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Hydrogen Fuel Cell: Technology and Applications

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***Abstract*:- A Hydrogen Fuel Cell is well known as an electrochemical power generator which generates energy by combining hydrogen and oxygen. A fuel cell as a systematic conversion technology and hydrogen as an conveyor of clean energy have promising to contribute to directing an energy challenges currently being faced by almost all countries in the world. They will have an important role to play in a number of energy end use sectors. To overcome the problems on energy sustainability and pollution associated with traditional fuel technologies these HFC's are rapidly becoming an alternative of green energy technology. Pollutants from traditional and ancient fuels have a negative impact on the eco-friendly scientific environment. And hydrogen is one of the best energy sources to employ over other renewable energy sources since it has the power to produce massive amounts of clean energy. The Hydrogen Fuel Cell (HFC) is proving to be a very promising future fuel in terms of lowering greenhouse gas emissions and reducing pollutants in the environment. In this work, a quick overview of hydrogen fuel cells is provided.**

Keywords:- Fuel Cell, Hydrogen, Power generator, clean energy, Sustainability, etc.

INTRODUCTION:

The innovative technology of Fuel Cell is established and developed in many countries in the world now days. Fuel Cell systems have been renowned for their various advantages like high performance, efficient, high durability and ecofriendly with compared to other traditional power sources. As for that, many countries around the globe are trying to substitute ordinary power sources with fuel cells from time to time as this technology is rapidly evolving all around the globe. A Fuel Cell can be described as an electrochemical cell in which the chemical energy is transformed directly and effectively into electrical energy of conventional fuels [1]. And the most abundant and clean energy chemical element Hydrogen which accountings 75% of normal matter by mass and 90% over by the number of atoms. In a fuel cell system, when hydrogen is oxidized electrochemically, it generates pure water without emission of carbon dioxide. Hydrogen has many expanding application in various industrial fields such as power generation and equipment manufacturing for its clean and efficient advantages [2]. And because of rapid development, it has become obvious that many leading countries involves hydrogen fuel cell developments in their strategies to promote Fuel Cell industries. Thus, in this review we focus on Fuel Cell, its principle, types and applications.

HYDROGEN ENERGY:

Hydrogen is practical of the effective elective powers for replacing the long-term fossil fuel. Hydrogen is intrinsically 61a lightweight iota found in plenitude on soil within the shape of 61a chemical compound, like water, for illustration. It has monstrous vitality substance compared to ordinary fossil powers. On the other hand, the bond vitality required to break 61a reversible hydrocarbon bond is comparatively less, and thus, comparatively less vitality is required to get hydrogen from its chemical compounds. Indeed routine fossil fills are complex compounds of hydrocarbons wherein hydrogen is considered to be the essential fueling source. It is the cleanest fuel ever found and can be gotten from water disassociation utilizing power. Owing to its properties, hydrogen is considered as 61a practical elective fuel competent of nourishing the fuel cells on-board electric vehicles with no outflows. This would not as it were illuminate the issue of GHG outflows from vehicles but too resolve the issue of persistently draining oil saves. Other than, hydrogen fuel cells in combination with electric engines are 2–3 times more proficient than gasoline-powered inner combustion motors. In any case, its capacity in a proficient and secure way is however to meet the benchmark. So, hydrogen is unquestionably long-term fuel for assembly the vitality needs of mankind, being 61a green source of vitality with moo GHG outflows and low-carbon impression compared to the ordinary vitality sources [17].

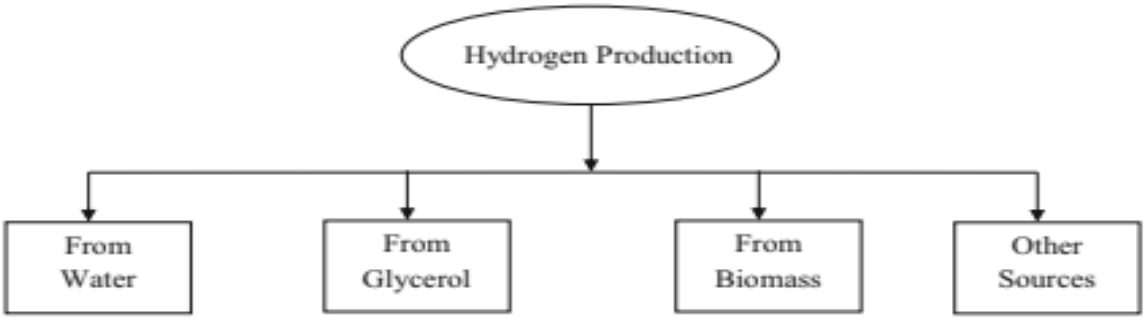

Fig.1) various sources for hydrogen production.

