UTILITY ELECTRICITY FROM FUEL CELLS

CHANG H. LEE
〈李昌鎬. PROJECT ENG.
ENERGY RESEARCH CO.〉

ABSTRACT

The past three decades have been marked by a renewed interest in the fuel cell as a power source. The concept of an efficient converter for the direct production of electricity from commercially available fuels has taken up anew as a scientific challenge, and much progress has been made. The status of fuel cell technology development will be reviewed.

Invented in 1839, the fuel cell did not receive its first practical application until over a hundred years later, when hydrogen-oxygen fuel cells provided on-board power for the Gemini and Apollo spacecraft, but that was an exotic and expensive application. Now the fuel cell, vastly improved over the spacecraft versions, appears to have reached a stage where it can make a significant contribution to power supply for the utilities.

INTRODUCTION

A fuel cell is a highly efficient device that electrochemically converts fuel energy to electricity (Figure 1). In conventional generators, such as diesel or steam turbine generators, heat derived from combustion or nuclear fission provides the driving force to create mechanical energy to drive an electric generator. Thus, these conventional systems involve several energy conversion steps, and their efficiency is limited by the thermal energy step. The fuel cell, on the other hand, involves direct energy conversion, and its efficiency is not subject to limitations inherent in the thermal cycle.

The modular construction of fuel cell generators provides a size flexibility from kilowatt to megawatt capacities. The almost nonpolluting, practically noiseless operation permits location in large load centers and even on-site in urban, rural and residential areas, avoiding distance transmission and distribution losses. New modular units can be added in parallel to a fuel cell power plant. With a short installation time, rapid demand growth can be met with additional generation capacity and minimal excess capacity.

With current technology, phosphoric acid fuel cell power plants can utilize natural gas, synthetic natural gas, propane, or low-sulfur content light distillates. Second generation power plants (molten carbonate fuel cell) will have the capability to operate on diesel or kerosene type fuels.

DESCRIPTION OF THE FUEL CELL SYSTEM

Fuel cell power plants (Figure 2) will comprise three subsystems: the fuel conditioner, the fuel cell section, and the inverter. The fuel conditioner converts the hydrocarbon fuel into a gaseous mixture of hydrogen and carbon dioxide. Currently, steam reforming is used to react a fuel (gaseous or light distillate hydrocarbons) and water to produce hydrogen, carbon dioxide and carbon monoxide. If the product gas is to be used in acid fuel cells, the carbon monoxide is reated with steam in a shift converter to reduce its concentration to less than one percent. Eventually, large central station power plants using molten carbonate fuel cells could integrate a coal-gasification unit (in place of a reformer) with a fuel cell section at a projected coal-to-electricity efficiency of 50 percent.

The fuel cell power section consists of many individual cells in which the processed fuel and oxygen from the air are reacted to produce direct current electricity. A number of these cells are connected electrically in series to generate hundreds of volts. Sufficient cell stacks are connected in parallel to produce the desired power level, which may be kilowatts to megawatts. Three components of a single fuel cell are (Figure1): (1) an anode, where oxidation of the fuel occurs, (2) a cathode, where reduction of the oxidant occurs, and (3) an electrolyte, which separates the anode and cathode and conducts the required ions from one to the other.

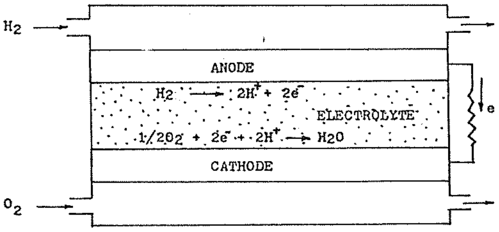

Figure 1 . Concept of a Fuel Cell.

The ideal potential of each cell is generally between 1 and 1.2 volts and is related to the sum of the free energy changes occurring at each electrode. The current, on the other hand, is directly related to the area of the cell. Therefore, voltages higher than one volts are generally obtained by stacking fuel cells in series and current increases are obtained by increasing the cell area. Because the conversion of fuel energy to electricity occurs at the molecular level (a fuel cell is not a heat engine), essentially the same conversion efficiency is attainable for any plant size and whether the plant is operating at full or partial capacity. Actually, unlike conventional generation equipment, fuel cell efficiency increases as load is reduced from the full rated power of the cell.

The last subsystem of the fuel cell power plant is a static inverter that converts the d-c output of the fuel cells to a-c. The inverter must be carefully designed and controlled so that it produces an electronically compatible wave form and synchronous frequency characteristics for integration with conventional electrical supplies.

