INTRODUCTION TO FUEL CELLS

R.K. Shah
Subros Ltd., Noida, UP, India, E-mail: rkshah@gmail.com

A fuel cell is an electrochemical device (a galvanic cell) which converts free energy of a chemical reaction into electrical energy (electricity); byproducts are heat and water/steam if hydrogen and air are the reactants; in some fuel cell types, the additional byproducts may be carbon dioxide and leftover lower forms of hydrocarbons depending on the fossil fuels used. There is no combustion in this process and hence no NO\textsubscript{x} are generated. Sulfur is poison to all fuel cells so it must be removed from any fuel before feeding to any fuel cell type. A fuel cell produces electricity on demand continuously as long as the fuel and oxidant are supplied. For reference, primary cell or battery is also an electrochemical energy producing device (one-way chemical reaction producing electricity) and needs to throw away once the battery is discharged. A rechargeable or secondary battery is an electrochemical energy storage device having reversible chemical reaction producing or using electricity, but it also has a limited life.

The components of a fuel cell are anode, anodic catalyst layer, electrolyte, cathodic catalyst layer cathode, bipolar plates/interconnects and sometimes gaskets for sealing/preventing leakage of gases between anode and cathode. The stack of such fuel cells (a repeated stack of such components) is connected in series/parallel connections to yield the desired voltage and current. The anode and cathode consist of porous gas diffusion layers, usually made of highly electron conductivity materials (and having zero proton conductivity theoretically) such as porous graphite thin layers. One of the most common catalysts is platinum for low temperature fuel cells and nickel for high temperature fuel cells, and other materials depending on the fuel cell type. The electrolyte is made of such material that it provides high proton conductivity and theoretically zero electron conductivity. The charge carriers (from the anode to the cathode or vice versa) are different depending on the type of the fuel cells. Some details are presented in Table 1. The bipolar plates (or interconnects) collect the electrical current as well as distribute and separate reactive gases in the fuel cell stack.

| Table 1 Some characteristics of important fuel cells |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| PEMFC                           | DMFC                            | AFC                             | PAFC                            | MCFC                            | SOFC                            |
| Primary applications            | Automotive and stationary power | Portable power                  | Space vehicles and drinking water | Stationary power                 | Stationary power                 | Vehicle auxiliary power         |
| Electrolyte                     | Polymer (plastic) membrane      | Polymer (plastic) membrane      | Concentrated (30-50%) KOH in H\textsubscript{2}O | Concentrated 100% phosphoric acid | Molten Carbonate retained in a ceramic matrix of LiAlO\textsubscript{2} | Yttrium-stabilized Zirkondioxide |
| Operating Temp. Range           | 50-100°C                        | 0-60°C                          | 50-200°C                        | 150-220°C                       | 600-700°C                       | 700-1000°C                       |
| Charge Carrier                  | H\textsuperscript{+}            | H\textsuperscript{+}            | OH\textsuperscript{−}           | H\textsuperscript{+}            | CO\textsubscript{3}\textsuperscript{−} | O\textsuperscript{2}             |
| Prime Cell Components           | Carbon-based                    | Carbon-based                    | Carbon-based                    | Graphite-based                  | Stainless Steel                 | Ceramic                          |
| Catalyst                        | Platinum                        | Pt-Pt/Ru                        | Platinum                        | Platinum                        | Nickel                          | Perovskites                     |
| Primary Fuel                    | H\textsubscript{2}              | Methanol                        | H\textsubscript{2}              | H\textsubscript{2}              | H\textsubscript{2}, CO, CH\textsubscript{4} | H\textsubscript{2}, CO            |
| Start-up Time                   | Seconds-minutes                 | Seconds-minutes                 | Hours                           | Hours                           | Hours                           | Hours                           |
| Power Density kW/m\textsuperscript{3} | 3.8 – 6.5                      | ~0.6                            | ~ 1                             | 0.8 – 1.9                       | 1.5 – 2.6                       | 0.1 - 1.5                       |
| Combined cycle fuel cell Eff.   | 50-60%                          | 30-40% (no combined cycle)      | 50-60%                          | 55%                             | 55-65%                          | 55-65%                          |

