Fuzzy logic MPPT control algorithm for a Proton-Exchange Membrane Fuel Cells System

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ABSTRACT

Fuel cells output power depends on the operating conditions, including cell temperature, oxygen pressure, hydrogen pressure, tempureter . In each particular condition, there is only one unique operating point for a fuel cell system with the maximum output. Thus, a maximum power point tracking (MPPT) controller is needed to increase the efficiency of the PEMFC systems

In this paper an efficient method fuzzy logic controller is proposed for MPPT of the proton exchange membrane (PEM) fuel cells, boost converter. FLC adjusts the operating point of the PEM fuel cell to the maximum power by tuning of the boost converter duty cycle. To demonstrate the performance of the proposed algorithm, simulation results are sumulated in two cases, in normel condution and variation in temperature .the FLC algorithm with fast convergence, high accuracy and very low power fluctuations tracks the maximum power point of the fuel cell system

I. Introduction

A fuel cell considering as renewable source of energy and its electrochemical device mixing hydrogen and oxygen to generate electricity and water and heat as its by-product. the similarity of battery and fuel cell is both convert the energy produced from chemical energy into a usable electric power. Fule cells are more productive and more effective, work silently, and to remove emissions from fossil and greenhouse gas combustion [1].

Popular types of fuel cells include the proton exchange membrane fuel cell (PEMFC), phosphoric acid fuel cell, alkaline fuel cell, direct methanol fuel cell, molten carbonate fuel cell, and solid oxide fuel cell. Because of the performance of the PEMFC like low weight, high power density, and clean, pollution free operation. From the operational point of view, a relevant aspect is their low temperature of operation [2], the most popular type of fuel cellsand the best is PEMFC, theo utput characteristics of pemfc are nonlinear and influenced by such parameters as the cell temperature, oxygen pressure, hydrogen pressure, and membrane water content. In each particular condition, for a fuel cell system with full performance, there is only one specific operating point[3], it is important to find the optimal operating voltage (or current) of fuel cell systems in order to increase the efficiency of fuel cells.

There is many different methods for MPPT in the literature[4]–[6] such as, perturb and observe (P&O) variable stem IC technique-based MPPT for the PEMFC [7], ANFIS-based MPPT [8] hill climbing (H&C), sliding mode control[9],PS0[10],) SMC[11]), hysteresis controller(HC)[12], and fuzzy logic controller (FLC)[13]. Most of these methods have been applied to photovoltaic systems MPPT[14].However the P&O control strategy aimed at extracting the maximum allowable power from a Fuel Cell,and thise algorithm applied to improve the power extracted from PEMFC [15],[3].

PEMFC system has non-linear P-I characteristics, as discussed earlier. The strategies based on AI provide a better approach for non-linear processes, forthermor to extract the MPPT we use the FLC the advantages of FLC include rapid reaction, flexible operation and also the exact system mathematical model. For the formulation of fluffy inference rules, FLC uses expert expertise. The FLC is thus dependent on the operator or control engineer's ability [16], [17].

Based on the above literature in the paper focus on the static, and the dynamic models because of their simplicity, clarity, and their real description of the electrical equivalent circuit of the fuel cell. And in order to maintain the power to its maximum, several control algorithms are developed fuzzy logic controller (FLC) thechnique is one of them.

The paper is organized as follows. The studied system is described and models of PEM fuel cells are presented in system description .. bosst converter and FLC is described the boost converter and fuzzy logic controller to extract the maximum power poit from the PEMFC than simulation results and finally, a conclusion.