FUEL CELL EFFICIENCY

In a conventional power generation by means of a heat engine, a multistage process is required. The fuel is first burned to give hot combustion gases. These are then used either directly or to generate steam as the working fluid. The heat engine or turbine drives an electric generator which produces electricity. The fuel cell system consists simply of an electrochemical generator as described before.

In the case of the heat engine, its themal efficiency is given by the work produced W divided by the calorific value of the fuel $\triangle H$.

$$Nt = W/\triangle H \qquad (1)$$

The maximum amount of work done by a heat engine is determined by the Carnot cycle and given by

$$W = \triangle H T_1 - T_2/T_1 \qquad (2)$$

where T_1 is the inlet temperature and T_2 the outlet temperature. The maximum Carnot efficiency Nc for a heat engine thus becomes

$$Nc = (T_1 - T_2)/T_1 \qquad (3)$$

Further, reduced by such factors as combustion

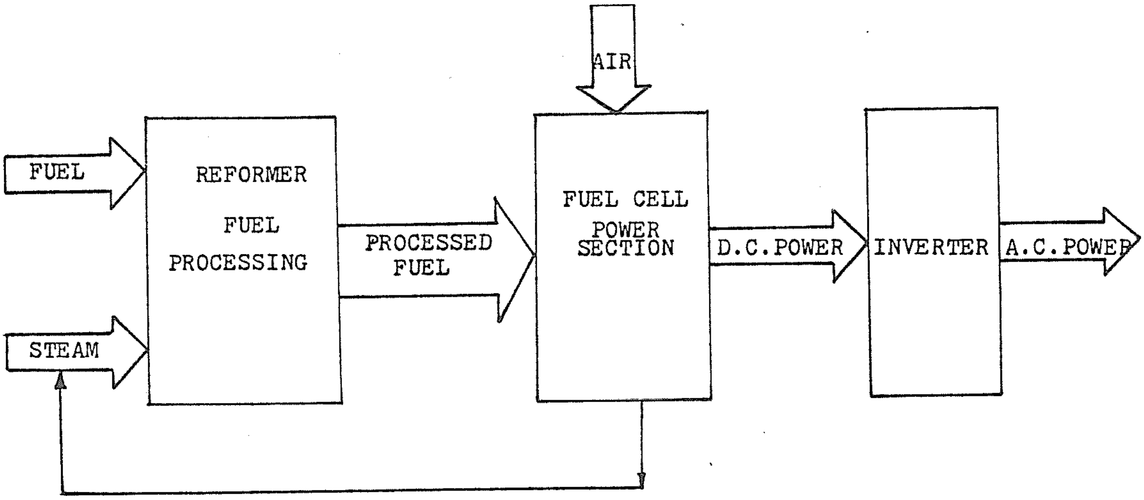

Figure 2. Fuel Cell Power Plant System

inefficiency, heat, friction, and generator losses, the overall efficiency for most systems, is less than 35% (Figure 3).

The thermal efficiency of the electrochemical system Ne, which operates isothermally rather than through a temperature cycle, is determined by

$$Ne = \triangle G / \triangle H \qquad (4)$$

Maximum efficiency of 97% for a molten carbonate fuel cell operating at 650°C and 1 atmosphere are obtained.

FUEL CELL STATE OF THE ART

The concept of the fuel cell was proven in real hardware terms in 1967 when the Apollo space program succeeded in putting man onto the moon. All of the life support and communications on board the Apollo command and service modules were supplied by hydrogen-oxygen fuel cells. Previously, all the Gemini missions had also been powered by fuel cells. Detailed descriptions are given in reference (2). These aerospace systems proved the concept but did not resolve problems of cost and fuel choice that face commercial application of fuel cells.

Over the past twenty years, the problems have been much better defined, many answers have been found, and fuel cells can be seen as a commercial possibility for the early 80's. A number of altenate fuel cell concepts are now under active development throughout the world. In the United States, aside from space and military applications, the emphasis, in the areas of general consumer and industrial needs, has been on fuel cells that can utilize the fossil fuel resources. The U.S. fuel cell technology nearest to commercial use is the phosphoric acid system. Under the program called TARGET (Team to Advance Research for Gas Energy Transformation) sponsored by Pratt & Whitney and a consortium of gas utilities, the 4.5 megawatt demonstration plant is in completion stage in New York city and is scheduled to be operated for 6,700 hours.

The electrolyte of the phosphoric acid cell is an aqueous solution of phosphoric acid in a porous matrix. Porous carbon electrodes are catalized with small quantities of a nobel metal such as platinum. This system uses steam reforming of natural gas or naphtha and shift conversion to reduce carbon monoxide content, producing a hydrogen-carbon dioxide fuel mixture for the cell. At the present stage of development, acid fuel cells require relatively pure hydrogen. To produce a suitable fuel by such coal gasification may require costly cleanup to remove hydrogen sulfide, ammonia, and other impurities. Efforts are being made to reduce the cell sensitivity to impurities or to develop more ecomomic fuel processing systems.

