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OPTIMAL CONTROL OF PROTON EXCHANGE MEMBRANE FUEL CELL BASED ON PARTICLE SWARM OPTIMIZATION AND GENETIC ALGORITHM

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Abstract

Since the operation of a Proton Exchange Membrane Fuel Cell (PEMFC) is extremely nonlinear process as well as its parameters change when it is operating, a designer can't easily to control it; accordingly conventional controllers cannot satisfy the control objectives as well as the intelligent controllers. Thus, in this paper an intelligent controller is proposed for fuel cell stack control system based on Particle Swarm Optimization (PSO). In order to analyze the efficiency of this method, the results are compared with other intelligent controller based on Genetic Algorithm (GA). The simulation results demonstrate the high performance capability of both proposed controllers in terms of precise and convergence speed.

Keywords: Intelligent controller, Genetic Algorithm, Particle swarm optimization, Proton exchange membrane fuel cell.

1. Introduction

Due to the pollution resulted from using of fossil fuels and increasing demand for energy, the renewable energy resources have been mostly regarded in recent years. In past decades fuel cells with many reasons such as excellent reliability, high efficiency and their low emissions to the environment have been considered by researchers [1]. Among of various kinds of fuel cells, most attention has been attracted toward Proton exchange membrane fuel cell (PEMFC) due to many advantages such as low operating temperature, high power density, low noise, light weight and so on [2].

Fuel cell is a new device for generating electrical power that directly converts hydrogen and oxygen chemical energy to electrical energy during a chemical reaction. PEMFC is a multi-input and multi- output system with nonlinear relations between its inputs and outputs which some of its parameters change during of time, so the controlling of PEMFC is very hard job and the Conventional controllers can't satisfactory control it.

In recent years many models and controllers have been proposed in literature to control the PEMFC and some of them have given satisfactory results. In [3] PEM fuel cell has been successfully modelled by support vector machine. The authors in [4] have developed an adaptive control using neural networks and approximate models, which achieved a good performance of the controller.

In this paper the objective is to propose a new control strategy using the intelligent methods of Particle Swarm Optimization and Genetic Algorithm for control of PEMFC voltage. At first the common model of PEMFC is introduced and the controlling of the system is done based on this model. Since the output voltage of fuel cell is affected by hydrogen and oxygen partial pressures, by precise regulation of these gases the output voltage can be retained constant when the current changes.

This paper is arranged as follows. In section II, existing dynamic model of PEMFC is presented. PSO and GA algorithms are briefly introduced in section III. Section IV indicates the topology of proposed controllers. Simulation results are stated in section V and finally the conclusion is situated in section VI.

2. PEMFC Modeling

PEMFC is an electrochemical device that can produce electricity as long as the hydrogen and oxygen gases are supplied to it. The chemical reactions that occur at the PEMFC sides are as follows [1]:

$$\text{Anode side: } H_2(g) \longrightarrow 2H^+ + 2e^- \tag{1}$$

$$\text{Cathode side: } 2H^+ + 2e^- + 0.5O_2 \longrightarrow H_2O \tag{2}$$

Then, the full reaction occurred in fuel cell is:

$$H_2 + 0.5O_2 \longrightarrow H_2O + heat + electricity \tag{3}$$

Several analytical and experimental models to indicate the PEMFC internal behaviour have been introduced in literature. Based on developed model in [1] the electrical equivalent circuit for a single fuel cell can be shown by Fig. 1.

Using the equivalent circuit the cell voltage can be represented by (4) [1]:

$$V_{fc} = E_{Nernst} - V_{act} - V_{ohmic} - V_{con} \tag{4}$$

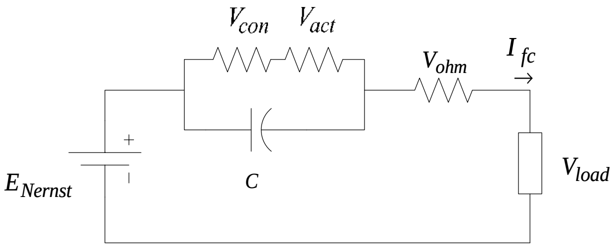

Fig. 1. Electrical equivalent circuit of single fuel cell

In the equation above, E_{Nernst} is the PEMFC open circuit voltage and indicates the reversible voltage. V_{act} is activation voltage drop, including anode and cathode. V_{ohmic} is ohmic voltage drop that results from the resistance to the electrons transfer through the collecting plates and carbon electrodes, and the resistance to the protons transfer through the solid membrane and V_{con} represents the voltage drop which is caused due to the reduction in concentration of the reactant gases. The mentioned voltages can be calculated by following expressions [1].