The anode reaction in fuel cells is either direct oxidation of hydrogen, or methanol or indirect oxidation via a reforming step for hydrocarbon fuels. The cathode reaction is oxygen reduction from air in most fuel cells. For hydrogen/oxygen (air) fuel cells, the overall reaction is

\[
H_2 + \frac{1}{2} O_2 \rightarrow H_2O \quad \text{with } \Delta G = -237 \text{kJ/mol}
\]

(1)

where \(\Delta G\) is the change in Gibbs free energy of formation. The product of this reaction is water released at cathode or anode depending on the type of the fuel cell. The theoretical voltage \(E^\circ\) for an ideal H\textsubscript{2}/O\textsubscript{2} fuel cell at standard conditions of 25°C and 1 atmosphere pressure is 1.23 V. The typical operating voltage is about 0.6-0.7 V for high performance fuel cells.
Some general information for fuel cells: Cell voltage is 0.6 – 0.7 volts in high performance fuel cells and may be 0.2-0.4 V for DMFC. Stack voltage depends on the number of cells in a stack and their series/parallel connection. Cell current depends on the area (the size) of a cell. Energy density is the amount of energy stored in a fuel cell per unit volume. Power is voltage times current (VI) and also energy per unit time. Specific power is defined as power per unit mass. Cell power density is power per unit volume of the cell. A fuel cell for portable devices (laptop) needs low power density (few W) but needs high energy density so that one can run the laptop for a week for example. A car during high acceleration requires high power density. A car also needs high energy density so that one can drive the car with full fuel charge for about 400-500 km.

The major types of fuel cells being developed/used are: Proton Exchange Membrane Fuel Cells (PEMFC) for transportation power generation; Direct Methanol Fuel Cells (DMFC) for portable power generation; Alkaline fuel cells (AFC) for space program for producing electricity and drinking water for astronauts; Phosphoric Acid Fuel Cells (PAFC), Molten Carbonate Fuel Cells (MCFC) and Solid Oxide Fuel Cells (SOFC) for stationary power generation applications. Many fuel cells are also being developed as well as some of the foregoing fuel cells are also used for other applications than those mentioned.

Characteristic of fuel cell systems is generally high efficiency since it is not limited by Carnot efficiency. Efficiency can be very high (up to 55-65%) for the fuel cells with a combined cycle and/or cogeneration compared to the system efficiency of current power generation of up to about 40-45%. Fuel cell power can reduce costly transmission lines and transmission losses for a distributed system. No moving parts in fuel cells and a very few moving parts in the fuel cell system so that it has higher reliability compared to an internal combustion or gas turbine power plant.

Fuel cell power plant emissions are at least 10 times lower than the most stringent early 2000 California emissions standards. The fuel cell power plant has water as a byproduct so that it requires very low water usage, if any, compared to the steam power plants. Also the water discharged from fuel cell is clean and does not require any pretreatment. The fuel cell power plant produces very little noise compared to conventional steam or gas turbine power plant. Noise is generated only from the fan/compressor used for pumping/pressurizing the cathode air. No ash or large volume wastes are produced from fuel cell operation. However, the fuel cell power plant produces CO₂ emissions if fossil fuels are used for generating hydrogen. As mentioned earlier there are no NOₓ or SOₓ emissions from fuel cells.

Unique operating characteristics of fuel cell power plants are as follows. Beneficial operating characteristics of fuel cells saves cost, and other benefits include load following, power factor correction, quick response to generating unit outages, control of distribution line voltage and quality control; Can control real and reactive power independently; Control of power factor, line voltage and frequency can minimize transmission losses, reduce requiremnt for reserve capacity and auxiliary electric equipment; fuel cells have an excellent part load heat rate and can respond to transmission loads.

