Chinese J. Chem. Eng., **14**(3) 349—356 (2006)

Daily Operation Optimization of a Residential Molten Carbonate Fuel Cell Power System Using Genetic Algorithm*

LI Yong(李勇), CAO Guangyi(曹广益) and YU Qingchun(余晴春)**
Institute of Fuel Cell, Shanghai Jiaotong University, Shanghai 200030, China

Abstract To decrease the cost of electricity generation of a residential molten carbonate fuel cell (MCFC) power system, multi-crossover genetic algorithm (MCGA), which is based on "multi-crossover" and "usefulness-based selection rule", is presented to minimize the daily fuel consumption of an experimental 10kW MCFC power system for residential application. Under the operating conditions obtained by MCGA, the operation constraints are satisfied and fuel consumption is minimized. Simulation and experimental results indicate that MCGA is efficient for the operation optimization of MCFC power systems.
Keywords molten carbonate fuel cell power system, fuel consumption, operation optimization, multi-crossover, residential fuel cell, genetic algorithm

1 INTRODUCTION

Molten carbonate fuel cell (MCFC) power system is a new promising power generation device, which has high efficiency, low emission and perfect cogeneration capability[1]. For a residential MCFC power system, the cost of electricity generation should be minimized by decreasing daily fuel consumption. The operating condition that includes fuel cell current density, flow rate of fresh air and cathode outlet gas recycle ratio is essential for the fuel consumption of system. Therefore, the optimization of operating conditions is necessary.

The efficiency of fuel cell as a function of fuel cell voltage was defined[2,3] and the effects of system configuration and operating condition on MCFC power system efficiency were studied based on process simulation[4]. Au *et al.* studied the influence of operating temperature on the efficiency of a combined heat and power fuel cell plant[5]. But the problem how to decide the optimal operating condition for minimization of fuel consumption in daily operation is not explored.

In the operation of residential MCFC systems, power consumed by gas supply devices is auxiliary for the system, which will increase the total fuel consumption when it is supplied by the MCFC system itself. To minimize fuel consumption, the optimization of operation should be carried out with respect to operating conditions including current density of fuel cell, cathode outlet gas recycle ratio and flow rate of fresh air. Other operating parameters are fixed in practical operation or have little influence on fuel cell efficiency.

MCFC operation optimization is subject to certain constraints. Since the model is a complex nonlinear function of operating conditions, genetic algorithms (GAs) that have the ability of multi-model function search can be utilized. There are several genetic algorithms[6—8] for the search of multi-model functions, but their operations are complex, and additional operations are needed.

In this paper, we presented the multi-crossover genetic algorithm (MCGA) that can be used to the optimization of multi-model functions. And this algorithm is utilized to the operation optimization of an experimental 10kW MCFC power system for residential application.

2 MODEL FOR MCFC OPERATION OPTIMIZATION

The schematic of the MCFC power system studied is shown in Fig.1. An external reformer converts natural gas into hydrogen rich gas, which is supplied to the anode compartment of the MCFC stack.

In this paper, we assume that the composition of anode gas is fixed and expressed as:

$$S_a \equiv \{H_2, CO_2, H_2O\} \tag{1}$$

Received 2005-05-31, accepted 2006-03-30.
* Supported by the High Technology Research and Development Programme of China (No.2002AA517020).
** To whom correspondence should be addressed. E-mail: 023liyong@sjtu.edu.cn

