ZENITH International Journal of Multidisciplinary Research ____________ISSN 2231-5780
Vol.9 (3), March (2019), pp. 405-415
Online available at zenithresearch.org.in

THE CURRENT STATUS OF FUEL CELL TECHNOLOGY FOR PORTABLE STATIONARY APPLICATIONS

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Abstract

Fuel cells are energy conversion devices in which a fuel (e.g. hydrogen, methane) and an oxidant (e.g. air, oxygen) react in order to produce electrical energy and heat. The advantage of a fuel cell is that it can convert chemical energy directly into electrical energy with greater efficiency than traditional mechanical systems. Except the chemical reaction products such as water in the case of hydrogen as fuel there are no further by-products. The fuel cell will continue to generate power till the fuel is supplied to it. As per the current scenario there is need of sustainable energy technology, therefore fuel cells are under development for portable and stationary application. This paper reviews the current status of fuel cell technologies with their various types for portable and stationary application. Further discus on the fuel cell technology develop and commercialized in India.

Keywords

Fuel Cell, PEMFC, DMFC, AFC, PAFC, MCFC, SOFC, portable power, Stationary applications.

Introduction

Fuel cells are the electrochemical power source, which directly convert fuel into electricity without the need for combustion. Compared to the thermo-mechanical energy conversion processes, which are used now-a-days, fuel cells are very efficient (up to 60% efficiency in conjunction with steam turbines) since, they are not subjected to the Carnot limitations. In addition to this, the advantages of the fuel cells include reliability, multi-fuel capability, flexibility, durability, scalability and ease of maintenance. Again, fuel cells work silently, so it reduces noise pollution [1].

The fuel cell consists of three basic elements: electrolyte, anode and cathode. The electrolyte, generally, defines the types of fuel cell. It provides a physical barrier to prevent the direct mixing of the fuel and the oxidant, allows the conduction of ionic charge between the electrodes and transports the dissolved reactants to the electrode. The anode, which breaks down the fuel (most commonly hydrogen) into electrons and ions. The anode is, generally, made up of very fine platinum powder. The cathode, with the help of oxidant (air or pure oxygen), turns the ions into the byproducts like water or carbon dioxide. A typical fuel cell produces a voltage from 0.6 to 0.7 volt at full rated load [2,3].

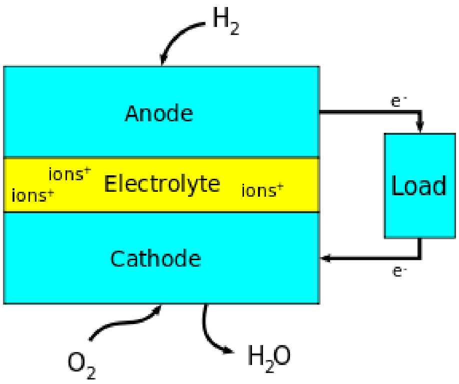

Fig.1: Schematic of fuel cell

Sir William Grove developed the fuel cell around 1839, just 39 years after the invention of the battery by Alessandro Volto. But it became the subject of intense research and development in the 1960s, when NASA developed fuel cells for its space program. The fuel cells are commercially introduced in transport in the 1990s and in stationary applications in the 2000s [4]. Generally, fuel cells applications are broadly divided into three categories: Portable fuel cells [including Auxiliary Power Units (APU)], Stationary applications [fuel cells for a fixed location] and Transport applications [fuel cells for vehicles]. The power of portable fuel cells can be used for small electronic devices, battery charger, portable soldier power, boat, etc. The power generated from such fuel cell are up-to 20 kW. The power of stationary fuel cells can be used for UPS, small stationary micro CHP, stationary combined heat and power system, etc. The power generated from such fuel cell are from 0.5 kW to 500 kW. The power of fuel cells applicable for transport can be used for electric vehicles, forklifts, etc. The power generated from such fuel cell are from1 kW to 100 kW. It is found that the applications of fuel cell for stationary purpose yet not met. There are some obstacles for to commercial deployment such as high costs, a lack of reliability, too much machine complexity and a shortage of fuel supplies. This paper reviews the different types of fuel cells and their use for stationary applications.