Fuel cell power plant provides good planning flexibility. Fuel cell performance is independent of the power plant size. In general, the efficiency does not deteriorate going from MW to kW to W size power plants. Fuel cells generally can meet the electric demand as needed without the cost of overcapacity or undercapacity. The unit can slow down or accelerate its response to the growth. Distributed power supply to consumers in any capacity can benefit in many ways for cost, reliability, high efficiency, meeting load demand, etc.

For automotive and stationary power generation applications, the fuel cells have very low emissions, high efficiency, quiet if no bottoming cycle is used, and gradual shift from fossil fuels to other fuels. However, the most challenges at present are: high cost and packaging, low performance and durability, hydrogen infrastructure, and availability of suitable fuels. References [1-4] provide more detailed information on the areas covered in this chapter.

Electrochemistry and Thermodynamics

The electrical work done in any system is represented by the Gibbs free energy – energy available to do external work, neglecting any work done by changes in pressure and/or volume. In a fuel cell, the external work involves moving electrons around an external circuit.

When we analyze any electrochemical reaction, there will be a change in the Gibbs energy of formation due to energy release. We evaluate it with the difference in the free energy of the products minus that of the reactants or input. The theoretical/ideal electrical potential \( E^0 \) for hydrogen/oxygen fuel cell is 1.23 V at 25°C and 1 atmospheric pressure. The theoretical electrical potential \( E \) for a fuel cell with operating pressure and temperature different from 25°C and 1 atmospheric pressure for hydrogen and oxygen is given by Nernst equation as follows.

\[
E = E^0 + \frac{RT}{2F} \ln \left( \frac{P_{H_2}P_{O_2}^{0.5}}{P_{H_2O}} \right)
\]

where all \( P \) are the operating partial pressures of appropriate reactants and products in atmospheric units, \( T \) is the temperature in K, \( R \) is the gas constant for a particular gas in J/kg K and \( F \) is the Faraday constant in C/gm mole. The theoretical operating voltage \( E \) increases with increasing partial pressures of hydrogen and concentration of oxygen or the system pressure, and decreases with increasing fuel and oxygen utilization (reducing \( P \)) and increasing operating temperature.
The actual useful voltage \( V \) obtained from a fuel cell with the load is different from the theoretical/ideal voltage \( E \) from thermodynamics. This is due to losses associated with the operation, fuel cell materials used, and the design. These losses are: ohmic \( i r \), activation \( \text{Aln}(i/i_0) \), fuel crossover and internal current leakage \( \text{Aln}(i/i_0) \), and mass transport or concentration losses \( \text{mexp}(ni) \) [Larminie and Dicks, 2003]:

\[
V = E - ir - \text{Aln}\left(\frac{i + i_n}{i_0}\right) + \text{mexp}(ni) \tag{3}
\]

where \( i \) – the current density, \( \text{A/cm}^2 \); \( r \) – electric resistance per unit area, \( \Omega/\text{cm}^2 \); \( A \) – coefficient in natural logarithm form of Tafel equation, \( \text{V} \); \( i_n \) – fuel crossover current density, \( \Omega/\text{cm}^2 \); \( i_0 \) – exchange current density at an electrode/electrolyte interface, \( \text{V} \); \( m \) – a constant, \( \text{cm}^2/\text{A} \). Usually the desired actual/operating cell voltage is about 0.6 to 0.7 V, although the methanol fuel cell may have one half or lower of that voltage. The typical voltage \( V \) versus current density \( i \) for a PEMFC and SOFC are shown in Fig. 1a and 1b. One can see that for the low temperature fuel cell (PEMFC), all losses are important while for the high temperature fuel cell, only the ohmic and concentration losses are important.

