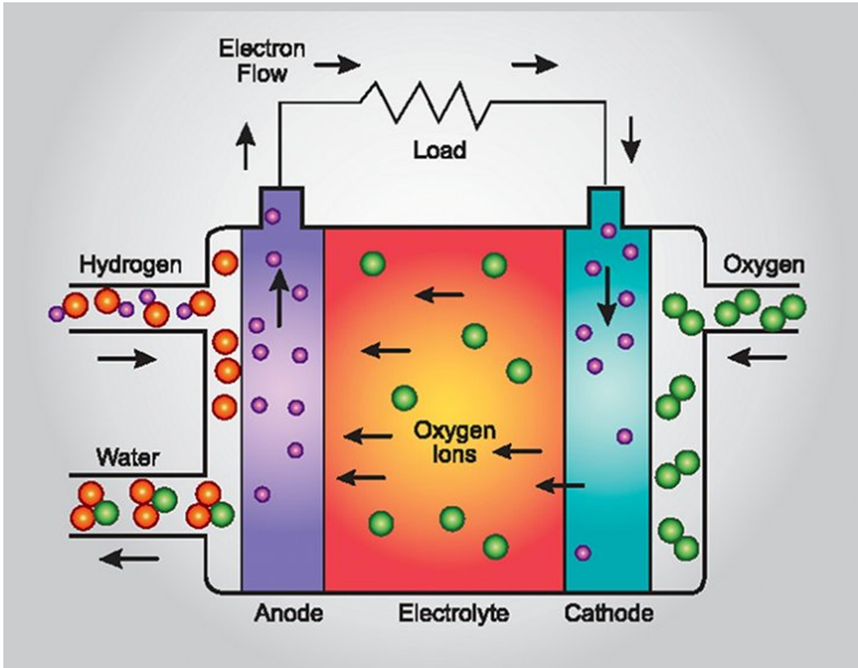

Figure 1.6: Proton Exchange Membrane Fuel Cell (PEMFC)

The relative simplicity of the oxidation of methanol at the anode to free protons and electrons makes it an alluring wellspring of fuel. Contrasted with hydrogen energy components, DMFC is further favorable for its simplicity of fuel conveyance, capacity, also, absence of humidification necessities, as well as its decreased plan intricacy and high power thickness [13]. In spite of these convincing benefits, DMFCs are in any case hampered by the low electro-action of the methanol oxidation at the anode, and the huge measure of undesired methanol shipped through the PEM from the anode to the cathode. This is alluded to as methanol hybrid, and it proceeds to be risky [5]. In direct methanol power devices, the arrangement of methanol furthermore, water is taken care of to the anode where it is inside transformed by the impetus and oxidized to free electrons and protons as follows:

$$CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^- \quad (1.4)$$

The cathode reaction for DMFC is similar to a hydrogen fuel cell:

$$\frac{3}{2}O_2 + 6H^+ + 6e^- \rightarrow 3H_2O \quad (1.5)$$

Combining equations 1.4 and 1.5, gives an overall cell reaction:

$$CH_3OH + \frac{3}{2}O_2 \rightarrow CO_2 + 2H_2O \qquad (1.6)$$

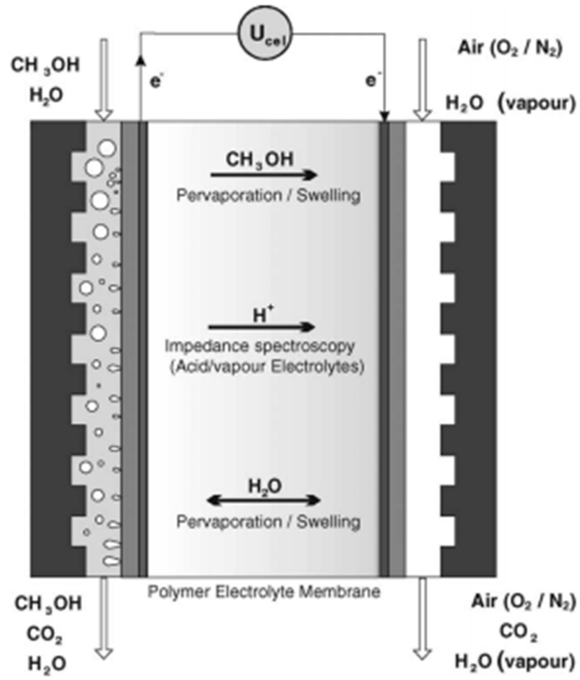

Figure 1.7: Direct Methanol Fuel cell (DMFC)