II. System description

The PEMFC operated by pure hydrogen oxygen, connected to DC/DC converter boost withch is controlled with PWM . In the system have ole fuzzy logic controller block in order to extract the maximum power and maintiant it at the maximum value. The globle sytem is shown in the Figure (1) below

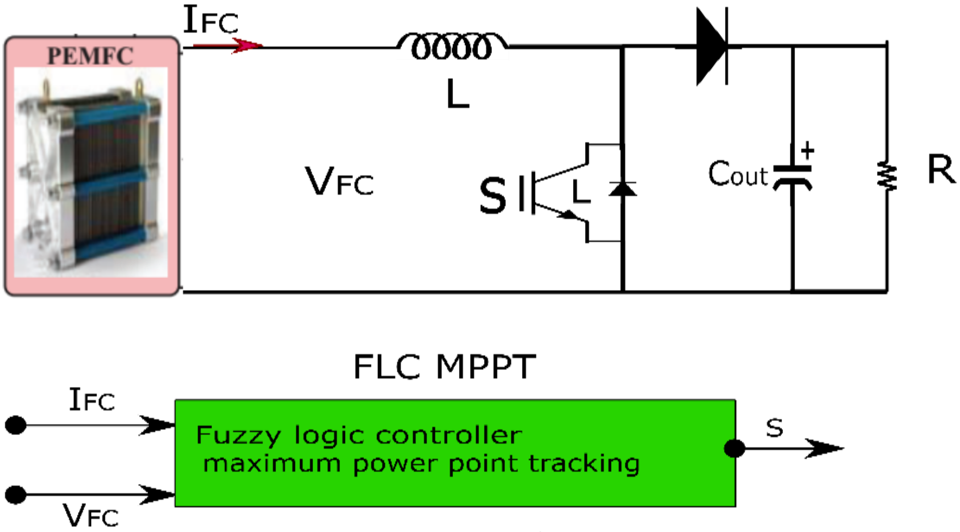

Figure 1. system confugiration

III. Mathematical modeling of PEMFC

The voltage produced at the output of fuel cell is less than the expected value due to internal losses; activation, ohmic and concentration losses.

$$V_{FC} = E_{nernst} - V_{act} - V_{ohm} - V_{cons} \tag{1}$$

Where vfc is the FC out put voltage E_{nernst} represents the reversible voltage; V_{act} is the voltage drop due to the activation of the anode and cathode; V_{ohm} is a measure of ohmic voltage drop ; V_{cons} represents the voltage drop.

For n cells connected in series and forming a stack, the voltage (Ecell), can be calculated by:

$$E_{cell} = nV_{FC} \tag{2}$$

Whrere :

$$E_{nernst} = 1,229 - (0.85.10^{-3}(T - 298,15)) + 4,31.10^{-5} T(\ln P_{H_2} - \ln P_{O_2}) \tag{3}$$

$$V_{act} = -[\zeta_1 + \zeta_2 T + \zeta_3 T \ln(C_{O_2}) + \zeta_4 T \ln(i_{FC})] \tag{4}$$