Types of Fuel Cell

Fuel cells are generally classified into five types on the basis of electrolyte material used and operating temperature. A brief description of these types of fuel cells are as follows;

A. Polymer electrolyte membrane fuel cell (PEMFC)

Polymer electrolyte membrane fuel cells (also called Proton exchange membrane fuel cells) operate below the 100 ^{0}C, possess a quick start-up time and are comparatively simple in their construction [5]. For efficiently catalyze the oxidation of hydrogen and reduction of oxygen, platinum is used for both the fuel and oxidizer electrodes respectively. The electrolyte separating the electrodes is a proton (H^+) conducting polymeric membrane, such as Nafion, a a sulfonated fluoroethene membrane that is mechanically strong and chemically stable. PEMFC are suited to a number of applications, thus providing a number of market opportunities. PEMFCs are used in transportation as well as in portable and stationary applications. Initially it is found that PEMFC was less considered for stationary applications than other types of fuel cell. But due to rapid change in technology its manufacturing cost decreases and hence its demand increases for such applications.

The high efficiency and less emission of PEMFC allow their use for the expansion of the electric network. Therefore, a part of the loads of the electrical network can be directly managed by many power systems which are distributed inside different types of organizations and structures, that lower the burden placed on the power plants [6].

For distributed power generation system several companies are working on development of small (1-10 kW) fuel cell power system intended to be used in homes. Some of them are combined with boilers to provide both electricity and heat [7]. For backup power, Ballard announced plans to commercialize 1 kW backup power generators in cooperation with coleman, but then brought back the technology and continued to sell the units. Proton energy system demonstrated regenerative fuel cells combining its own PEM electrolyzer technology with Ballard’s Nexa units [8]. A regenerative fuel cell generates its own hydrogen during period when electricity is available.

For portable power many companies are developing miniature fuel cells as battery replacements for various consumer and military electronic devices. power cells for battery replacements with power below 100 W. Major electronics companies, such as Toshiba, Sony, Motorola, LG, and Samsung, have in-house R&D units for portable fuel cells. Because of fuel storage issues, most of them use methanol in either direct methanol fuel cells or through micro-reformer in regular PEM fuel cells [7].

The direct methanol fuel cell (DMFC) is type of proton exchange membrane fuel cell; it also usesa polymer membrane as the electrolyte. With the use of platinum-ruthenium catalysts at the anode, methanol diluted in water can be used as the fuel source in a polymer fuel cell instead of hydrogen. A DMFC operate between the temperature 50 to 120 ^{0}C and has efficiencies of around 40% [9]. DMFCs are fabricated for portable power applications. They can be manufactured to power laptops, cellular phones, tools, video cameras, and so on with advantages of light weight, high efficiency and long-lasting time. Normally, the energy life measured is in days or weeks, rather than hours that is the usual life of batteries in these devices.

B. Alkaline Fuel Cell (AFC)

Alkaline fuel cells (AFCs) were the first practical fuel cells technologies to be developed for space program to produce electrical energy and water on-board spacecraft. It operates at temperature 100 – 250 °C. It has high conductivity and boiling point of a concentrated alkaline solution such as potassium hydroxide as an electrolyte [10]. It uses the metals (e.g. Ni, Ag, metal oxides, spinels and noble metals) as a catalyst at the cathode and anode. AFCs are fueled by hydrogen. An oxidant must be pure oxygen, not air, due the carbonatation of the electrolyte by CO_2 contained in the air (300 ppm) is fed to the cathode while a fuel is fed to the anode to supply hydrogen. Each cell generates a voltage between 0.5 V and 0.9 V depending on the design with an electrical efficiency that can be up to 65% [6, 11].