The most promising of the next generation of fuel cells to follow the phosphoric acid cells is the molten carbonate fuel cell. The latter uses alkali metal carbonates in a ceramic matrix as the electrolyte. At room temperature, the electrolyte mixture is a solid and resembles a ceramic tile, At the cell operating temperature 1200° F, the carbonates are molten and serve as good ionic conductors. The porous nickel electrodes do not require nobel metal catalysts because, at the cell temperatures, nickel is sufficiently active to act as a catalyst.

The main advantage of the molten carbonate cell is the high power density that is procuced at higher voltage levels than can be accomplished with first generation phosphoric acid cells. In addition, the cell will tolerate higher levels of impurities in both the fuel and air streams, and the higher temperature of the molten carbonate cell permits more efficient use of cell waste heat in integrated systems. In such a system, the heat could be recovered to generate steam for fuel processing or generate additional power with a bottoming cycle.

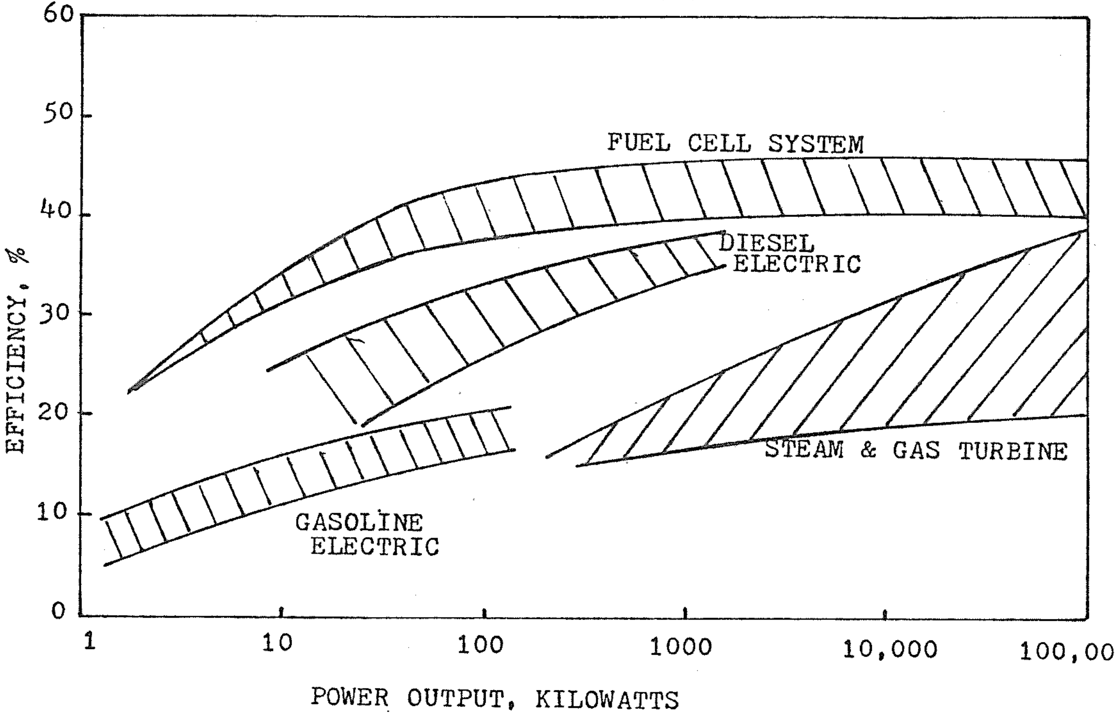

Figure 3. Power System Efficiency Comparison.

THE FUTURE FOR THE FUEL CELLS

The 40% conversion efficiency of current fuel cells offers marked improvement over the average 22% efficiency of gas turbines. In 10 years, fuel cells should have up to 50% efficiency in converting oil and coal to electricity and even higher efficiency when waste heat utilization is employed. With present technology, the mid 1980's could also see smaller fuel cell units providing electrical and thermal energy to shopping centers, building complexes, and small industry. Savings of 50% of present fuel requirements would be made possible by fuel conversion efficiency, utilization of waste heat, and elimination of transmission and distribution losses.

A number of other applications are conceivable: conversion of methane vented from coal mines, vehicular propulsion, the use of gaseous fuels produced by pyrolysis and conversion of urban waste and sewage sludge, and the use of waste hydrogen from petroleum and electrolytic processes.