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Adjusting Parameters of Lead Lag Controller Using Simulated Annealing to Control Fuel Cell Voltage

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Abstract: In this study, a Lead Lag controller is introduced for fuel cell. This fuel cell is of Proton Exchange Membrane Fuel Cells (PEMFCs) type which will be introduced and implemented, and then to control the voltage of the fuel cell during load changes, an optimal controller is proposed based on Simulated Annealing (SA) algorithm. Fuel cell output voltage should be kept in a constant value during the load variations. In order to use this algorithm, at first, the problem is formulated as an optimization problem including the objective function and constraints, then SA method is utilized to achieve the most suitable controller. Simulation are performed for load changes in time domain. Simulation results show the effectiveness of the proposed controller and its accuracy.

Key words: Lag lead controller, optimal control, PEMFC, simulated annealing

INTRODUCTION

Proton Exchange Membrane Fuel Cells (PEMFCs) consist of a cathode and an anode as well as a proton conducting like an electrolyte between the anode and cathode. Hydrogen gas obtained from the methanol is inserted to the end of the anode blade (negative electrode), and also oxygen or air to the end of the positive electrode of the cell (cathode) (Mo *et al*., 2005).

To produce electrical energy using fuel cell, it is important to fix the output voltage of the fuel cell for different loads to supply loads with high quality power. However, fuel cell output voltage changes for different loads, to keep constant fuel cell voltage, using a controller is indispensable. the simplest type of controllers usually used are PID or Lag Lead.

In Mo *et al*. (2005), a type of fuzzy controller is proposed to control the fuel cell output voltage. In order to control the voltage and current of the fuel cell, in (Anucha *et al*., 2007), BP and RBF networks are used. The speed and accuracy of the proposed algorithms are satisfied for this system. In Yanjun *et al*. (2006), artificial neural networks are used to control the temperature of the fuel cell. However, to achieve an efficient control, in (Almeida and Simoes, 2003) an optimized neural controller with Cerebellar Model Articulation Controller (CMAC) is utilized.

The studied fuel cell is of multiple fuel cells, however, it is assumed that the anode and cathodes mass are compacted just in one fuel cell (Liyan *et al*., 2006).

Proposed methods are used to control only one parameter of the fuel cell in which just the fuzzy methods or neural network are used. Some of these systems initially detect and then control the system which in turn will make slower the control task and in some cases causing long transient responses.

In this study a simple Lead Lag controller has been used to control the fuel cell voltage, except that the controller parameters have not been achieved through trial and error method, rather the SA method is used. At first, the problem is formulated as an optimization problem and then this optimized problem is solved using the SA method, and optimal results are proposed for controller parameters.

DYNAMIC MODEL OF THE FUEL CELL

To study the dynamic model of the fuel cell, at first, the general schematic, structure and function of the fuel cell should be studied. The schematic system of the studied fuel cell in this paper is shown in Fig. 1. The mass of the anodes and cathodes are considered as a sole compact anode and cathode (Liyan *et al*., 2006).

In this study, the dynamic model of the fuel cell is considered as in (Mo *et al*., 2005). The output voltage of the fuel cell is obtained by subtracting the voltage drops from the regressive voltage. Equation (1) shows how to calculate the fuel cell output voltage (Larminie and Dicks, 2001; Zhan *et al*., 2007).

$$Vs = n\,(E_{reversable} - V_{act} - V_{ohmis} - V_{con}) \qquad (1)$$

where, Vs is the accumulated fuel cell output voltage in volts, is the number of cells in the accumulated fuel cell, is the voltage drop resulting from anode and cathode

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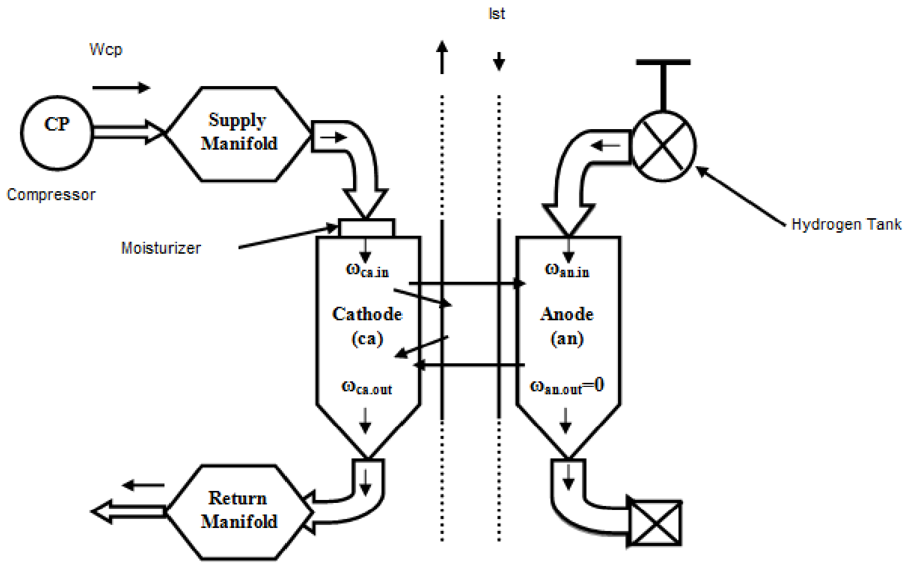