$$E_{Nernst} = 1.229 - (T - 298.15)(0.85\times 10^{-3}) + 4.31\times 10^{-5} T[Ln(p_{H_2}) + \frac{1}{2} Ln(p_{O_2})] \tag{5}$$

Where T is the cell operation temperature in (K); P_{O2} and P_{H2} are the partial pressures of oxygen and hydrogen (atm).

$$V_{act} = -[z_1 + z_2 T + z_3 T \cdot Ln(c_{O_2}) + z_4 T \cdot Ln(I_{fc})] \tag{6}$$

Where I_{fc} is the fuel cell operating current (A), the z_i are parametric coefficients for each cell and C_{O2} is the consideration of oxygen in the catalytic interface of the cathode (mol/cm^3).

$$V_{ohmic} = I_{fc}(R_m + R_c) \tag{7}$$

Where R_C shows the resistance to the transfer of protons through the membrane usually considered constant and R_m represents the equivalent resistance of the membrane which is calculated by:

$$R_m = \frac{r_m . l}{A} \tag{8}$$

Where ρ_m is the specific resistivity for the membrane for the electron flow (Ω.cm), A is the cell active area (cm^2) and r_m is the thickness of membrane (cm).

$$V_{con} = -b.Ln\left(1 - \frac{J}{J_{\max}}\right) \tag{9}$$

Where b (V) is a constant value which depends on the cell operation state and J (A/cm^2) is the current density of the cell.

As the equivalent circuit indicate, the PEMFC has also a dynamic behaviour. This dynamic behaviour is caused due to one phenomenon known as “charge double layer”. There is a charge accumulation on the surfaces of two materials when are differently charged and are in contact. The charge layer on the interface electrode/electrolyte acts as storage of electrical charges and energy and behaves as an electrical capacitor. Therefore, it can be considered as a first order delay that exists in activation and concentration voltage drops. The time constant, associated with this delay can be calculated by [1]:

$$t = c \cdot R_a \tag{10}$$

The parameter of C is the system equivalent capacitor (F) which is about some few Farads. The equivalent resistance R_a is determined from the cell output current and of the calculated activation and concentration voltages.

$$t = c.R_a = c.\left(\frac{V_{act} + V_{con}}{I_{fc}} \right) \tag{11}$$

In broad terms, the capacitive effect ensures the good dynamic performance of the cell, since the voltage moves smoothly to a new value in response to a change in the load current [1].

In the wide rang to use in large demands, several fuel cell must be connected together, forming a stack, which overall voltage is the summation of voltage of fuel cells.

3. PSO and GA

3.1.PSO algorithm

Particle swarm optimization is an optimization method based on population which was proposed by Kennedy and Eberhart in 1995 [5]. This algorithm is inspired by social search for food by birds and fishes. In PSO, each particle is a representative of a solution for the problem and moves in the search space with a velocity according to its own previous best solution and its group’s previous best solution [5]. Some of interesting characteristics of PSO are it’s simplicity of application and its high speed as compared to other evolutionary optimization methods.

In PSO based on following equations, particles update their situations and move in search space as long as to converge to the optimal solution [5]:

$$\begin{aligned} v_i(t+1) = w.v_i(t) + c_1.rand_1\left(p_i(t) - x_i(t)\right) \\ + c_2.rand_2\left(g(t) - x_i(t)\right) \end{aligned} \tag{12}$$

$$x_i(t+1) = x_i(t) + v_i(t+1) \tag{13}$$

Where

- $v_i(t+1)$ is the updated speed vector of the ith particle
- c_1, c_2, w are the weighting factors
- $x_i(t+1)$ is the updated position of the ith particle
- $rand_1, rand_2$ are random coefficients
- $p_i(t)$ is the best position of the ith particle
- $g(t)$ is the best global position of particles

3.2. GA algorithm

The basis of Genetic Algorithm is the random search of space. GA in more times converges to the optimum solution and as compared to conventional optimization methods has some differences. Because of GA for searching the space, selects several initial points thus don’t fall in local minimums. Stages of Genetic Algorithm are shown bellow [6]:

- objective function
- production of initial population
- selection

- crossover
- mutation
- Stopping criteria.