Because of the high reactivity of OH^- ions with carbon and its composites the smallest amount of CO_2 can affect the efficiency of the cell. This infers that the cell must be fueled with pure hydrogen and oxygen which is not hazardous outside the atmosphere but it is dangerous inside atmosphere. Therefore, very expensive purification systems are required which increase the effective cost of a power generator based on AFCs. Hence, AFCs are not a suitable technology for static or portable applications on earth [6].

C. Phosphoric Acid Fuel Cell (PAFC)

The phosphoric acid fuel cell uses phosphoric acid as the electrolyte,operates between the temperature 150 ^{o}C to 200 °C and efficiency ranges from 40 to 80 percent. At lower temperatures, phosphoric acid is a poor ionic conductor and CO poisoning of the Platinum electro-catalyst in the anode becomes severe. The use of concentrated phosphoric acid (100 percentage) minimizes the water vapor pressure so water management in the cell is not difficult. The matrix most commonly used to retain the acid is silicon carbide, and the electro-catalyst in both the anode and cathode is Platinum [12, 13]. Existing phosphoric acid cells have outputs up to 200 kW, and 11 MW units have been tested.

This was the first fuel cell technology that commercialized. The number of units manufactured are more than other fuel cell technology, with more than 85 *MW* of demonstrators that have been tested, are being tested, or are being manufactured around the world. The majority of the plants are in the 50 to 200 kW limit range, but large plants of 1 MW and 5 MW have been developed. 11 MW of grid quality ac power were operated as a largest plant till now. In U.S., majority of efforts were taken for developing the PAFC for stationary, dispersed power plants and on-site cogeneration power plants. The major industrial participants are UTC Fuel Cells in the U.S. and Fuji Electric Corporation, Toshiba Corporation, and Mitsubishi Electric Corporation in Japan [13].

Phosphoric acid fuel cell has ability to supplied stationary power for nearly 10 years. In the new Conde Nast Building at four Times Square in New York City, a model PC25 power plant from ONSI Corp. supplying supplemental power. Again when New York city get blackout, that time this building remains lighted, that provide the powerful publicity of fuel cell technology. In 1997, 200 kW ONSI unit powered the Yonkers Waste Treatment plant of New York. [14]. At the US Postal Service headquarters of Anchorage, Alaska five 200 kW PAFC systems were installed in 2000. A major call routing centre in New York, serving 40,000 phones, is installing seven 200 kW PAFC systems fueled by natural gas. Its total capacity will be 1.4 MW and will be the largest installation in the world. At the Australian Technology Park, Sydney, 200 kW PAFC were installed.

D. Molten Carbonate Fuel Cell (MCFC)

The molten carbonate fuel cell uses molten carbonate as an electrolyte, operates between the temperature 600 ^{0}C to 700 ^{0}C and efficiency ranges from 45 to 65 percent. At lower temperature, the conductivity of electrolyte is poor that leads limited operating temperature interval. At higher operating temperatures, Ni (anode) and nickel oxide (cathode) are suitable to promote reaction. Due to high operating temperature there is no need of noble metals catalysts for the cell electrochemical oxidation and reduction processes [13]. At the anode, hydrogen

Vol.9 (3), March (2019), pp. 405-415
Online available at zenithresearch.org.in

reacts with the ions to produce water, carbon dioxide, and electrons. The electrons travel through an external circuit, providing electrical power along the way and return to the cathode. There, oxygen from air and carbon dioxide recycled from the anode react with the electrons to form CO_3^{2-} ions that replenish the electrolyte and transfer current through the fuel cell [15].

Recently more work focus on development of molten carbonate fuel cell for stationary and marine applications as there is no issue of larger size, larger weight and slow start up time. Also, more works are running on this fuel cell for use of conventional and renewable fuels. Many more projects demonstration in stationary applications are running and some are completed. Currently, MCFC designs exist for units of 50 to 100 *MW* capacity but demonstration units have produced only up to 2 MW. At present, one industrial corporation is actively pursuing the commercialization of MCFCs at Fuel Cell Energy of U.S. Europe and Japan each developer pursuing the technology of MTU Friedrichshafen, Ansaldo of Italy, and Ishikawajima-Harima Heavy Industries of Japan [13].

