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An Adaptive fuzzy logic control (AFLC) strategy for PEMFC fuel cell

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***Abstract*— The performance of PEMFC, being important and getting more and more attention in recent years, is known to be influenced by many parameters such as operating temperatures both fuel cell and humidifiers, pressure, flow rates and relative humidity of fuel and oxidant gases. Also a fuzzy logic controller (FLC) technique control is used to control the fuel cell output power by controlling input gases flow rate. Moreover the mathematical modeling and simulation of PEMFC fuel cell is introduced. The membership functions for inputs and output are Gaussian type, Simulation results obtained using Matlab/Simulink, and Fuzzy Logic Toolbox is presented to verify the effectiveness of the proposed control algorithm.**

Keywords- PEMFC fuel cell, Fuzzy Logic Control, Matlab/Simulink, gases flow rate.

I. INTRODUCTION

Fuel cells are promising energy sources that produce electrical currents with almost null pollutant emissions. Fuel cell technology plays an important role in the development of alternative energy. In the recent years there was an increasing interest in fuel cell technology. One of the most interesting fuel cells types is the proton exchange membrane fuel cell (PEMFC) due to its high efficiency [1], and it is one of the promising technologies for power generation in future [2].

The PEMFC needs to be controlled rapidly and efficiently in correct operating conditions. One of the significant challenges in control algorithms is that many parameters such as operating temperatures, pressure and flow rates of fuel and oxidant gases and so on affect the performance of PEMFC [3].Many research studies such as many linear controllers have been carried out on proton exchange membrane fuel cell technology. However, the complex and nonlinear dynamics of PEMFC make it hard to maintaining a fuel cell system in correct operating conditions when subjected to fast load changes [4].

On the other hand, fuzzy logic controller has attracted the attention of researchers because it can deal with nonlinear systems and does not need precise mathematical modelling of the system [5]. Compared with conventional PI controller, fuzzy logic controller has the potential to provide an improved performance even for a system with wide parameter variations [6]. The fuzzy logic controller has advantages of robust, simple, easily to be modified, usable for multi input and output sources, and to be implemented very quickly and cheaply.

The major contribution of this paper the improvement of the performance of PEMFC. In this framework, a robust controller is developed to regulate the input hydrogen and oxygen of PEMFC.

The paper is organized as follows: Section 2 presents the dynamic model of the PEMFC fuel cell. The proposed control structure is addressed in Section 3. Here PEMFC hydrogen molar flow controller based on fuzzy logic is implemented. To demonstrate the effectiveness of the proposed strategy, simulation results are presented in Section 4; and finally, in Section 5, conclusions are given.

II. PEMFC FUEL CELL MODEL

The model of fuel cell used in this study is based on the dynamic Proton Exchange Membrane Fuel cell (PEMFC) development in references [7], [8]. This model is based on simulating the relationship between output voltage and partial pressure of hydrogen, oxygen. The relationship between the modular flows of any gas through the valve is proportional to its partial pressure inside the channel [9]. For hydrogen, this relationship can be expressed as follows

$$\frac{qH_2}{pH_2} = \frac{k_{an}}{\sqrt{M_{H_2}}} = k_{H_2} \qquad (1)$$

With, pH_2 hydrogen partial pressure (atm),kan anode valve constant (Kmol Kg (atm s)$^{-1}$),MH_2 molar mass of hydrogen (kg kmol^{-1}),kH_2 hydrogen valve molar constant (kmol(atm s)$^{-1}$).

Finally, For hydrogen molar flow, there are three significant factors which are hydrogen input flow, hydrogen output flow, and hydrogen flow during the reaction [7]. Relation between these three factors is:

$$\frac{d}{dt}(p_{H_2}) = \frac{RT}{V_{an}}(q_{H_2}^{in} - q_{H_2}^{out} - q_{H_2}^{r}) \qquad (2)$$

With,R universal gas constant ((1atm)/(kmol K)),T absolute temperature (K),V_{an} volume of the anode (ℓ), qH_2^{out} hydrogen output flow (kmol s^{-1}), qH_2^{in} hydrogen input flow (kmol s^{-1}), qH_2^{r} hydrogen flow that reacts (kmol s^{-1}).

According to the basic electrochemical relationship between the hydrogen flow and the FC system current, the flow rate of reacted hydrogen is given by[10], [7]:

$$qH_2^{r} = \frac{NI}{2F} = 2K_r I \qquad (3)$$

Where K_r is a modeling parameter constant (kmol (sA)$^{-1}$). Which has a value of $\frac{N}{4F}$.