CHAPTER 2

LITERATURE REVIEW

Science and technological advancements have made a significant contribution to sustained industrial expansion and development. This type of evolution is critical for the future because it leads to growth and higher quality of life. However, if not adequately controlled, it can cause considerable environmental damage by introducing foreign materials into and polluting the atmosphere. Pollution is a by product of human activity that began with basic agricultural farming techniques and continues now with high-tech industrial activities. For the survival of a nation's economy and the well-being of its citizens, industrialization is extremely desirable.

However, if the detrimental influence caused by the entry of its undesirable by–products into natural systems is allowed to grow unchecked, it might be disastrous. As a result, environmental effect must be considered during the design, development, and operation of process industries. As a result of the, natural systems such as the atmosphere, land, and sea, as well as plant life, have been documented to be affected. As we all know, limited-resource fuels are extremely important, therefore in order to lessen our reliance, we must consider alternative sources of energy that are readily available in the environment and do not have a negative impact on the ecosystem. The new energy conversion technology should be high efficient than traditional heat engines, emitting little or no pollution, and be compatible with renewable energy sources for long-term sustainability [14]. The mid-nineteenth-century transition of the world energy supply from wood to hay to coal, and nuclear to oil and gas. The worldwide energy movement from solid to liquid, then from liquid to gases, and finally to non-polluting energy sources, as shown by hydrocarbon and eventually natural gas [15].These alternative sources should have economical balance as if we want to switch from one energy other sources of energy and pollution in the environment should be less [16]. We have now entered the age of non-polluting energy sources, according to recent additions to the literature. Fuel cells are projected to play a vital part in the development of non-polluting energy sources on a global scale.

Fuel cells are projected to play a significant part in accomplishing these objectives to decrease greenhouse gas emissions by 39.9% relative to 1991 levels, achieve a renewable energy role of at least 27percent in the EU, and rise in energy efficiency by at least 27%. [17].

Fuel cells have been highlighted as one of the most promising and viable clean energy technologies, fitting all of the conditions for energy security, economic growth, and environmental sustainability, and have received a lot of attention as a potential power generation system replacement [4]. The perfect blending of aids from energy sources, owing to their capacity to mimic the simplicity of refueling and nonstop operating potential of IC engines, as well as the extremely efficient and silent operation of batteries: As a result, fuel cells appear to be a perfect energy substitute [18]. They don't require the same amount of recharging as batteries and don't produce the same amount of pollutants. Fuel cells use an electrochemical reaction to create electricity directly from fuel, which is a very efficient technique [5]. Fuel cells can be utilized in a variety of ways because they generate electricity in such a simple manner, and they have been deployed among electricity consumers as a tactic to increase their market penetration [19]. When combustion occurs Engines produce power, but waste heat absorbs a large portion of the energy produced by combustion. Their low efficiency is due to friction.

The absence of contact inside an energy unit, combined with the absence of moving parts, contributes enormously to the low upkeep expected by energy units [20]. Different results of ignition incorporate contaminations like sulfur dioxide and nitrogen oxides. Power devices, again due to their specific instrument of activity, produce insignificant or no toxins, rely upon the kind of power device [21]. The Unified State Department of Energy (DOE) projected that if 10% of cars utilized in the Assembled State were controlled by energy units, air poisons would be cut by 1,000,000 tons each year and 60 million tons of carbon dioxide would be killed from the yearly ozone depleting substance creation. The DOE has additionally expressed that high level energy units utilizing flammable gas might actually lessen carbon dioxide emanations by 60% contrasted with an ordinary coal plant, and by 25% contrasted with the present regular gas plants [19]. Energy units running on hydrogen inferred, truth be told from a sustainable source would emanate just vaporous water [22]. One more advantage of the utilization of power devices, making it like some modern ignition cycles and better than others, is the capacity to catch over abundance heat produced for use in a cogeneration-like way or for space/water warming. These techniques for expanding the general proficiency of the power module have been displayed to push the proficiency to around 80% for both phosphoric corrosive and liquid carbonate power devices. Like burning motors, energy units work utilizing fuel from tanks that can be effectively refueled for however long fuel is taken care of, and the cell can run consistently. The significant benefits that energy units hold over inner burning motors, in any case, are high effectiveness of activity and absence of unsafe toxins.