![Fig. 1 Voltage versus current density curve for a typical (a) low temperature and (b) high temperature fuel cells, from Larminie and Dicks (2003).](image)

There are many fuel cell efficiencies depending on the fuel cell type, fuel utilization and the fuel type. The overall fuel cell efficiency for a specified fuel cell stack is then

\[
\varepsilon_{fc} = \varepsilon_{cell} \varepsilon_{e} \varepsilon_{F} \varepsilon_{H} \tag{4}
\]

These efficiencies are defined as follows: \( \varepsilon_{cell} \) = the thermodynamic fuel cell efficiency, defined as the ratio of the electric energy produced divided by the enthalpy change of electrochemical reaction or energy released in burning the fuel; \( \varepsilon_{e} \) = electrochemical efficiency, defined as the ratio of the actual cell voltage \( V \) to theoretical maximum voltage \( E \); \( \varepsilon_{F} \) = Faradaic efficiency, defined as the ratio of experimental (actual) current \( I_{exp} \) to the maximum possible current \( I_{max} \); \( \mu_{H} \) = fuel utilization coefficient, defined as the actual fuel reacted to the fuel supplied to the fuel cell on a mass basis; and \( \varepsilon_{H} \) = hydrocarbon efficiency, defined as the ratio of the heating value of all fuel components that are converted electrochemically (e.g., \( \text{H}_2 \)) to the heating value of the fuel supplied (e.g., natural gas). Note that not all of the above fuel cell efficiencies are important for every fuel cell type to be discussed in this chapter. Note also that the total fuel cell efficiency is still 40-50% with all these factors for the fuel cells considered in this chapter except for DMFC. It is higher than any fossil fuel power generation by steam or gas turbine including microturbines.

**Proton Exchange Membrane Fuel Cells (PEMFC)**

The PEMFC is also referred to as the Solid Polymer Fuel Cell; the name is derived from the special “plastic” membrane used as an electrolyte. The components of a single cell are: an electron conducting anode (a porous gas diffusion layer as an electrode and an anodic catalyst layer), a proton conducting electrolyte (hydrated solid membrane), an electron conducting cathode (a cathodic catalyst layer and a porous gas diffusion layer as an electrode), and current collectors with the reactant (gas) flow fields. Current collectors are bipolar plates in a stack; they contain over 90% of the volume and 80% of the mass of a fuel cell stack. The bipolar plate is the most expensive part of the fuel cell. Platinum or platinum alloys in nanometer size particles are the electrocatalysts used with Nafion membranes. The anode-electrolyte-cathode assembly is referred to as Membrane Electrode Assemblies (MEAs), only a few hundred
micron thickness; it is the heart of PEMFC. If heat generated in the fuel cell due to exothermic reaction is large, cooling passages are provided by a central channel in each bipolar plate.

A stack of cells is connected in series, and cell stacks (modules) connected in series and parallel to obtain the desired current and voltage. Sources of pressurized air and CO free (very essential to have CO less than 10 ppm) hydrogen gas are required for generating the desired electric power. The cell voltage at the design point is around 0.7 V and power densities of up to 1 W/cm² of electrode area when supplied with hydrogen and air. Oxygen reduction is more complex and results in significant overpotential at the cathode. The PEMFC relies on the presence of liquid water to conduct protons effectively through the membrane, and moisturization of the membrane limits the operating temperature of the PEMFC. Systems for thermal management in the cells and water management in the MEAs are essential for efficient operation of the PEMFC. Use of pure oxygen instead of air results in about 30% performance improvement. The PEMFCs are used in applications that require small, medium and large electric power generation.

