PEM Fuel Cell for hybrid power system and Application: A Review

Phanishwar Nath Shukla
Research Scholar, Department of Electrical and Electronics Engineering, Rabindranath Tagore University, Bhopal

Dr. Taruna Jain
Assistant Professor & HoD, Department of Electrical Engineering, UIT, Barkatullah University, Bhopal

Dr. A.K. Kurchania
Professor and Director, Renewable Energy, Rabindranath Tagore University, Bhopal

Abstract- The global electricity systems are currently shifted from the traditional centralized to distributed generation technologies. This development, coupled with the necessity to address the concerns of an environmental friendly and clean technology, reliability is part of the critical factors responsible for growing interests in Distributed generation systems across the world. In addition, it is necessary to develop more diversified electrical energy production with current renewable technology. Among several technologies nowadays, Fuel Cell (FC) appears as a promising alternative technology for electricity generation for the residential and commercial sector. In recent year's fuel cell (FC) technology are considered as reliable energy resources on the basis of being clean, pollution-free, and efficient, including their potential for storage, in the hydrogen form, compared to other available systems. This review paper discusses the potential of PEMFC and PV-PEMFC hybrid technologies for Distributed generation system applications. Such efforts can help achieve energy security by growing a diversified energy system for various applications. FCs is good energy sources to provide reliable power at a steady rate. PV-PEMFC is considered as the most promising options for Distributed generation.

Keywords – Fuel Cell, PEM (Proton exchange membrane) Fuel Cell, PV, Distributed generation (DG)

I. INTRODUCTION

Fuel cells are the most energy efficient technology for generating power and promising substitute for fossil fuels to provide energy for rural areas where there is no access to the public grid or huge cost of wiring and transferring electricity is required. Distributed generation systems are being employed both for grid connected and commercial purposes in several developed and developing countries and are fueled by several resources like solar, wind, biomass, and hydro. The issue of reliability of some of the existing Distributed generation systems, especially the solar-photovoltaic (PV) system. Recently, fuel cells have been considered to be an important technical option on route to a future low-carbon built environment. This is because of the ability of fuel cells, depending on hydrogen production technique, to produce electrical power with little or no emission of harmful pollutants such as CO_2 [1].
To avoid problems caused by the weather and environmental uncertainties, the reliability of a continuous production of energy from renewable sources, that requirement fulfill by fuel cell technology provide best results without intermittent nature [2]. A lack of awareness of the intermittent properties of solar irradiation, as well as poor technical design, is two of the primary causes of system failure. FCs can provide continuous operation, that is, they can be operated all the time, as long as the fuel is fed to the system making them a highly reliable energy option that can serve as a backup for variable characteristics in renewable energies.

Fuel cell systems for stationary applications promise significant benefits to end users, such as more power and heat for the same amount of fuel and lower pollutants [3]. The power produced by a fuel cell depends on several factors, including the fuel cell type, size, temperature at which it operates, the PEM Fuel cell have incorporated with that properties. A fuel cell is an electrochemical converter. It converts chemical energy of fuel (generally hydrogen) into electricity. PEM fuel cell is more attractive option for electricity generation [4]. Hydrogen-powered fuel cells are not only pollution-free, but they can also have more than efficient of traditional electricity generating technologies. It has the following advantages: simple structure, low-temperature operation, high power density nearly zero pollutants compared to any other conventional & non conventional source. The Proton exchange membrane whose operating temperature is usually very low compare to other fuel cells and run on pure hydrogen are used in verity of stationary and transport application such as electric vehicle.