There is, in any case, significant inspiration to tackle these issues since power modules offer a few benefits over different strategies for power creation. Interest in research and advancement in energy component innovation is accordingly expanding quickly, and it ought to be noticed that states, colleges and organizations are all progressively adjusting to the innovation of power devices [16]. Moreover, it very well may be noticed that power modules have been effectively conveying capacity to a few models and concentrated applications in late many years. The power result of an energy unit stack is effectively adaptable to give the perfect sum of power for a PC, little vehicle, a city transport, or even utility age and power building not associated with a public network [23]. The creator basically needs to choose the right kind of power module for the application. Thusly, business energy component stacks are now becoming accessible on the lookout; shoppers today can purchase a lightweight 1200 watt power module stack from Ballard Power Frameworks, empowering them to create power any place there is a wellspring of hydrogen. In spite of the fact that power modules innovations are not the most perfect elective clean energy (on the grounds that the innovation of energizes on which they depend are created through a process that may not be natural cordial) they in any case permit the outflow points of contamination to be driven further back in the chain where they can be all the more without any problem gathered and managed.

Shockingly, energy units are frequently viewed as addressing an innovation of things to come in their ability for supportable power age; in actuality they are one of the most established energy change gadgets [5]. They have not been completely marketed in a very long while of their acknowledgment due for the most part to the significant expense of their turn of events and application for reasonable purposes. This has brought about the view of power module improvement as slacking behind when contrasted and the serious advancements of intensity motors, for example, the steam and gas powered motors. To accomplish the commercialization of fuel cell innovation, particularly Proton Exchange Membrane Fuel Cell (PEMFC), there is a need to decrease the expense of the film and different parts of the energy component, as well as the restraining infrastructure of layer amalgamation advancements by a couple of organizations and countries. Pertinent writing uncovers that during the last many years an expense decrease of

10% has been accomplished; yet more examination is expected to lessen the expense of an energy units framework to a serious level. This could be accomplished by cost decrease in all parts of power devices creation, material frameworks and application, along with those of related parts. With respect to the commercialization of power devices, the usage of the locally accessible material (for example polystyrene butadiene elastic) in the union of the film and its joining with carbon nanoparticles to work on its characteristics as far as proton conductivity, warm steadiness, dissolvable take-up, porosity to dissolvable and fuel hybrid will add to the decrease in the expense of power module creation and the improvement of its proficiency. This will have the ideal consequence of tracking down additional applications for energy unit innovation, and is the focal point of this current research.

CHAPTER 3

EXPERIMENTAL SETUP AND METHODOLOGY

The proton-exchange membrane-hydrogen-based fuel cell has an easy operating principle. The complete fuel cell is made up of a series of stacked cells (as same as the cells of a car battery). The proton exchange membrane separates every cell in the stack, which consists of a cathode and anode. The PEM acts as an insulator between adjacent "half cells" while also allowing hydrogen protons generated during the process to migrate. Each cell's anode receives hydrogen, while the cathode receives air or oxygen. On the anode side, hydrogen gives out electrons, which are directed by an exterior circuit before returning to the system on the cathode side to recombine with H_2 ions and O_2 to generate water. Below is a more detailed description of the procedure.