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PRINCIPLES OF FUEL CELL:

A Fuel cell is an energy conversion device that directly converts chemical energy of fuels in electrical energy with high efficiency and low impact on environment [3]. There are various types of Fuel cell systems, But the function of all systems is same. The Fuel cell system mainly consists of three parts are an anode, cathode and an electrolyte pillar. And according to the electrolyte material the Fuel Cells are classified [4]. The simple arrangement of Fuel cell system and the chemical reactions involved in an anode, cathode and an electrolyte membrane in electricity production are given below [4, 5];

Anode reaction, $H_2 \Rightarrow 2H^+ + 2e^-$ (1)

Cathode reaction, $½\ O_2 + 2H^+ + 2e^- \Rightarrow H_2O$ (2)

Overall reaction, $H_2 + ½\ O_2 \Rightarrow H_2O$ (3)

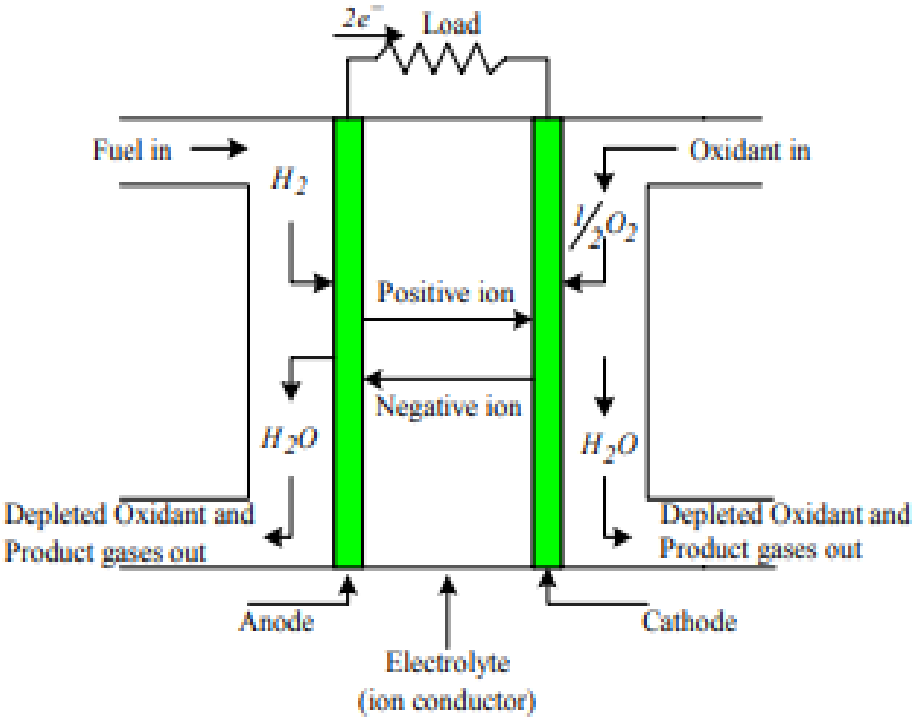

Fig. 2) Fuel Cell Operation Diagram

The working of Fuel cells involves the passing of hydrogen and oxygen into a concentrated solution via electrode. Hydrogen or fuel is introduced into the anode side of the fuel cell, while oxygen or air is introduced into the cathode side. As the gas tries to pass through the electrolyte membrane on the anode side of the cell, electrons are separated. The electrolyte membrane acts as a filter, separating electrons from hydrogen ions and allowing only the latter to flow through. The hydrogen ions that travelled through the membrane interact with oxygen atoms from the air supply in the cathode compartment to form H2O as a by-product, as well as heat. The details are shown in the Fig.1 [4, 6].

COMPONENTS OF FUEL CELL SYSTEMS:

The fuel cell has four components;

I. **Anode:** The fuel cell's negative post serves a variety of purposes. It transports the liberated electrons from hydrogen molecules to an external circuit. It is etched with channels that evenly distribute hydrogen gas throughout the catalyst's surface.