II. LITERATURE SURVEY

Akimotoa et. al. [5] considered the Proton exchange membrane fuel cells (PEMFCs) for small-scale renewable energy applications because of low operating temperature, a short start-up time, and a high power density. They examine PEMFCs that have been designed with both air and water cooling systems. Rahaman and Islam [6] investigate the Low temperature helps to start fast and results in less wear on system components, resulting in better durability. Lai and Ellis [7] analyzed a fuel cell system as a reliable source; it can continuously provide power to the load making it more desirable for distributed generation than PVs or wind. Sharaf and Orhan [8] examine Polymer electrolyte membrane, also proton exchange membrane; fuel cells (PEMFC) in particular are one of the most promising types already in the early commercialization stage. Martin et. al. [9] presented the main characteristics of the start up and shutdown processes of a commercial fuel cell. They perform different tests and developed an electrical micro-grid fed with the fuel cell system with different parameters. Rahman and Tam [10] presents the concept and feasibility study results of applying fuel cells to provide operational support to photovoltaic (PV) arrays. Through simulation using actual data, it is shown that it is feasible to use fuel cells in coordination with PV to meet variable loads for either utility or stand-alone applications. The PV-fuel cell hybrid operation overcomes the intermittency problem inherent with PV and makes PV electric power generation more attractive. Khanh et. al. [11] presents a method to operate a grid-connected hybrid system. Their operating technique analyzed a flexible operation mode and change that always works the PV array at maximum output power and the PEMFC in its high efficiency performance band, improving system performance, increasing system stability, and reducing the number of operating mode changes.

III. DESCRIPTION OF FUEL CELL SYSTEMS

FCs was discovered in 1839 by a physicist named William R. Grove. In 1959, Francis Thomas Bacon, demonstrated the first fully-operational fuel cell. This technical breakthrough was made by reversing water electrolysis to generate direct current (DC) output from hydrogen (H_2) and oxygen (O_2). FC uses an electrochemical technique that is effectively a reversed electrolysis reaction. A fuel cell is a device in which the energy of a fuel is converted directly into electricity by an electrochemical reaction. A fuel cell is highly dependent on catalytic electrodes, which perform the electrochemical reaction that converts fuel into electric energy without the involving the burning process. Efficiencies of fuel cells (40–85%) are considerably high compared to heat engines [12].

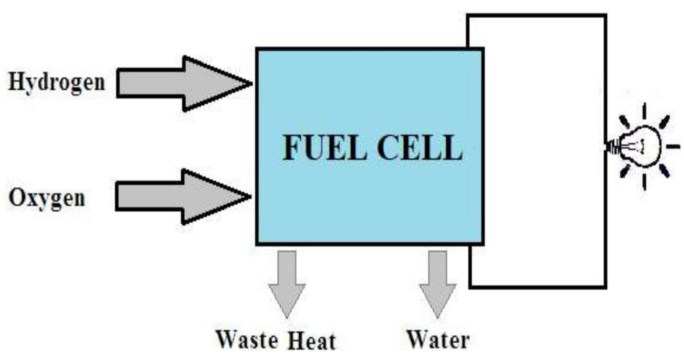

Figure 1. Block Diagram of a Fuel Cell

The FC technologies as an alternative resource to traditional energy production resources was presented FCs may be described as a kind of “electrochemical” device, which can over a continuous conversion of chemical energy to electrical energy, while the thermal energy developed and the water formed in the process are the by-products, the condition for continuous energy generation being the constant supply of the fuel and oxidant. A single fuel cell is made up of an anode and a cathode with an electrolyte in the middle. A single fuel cell is made up of an anode and a cathode with an electrolyte in the middle. Fuel, such as natural gas, biogas, or hydrogen, is introduced into the anode side, while an oxidant is introduced into the cathode side, resulting in a reaction that transports electrons through the fuel cell's circuit, producing electricity [13].

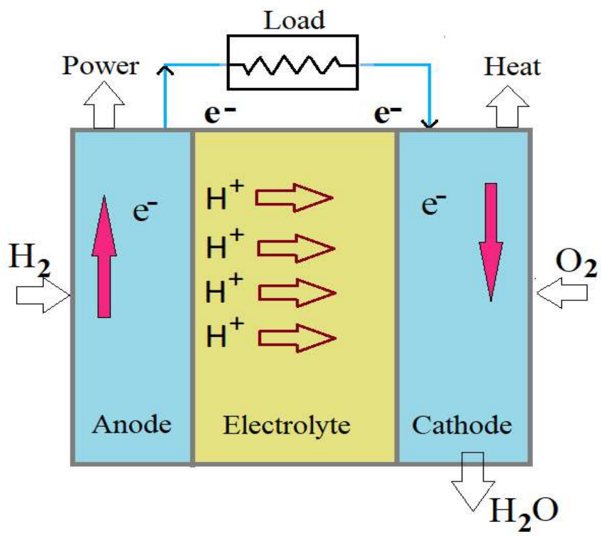

Figure 2. Schematic diagram of fuel cell

Fuel cell technologies can be classified by electrolyte, fuel source, operating temperature, or application, but the operating temperature is perhaps the most important distinguishing feature as it affects all of the other characteristics.

