Fuel Cell Technology

An Online Continuing Education Course for Engineers

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Introduction

Fuel cells are one of the cleanest technologies for generating electricity. Since there is no combustion, there are none of the pollutants commonly produced by boilers and furnaces. For fuel cell systems designed to consume hydrogen directly, the only products are electricity, water, and heat.

Fuel cells are electrochemical devices that convert chemical energy from fuels into electrical energy directly, promising power generation with high efficiency and low environmental impact. Because the intermediate steps of producing heat and mechanical work typical of most conventional power generation methods are avoided, fuel cells are not limited by thermodynamic limitations of heat engines, and because combustion is avoided, fuel cells produce power with minimal pollutants. However, unlike batteries, the reductant and oxidant in fuel cells must be continuously replenished to allow continuous operation. Hydrogen is the most common fuel source, and oxygen is the most common oxidizing agent.

Fuel cells are an important technology for a potentially wide variety of applications including on-site electric power for households and commercial buildings; supplemental or auxiliary power to support car, truck and aircraft systems; power for personal, mass and commercial transportation; and the modular addition by utilities of new power generation closely tailored to meet growth in power consumption. This course focuses solely on applications in the electric power industry.

The concept of fuel cells is not new. In fact, the first fuel cell is believed to have been built in 1838 by Sir William Grove, a Welsh physicist. His fuel cell is the basis of today’s phosphoric acid fuel cell. In the 1930s, Francis Thomas Bacon developed an alkaline fuel cell (AFC), which was used in NASA spacecraft in the 1960s. The alkaline fuel cell is sometimes referred to as a “Bacon fuel cell.”

One of the most promising applications for fuel cells is in distributed generation. Distributed generation involves small, modular power systems that are situated at or near their point of use. The typical system is less than 30 MW, used for generation or storage, and extremely clean.

Examples of technologies used in distributed generation include gas turbines and reciprocating engines, biomass-based generators, solar power, and photovoltaic systems, fuel cells, wind turbines, micro-turbines, and flywheel storage devices. See Table 1 for the size and efficiencies of selected systems.

Table 1
Attributes of Distributed Generation Systems

Type	Size	Efficiency, %
Reciprocating Engines	50 kW – 6 MW	35
Microturbines	10 kW – 300 kW	30
Phosphoric Acid Fuel Cell (PAFC)	50 kW – 1 MW	40
Solid Oxide Fuel Cell (SOFC)	5 kW – 3 MW	60
Proton Exchange Membrane Fuel Cell (PEM)	<1 kW – 1 MW	40
Photovoltaics (PV)	1 kW – 1 MW	NA
Wind Turbines	150 kW – 500 kW	NA

The market for distributed generation is aimed at customers dependent on reliable energy, such as hospitals, manufacturing plants, grocery stores, restaurants, and banking facilities. There is currently over 15,000 MW of distributed power generation operating in the U.S. There is also a demand for capacity additions that offer high efficiency and use of renewables as the pressure for enhanced environmental performance increases.

Some of the applications for distributed generation systems include:

- Peak shaving – Power costs fluctuate hour by hour depending on demand and generation; therefore, customers would select to use distributed generation during relatively high-cost, on-peak periods.
- Combined heat and power (CHP) – The thermal energy created while converting fuel to electricity would be utilized for heat in addition to electricity in remote areas, and electricity and heat for sites that have a 24-hour thermal/electric demand.
- Grid support – Strategic placement of distributed generation can provide system benefits and preclude the need for expensive upgrades and provide electricity in regions where small increments of new baseload capacity are needed.
- Standby power – Power during system outages is provided by a distributed generation system until service can be restored. This is used for customers who require reliable back-up power for health or safety reasons, companies with voltage-sensitive equipment, or where outage costs are unacceptably high.
- Remote/Standalone – The user is isolated from the grid.

Distributed generation systems have small footprints, are modular and mobile, making them very flexible in use. The systems provide benefits at the customer level and the supplier level. Benefits to the customer include high power quality, improved reliability, and flexibility to react to electricity price spikes. Supplier benefits include avoiding investments in transmission and distribution capacity upgrades by locating power where it is most needed and opening new markets in remote areas. The improved efficiencies also reduce greenhouse gas emissions.

However, several barriers and obstacles must be overcome before the distributed generation can become a mainstream service. These barriers include technical, economic, institutional, and regulatory issues. Many of the proposed technologies have not yet entered the market and will need to meet performance and pricing targets before entry.