Fig. 1: Fuel cell supply system

activity in volts, is the ohmic voltage drop in volts, is a certain amount of resistance in transferring electrons and protons in the electrolyte between the anode and cathode. is resulting from the mass transfer of oxygen and hydrogen. in is calculated Eq. (1) through the following equation (So and Li, 2000; Mann *et al*., 2000):

$$E_{reversable} = 1.229 - 0.85 \times 10^{-3} (T - 29815) + 4.3085 \times T \times [\ln (PH_2 + 0.5 \ln (PO_2)] \quad (2)$$

where, there is the cells temperature in Kelvins, PH_2, PO_2 are effective partial pressure (atm) of hydrogen and oxygen, respectively, which can be calculated by the following equation.

$$PO_2 = Pc - P_{H_2o}^{sat} - P_{N_2}^{channal} \exp\left(\frac{0.291\left(\frac{i}{A}\right)}{T^{0.932}}\right) \quad (3)$$

$$PH_2 = 0.5P_{H_2o}^{sat}\left[\frac{1}{\exp\left(\frac{1.635\frac{i}{A}}{T^{1.334}}\right)\cdot\left(\frac{P_{H_2o}^{sat}}{P_a}\right)} - 1\right] \quad (4)$$

where, PO_2 and PH_2 are the anode and cathode inlet pressure in atmospheres, A is the effective electrode area in, i is the current of each cell in amperes, is the amount of saturated steam pressure which its value depends on the fuel cell. is the partial pressure of in the cathode gas flow channels in atmospheres can be calculated using the following equation(Trung and Ralph, 1993).

$$P_{N_2}^{channel} = \frac{0.79}{0.21} PO_2 \quad (5)$$

All the quantities used in this paper are data available in (Mo *et al*., 2005).

CONTROLLER DESIGN PROCESS

Simulated annealing: The performance of this optimization algorithm like the other algorithms is based on a stochastic search in the case area. At first, several initial conditions are considered to start the algorithm. In this process, decision making is based on particles energy such that a motion is acceptable just when a particle x0 with the energy E0 going to the state x with the energy E in which the current state is better than previous, then the latter is selected if not prior is acceptable with the probability of

$$p(x) = e^{\frac{E - E_0}{k_B T}} \quad (6)$$

In which, Kg is Bultzmen coefficient, T is temperature, the probability of accepting bad point is high when the energy level at the current state is lower than the previous and also the temperature is high. At T = 0, the bad state never accepted. During this process, temperature

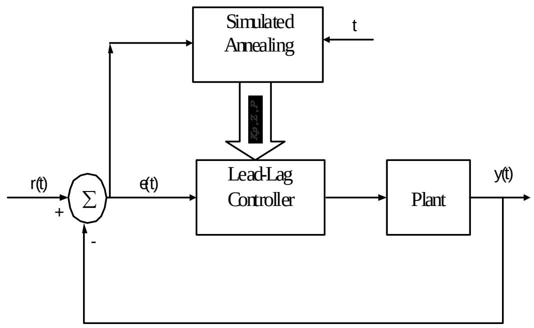

Fig. 2: Block diagram of the proposed controller to control the voltage of fuel cell

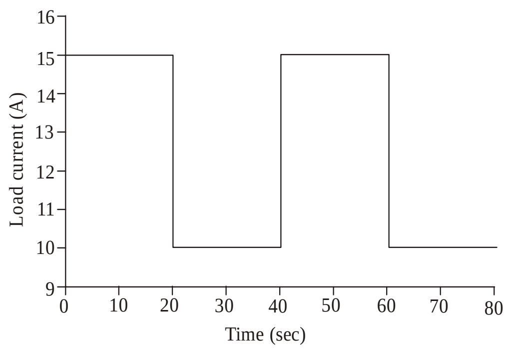

Fig. 3: Considered of bad condition of load for the studied system

is decreased from the initial temperature T0 to zero based on an annealing law meant search algorithm. Since this algorithm is robust, therefore could be more effective than the their algorithms in finding optimum solutions. One of the annealing laws in this algorithm is as:

$$T(i) = \frac{T_0}{In(i)} \tag{7}$$

where, i is the number of iterations

Using SA algorithm to adjust controller parameters: With the increasing development in controlling systems and also applicability of these controllers, in power systems, simple controllers are still considered effective controllers. In most cases, compensators are lead Lag controllers which they can be implemented easily both in analog and digital systems. In this study, lead Lag controller is used to control voltage of fuel cell. The controller schematic is shown in Fig. 2.