GA algorithm has been discussed is many literatures. Therefore in here, we avoid from more details.

4. Proposed Control Design

In this paper the aim is to propose a control strategy using the Particle Swarm Optimization for control of PEMFC voltage. Since the output voltage of fuel cell is affected by hydrogen and oxygen partial pressures, with precise regulation of these gases, the output voltage can be retained constant when the current changes.

Since the output voltage of cell changes when the current changes, proposed controller finds the optimal hydrogen and oxygen partial pressures that minimize the objective function and applies to system. The objective function is defined by deviation actual output voltage from desired voltage.

$$Obievtive-Function=\left|V_{ref}-V_S\right| \tag{14}$$

Where V_{ref} is the reference voltage and V_S is the output voltage of the PEMFC stack. In this paper finding optimal pressures in each time is calculated by using Particle Swarm Optimization and Genetic Algorithm and then they are applied to the system.

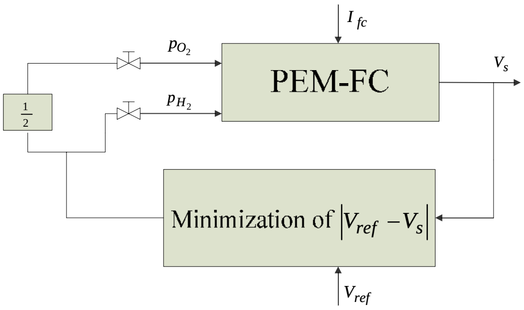

Fig. 2. Schematic of proposed controller for PEMFC

Since the stoichiometric consumption rate for the two gases is constant, the oxygen partial pressure is considered in this controller half of the hydrogen partial pressure. Therefore in the control system, only one controller has been adopted in conjunction with two independent gains, one for hydrogen line actuator and the other for the oxygen line actuator [7]. Schematic of the control system is shown in Fig.2.

5. Simulation Results

This paper makes use of a PEMFC which its parameters are shown in TABLE I, in order to test the proposed control design. The control goal is to adjust the stack voltage at 22 (V). Fig. 3 shows the variation of load current. The output voltage of stack with the PSO controller is indicated in Fig. 4 and calculated optimal hydrogen and oxygen partial pressures for the system are indicated in Fig. 5. The output voltage of stack with the GA controller is indicated in Fig. 6 and calculated optimal hydrogen and oxygen partial pressures are shown in Fig. 7.

Table1. PEMFC Parameters

Param.	Value	Param.	Value
n	32	ζ_2	0.00286
T	$333\ K$	ζ_3	7.6×10^{-5}
A	$64\ cm^2$	ζ_4	-1.93×10^{-4}
l	$178\ \mu m$	ψ	23
P_{H2}	$1{\sim}3\ atm$	J_{max}	$469\ mA/cm^2$
P_{O2}	$1{\sim}3\ atm$	J_n	$3\ mA/cm^2$
B	$0.016\ V$	I_{max}	$30\ A$
R_C	$0.0003\ \Omega$	C	$3\ F$
ζ_1	-0.948		