$$V_{ohm} = (R_m + R_c) i_{FC} \tag{5}$$

$$V_{cons} = -B \ln\left(1 - \frac{J}{J_{\max}}\right) \tag{6}$$

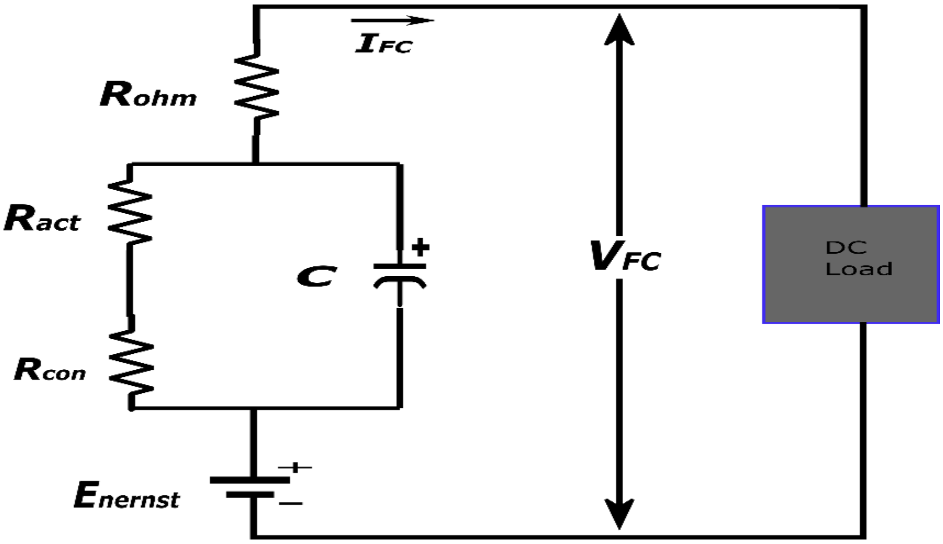

Figure 2. Electrical model of PEMFC

The next table represent the PEMFC parameter

Table 1. Fuel cell model parameters

Symbol	Parameter	value
P_{H_2}	haydrogen pressuer	1 (atm)
P_{O_2}	oxygen pressuer	1.5 (atm)
T (kalven)	Temperature	328 K
C_{O_2}	Concentration of oxygen	$P_{O_2} / [5,08.10^5((-498)/T)]$
ζ_1	Coefficient of the activation over voltage	-0.514
ζ_2	Coefficient of the activation over voltage	$0.00286 + (0.0002\ln(A)) + (4.3\ln(C_{H_2})1.10^{-5})$
ζ_3	Coefficient of the activation over voltage	$0.41.10^{-4}$
ζ_4	Coefficient of the activation over voltage	$-0.93.10^{-4}$
C_{H_2}	Concentration of haydrogen	$5.64.10^{-5}$
A	Fuel cell activation are	$70cm^2$
B	Concentration loss coefficient	$0,0016$
$J_{\max}$	Maximum current density	$1,5A/cm^2$
J	Current density	$\frac{i_{FC}}{A}$

IV. Boost converter

The Boost DC/DC converter is a switching power supply not-isolated from the source. It can be directly connected to the fuel cell. It's applied, in this case, for fuel cell which must operate in steady state conditions. The role of this device is to maintain the rated power of PEMFCt o its maximum point in order to optimize its operating.[18], to determination of the duty cycle is based on the exact knowledge of DC-DC Boost converter model as shown in figure 3 . Furthermore the boost converter hase two states ON and OFF.
Switching state is ON the quation described :

$$\begin{cases} L\dfrac{di_{FC}}{dt} = V_{FC} \\ C\dfrac{dV_{out}}{dt} = -I_{inv} \end{cases} \tag{7}$$

Switching state is OFF :

$$\begin{cases} L\dfrac{di_{FC}}{dt} = V_{FC} - V_{out} \\ C\dfrac{dV_{out}}{dt} = -I_{out} + I_{FC} \end{cases} \tag{8}$$