The molar flow of hydrogen that reacts can be found from the basic electrochemical relationship between hydrogen flow and the fuel cell system current [10]

The partial pressure of the flow of hydrogen is determined by the following differential equation: [8].

$$pH_2 = \frac{1/K_{H_2}}{(1+\tau_{H_2}^{S})}(q_{H_2}^{in} - 2K_r I) \qquad (4)$$

Where:

$$\tau_{H_2} = \frac{V_{an}}{RTK_{H_2}} \qquad (5)$$

$$qH_2^{in} = \frac{2K_r}{U_{opt}}\left(\frac{1}{1+\tau_f^{S}}\right)$$
(6)

Similar operation can be done oxygen partial pressure. [13].

The Nernst's equation and Ohm's law determine the average voltage magnitude of the fuel cell stack [7]. The following equations model the voltage of the fuel cell stack:

$$V_{stack} = N_{cell}.V_{cell} = N_{cell}(E_{cell} - \eta_{act} - \eta_{ohm} - \eta_{conc})$$
(7)

$$E_{cell} = 1{,}229 - 0{,}85.10^{-3}(T - 298{,}15) + 4{,}3085.10^{-5}.T\left[\ln PH_2 + 0{,}5\ln PO_2\right]$$
(8)

$$\eta_{act} = \xi_1 + \xi_2 T + \xi_{3.}T\ln(CO_2) + \xi_4.T\ln(I)$$
(9)

$$\eta_{ohm} = I(R_m + R_c)$$
(10)

$$\eta_{con} = -B\ln\left(1 - \frac{I}{I_{\lim}}\right)$$
(11)

The instantaneous electrical power supplied by the cell to the load can be determined by the equation:

$$p_{fc} = I.V_{stack} \tag{12}$$

Where V_{stack} is the cell output voltage for each operating condition, and P_{fc} is the output power.

This model is verified and the parameters are given in [8].

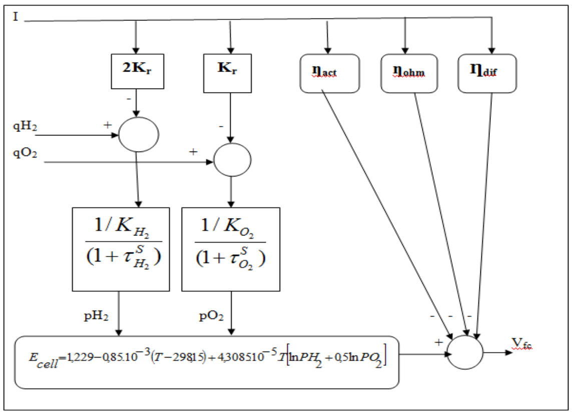

Figure. 1 PEMFC Fuel cell model.

III. STRATEGY OF A FUZZY LOGIC CONTROLLER (FLC)

The power flow from the PEMFC to the load is controlled though controlling the flow of hydrogen. The proposed fuzzy logic controller controls the active power by controlling the hydrogen flow [11].

In this case the controller is FLC having inputs the error *e* (*k*) and change of error *ce*(*k*). The output of the controller is the duty ratio of the hydrogen flow $u_{H2}(k)$. The error, change of error and output of the controller are given.

$$e(k) = q_{H_2} - q_{H_{2b}} \tag{13}$$

$$ce(k) = e(k) - e(k-1) \tag{14}$$

$$u_{H_2}(k) = u_{H_2}(k-1) + \Delta u_{H_2}(k) \tag{15}$$

Where qH_2 is the flow hydrogen from the current feedback signal were is proportional to the load, qH_{2b} is the hydrogen flow feedback signal, $uH_2(k)$ is the inferred change of duty ratio by fuzzy controller.

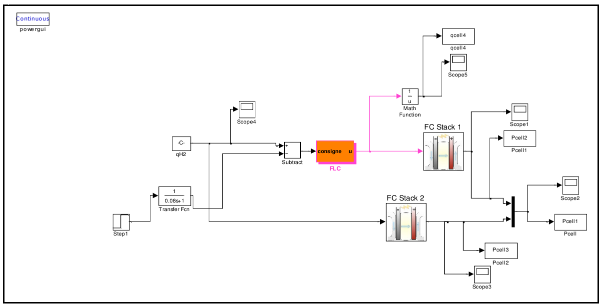

Figure. 2 Fuzzy logic block diagram of PEMFC fuel cell

The membership functions for inputs and output are Gaussian type. The membership functions for error, change of error and control are presents in figures 3 to 6. The fuzzy domain for *e*[-1, 1], e_c is [-0.5, 0.5], and for *u* is [-4e-5, 4e-5]. In this paper, the output control *u* of the fuzzy controller is designed as qH_2, that is the input molar flow of hydrogen of the PEM fuel cell.