South Korea installed 60 MW capacity molten carbonate fuel cell system. The POSCO Energy firm of Korean supply such systems. POSCO imports molten carbonate fuel cell technology from Fuel Cell Energy which is based in USA and completes the integration of fuel cell stacks as per facility requirement in Korea. Currently, POSCO Energy developed and produces 2.5 MW fuel cell. They installed a total of 166.7 MW of fuel cell in over twenty locations in Korea, including Gyoenggi Green Energy, the world's largest fuel cell power generation plant [16, 17].

E. Solid Oxide Fuel Cell (SOFC)

The solid oxide fuel cell operates in the temperature range of 700 – 1000 ºC. The thermodynamic efficiency of the SOFC for methane conversion is nearly 100% at this temperature. Chemical-to-electrical efficiencies exceeding 45% can be obtained even in small (~kW) scale applications and up to 60 % in large (~ 100 kW to MW) scale applications [18]. SOFC uses solid electrolyte usually yttria stabilized zirconia (YSZ). The anode and cathode both are highly porous and separated by a gastight electrolyte, which conducts O^{2-} ions. The material used foe this cell is moderate in cost. The anode exposed to fuel and the cathode exposed to air. The oxygen ions react catalytically with fuel at the anode/electrolyte interface,

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because of this water, carbon dioxide, heat, and electrons are produced. The electrons flow through external circuit, provide electricity.

As this fuel cell uses solid electrolyte, it can be construct with various shapes, such as tubular, planar, or monolithic. Due to solid ceramic construction of cell reduces the problem of corrosion. Similar to MCFC, in this cell CO is useful as a fuel and its kinetics are relatively fast. But for this cell there is no need of CO_2 at cathode as like MCFCs. The planer SOFC with thin electrolyte achieved the power densities close to PEFC. In recent year the SOFC received more attention as it is clean, low-pollution with its better efficiency and durability. Again, SOFC is more flexible than others fuel cells in terms of fuels use in it.

The Delphi develops a Solid Oxide Fuel Cell (SOFC) Auxiliary Power Unit (APU) for stationary as well transportation applications. Delphi working under U.S. department of energy solid state energy conversion alliance (SECA) to develop its SOFC for the use of stationary power plant. The APUis a high-efficiency electrochemical generator provideselectrical power up to 5 kW. It can use many types of fuels such as natural gas, diesel, bio-diesel, propane, gasoline, coal derived fuel and military logistics fuel. This APU can generate 110 V_{AC} and/or 12 V_{DC} voltage, its fuel efficiency is 40 to 50%, low noise (less than 60 dBa at 3 meter), ultra-clean and nearly zero emissions [19].

Fig. 2: Delphi Solid Oxide Fuel Cell Auxiliary

Recently, the Ultra Electronics USSI of U.S. has received a $1.2 million contract for D245XR and D350XR fuel cells, for use in Group 1 unmanned aerial systems (UAS). The advanced solid oxide fuel cell power systems provide UAS platforms with advanced sensor capabilities, extended operational range, and more than 8 h flight time in a compact UAS [20]. The AVL's develops a solid oxide fuel cell combined heat and power (AVL SOFC CHP) for stationary power generator. A SOFC CHP system generates a 5 kW power, while the more work carried out for generating 200 kW power output from power plant. This system is a clean, efficient, cost-effective and near about zero pollutant emissions at efficiencies of up to 60% [21].