At the anode side of the cell, hydrogen is used to generate electricity. A specific platinum catalyst is deposited on the proton exchange membrane, causing hydrogen molecules that come into touch with it to divided into two H+ ions (hydrogen ions). Every hydrogen atom from the unique H_2 molecule must give up an e^- in order to generate the positive hydrogen ion. This is where the graphite comes in, because the suddenly "free" e^- are routed through an external circuit by the extremely conductive graphite anode. The H_2 is oxidized at the anode (its electrical the charge has grown due to the loss of electrons, resulting in a higher positive charge). On the cathode side of the cell, oxygen molecules travelling into the proton exchange membrane's surface are cleaved into two highly reactive oxygen atoms, while newly created hydrogen ions (protons) continue to travel through the proton exchange membrane (the oxygen molecule, O_2, is relatively stable while oxygen atoms are not). While this is going on, e- released from H_2 molecules that were earlier at the anode coming back to the exterior circuit via the very highly conductive graphite cathode. At the interface between the proton exchange membrane and the cathode, one O_2 atom, two H_2 ions, and two returning electrons combine to produce a water molecule. At the cathode, the entire reaction is a reduction (electrons are added to oxygen reducing its charge).

Totally, H_2 is oxidized, oxygen is decreases, e^- are freed and rejoined, and the "chemical pressure" of all of this is employed to generate electricity in the cell stack. Water is released into the environment as a by-product of this electrolytic "combustion." As long as fuel is available, the above process occurs in each cell in the stack. Each cell pumps electrons unconfined by the earlier cell, as a result in an overall stack pressure, or voltage, equal to each cell's voltage multiplied by the number of cells in series (the total number of cells in the stack).

3.1 Technical fuel cell specification

Table 3.1 Specification of fuel cell

Types of Fuel cell	**PEM**
Number of cells	48
Rated power	1000 W
Performance	28.8 V@ 35 A
H2 Supply valve voltage	12V
Purging valve voltage	12 V
Blower voltage	12V
Reactants	Hydrogen & air
External temperature	5 to 30*c
Max. stack temperature	65*c
H2 pressure	0.45 – 0.55 bar
Hydrogen purity	>= 99.995% dry h2
Humidification	Self-humidified
Cooling	Air (integrated cooling fan
Stack weight (with fan and casing)	4000grams (+-100grams)
Controller weight	400 grams (+- 30 grams)
Dimension	23.3 cm x 26.8 cm x 12.3 cm
Flow rate at max output *	13 LPM
Startup time	<= 30S at ambient temperature
Efficiency of stack	40% @ 28.8 V
Low voltage shut down	24 V
Over current shut down	42 amp
Over temp shut down	65*C
External power supply **	13V (+- 1V), 8amp