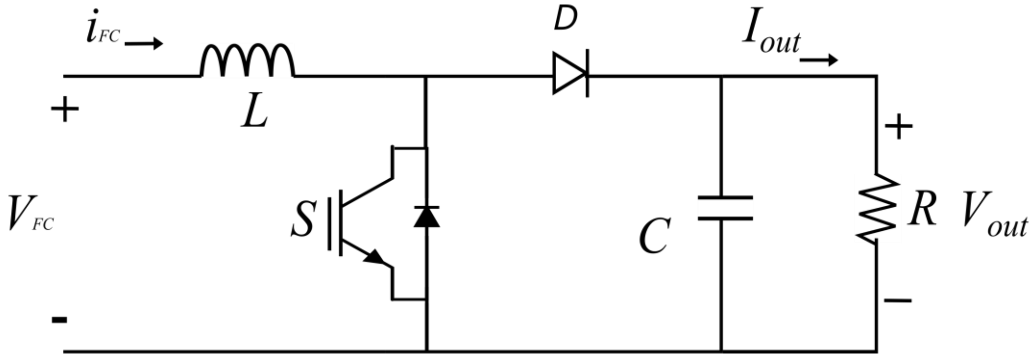

Figure 3. BOOST equivalent circuit

V. Fuzzy logic controller

The fuzzy logic controlle has wide range of application in renewable energy application the FLC has been incread over the last dacade beacase of its simplicity, deal with imprecise inputs, doesn't need an accurate mathematical model and can handle nonlinearity[19]. The FLC mechanism can be separated into 3 parts, the fuzzification step , rule evaluation and defuzzification .thease components and the general architecture shwn in figure 4.
In order to extract the maximum power from the PEMFC, fuzzy logic controller is applied to the boost converter. The FLC has the same objectives of regulation such as a classic regulators used in automatic control theory[20]. So the optimization of the output PEMFC power is achieved,in this study the inputs of the the FLC will be the error $E(k)$ and the change in error $CE(k)$ at a sample time k, which are defined by (9) and (10). The output will be the duty cycle D

$$E = \frac{dP}{dI} \tag{9}$$

$$CE = E(k) - E(k-1) \tag{10}$$

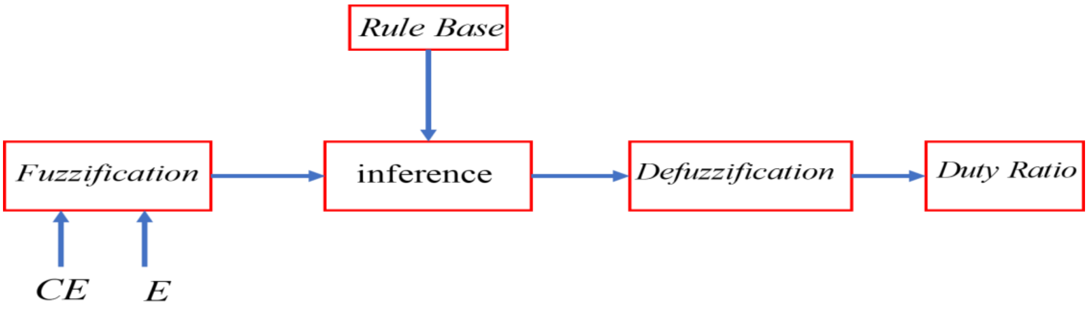

Figure 4. Block diagram of FL approach

VI. Simulation and results

In this section, we presant the obtaned sumulation results of PEMFC system; this system has been implimented using MTLABE/sumilink envirmenet. It should be noted that our proposed system contanes PEMFC with 50 cells, a boost DC/DC converter and MPPT fuzzy logic controller in normel operating condition and temperature variation

VI.II. Nolmal operation conditions

In this case PEMFC contanes inputs hydrogen pressure (atm), oxygen pressure , temperature (k), full cell active array, Figure 5 show the result of power of feul cell against feul cell current at steady stated . for the power , the power is increased gradually to the maximum power point the maximum power poducted by the fuel cell is 9.49 W whne the current 28.6

The time variations of the fuel cell current, The time variations of the fuel cell voltage , the pressure of oxygen, hydrogen and tempreture are constant at these values 1(atm) and 1,5 (atm) and 328 K respectively. The MPPT trajectories for FLC are presented in figure (6,7 and8).It shows that FLC has better performance and fast time response and very high power extraction around the MPP