II. **Cathode:** The positive post of the fuel cell is carved with channels that transfer oxygen to the catalyst's surface. It also transports electrons from the external circuit back to the catalyst, where they can mix with hydrogen ions and oxygen to generate water.

III. **Electrolyte:** The proton exchange membrane is a membrane that allows protons to pass through. Only positively charged ions pass through this highly prepared material, which resembles typical kitchen plastic wrap. Electrons are blocked by the membrane.

IV. **Catalyst:** A unique substance that makes it easier for oxygen and hydrogen to react. It's often made of platinum nanoparticles that have been very lightly coated on carbon paper or fabric. The catalyst is rough and porous so that the platinum's surface area is exposed to the hydrogen or oxygen to the greatest extent possible. PEM is exposed to the platinum-coated side of the catalyst [7].

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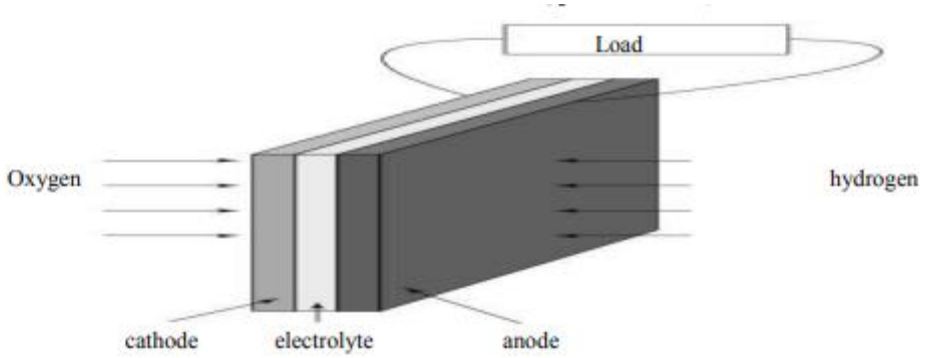

Fig. 3) Construction of Fuel Cell

TYPES OF FUEL CELL SYSTEMS:

The type of membrane utilized in fuel cell devices is categorized.

Fuel Cell	Abbreviation	Membrane
Solid Oxide Fuel cells	SOFC	Yttria-stabilized zirconia
Direct methanol fuel cell	DMFC	Solid polymer electrolyte (Nafion)
Phosphoric Acid fuel cell	PAFC	Phosphoric Acid (H_3PO_4)
Polymer electrolyte fuel cell Or Proton exchange membrane	PEMFC	Solid polymer electrolyte (Nafion)
Alkaline fuel cell	AFC	Aqueous solution Potassium Hydroxide (KOH)

Table 1) Types of Fuel cell Systems

The table 1 shows the common fuel cell systems with their membrane used [4].

I. **Solid Oxide Fuel Cell (SOFC):** As Fuel cells are characterized by their electrolyte material, The SOFC has a Solid oxide or ceramic electrolyte [8]. Negative oxygen ions are carried from the cathode to the anode by the electrolyte. Electrochemical oxidation of hydrogen, carbon monoxide, or other organic intermediates of oxygen ions happens on the anode side. SOFCs offer a number of benefits, including high combined heat and power efficiency, long-term stability, fuel flexibility, low emissions, and a low cost. And the largest disadvantage is the high operating temperature which results in longer start-up times and mechanical and chemical compatibility issues [9].

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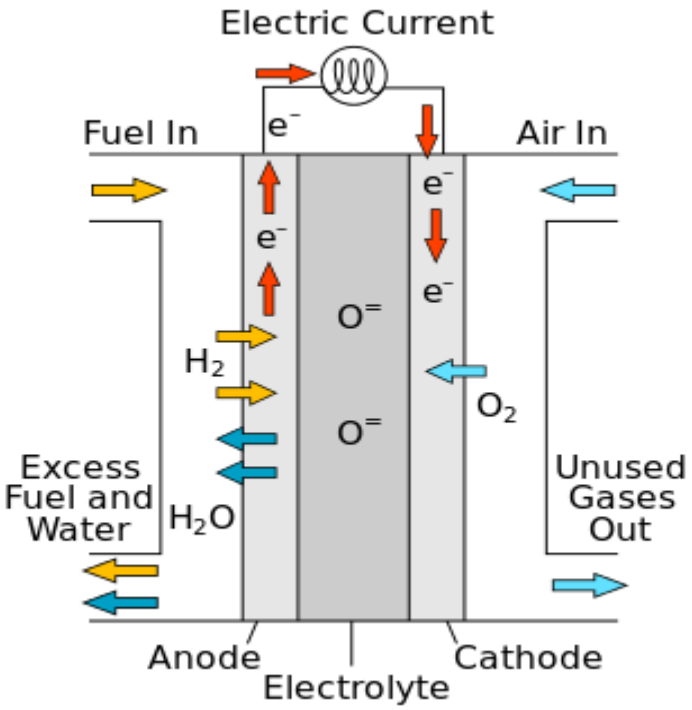