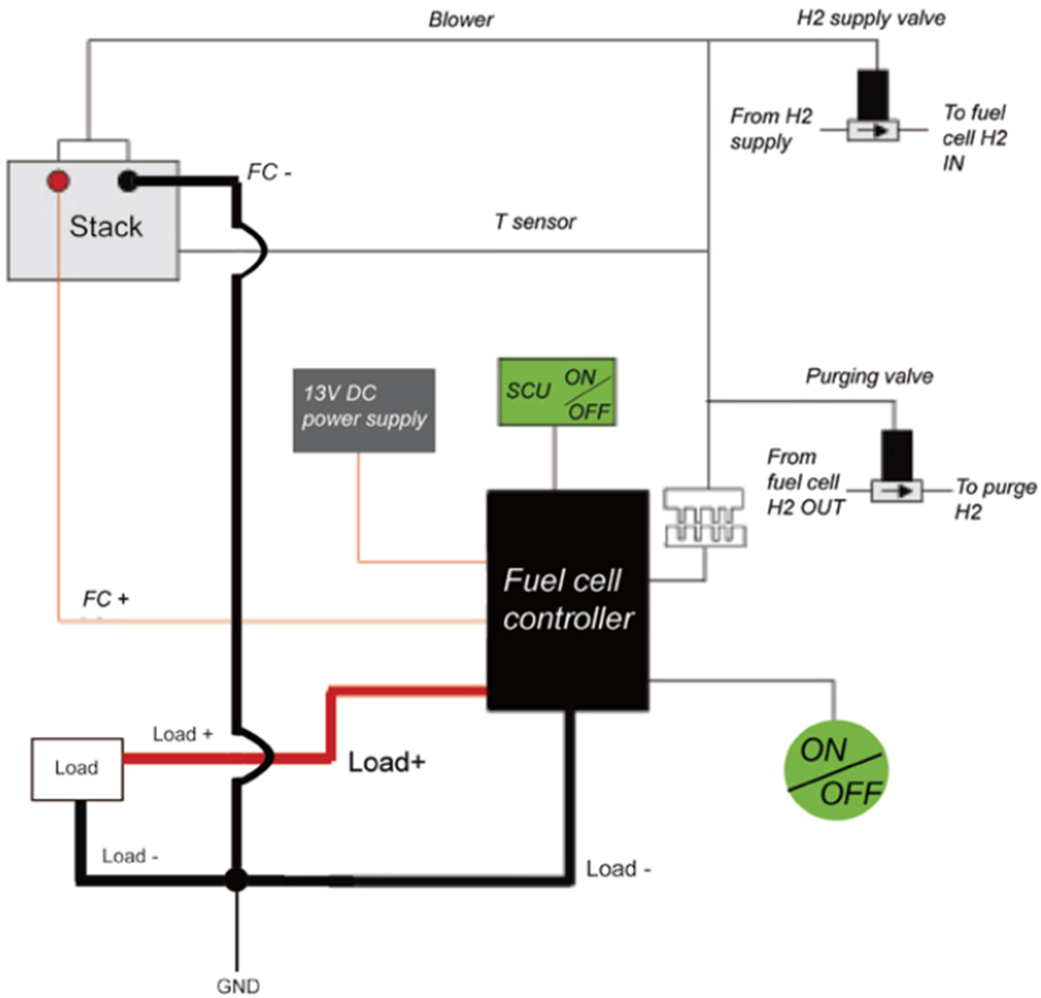

Figure 3.1. System setup diagram

3.2 Methodology

1. Characteristics of fuel cell with the help of resistive load.
2. Output power variation of fuel cell with change in Hydrogen supply.
3. Evaluation of Fuel cell system performances with only DC load connected to the charge controller with battery bank.
4. Evaluation of Fuel cell system performances with only AC load connected to the inverter with battery bank.

3.3 Operating Principle

The operational principle of a proton-exchange membrane-hydrogen-based fuel cell is straightforward. A set of stacked fuel cells make form the entire fuel cell (similar to the cells of a car battery). The proton exchange membrane separates each cell in the stack, which consists of a cathode and anode. The PEM acts as an insulator between the adjacent "half cells" while also allowing hydrogen protons generated during the process to migrate. Each cell's anode receives hydrogen, while the cathode receives air or oxygen. On the anode side, hydrogen gives out electrons, which are directed by an outside circuit before returning to the system on the cathode side to recombine with hydrogen ions and oxygen to generate water. Below is a extra detailed description of the procedure.

At the anode side of the cell, H_2 is used to start the power generation process. A specific platinum catalyst is deposited on the proton exchange membrane, causing hydrogen molecules that come into touch with it to split into two H^+ ions (hydrogen ions). Each H2 atom from the real H2 molecule must give up an electron in order to generate the positive hydrogen ion. This is where the graphite comes in, because the suddenly "free" electrons are carried away by the highly conductive graphite anode and directed to an outside circuit, where they create energy. At the anode, H2 is oxidized (its electrical charge in increased due to the shedding of electrons which results in an increased positive charge). On the cathode side of the cell, oxygen molecules travelling into the proton exchange membrane's surface are cleaved into two highly reactive oxygen atoms, while newly created hydrogen ions (protons) continue to travel through the proton exchange membrane (the oxygen molecule, O_2, is relatively stable while oxygen atoms are not). During this time, electrons released from hydrogen molecules at the anode return to the external circuit via the highly conductive graphite cathode. At the interface between the proton exchange membrane and the cathode, one oxygen atom, two hydrogen ions, and two returning electrons combine to produce a water molecule. At the cathode, the entire reaction is a reduction (electrons are added to oxygen reducing its charge).