Seven uniformly distributed Gaussian membership functions are used for the fuzzification of the inputs. Each of the FLC input signals and output signals are fuzzy variables and are assigned seven linguistic variables, namely, NB, NM, NS, Z, PS, PM, and PB, which stand for negative big, negative medium, negative small, zero, positive small, positive medium and, positive big, respectively. The rule base of active power controller has been listed in Table 1.

TABLE 1. FUZZY CONTROL RULES

ΔuH_2		*e*						
		NB	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
ce	**NB**	NB	NB	NB	NB	NM	NS	Z
	NM	NB	NB	NB	NM	NS	Z	PS
	MS	NB	NB	NM	NS	Z	PS	PM
	Z	NB	NM	NS	Z	PS	PM	PB
	PS	NM	NS	Z	PS	PM	PB	PB
	PM	NS	Z	PS	PM	PB	PB	PB
	PB	Z	PS	PM	PB	PB	PB	PB

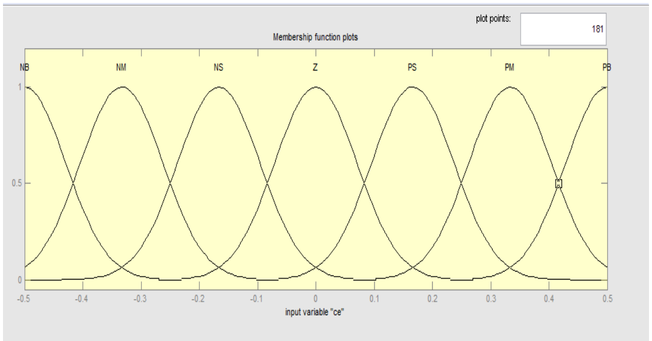

Figure. 3 Membership function of the error *e* .

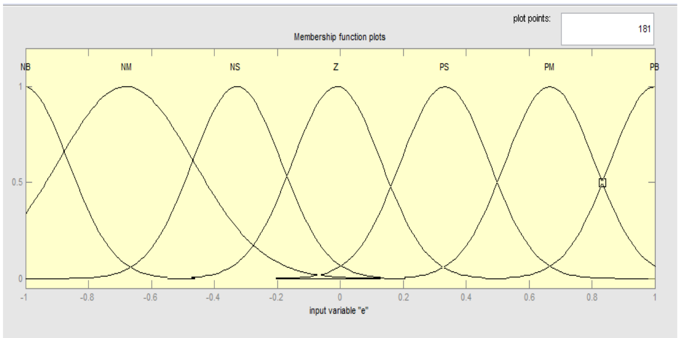

Figure. 4 Membership function of the change of error *ce* .

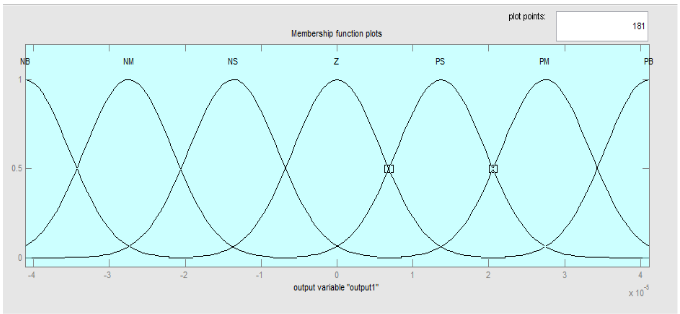

Figure. 5 Membership function of the control u.

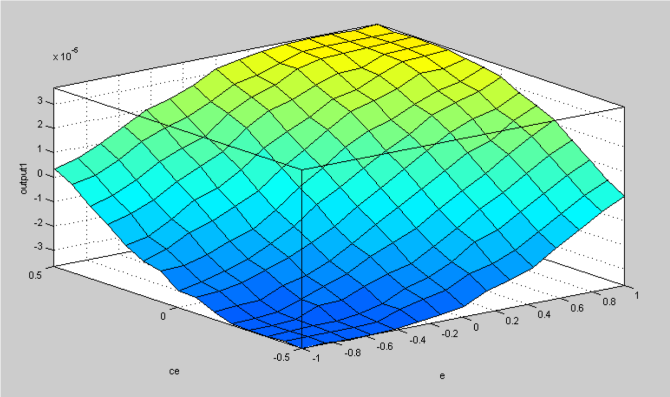

Figure. 6 The control surface.