In order to design controller using SA, here, variation are considered as Fig. 3, and controller is designed for this load current condition.

Now, problem should be formulated as an optimization problem and then solved. Selecting objective function is the most important part of this optimization problem. Because, choosing different objective functions may completely change the particles variation. Here in this optimization problem, square of the error signal is used:

$$J = \int_0^{t=tsim} \left| v_{out} - v_{ref} \right|^2 dt \tag{8}$$

where, *Tsim* is the simulation time at which the objective function is calculated. It shoal be reminded that the less the objective function value, the more optimized the solution. Each optimization problem is optimized under a number of constraints, at this problem, the constraints should be expressed as:

$$\begin{aligned} &\textit{Minimize J subject to} \\ &K_p^{\min} \le K_p \le K_p^{\max} \\ &Z^{\min} \le Z \le Z^{\max} \\ &P^{\min} \le P \le P^{\max} \end{aligned} \tag{9}$$

where

$$\begin{aligned} &0 < K_p < 500 \\ &0 < Z < 50 \\ &0 < P < 50 \end{aligned} \tag{10}$$

In this problem, the number of particles, particles dimension, iterations are selected 60, 3, 60, respectively. After optimization, results are determined as:

$$K_p = 442.034,\ Z = 7.86,\ P = 3.12 \tag{11}$$

Controlling PEMFC voltage versus load changes (Ist): It is clear from the dynamic performance of fuel cell that the output voltage of fuel cell is severely changed with load changes. So, it is obvious that its voltage should be controlled for electric generation. To control the output voltage, various controllers could be utilized among them the simplest is Lead Lag.

In this section, output voltage for different load changes will be controlled using classic Lead Lag controller which its coefficients are as given in Eq. (11). Figure 4 depicts the anode and cathode pressure, system load, output voltage and reference voltage. For better showing, output voltage is illustrated in Fig. 5. According to the Fig. 5, in areas with severe changes in system load, voltage characteristic includes an overshoot. In Fig. 6, output voltage error, difference between output voltage and reference voltage, is shown which reaching its peak value at 0.75 volt.

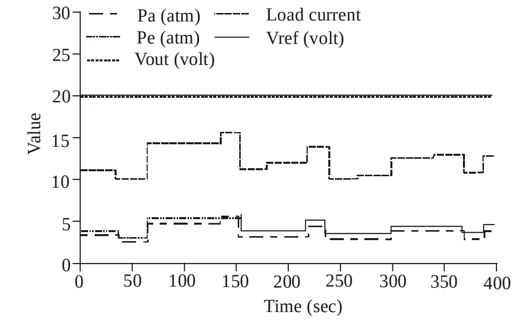

Fig. 4: Anode and cathode gas pressure, the system load, output voltage and reference voltage of the proposed controller

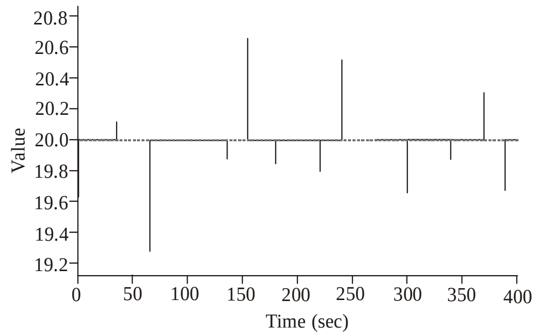

Fig. 5: Fuel cell output voltage of the proposed controller

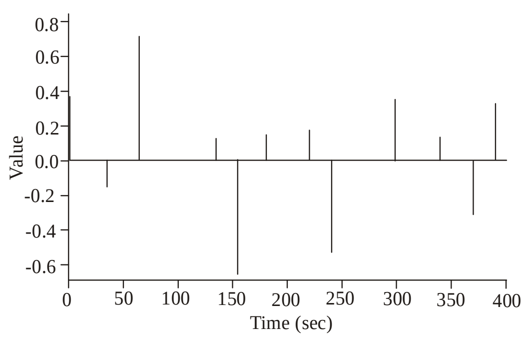

Fig. 6: Difference between the output voltage and the reference voltage of the proposed controller

CONCLUSION

In this study, the Lead Lag controller based on SA algorithm was proposed to control the fuel cell output voltage. This controller is simple and in practice do not need system relationships also could obviate the difficulty of the previous controllers and it is more efficient. To solve the problem, at first, the problem was formulated in the form of the optimization problem which its objective function was defined and written in time domain and then the problem has been solved using SA. And the optimum state for Lead Lag coefficients were determined using the algorithm.

It was shown that the proposed controller was able to effectively control the output voltage of fuel cell. This claim was verified for different load conditions in time domain using simulations on Matlab/Simulink environment.

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