Overall, hydrogen is oxidized, O_2 is decrease, electrons are freed and rejoined, and the "chemical pressure" of all of this is employed to generate electricity in the cell stack. Water is released into the environment as a by-product of this electrolytic "combustion." As long as fuel is available, the above process occurs in each cell in the stack. Each cell's e- is released by the previous cell, resulting in a total stack pressure, or voltage, equal to the voltage of each cell multiplied by the number of cells in series (the total number of cells in the stack).

3.3.1 Characteristics of fuel cell with the help of resistive load.

A PEM fuel cell's performance curve is not linear, but it does attain a maximum performance at a specific current. When fuel cells are employed in practice, it is critical that they be run at the current that produces the most power. For additional power, fuel cells are interconnected to form enormous stacks (fuel cell stacks). Each individual fuel cell must be run optimally in order for the stack to provide the maximum amount of power. The current voltage characteristic of a PEM fuel cell is recorded and studied in this experiment to find at which current the best performance can be obtained.

Experimental set-up and procedure:

For this experimentation, make the arrangements according to the fig.3.1. In this set-up, fuel cell will be connected with hydrogen cylinder through rotameter and pressure gauge and output of fuel cell will be connected to the charge controller and battery through voltmeter and ammeter. Final connection will be done by connecting battery to the inverter for AC output.

3.3.2 Output power variation of fuel cell with change in Hydrogen supply.

For this experiment, the set-up of fuel cell will be connected with hydrogen cylinder through rotameter and pressure gauge and output of fuel cell will be connected to the charge controller, battery and DC load through DC voltmeter and ammeter. This experiment can also be done by connecting Inverter and AC load in place of DC load through DC and AC voltmeters and ammeters.

Fuel cell output voltage and current will be measured with the help of DC voltmeter and Ammeter just after the fuel cell and noted down in tabular form with varying hydrogen supply rate.

3.3.3 Evaluation of Fuel cell system performances with only DC load connected to the charge controller with battery bank.

For this experiment, the set-up of fuel cell will be connected to the hydrogen piping through rotameter, pressure gauge and ball valve. Output of fuel cell will be connected with Charge controller through DC ammeter and voltmeter and finally charge controller output will be connected with battery bank and DC load (both in parallel) through DC voltmeter and ammeter.

3.3.4 Evaluation of Fuel cell system performances with only AC load connected to the inverter with battery bank.

For this experiment, the set-up of fuel cell will be connected to the hydrogen piping through rotameter, pressure gauge and ball valve. Output of fuel cell will be connected with. Charge controller through DC ammeter and voltmeter and finally charge controller output will be connected with battery bank and Inverter (both in parallel) through DC voltmeter and ammeter. Inverter output will be connected with AC load through AC voltmeter and ammeter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Characteristics of fuel cell with the help of resistive load.

Fig 4.1 represents the V-I characteristics of the fuel cell at a hydrogen flow rate of 15, 13, and 11 liters per minute (LPM) respectively. This graph represents that the current is inversely proportional to the voltage as we increase the load or resistance, the current of the fuel cell increases and the voltage drops slightly.