IV. SIMULATIONS RESULTS

In order to verify the validity of the proposed fuzzy controller, simulation operation was carried out in the MATLAB SIMULINK simulation platform [12]. The controller was designed to control the output power of the PEMFC by adjusting the hydrogen flow.

TABLE 2

MAIN PARAMETERS OF PEMFC[8].

N (cell)	T (k)	Rc (Ω)	PH$_2$ (Atm)	A (cm)	L (μm)	ψ	I$_{lim}$	P$_{net}$ (w)
4	343.15	0.0003	0.02	16	230	14	0.0496	1.2

A. The first case: Simulation results of uncontrolled PEMFC

In the normal condition of no controller exists in its system, Figure. 7. Shows the input molar flow of fed hydrogen after gas processing response and this hydrogen flow will be fed to PEM stack unit. From Figure 7, we can see that the gas reaction process requires a short time of delay to response. the PEMFC cannot output constant power, and this can be seen from Figure.8.

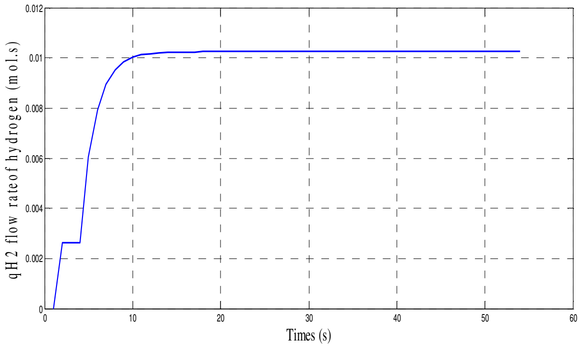

Figure. 7 Hydrogen flow rate change without FLC

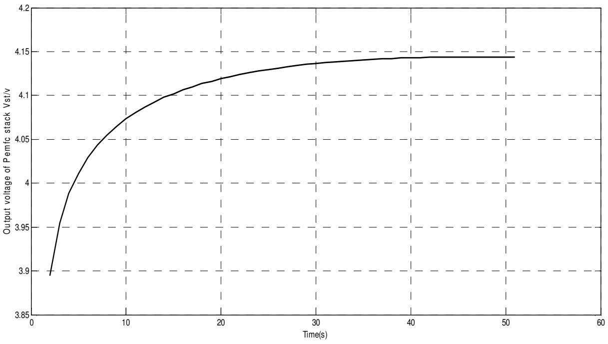

Figure.8 output voltage change without FLC

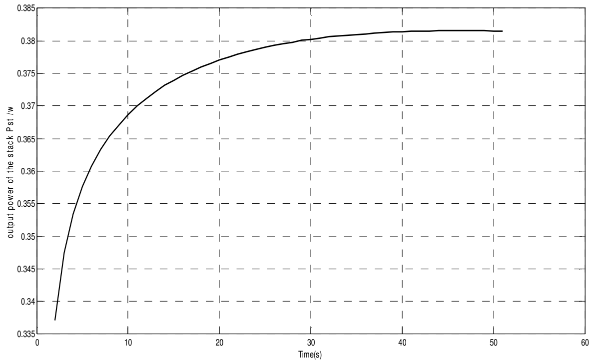

Figure.9 output power change without FLC

B. *The second case: Simulation results with Fuzzy Control PEMFC*

The output voltage of PEMFC system increases when the output power increases. This relation between power and the voltage of the FC system authenticates the reliability of the PEMFC model. The transient response of the PEMFC system voltage to the load changes varies according to the amount of power supplied by the PEMFC system as shown in Figure.11. The power produced by PEMFC system is given in Figure.12.

Figure.10 shows the Hydrogen flow rate change with FLC ,it is evident that the hydrogen flow rate decreases with time as more and more hydroge flow rate extracted from the PEMFC stack.