Fig. 4) Solid oxide Fuel cell

II. **Direct Methanol Fuel Cell (DMFC):** In a DMFC system, methanol can be used directly as a fuel in the FC. Methanol is a type of organic fuel that is made from coal or agricultural waste. The cathode and anode of DMFCs are both platinum and platinum-adopted catalysts. Trifluromethane sulfonic acid was employed as the electrolyte solution. A DMFC is a type of non-fuel flexible fuel cell that operates at low temperatures. Initially, these fuel cells were used in small portable electronic devices like laptops and cell phones [10].

III. **Phosphoric Acid Fuel Cell (PAFC):** A liquid phosphoric acid electrolyte is used in this type of fuel cell. Phosphoric acid (H3PO4) is a viscous liquid contained in the FC in a porous silicon carbide matrix by capillarity. PAFCs are medium-temperature fuel cells that conduct hydrogen ions rather than oxidizing ions, hence they are not as fuel-flexible as high-temperature fuel cells. While PAFCs are predominantly used for stationary power, they have also been implemented in some large-scale vehicles, such as public buses [11].

IV. **Polymer Electrolyte Fuel Cell (PEMFC):** The solid polymer membrane is used as an electrolyte in this form of fuel cell, which is the most popular. The membrane is constructed of perflurosulfonic acid in this case. This membrane allows protons to pass through but prevents electrons from passing through. This fuel cell has a low temperature range and operates at roughly 80 degrees Celsius. These cells are now mostly employed in the automotive industry. The advantage of these types of fuel cells is that they are very efficient and power density in the automotive engine size [4, 12].

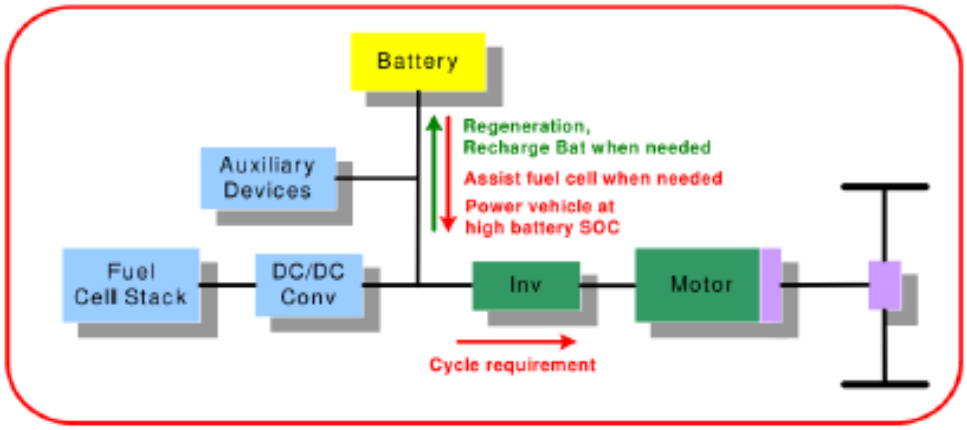

Fig.4) Basic structure of Fuel cell based Electric Vehicle [4, 13].

V. **Alkaline Fuel Cell (AFC):** To conduct ions between electrodes, AFCs employ an aqueous solution of potassium hydroxide (KOH) as the electrolyte. The ion conduction process differs from PEMFCs because the electrolyte is alkaline. The hydroxide ion (OH) carried by the alkaline electrolyte has an impact on various other features of the FC.