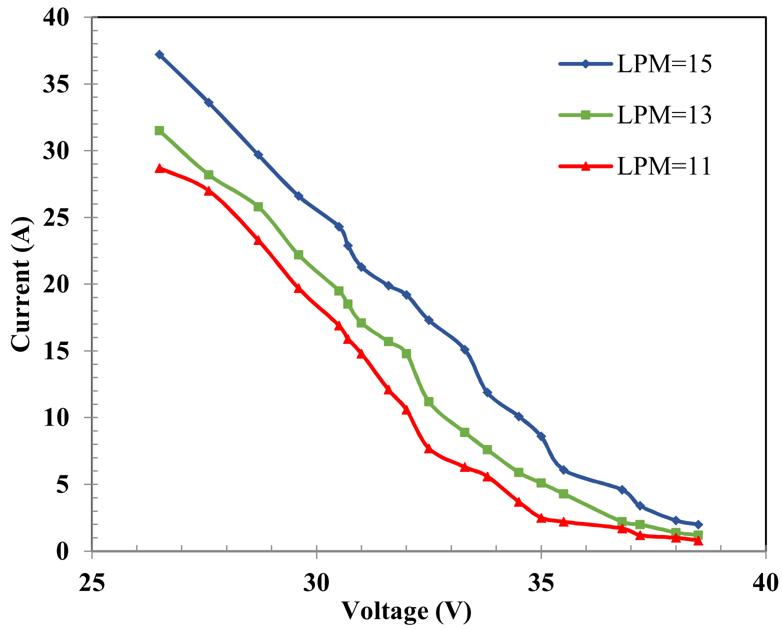

Figure 4.1: V-I characteristics of fuel cell

4.2 Output power variation of fuel cell with change in Hydrogen supply.

Fig 4.2. represents the relationship between Power and voltage of fuel cell at a different hydrogen flow rate of 15, 13, and 11 liters per minute (LPM) respectively. Results indicated that the power of the fuel cell increased with decreasing in voltage of the fuel cell due to an increase in load or resistance. The maximum power is obtained at the flow rate of 15 LPM as compared to

11 LPM and 13 LPM. At 35V the current generated are 8.6A, 5.1A, and 2.5A, and the power obtained is 301W, 178.5W, and 87.5W respectively for 15, 13, and 11 LPM.

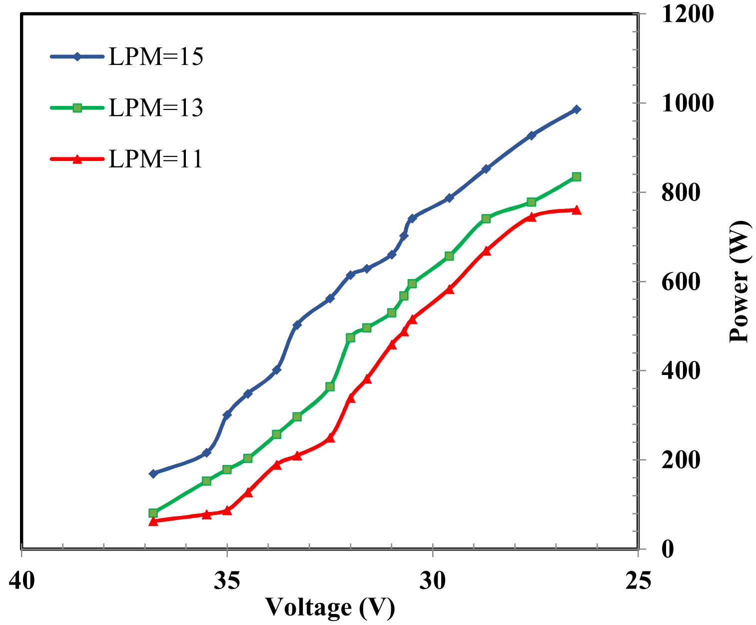

Figure 4.2: Characteristics of fuel cell at different flow rate of hydrogen

4.3 Evaluation of Fuel cell system performances with only DC load connected to the charge controller with battery bank.

Fig 4.3. represents the curve between Charge controller efficiency (η) and Power at DC load in watt at constant of hydrogen supply which is followed by the no. of experiments done in the system. This graph represents that as we increase the load or resistance the power of the fuel cell increases but the Charge controller efficiency is firstly increasing and then after achieving the maximum efficiency it drops down slightly.