Fuel Cell Technology in India

In India some organizations such as, CFCT-ARCI, CSIR-Network Labs, NMRL, VSSC, BHEL are engaged in development of polymer electrolyte membrane fuel cells system, but it has not reached the stage of commercialization. Bharat Heavy Electrical Ltd. had developed a 50 kW capacity PAFC system but due to non-availability of carbon paper they unable to do work further. Bharat Heavy Electrical Ltd. use the 200 kW PAFC system of M/s Toshiba Corporation of Japan. Naval Materials Research Laboratory (NMRL), Ambernath developed such systems of 1-15 kW capacity for M/s Thermax Ltd, Pune and around 24 numbers of 3 kW capacity for DRDO.The CSIR-CECRI, Karaikudi develop the MCFC multi-cell stack in their laboratory. Also, TERI, New Delhi with financial support from MNRE, carried out a demonstration project based on an imported MCFC unit. The CSIR-CGCRI, Kolkata has demonstrated a 500 W anode supported stack with planar configuration using ferritic steel as the bipolar plate. Another major effort taken by NFTDC, Hyderabad in collaboration with University of Cambridge, UK, for development of 3rd generation metal supported SOFC technology. Several other institutions of the country also come forward for developing the SOFC technology as per R&D capability on different aspects of the technology.

In addition to this some companies in India develop some fuel cell technology and commercialized them; FC TecNrgy Pvt Ltd., Gurgaon, India, is a Fuel Cell based energy and Power Management solution provider for the Oil & Gas, Telecom and Defense & Security industries to run/ provide back up for their mission critical devices/equipment/ sensors especially in remote areas that have limited power or are located off the Grid. Their Fuel cell use Methanol as a fuel, it is light weighed and producing high energy density. For Defense and security, they develop(a) EMILY 3000 fuel cell generator which produce maximum power up to 125 watt and function as charging device for up to 4 batteries simultaneously, (b) JENNY 600S produce power up to 25 watt, (c) JENNY 1200 produce power up to 50 watt,(d) JENNY ND Terra which reliably provides electricity for undercover monitoring, reconnaissance, and property protection and (e) The all-in one Energy Box based on fuel cell produce power up to 110 watt, it is an ideal power supply or back-up solution for remote, high altitude and glaciated areas which are located away from the grid. For industrial and commercial purpose, they develop (a) EFOY Pro 12000 Duo. of power output 500 watt, applicable for backup power supply for wind and telecommunication systems, off-grid power supply for surveillance, traffic management and environmental sensors and on-board use in control vehicles, (b) Model T1 is a 1.5 kW Direct Methanol Fuel Cells (DMFC) that excel in battery charging roles for a wide variety of stationary applications such as Telecom Towers/Repeaters base stations, Micro Grid for small villages and military posts, Fence lighting and surveillance, in the oil and gas industry (SCADA System and chemical injection plants), etc. and (c) Model T3 of power output 3 kW, it has same applications as of Model T1 [22].

Nishal Enterprises Pvt. Ltd., Mumbai, India offer a fuel cell system to meet the power requirements of telecom towers, small commercials, material handling and industrial applications. They develop (a) UPS fuel cell based on PEM fuel cell, store power on-site in the form of hydrogen cascades which is replenished through a low-cost hydrogen supply chain mechanism. It is best suitable for demand centers that have low cost hydrogen. (b) Electrolyser integrated with fuel cell capable to generate hydrogen on site through and store the hydrogen gas in the on-site cascade cylinders. It is best suitable for demand centers which have renewable energy as the primary source of energy. (c) Methanol reformer integrated with fuel cell store hydrogen gas required to power the fuel cell. This system can be very attractive solutions in regions where the electricity grid is unstable and it can be a complete off grid solution [23].

Conclusion

The Fuel cell technology has variety of portable and stationary applications due to its fuel flexibility and working efficiency. Fuel cells are developed such that they replace batteries and old electric power sources in most of the places. Polymer electrolyte membrane fuel cells are very much applicable for portable applications. Out of five types of fuel cell Alkaline fuel cells (AFCs) are very less attended for portable and stationary applications. Many organizations in the India also come forward to develop fuel cells technology and commercializing them. Fuel cell technology have the potential to replace traditional portable and stationary power supply.

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