**Direct Methanol Fuel Cells (DMFC)**

The DMFC is a special form of low-temperature fuel cells based on the PEM technology. It produces power by direct conversion of liquid methanol (no need of hydrogen) to hydrogen ions on the anode side of the fuel cell. The DMFC has all fuel cell components (anode, cathode, membrane and catalysts) the same as those of a PEMFC. The system is simpler to use and easy to refill due to methanol in liquid form. The main difference between the DMFC and PEMFC is the sluggish reaction (significant activation overvoltages) at the anode and hence requires: (1) about the same amount of catalyst on the anode as on the cathode of the DMFC; (2) high surface area 50:50% Pt/Ru (more expensive bimetal) alloy as the anode catalyst to overcome the sluggish reaction; and (3) the catalyst loading 10 times higher than that for the hydrogen/air PEMFC. And still the DMFC results in the useful voltages only 0.2-0.4 V. Hence, DMFC can compete in the marketplace where higher costs are sustainable. There are a number of advantages for the methanol fuel cell: liquid fuel, high energy density, no reforming needed, no problem of membrane humidification, quick start-up, etc. There are several major drawbacks of this fuel cell: low power density due to poor kinetics of the anode reaction, significant fuel crossover, safety concerns, etc. Flooding by methanol/water mixture is required in DMFC, and CO₂ must be expelled quickly. In hydrogen PEMFC, flooding is highly undesirable and gas has to be drawn in. Currently, the immediate applications of DMFC are where low power but higher energy density is required, particularly for the applications where Lithium-ion batteries are used for portable power applications.

**Alkaline Electrolyte Fuel Cells (AFC)**

As the name indicates, the electrolyte is an alkaline solution for AFC (OH⁻ ion moving across the electrolyte). There are three types of AFCs: mobile electrolyte, static electrolyte and dissolved fuel. The first two are being used in the space program.

The AFCs have the major advantages of lower activation overpotential at cathode, typical high operating voltage (0.875 V), inexpensive electrolyte material; electrodes can be made from non-precious metals and no need for bipolar plates. Also, the water management problem is simpler than the PEMFC. The major disadvantages of the AFCs are: low power density; and CO₂ is poison. The first real application of fuel cells started with the space program in late 1950s with the AFC and they continue till today for power generation in the space program. The mobile electrolyte system was used in the first AFCs in 1940s and is used in terrestrial systems. The Shuttle Orbiter uses a static electrolyte system.

**Phosphoric Acid Fuel Cells (PAFC)**

This fuel cell operates at 200°C, is well developed and is commercially available. The PAFC, like PEMFC, uses gas diffusion electrodes. Platinum or platinum alloys are used as the catalyst at both electrodes. The carbon is bonded with PTFE (about 30-50% weight) to form an electrode support structure. Electrolyte is a matrix 0.1-0.2 mm thick made up of silicon carbide particles held together with a small amount of PTFE. The pores of the matrix contain 100% phosphoric acid by a capillary action. Bipolar plates are multi-component in which a thin impervious carbon plate serves to separate the reactant gases in the adjacent cells in the stack; separate porous plates with ribbed channels are used for directing gas flow. The stack consists of a repeating arrangement of a ribbed bipolar plate, the anode, electrolyte matrix and cathode. Cooling channels are provided in the bipolar plates to cool the stack. Water cooling is used with 100 kW and larger power generation systems. Since the freezing point of phosphoric acid H₃PO₄ is 42°C, the PAFC must be kept above this temperature once commissioned to avoid the thermal stresses due to freezing and thawing. There will be some loss of H₃PO₄ over long periods depending upon the operating conditions. Hence, generally sufficient acid reserve is kept in the matrix at the start. The operating current densities are 150-400 mA/cm². The operating cell voltages are 600-800 mV. The ohmic loss in PAFCs is small. Although 300-400 units have been sold for the clean uninterruptible power applications, the market for the PAFC has not picked up due to its high cost.

**Molten Carbonate Fuel Cells (MCFC)**
The solid oxide fuel cells operate at temperatures where certain oxidic electrolytes become highly conducting oxygen ions $\mathrm{O^{2-}}$. The oxides used are mixtures of yttria and zirconia first demonstrated by Nernst in 1899. Thus the charge carrier is an oxygen ion and not a proton. Overall cell reaction is the formation of water and standard reversible potentials are the same as for other hydrogen/oxygen fuel cells. The typical operating temperature of the SOFC is 700-1000°C. Very unique tubular SOFC design concept has been developed to avoid the sealing problem for preventing anode/cathode gas leaks at the operating temperature of about 950-1000°C (no seals are available at these temperatures). This fuel cell is very expensive and has low power density. It has been developed and proven the durability requirements; however, due to high cost, it has not been marketable. Planar fuel cells in about 5 kW power generation capacities are being developed now. SOFC is of considerable interest since it has considerably high system efficiency compared to other fuel cell systems with cogeneration as a result of high operating temperatures, and negligible deterioration in performance over several years.