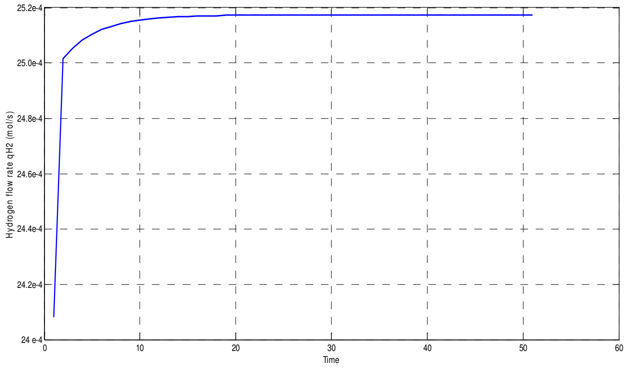

Figure.10 Hydrogen flow rate change with FLC

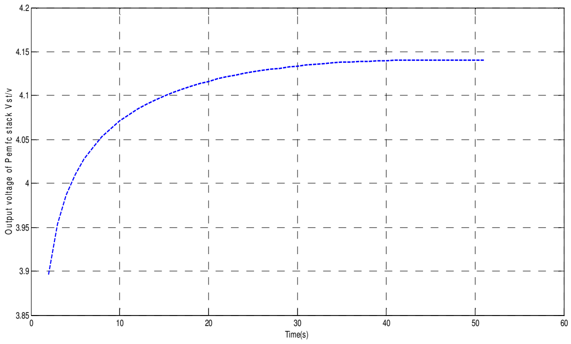

Figure.11 output voltage change with FLC

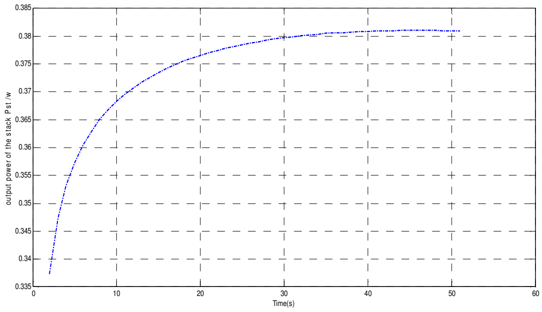

Figure.12 output power change with FLC

C. *Comparaison*

By comparing these figures with each other, it is clearly shown to us that the fuzzy controller proposed in this paper has the predomination of a faster time response and higher precision. The simulation results possess very similar characteristics and are as shown in Figures.13-14. The PEMFC voltage is back to a stable state in 40s at4.14v and the output power stabilized in0.382w.

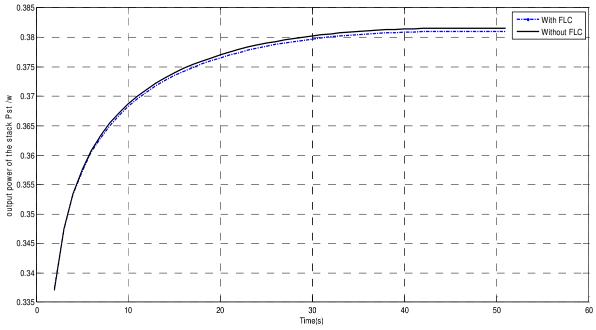

Figure.13 Comparaison between output voltage change without FLC and change with FLC

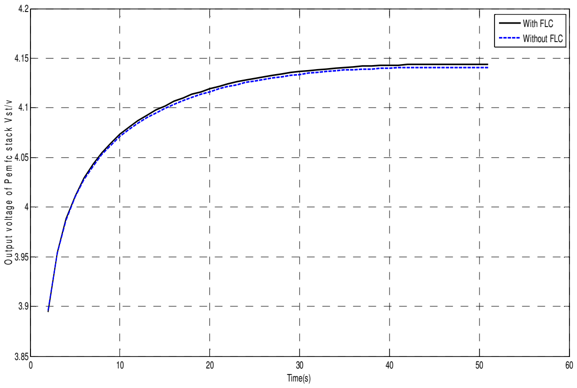

Figure.14 Comparaison between output power change without FLC and change with FLC

V. CONCLUSION

Modeling, control and simulation study of a fuel cell system is proposed in this paper.

In this paper, a fuzzy control strategy is proposed for the fuel cell system to evaluate the performance of this system during power quality disturbances. Also based on the dynamic modeling of power fuel cell ; the fuzzy controller is investigated to guarantee the safe operation of each component. The proposed control strategy for this kind of this system helps in delivering the maximum power of fuel cell power source and makes the proper operation of each power source under power quality disturbances. The effectiveness of the proposed system can be verified by using the MATLAB/SIMULINK environment.

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