The reactions are represented by Equations (i)–(iii) [14]. Equation (1) describes the reaction at the anode, i.e., the negative or hydrogen electrode, and Equation (2) represents the reaction at the cathode, or positive or oxygen electrode, of the FC. Equation (3) describes the overall reaction of fuel cell.

$$2\,H_2 \rightarrow 4H^+ + 4e^- \qquad \text{(i)}$$
$$O_2 + 4H^+ + 4e^- \rightarrow 2\,H_2O \qquad \text{(ii)}$$
$$2\,H_2 + O_2 \rightarrow 2\,H_2O + \text{Energy (Electrical and Thermal)} \qquad \text{(iii)}$$

Fuel cell power systems have a variety of characteristics that make them appealing in stationary and transportation applications. Unlike other power sources such as PVs, the fuel cell system has a control system that manages the balance of the plant and determines the static and dynamic characteristics of the power output. Furthermore, different fuel cell technologies can be chosen to align with the application requirements. For example, low-temperature fuel cells are suitable for both stationary and transportation applications, provided the low-grade heat.

Table 1: Comparison of fuel cell with other power generating systems [15]

	Capacity range	**Efficiency**	**Capital cost ($/kW)**	**O & M cost ($/kW)**
Diesel Engine	500 kW–50 MW	35%	200–350	0.005–0.015
Turbine generator	500 kW–5MW	29-42%	450–870	0.005–0.0065
Photovoltaic (PV)	1 kW–1 MW	6-19%	6600	0.001–0.004
Wind turbine	10 kW–1MW	25%	1000	0.01
Fuel cells	200 kW–2MW	40-85%	1500–3000	0.0019–0.0153

Asia Pacific is anticipated to overwhelm the worldwide fuel cells advertise owing to the increasing focus on reducing carbon emissions by generating electrical energy and propulsion power by clean sources such as fuel cells in the region, and persistent increase in investments and technology advancements associated with fuel cell technology. The Proton Exchange Membrane Fuel Cell (PEMFC) market is predicted to be the fastest growing in the fuel cell industry. Increasing renewable power generation and cleaner operation are the main reasons for encouragement to the growth of the market.

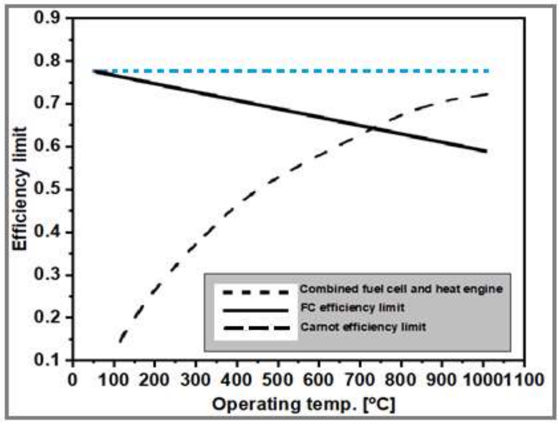

Figure 3. Ideal fuel cell and Carnot efficiencies

IV. PROTON EXCHANGE MEMBRANE FUEL CELL (PEMFC)

Among the different type of fuel cells, proton exchange membrane fuel cells (PEMFCs) have received a considerable amount of interest for both stationary and mobile applications owing to their characteristics such as high power density, low operating temperature, and low noise [16]. As the name suggests, the main operational part of the cell is the proton exchange membrane. PEMFCs are low temperature fuel cells with operating temperature around 80°C, which allows them to start quickly and results in less wear on system components along with better durability [17]. They are lightweight, compact devices with a quick start-up time. The sealing of electrodes in PEMFCs is easier than other types of fuel cells because of the solidity of the electrolyte. PEMFC systems are commonly used in portable and stationary applications. They also require little maintenance because the power generating stacks of the fuel cells contain no moving elements. Fuels for this type of cell technology include hydrogen and oxygen gases. As a result of the electrochemical reaction between hydrogen and oxygen in the cell, electricity, water and heat are produced. As Oxygen is found in air at a large number, we only need to produce hydrogen to run the cell. Hydrogen is produced through the electrolysis process. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes with a platinum or platinum alloy catalyst.