**Solid Oxide Fuel Cells (SOFC)**

The solid oxide fuel cells operate at temperatures where certain oxidic electrolytes become highly conducting oxygen ions $\mathrm{O^{2-}}$. The oxides used are mixtures of yttria and zirconia first demonstrated by Nernst in 1899. Thus the charge carrier is an oxygen ion and not a proton. Overall cell reaction is the formation of water and standard reversible potentials are the same as for other hydrogen/oxygen fuel cells. The typical operating temperature of the SOFC is 700-1000°C. Very unique tubular SOFC design concept has been developed to avoid the sealing problem for preventing anode/cathode gas leaks at the operating temperature of about 950-1000°C (no seals are available at these temperatures). This fuel cell is very expensive and has low power density. It has been developed and proven the durability requirements; however, due to high cost, it has not been marketable. Planar fuel cells in about 5 kW power generation capacities are being developed now. SOFC is of considerable interest since it has considerably high system efficiency compared to other fuel cell systems with cogeneration as a result of high operating temperatures, and negligible deterioration in performance over several years.

**Fuel Processing/Reforming**

As mentioned earlier, the fuel cell electrochemically oxidizes hydrogen to generate electricity, heat and water/steam. Hydrogen as a gas or liquid is not available in nature. It must be produced from the following sources: (1) Fossil fuels (near term source of $\mathrm{H_2}$): natural gas, petroleum (gasoline, diesel, JP-8), and coal and coal gases; (2) Bio-fuels (such as produced from biomass, landfill gas, biogas from anaerobic digesters, syngas from gasification of biomass and wastes, and pyrolysis gas; generally they contain mixtures of $\mathrm{CH}_4$, $\mathrm{CO}_2$ and $\mathrm{N}_2$, together with various organic materials); (3) Chemical intermediates (methanol, ethanol, $\mathrm{NH}_3$, etc.); and (4) Renewable energy sources, such as solar, wind, hydro, geothermal, etc. from which electricity is generated (which is a non-continuous supply) and is used to electrolyze water to generate hydrogen. From the cost consideration, at present, fossil fuels (natural gas) are considered for hydrogen source. Bio-fuels and chemical intermediates have some specific applications. Renewable energy sources are not cost competitive today.

Fuel processing is defined as conversion of the primary fuel (gaseous or liquid hydrocarbons) supplied to a fuel cell system to the fuel cell gas ($\mathrm{H_2}$ and maybe CO) supplied to the stack. Each fuel cell type has some particular fuel requirements. The fuel needs to be hydrogen rich and should contain less than 5-10 ppm CO for PEMFC, 0.5% CO for PAFC, and CO acts as a fuel (through water shift gas reaction) for MCFC and SOFC. Natural gas (methane) is also fine for SOFC and internal reforming MCFC, but is not acceptable for PAFC and PEMFC. Sulfur must be removed from all fuels to less than 0.5-2 ppm since it is poison to all fuel cells. Major fuel processing techniques are steam reforming, partial oxidation (catalytic and non-catalytic), autothermal reforming, and other techniques such as dry reforming, direct hydrocarbon oxidation and pyrolysis. CO clean up techniques for low temperature fuel cells are preferential oxidation, methanation, separation by membrane. Special reforming techniques for high temperature fuel cells are Direct Internal Reforming (DIR), Indirect Internal Reforming (HIR), and a combination of both DIR and HIR. Considerable advancement has taken place to reform fossil fuels to get hydrogen.
Hydrogen Infrastructure, Production, Safety and Storage

Hydrogen infrastructure needs to be developed to produce hydrogen from some of the techniques mentioned in the previous paragraph. Hydrogen molecule is the smallest molecule and hence all joints in a fuel stack system must be very tight or a good number of joints should be eliminated from the system. Hydrogen is a highly volatile and flammable gas, but being very light, it immediately goes up in the atmosphere. Hydrogen safety issue is a very important consideration, although it is not as dangerous as the gasoline.