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A redox reaction between hydrogen and oxygen generates power in the fuel cell. Hydrogen is oxidized at the anode in accordance with the reaction: Oxidation: $H2 + 2\ OH^- \rightarrow 2H2O + 2e^-$ (4)
Water is produced, and electrons are released. The electrons go through an external circuit before returning to the cathode, lowering the amount of oxygen in the process:
Reduction: $O2 + 4e^- + 2H2O \rightarrow 4\ OH^-$ (5)
Ions of hydroxide are produced. In order to produce two water molecules, the net reaction uses one oxygen molecule and two hydrogen molecules. This process produces electricity and heat as by-products [4, 14].

FUEL CELL TYPES	Polymer Electrolyte Membrane (PEM)	Alkaline (AFC)	Phosphoric Acid (PAFC)	Molten Carbonate (MCFC	Solid Oxide (SOFC)	Microbial Fuel Cell
Common Electrolyte	Perfluoro sulfonic acid	Aqueous solution of potassium hydroxide soaked in a matrix	Phosphoric acid soaked in a matrix	Solution of lithium, sodium, and/ or potassium carbonates	Yttria stabilized zirconia	Microbes
Operating Temperature	50-100°C 122-212° typically 80°C	90-100°C 194-212°F	150-200°C 302-392°F	600-700°C 1112-1292°F	700-1000°C 1202-1832°F	Ambient Temperature
Anode reactions	$H_2 \rightarrow 2H^+ + 2e^-$	$H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$	$H_2 \rightarrow 2H^+ + 2e^-$	$H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e^-$	$H_2 + O^{2-} \rightarrow H_2O + 2e^-$	
Cathode Reactions	$^{\cdot}1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$	$1/2O_2 + H_2O + 2e^- \rightarrow 2OH^-$	$1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$	$^{\cdot}O_2 + CO_2 + 2e^- \rightarrow CO_3^{2-}$	$1/2O_2 + 2e^- \rightarrow O^{2-}$	
Efficiency	60 % transportation 35% stationary	60%	40%	45-50%	60%	50%
Applications	• Backup power • Portable power • Distributed generation • Transportation • Specialty vehicles	• Military • Space	• Distributed generation	• Electric utility • Distributed generation	• Auxiliary power • Electric utility • Distributed generation	Bio energy process
Advantages	• Solid electrolyte reduces corrosion & electrolyte management problems • Low temperature • Quick start-up	• Cathode reaction faster in alkaline electrolyte, leads to high performance • Low cost components	• Higher temperature enables CHP • Increased tolerance to fuel impurities	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Suitable for CHP	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Solid electrolyte • Suitable for CHP & CHHP • Hybrid/GT cycle	Advantages of MFCs include use of wide variety of organic materials as fuels, as well as their efficient operation at ambient temperature
Disadvantage	• Expensive catalysts • Sensitive to fuel impurities • Low temperature waste heat	• Sensitive to CO2 in fuel and air • Electrolyte management	• Pt catalyst • Long start up time • Low current and power	• High temperature corrosion and breakdown of cell components • Long start up time • Low power density	• High temperature corrosion and breakdown of cell components • High temperature operation requires long start up time and limits	Low power densities as compared to other technologies put this technology at a slight disadvantages.

Table 2) Detail Classification of Fuel Cell [15]

APPLICATIONS OF FUEL CELL SYSTEMS:

Fuel cells are gaining popularity as a result of their efficiency. The process is pretty straightforward. The fact that it has a low emission device and is silent attests to the fact that it produces a space that may be used in today's period. It demonstrates that this technology has so many suitable qualities that it outperforms current combustion engines, pistons, and turbine technologies. Fuel cells have properties that allow them to be employed not just on a small scale, but also on a huge scale. Fuel cell technology has made such an impact on everything from portable power systems to vehicles, electronic equipment, and big applications. The key areas' applications are presented in the table:

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Attribute	Description Of the Attribute
Stationary Power	The fuel cells have found the major applications in power generation because of its higher efficiency. The low and high temperature fuel cell both are potential enough to be utilized in this area of application. The fuel cells like PEM, SOFC AND PAFC are generally employed for small power systems. The low temperature and high temperature fuel cell both have their own applicability. Generally the low temperature fuel cells have the advantage of giving faster start up time. The operating time needed is 40000 hours for the stationary applications. This start up operating time is a major obstacle in the fuel cell operation. There are fuel cells like SOFC and MCFC which are high temperature fuel cell. These type of fuel cell can directly be applied in place of heat cycle or can be used in an indirect way into combined systems of cycles.
Transportation	In today's era the means of transport plays a vital role. The ongoing technologies are not environmentally sustaining in nature. So there is need to change the technology. The scientists have realized that they can demonstrate the vehicles with PEMFC technology. This technology can replace the older complicated technology. PEMFCs have its own advantage of low operating temperature range. The PEM techniques are suitable for the transporting devices. The main favouring point to consider is these technologies don't require pure hydrogen used as fuel, can be operated without any rotating parts. Also, it doesn't exhibit any significant poisoning systems. There are benefits recognized recently in several companies like BMW, Delphi automotive systems, etc. They have developed SOFCs as auxiliary power unit and companies implementing PEM fuel cells replacing hydrogen combustion engine. It is implemented in BMW7series and was found successful.
Portable Devices	This will be the widely used major applications of fuel cell in the equipments such as portable computers, mobile phones, telephones and one of the important applications is military application. This area will include sustainability in terms of expansion.
Space Applications	Space applications have proved that this technology is the most viable option for conventional energy resource. It can produce 1.5 kilowatts of continuous electrical supply. It was exemplary seen in the Apollo missions. The powerful alkaline fuel cells were highly reliable. The fuel cell is capable for supplying almost 12 KW continual periods and 16 KW for short period. The shuttle program in itself is the major and outstanding reliability. This in space not only provided electrical power but also was used by astronauts for the drinking purposes.

Table 3) Application of Fuel cell technology [16].

CONCLUSION:

Over the last fifteen years, hydrogen and fuel cell technology has improved significantly. At a worldwide level, this area continues to encounter enormous technological, commercial, and infrastructure-related hurdles that must be overcome before fuel cells can achieve their full potential.

The information on fuel cells, including their detailed construction and operation, varieties of fuel cells, and their applications, is clearly explained in this article. In the future days, we may expect to see more fuel cell-based transportation, power plants, and electricity generators.

REFERENCES:

[1] N A Baharuddin , W N A Wan Yusoff1 , A J Abd Aziz1 and N Mohd Tahir.
[2] LixinFan· ZhengkaiTu· Siew HwaChan· Accepted 2 August 2021.
[3] Fuel cell handbook, U.S. Department of energy, office of fossil fuels, 7th edition, National energy technology laboratory, west Virginia, Oct. 2000.
[4] Yogesh Manoharan, Brayden Butler, Seyed Ehsan Hosseini, Hisham Alzahrani, Accepted 14 May 2019.
[5] A. Kirubakaran1 , Shailendra Jain1 , and R.K. Nema Accepted Jan. 2009.
[6] O'Hayre, R.P.; Cha, S.-W.; Colella, W.G.; Prinz, F.B., John Wiley & Sons: Hoboken, NJ, USA, 2016.
[7] Karishma Maheshwaril, Dr. Sarita Sharma, Dr. Ashok Sharma, Dr. Sanjay Verma, Accepted, 6 June 2016.
[8] MandeepSingh, DarioZappa, ElisabettaComini, Accepted 3 June 2021.
[9] S.P.S. Badwal, S. Giddey, C. Munnings, A. Kulkarni CSIRO Energy Technology, Accepted 29 Nov. 2014.
[10] Barbir, F. PEM Fuel Cells: Theory and Practice, 2nd ed.; Academic Press: Cambridge, MA, USA, 2013;ISBN 9780123877109.
[11] Stefani Vanussi Melo Guaitolini, Imene Yahyaoui, Jussara Farias Fardin, Lucas Frizera, Accepted on 22 March 2018.
[12] Srinivasan, S. Fuel cells: From fundamentals to applications. In Fuel Cells; Springer Science &Business Media: Boston, MA, USA, 2006.
[13] Briguglio, N.; Andaloro, L.; Ferraro, M.; Antonucci, V. Fuel Cell Hybrid Electric Vehicles. In Electric Vehicles, The Benefifits and Barriers; InTech: London, UK, 2011
[14] Garche, J.; Jörissen, L. Applications of Fuel Cell Technology: Status and Perspectives. Electrochem. Soc. Interface 2015.
[15] Comparision of fuel cell technologies, Study Report, US Dept. of Energy.
[16] Karishma Maheshwari, Dr. Sarita Sharma, Dr. Ashok Sharma, Dr. Sanjay Verma, Accepted 6 June 2018
[17] Manish Kumar Singla & Parag Nijhawan & Amandeep Singh Oberoi Pubished 4 Feb 2021.