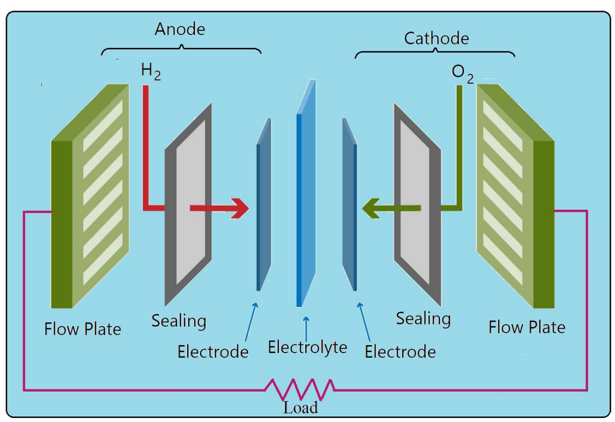

Figure 4. PEM Fuel Cell Stack

The materials used as anode and cathode electrodes in polymeric electrolyte membrane FCs are platinum or platinum-ruthenium and platinum, and Equations (iv) and (v) describe the reactions at the anode and cathode.

$$H_2 \rightarrow 2\,H^+ + 2\,e^- \qquad \text{(iv)}$$

$$0.5\,O_2 + 2\,H^+ + 2e^- \rightarrow H_2O \qquad \text{(v)}$$

PEMFCs have the largest range of applications as they are extremely flexible [18]. The PEMFC has the advantage for small IoT devices because the power density per volume is high.

V. APPLICATIONS OF FUEL CELL SYSTEM

The limited nature of fossil fuels, as well as the environmental challenges associated with their power generation systems, are important reasons driving the global community's attempts to adopt eco-friendly and sustainable energy options. One of the products of these efforts is the utilization of renewable energy resources, solar, wind, biomass, etc., which are already deployed in on-grid and off-grid micro grid systems around the globe [19]. However, FCs has a more prominent capability for power applications compared to other technologies, as they can also provide supportive functions such as voltage and frequency regulation, power quality support, etc. The capacity of FCs to deliver continuous power makes them a reasonable source for power generation and emergency/backup supply.

1. Fuel Cells in Microgrid Systems

Grid-integrated and grid-independent systems are two different ways that microgrid technologies are used in electricity systems. Whether the FC technologies are employed for grid-connected or off grid purposes, it is necessary to establish the fact that an FC power plant is more the FC stack. The FC stack produces direct current but most of the appliances within the residential, commercial, and industrial premises, for example, are alternating current (AC) powered. As a result, a power conditioning unit, commonly referred to as an inverter or the DC-AC converter, is used to convert the DC output of the FC stack to AC power. FCs also makes use of DC–DC power converters in addition to DC–AC power converters for power conditioning purposes [19].

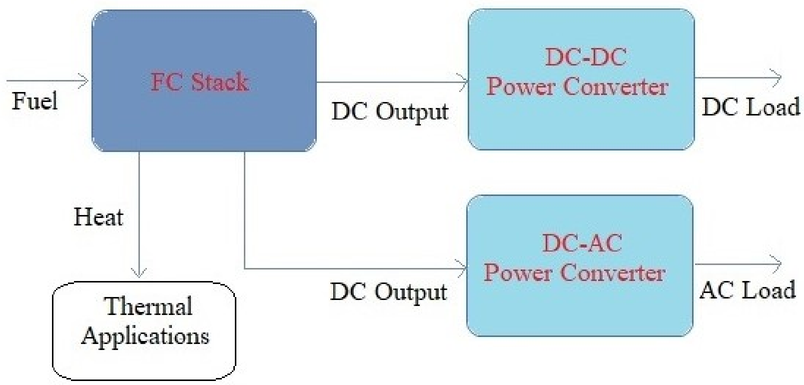

Figure 5. FC micro grid systems

2. Stand-alone application based PV-FC Hybrid System

The hybrid system composed of a Photovoltaic (PV) system and a Proton exchange membrane fuel cell (PEMFC) is considered. The PV system normally uses a maximum power point tracking (MPPT) technique to continuously deliver the maximum power to the load when variations in irradiation and temperature occur, which make it become an uncontrollable source. Synergy with PEMFC, the hybrid system output power becomes controllable.