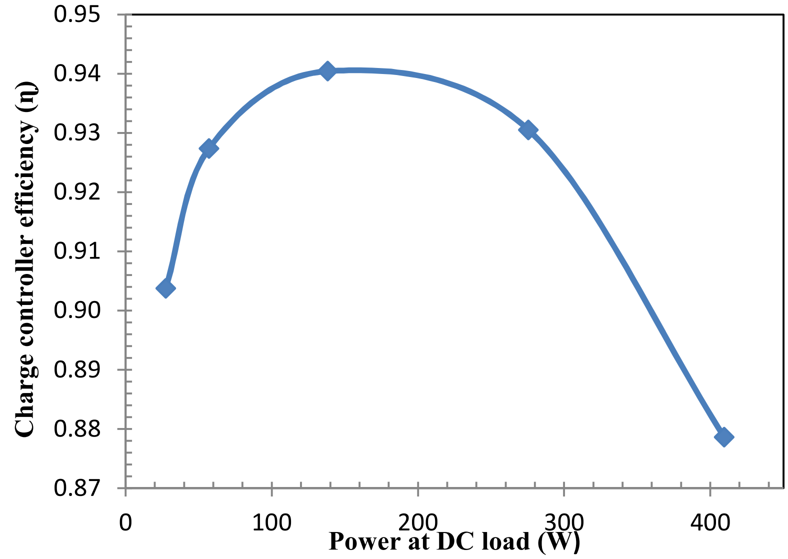

Figure 4.3 Power at DC load vs Charge controller efficiency

Regression Equation-

$y = -1E\text{-}06x^2 + 0.0005x + 0.8966$

$R^2 = 0.9669$

4.4. Evaluation of Fuel cell system performances with only AC load connected to the inverter with battery bank.

Fig 4.4. represents the curve between Charge controller efficiency (η) and Power at DC load in watt at constant of hydrogen supply which is followed by the no. of experiments done in the system. This graph represents that as we increase the load or resistance the power of the fuel cell increases but the Charge controller efficiency is firstly increasing and then after achieving the maximum efficiency it drops down slightly.

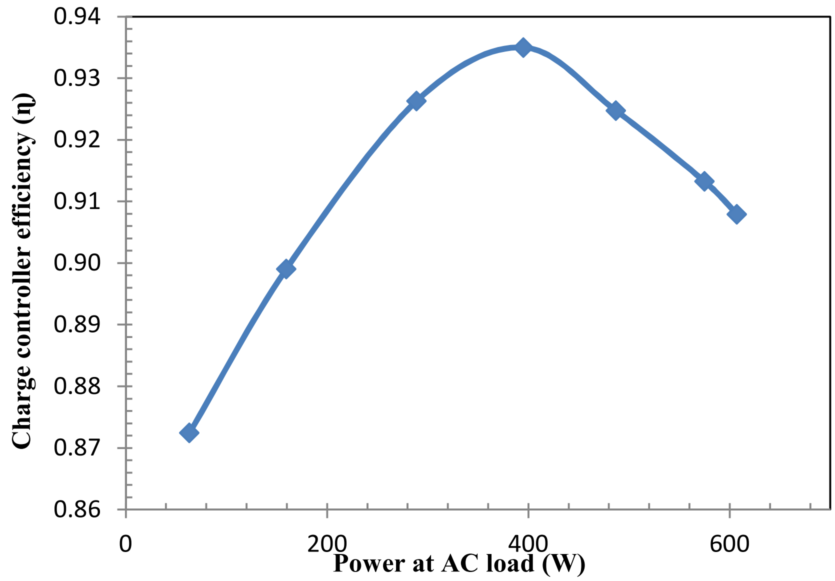

Figure 4.4 Power at AC load vs Charge controller efficiency

Regression Equation-

$y = -6E\text{-}07x^2 + 0.0004x + 0.8459$

$R^2 = 0.9908$

CHAPTER 5

CONCLUSIONS

The experimentation work was conducted on a Fuel Cell system. The entire experimental set-up is mounted at Green Energy lab, DTU, Delhi. The experimental work was conducted in the month of April, 2022. The whole investigation was carried out indoors in Green Energy Lab. A number of set of experiments was done employing different variable hydrogen flow rate (11, 13 & 15 lpm). During experiment process all readings were noted at regular intervals for different cases of work and to maintain the consistency of the results and uniformity of the data. The outcomes of experiment are listed as:

- The current is inversely proportional to the voltage as we increase the load or resistance.
- The maximum power is obtained at the flow rate of 15 LPM as compared to 11 LPM and 13 LPM.
- Charge controller efficiency is firstly increasing and then after achieving the maximum efficiency 94% and 93.4% it drops down slightly in the case of DC and AC load respectively.
- The power of the fuel cell is increased at the rate of 29% by increasing the flow rate from 11 to 15 LPM.

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