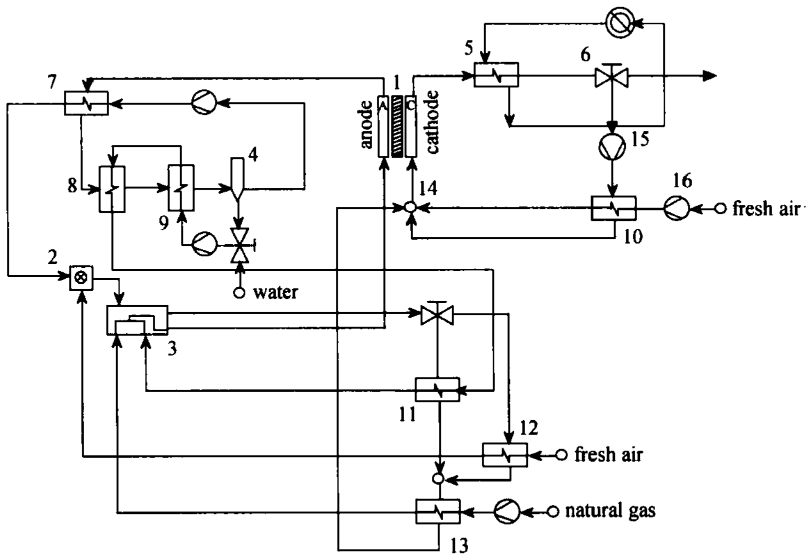

Figure 1 Schematic of a kind of MCFC power system
1—MCFC stack; 2—combustion chamber; 3—reformer; 4—moisture separator; 6—splitter; 5,7—13—heat exchanger; 14—mixer; 15—blower; 16—compressor

The set of cathode gas species is

$$S_c \equiv \{O_2, N_2, CO_2\} \quad (2)$$

The ordering is used to refer to individual gas species (*e.g.* $x_{a,2}^{in}$ is the mole fraction of CO_2 in anode gas).

The flow rate of anode gas is calculated from the Faraday's law of electrolysis:

$$N_a^{in} = \frac{iA_{total}}{2FU_{H_2}x_{a,H_2}} \quad (3)$$

The mixture of fresh compressed air, recycled anode outlet gas and recycled cathode outlet gas is supplied to the cathode compartment. The recycled cathode outlet gas flow rate is

$$N_c^{re} = R_y(N_c^{in} - 1.5r_{H_2}) \quad (4)$$

The flow rate of recycled anode outlet gas is

$$N_a^{re} = N_a^{in}x_{a,CO_2} + r_{H_2} \quad (5)$$

The consumption rate of hydrogen is

$$r_{H_2} = \frac{iA_{total}}{2F} \quad (6)$$

The flow rate of cathode inlet gas is

$$N_c^{in} = N_c^{re} + N_a^{re} + N_{air}^{in} = \frac{N_{air}^{in} + N_a^{in}x_{a,CO_2} - 1.5r_{H_2}R_y + r_{H_2}}{1 - R_y} \quad (7)$$

The flow rate vector of gas species in the cathode inlet gas is

$$[N_{c,O_2}^{in} \quad N_{c,N_2}^{in} \quad N_{c,CO_2}^{in}]' = \left[\frac{0.21N_{air}^{in} - 0.5r_{H_2}R_y}{1-R_y} \times \frac{0.79N_{air}^{in}}{1-R_y} \times \frac{N_a^{in}x_{a,CO_2} + r_{H_2}(1-R_y)}{1-R_y}\right]' \quad (8)$$

In the operation of a MCFC stack, the cathode gas is utilized to control the temperature of stack, and the flow rate of cathode gas is excessive above that required by the reaction.

To calculate the flow rate of cathode inlet gas, the MCFC stack model is required.

The cell voltage model of MCFC[9] is

$$E_{eq} = E_0 + \frac{RT^s}{2F}\ln\left(\frac{p_{a,H_2}p_{c,O_2}^{0.5}p_{c,CO_2}}{p_{a,H_2O}p_{a,CO_2}}\right) \quad (9)$$

$$E_0 = 1.2723 - 2.7645\times10^{-4}T^s \quad (10)$$

$$V_{cell} = E_{eq} - i(R_{ohm} + \eta_a + \eta_c) \quad (11)$$

$$R_{ohm} = 0.5\times10^{-4}\exp\left[3016\left(\frac{1}{T^s} - \frac{1}{923}\right)\right] \quad (12)$$

$$\eta_a = 2.27\times10^{-9}\exp\left(\frac{6435}{T^s}\right)p_{a,H_2}^{-0.42}p_{a,CO_2}^{-0.17}p_{a,H_2O}^{-1.0} \quad (13)$$

$$\eta_c = 7.505\times10^{-10}\exp\left(\frac{9298}{T^s}\right)p_{c,O_2}^{-0.43}p_{c,CO_2}^{-0.09} \quad (14)$$