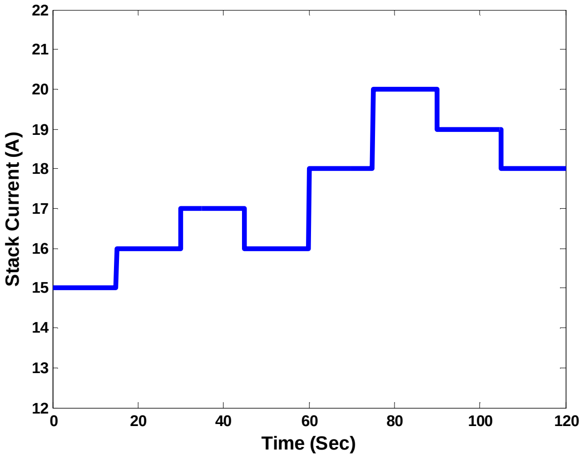

Fig. 3. Variation of the applied load current to the PEMFC system

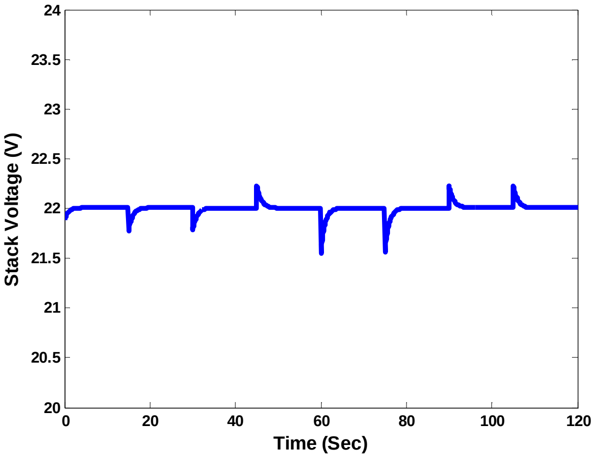

Fig. 4. Stack voltage with the PSO controller which is fixed at 22 (V)

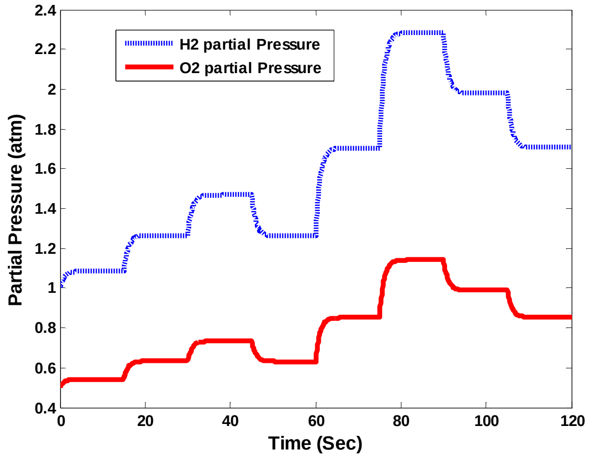

Fig. 5. Calculated optimal partial pressures by the PSO controller

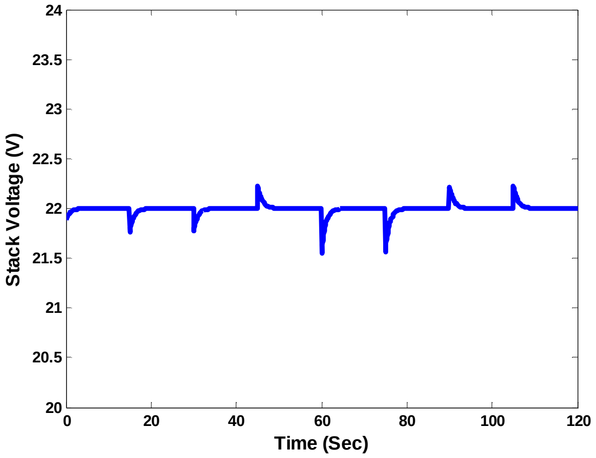

Fig. 6. Stack voltage with the GA controller which is fixed at 22 (V)

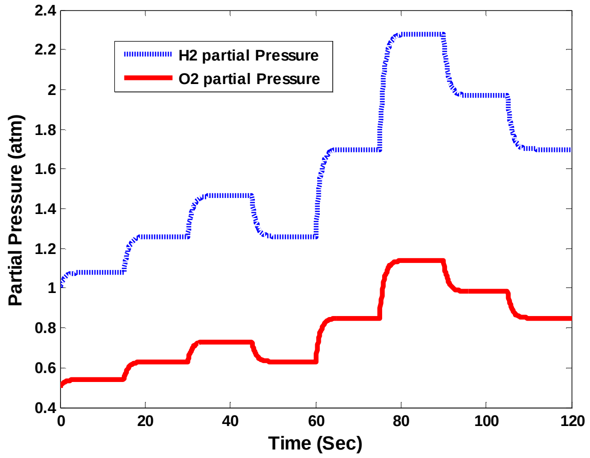

Fig. 7. Calculated optimal partial pressures by the GA controller

The simulation results show the desired performance of controllers. Both controllers have approximately the same precision to regulate the stack voltage at 22 (V) but PSO controller in terms of the lasted time for finding the optimal partial pressures acts better than GA controller. Moreover, the calculated partial pressures are same.

6. Conclusion

In this paper a new controller based on PSO and GA intelligent algorithms is developed to control the voltage of PEMFC stack. Design and simulation is performed and the obtained results show the efficiency of both controllers.

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