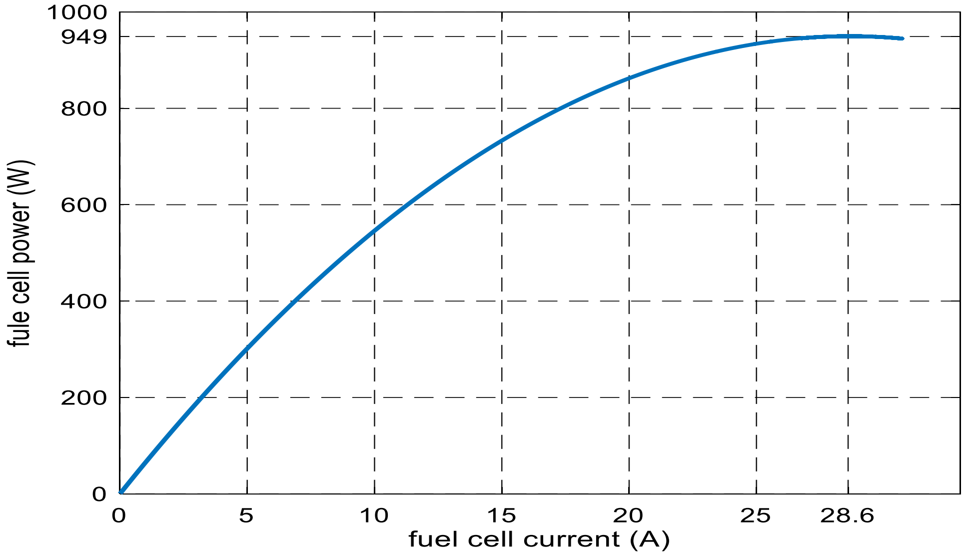

Figure 5. P-V feul cell caracterestic

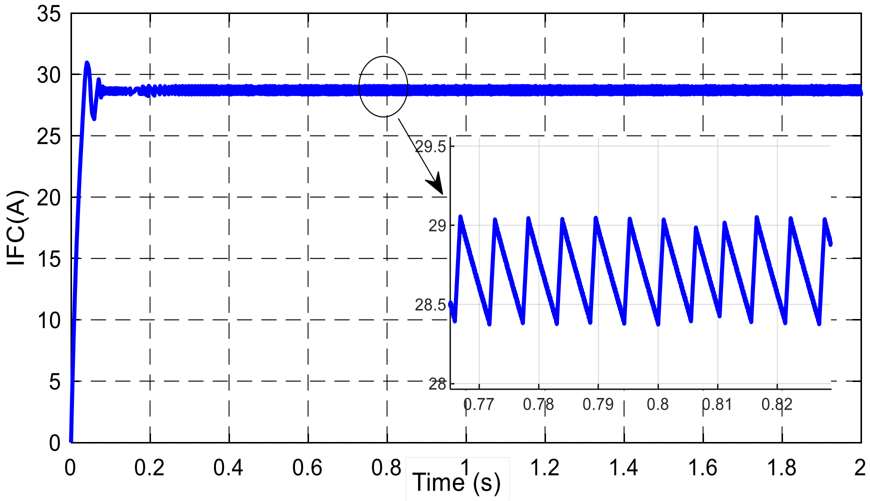

Figure 6. Fuel cell’s current with MPPT

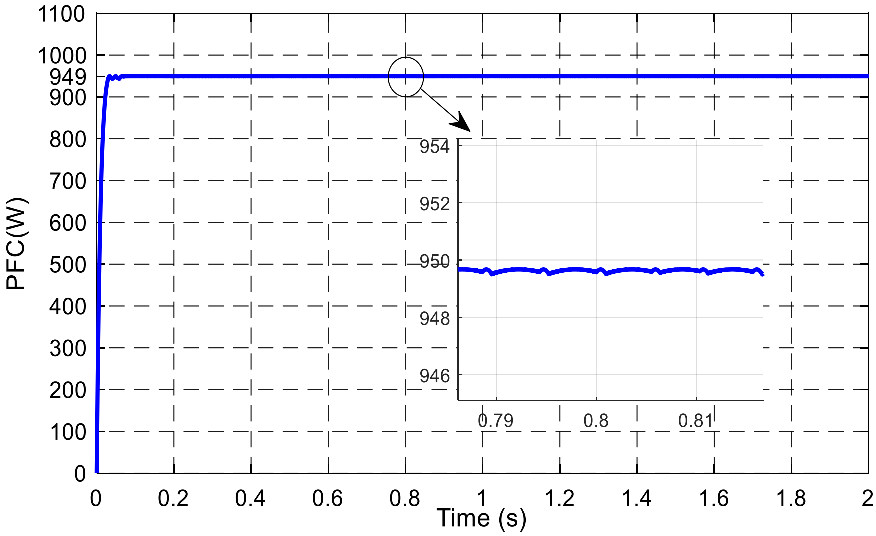

Figure 7.Fuel cell’s power with MPPT

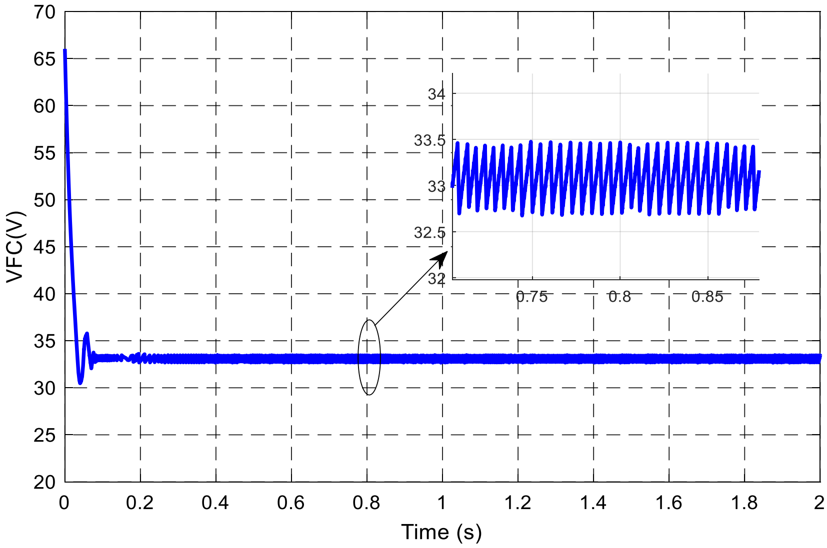

Figure 8. PEMFC voltage with MPPT

VI.II. Fast variation of the cell temperature

In order to verify the performance of and accuracy of the FLC under temperature variation of the PEMFC, a variation of temperature applied to the fell cell is shown in figure(9) the system operates in the temperature T=328 in the interval [0,1], the temperature decried to T = 298.15 (k) from time [1, 2] once again the temperature is increased to 323.15 (K) in the interval of time [2s, 3s].