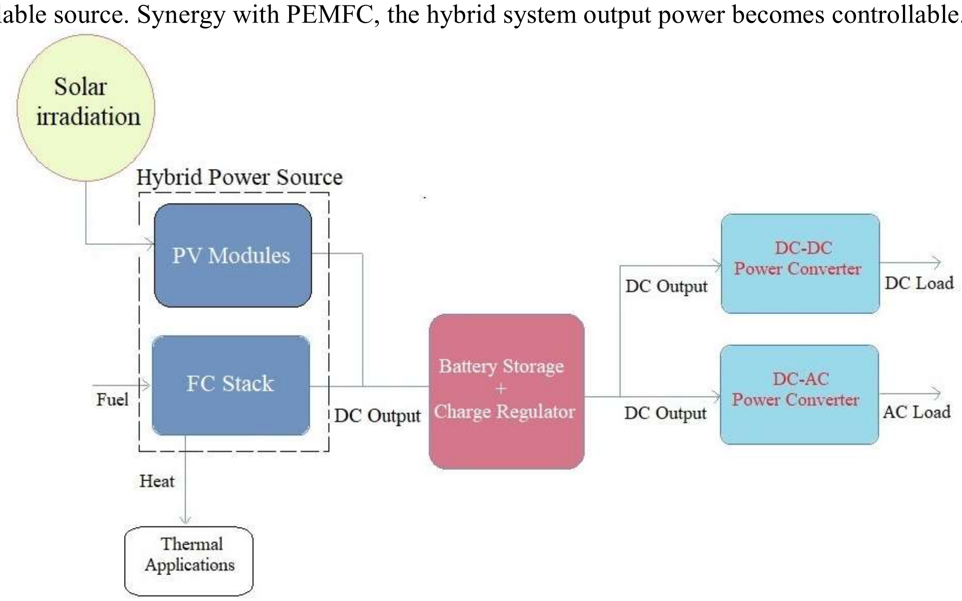

Figure 6. Stand-alone application based on the FC and PV power sources.

The coordination of the PV array and the PEMFC in the hybrid system, the operating strategy with a flexible operation mode change always operates the PV array at maximum output power and the PEMFC in its greatest efficiency performance band, thus improving the performance of system operation, enhancing system stability. The authors in this paper demonstrate a fuel technology with renewable source for distributed power generation and residential loads. In addition, the qualitative advantages of PEMFC based electricity generation by renewable fuel but did not perform any simulations to quantify these advantages. In short our work mainly focuses on clean energy generation with low temperature fuel cells for small scale applications.

VI. CONCLUSION

This paper presented a detailed review of proton exchange membrane fuel cell technologies, which are engaged for stationary (Residential, commercial, and industrial stationary power generation) applications as well as transportation (fuel cell electric vehicles) application. The proton exchange membrane FCs has a relatively low temperature and high specific power for distributed generation compared to other fuel cell technology. The paper demonstrated interests in the application of FCs in Distributed generation with hybrid systems based on some attractive features such as being clean, pollution-free, highly efficient, and promising energy resources for electricity generation applications that need more attention in research and development terms. The proton exchange membrane fuel cell is the most promising energy system used in electrical power generation as well as back-up power.

The author shows the interests in the application of FCs in microgrid systems based on some attractive features such as being green, environmental friendly, highly efficient, and flexible and promising energy resources for microgrid applications that need more attention in research and development terms. The review of FCs technology is expected to provide useful insights into advance research and developments in green energy generation through Distributed generation systems based on PV-PEMFC Hybrid technologies. PV-PEMFC hybrid system provides Long-term power generation systems can become a means of domestic self-sufficiency in which each consumer can generate energy. Eventually consumer replaces traditional electrical power within their homes, while the commercial sector could also benefit greatly. Nonetheless, further development and research are required in order to reduce their costs and improve their performance to produce reliable power generation for the near future as well as better business capabilities for the global market.

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