Hydrogen can be stored as a compressed gas or liquid, or in reversible or alkali metal and chemical hydrides. The advantages of storing hydrogen as a compressed gas are simplicity, indefinite storage time and no purity limits on the hydrogen. Metal hydride compounds must have the following characteristics: (1) The storage device must have important characteristic to release the hydrogen easily when desired. (2) The manufacturing process to store hydrogen in metal hydrides must be simple and inexpensive both from the cost and energy usage. (3) They must be safe to handle. Considerable R&D efforts and developments are going on for hydrogen infrastructure, production, safety and storage.

Fuel Cell Balance of Power Plant

In addition to the fuel cell stack system, the rest major systems of fuel cell power plants are: (1) Fuel reforming system that requires a fuel reformer, chemical reactors, heat exchangers, fans/blowers, burner, etc. Fuel flow rate to the fuel cell could use an ejector system to eliminate the fan for the fuel flow to the stack; (2) air management system that requires a compressor, turbine, heat exchangers, fan, motor, water tank, etc.; (3) power conditioning system that has inverter, converter, batteries, motor, etc.

We need to regulate the electric power output from the fuel cell stack since the voltage generated will not be constant, and will depend upon the operating current density (see Fig. 1) and power. Increasing the current will cause the voltage to fall in all electrical power generators, but this drop is much greater in a fuel cell. Voltage regulators, DC/DC converters and chopper circuits are used to control the fuel cell voltage to a fixed value, higher or lower than the fuel cell operating voltage. Fuel cell generates the DC power. If we need to connect to the grid lines or use all appliances and other business and household needs, the DC power needs to be converted to AC power using the inverters. Electric motors are used to drive any mechanical system by converting electrical power to the mechanical power. The fuel cell system requirements are as follows: The motors are used to circulate the reactant gases or cooling fluids, operate all the time when the fuel cell is in use, should have the highest efficiency and the longest life, and must not have sparks generated (a common occurrence in a brushed motor) which could be a disaster in the presence of hydrogen. Hence, the fuel cell requires brushless motors such as induction motors, brushless DC motors, and switched reluctance motors. For optimum cost of the system, the fuel cells are designed for maximum steady state power. The operating peaks are then taken care by rechargeable batteries or capacitors. When the fuel cell is not using the maximum power, the excess power is used to charge the batteries or the capacitors. This is the case in many systems, but if the power requirement is quite constant, there is no need for a hybrid system.

Concluding Remarks

A brief overview is presented in this chapter for introduction to various fuel cell types and associated issues. For further studies, there are many references available some of which are presented at the end [1-4]. Fuel cell technology is in the infant stage today, it has to compete with the current technology of power generation at the same or lower cost and the same or better reliability, durability and all other functional requirements. Methanol and other fuel cells will first be introduced commercially for portable power applications by about 2007 since the cost of these fuel cells are comparable with lithium ion and lithium potassium batteries. Fuel cell power plant for stationary power generation application will become acceptable and wide spread as the cost of such power plant becomes competitive with the current thermal/hydro/nuclear power plants. For transportation applications, fuel cells will utilize hydrogen as the fuel for fuel cells, generated at the fueling stations from fossil fuels or transported from the hydrogen generating station utilizing the renewable sources. In addition, infrastructure for hydrogen fueling stations needs to be developed before fuel cell operated vehicles become common. It may become reality by 2015 or later in developed countries. Within next 25-50 years, the fuel cell power plant use will become a reality in portable, stationary and mobile applications using a variety of fuels/methods for hydrogen generation. Eventually, with the renewable energy sources becoming cost effective for hydrogen generation, dependency on the fossil fuels will be diminished for electric power generation and also will eliminate the global warming.

References