The time variations of the fuel cell current voltage and power, are shown in figures (10,11 and 12) respectively. At 1s, with decreasing the temperature, the fuel cell current v decreases also with the voltage and power deincrease to . Then at 2s s with increasing the temperature, the fuel cell current increases and also voltage and power increase , as shown in figures (7, 8 and 9) . As can be seen,FLC have better time response. Also track the MPP as showen in figure (5) with very low power fluctuations

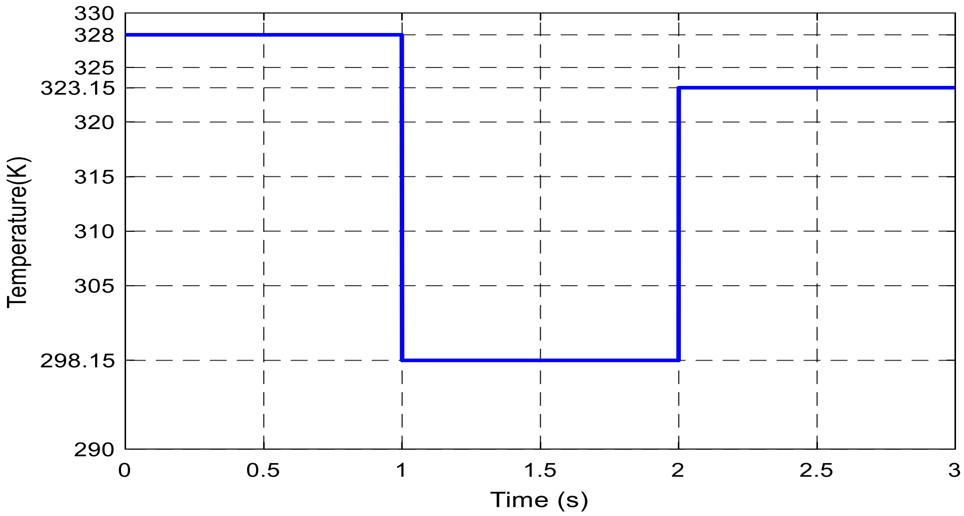

Figure 9: Time variations of PEMFC tempreture .