Fuel cells have been hindered by high initial costs. However, costs are expected to decline as manufacturing capacity and capability increase, and designs and integration improve. The fuel cell systems offer many potential benefits as a distributed generation system. They are small and modular, and capital costs are relatively insensitive to scale. This makes them ideal candidates for diverse applications where they can be matched to meet specific load requirements. The systems are unobtrusive, with very low noise levels and negligible air emissions. These qualities enable them to be placed close to the source of power demand. Fuel cells also offer higher efficiencies than conventional plants. The efficiencies can be enhanced by using the quality waste heat derived from the fuel cell reactions for combined heat and power and combined-cycle applications.

This course explains the technical concepts of fuel cells and the status of the most promising fuel cell types under development today. The first chapter in this course will provide an overview of the technology. Subsequent chapters are devoted to the different types of fuel cells. The final chapter provides an overview of the current fuel cell market.

Chapter 1 - Fuel Cell Technology

Fuel cells come in many varieties; however, they all work in the same general manner. The core components of a fuel cell include three adjacent segments:

1. The anode,
2. The electrolyte
3. The cathode.

Figure 1 shows a simplified block diagram of a fuel cell.

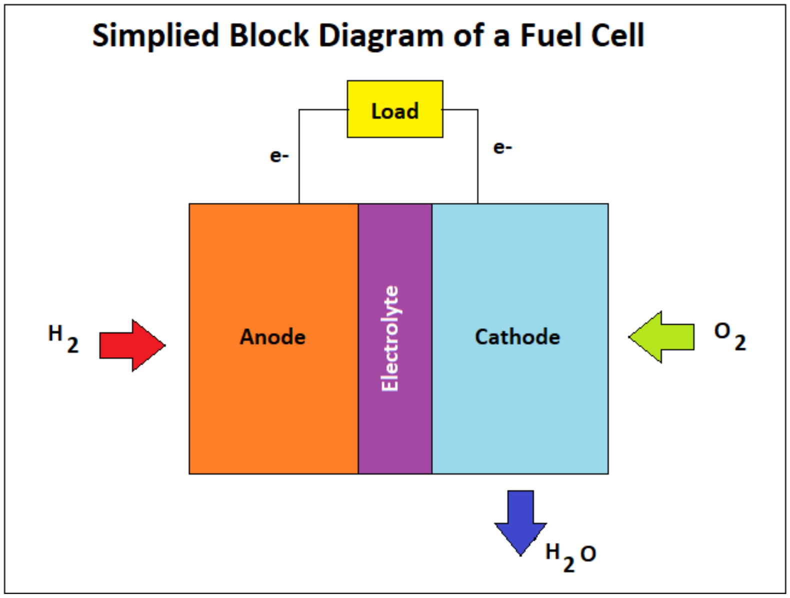

Figure 1

Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, and an electric current is created, which can be used to power electrical devices, normally referred to as the load.

At the anode, a catalyst oxidizes the fuel, usually hydrogen, turning the fuel into a positively charged ion and a negatively charged electron. The electrolyte is a substance specifically designed so ions can pass through it, but the electrons cannot. The freed electrons travel through a wire, creating the electric current. The ions travel through the electrolyte to the cathode. Once reaching the cathode, the ions are reunited with the electrons, and the two react with a third chemical, usually oxygen, to create water or carbon dioxide.

Design features in a fuel cell include:

- The electrolyte substance, which usually defines the type of fuel cell, and can be made from substances like potassium hydroxide, salt carbonates, and phosphoric acid.
- The fuel that is used. The most common fuel is hydrogen.
- The anode catalyst, usually fine platinum powder, breaks down the fuel into electrons and ions.
- The cathode catalyst, often nickel, converts ions into waste chemicals, with water being the most common type of waste.
- Gas diffusion layers that are designed to resist oxidization.

A typical fuel cell produces a voltage of 0.7 V at full rated load. To deliver the desired amount of energy, the fuel cells can be combined in series to yield higher voltage and in parallel to allow a higher current to be supplied. Such a design is called a fuel cell stack.

In this chapter, we look at cell structure and stacking, fuel cell systems, general characteristics, and the types of fuel cells.

Fuel Cell Structure

Fuel cell power systems have several components:

- Membrane electrode assem ctions take place,
- Stacks, in whi nnecting the cells to form units with the
- Balance of pla stream conditioning (including a fue electric power conditioning, a

In the following, an ove each of these categories.

Membrane Electrode A

The *membrane electrode* MEA converts chemical energy containe Components include the membrane, the on layers (GDLs). The basic physical structu nsists of an electrolyte layer in contact with an anode and side, as shown in Figure 1 above.