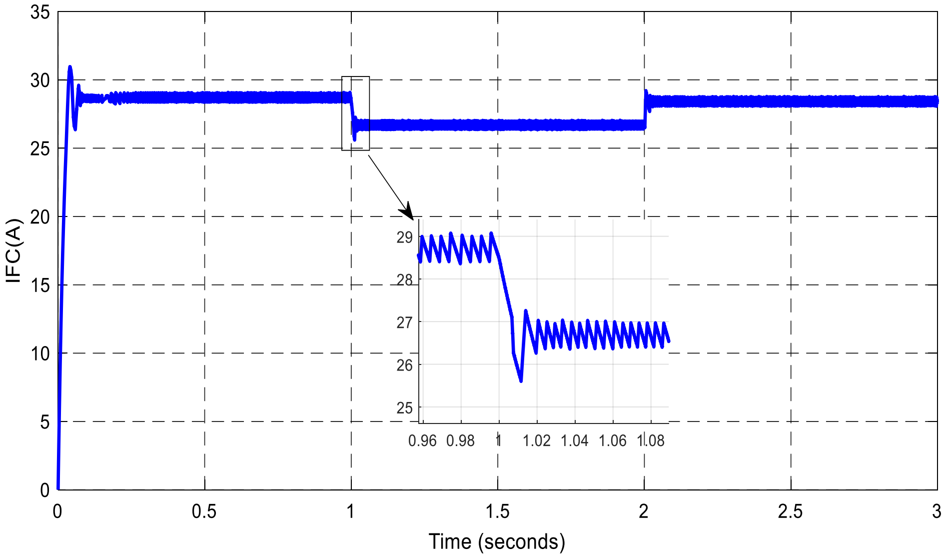

Figure 10. PEMFC current under fast variations of the cell temperature for FLC

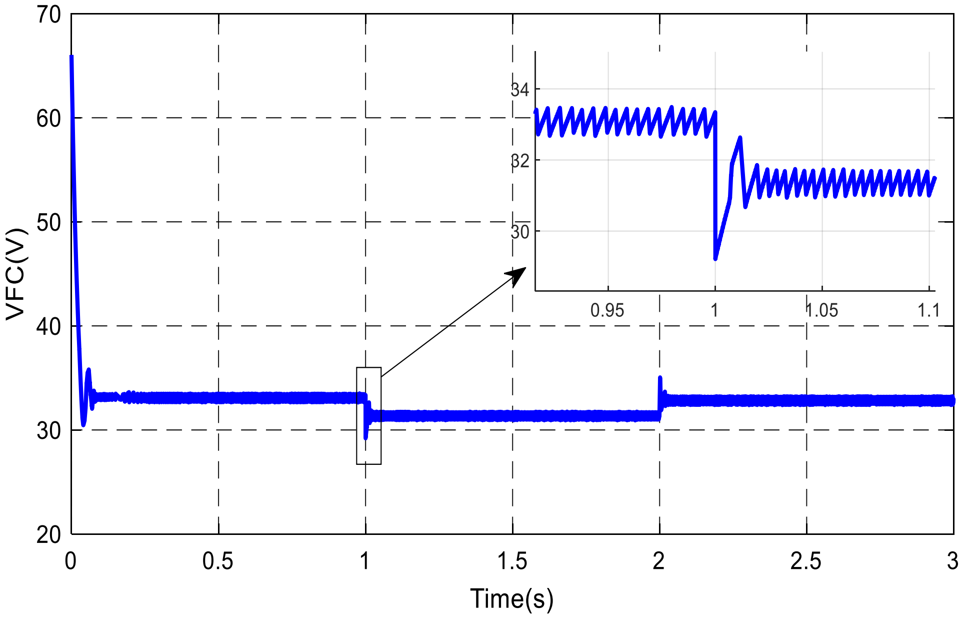

Figure 11.PEMFC voltage under fast variations of the cell temperature for FLC

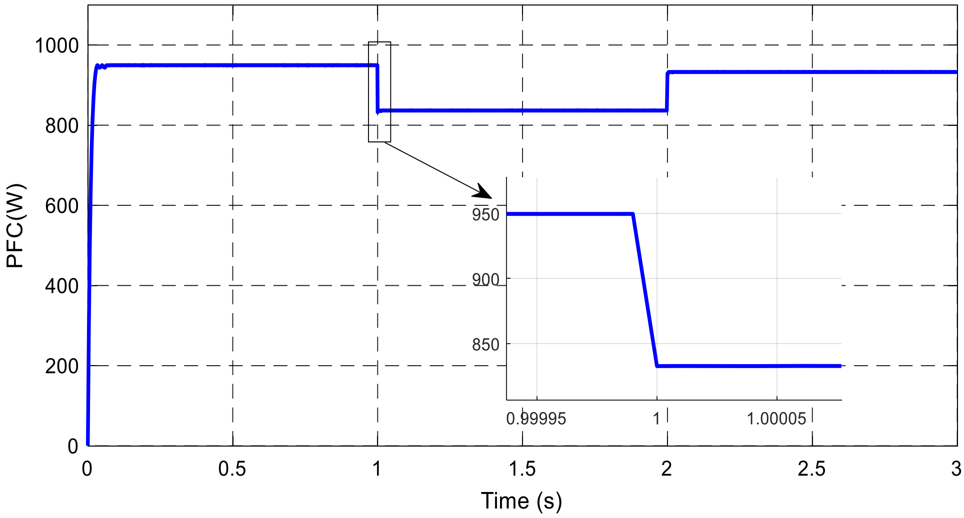

Figure 12.PEMFC power under fast variations of the cell temperature for FLC

VII. Conclution

In this paper, a fuzzy logic controller MPPT for PEM fuel cell is presented and its performance. the FLC operating point of the PEM fuel cell to the maximum power as we can see above by tuning of the boost converter duty cycle. The simulation result approved in cases the first fixed the PEMFC parameter and the second case with a variation of temperature. It is confirmed by a simulation study that FLC controller with high accuracy, good time response, and very low power fluctuations can track the real peak power point under different temperature. It was also demonstrated that the fuzzy control improves the tracking performance compared to the conventional P&O controller. The specialty of this FLC is that the rule base is very simple which increases the speed of computation of the processor. That is why the proposed FLC can track the MPPT very fast and accurately even if the environment changes abruptly. The performance of FLC shows that it is the improvements in transient, dynamic and steady state responses in MPPT.

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Table 2. Nomenclature

Symbels	Acronyms
V_{FC} ; PEMFC voltage i_{FC} : PEMFC current E_{nernst} : open circuit thermodynamic voltage V_{act} : activation over voltage V_{ohm} : ohmic over voltage V_{cons} : concentration over voltage P_{H_2} : hydrogen partial pressure P_{O_2} : oxygen partial pressure T : cell temperature C_{O_2} : oxygen concentration C_{H_2} : hydrogen concentration ζ_{1-4} : empirical coefficients of each cell R_c : proton resistance R_m : equivalent resistance electron flow A : area of membrane B : Concentration loss coefficient $J_{\max}$: Maximum current density J : Current density	MPPT : Maximum power point truking. PEMFC: proton exchange membrane fuel cell. P&O perturb and observation IC: incremental conductance H&C : hill climbing. FLC fuzzy logic controller. PSO: particle swarm optimization. SMC: sliding mode controller. DC:direct current .