International Journal of Engineering Research and Modern Education (IJERME)
Impact Factor: 6.525, ISSN (Online): 2455 - 4200
(www.rdmodernresearch.com) Volume 2, Issue 1, 2017

REACTANT FLOW CONTROL OF PEM FUEL CELL SYSTEM FOR ITS OPTIMAL PERFORMANCE

L. Madhuridevi*, A. Nagarajan & K. Sindhuja*****
Department of Electrical & Electronics Engineering, Karpagam College of Engineering, Coimbatore, Tamilnadu

Cite This Article: L. Madhuridevi, A. Nagarajan & K. Sindhuja, "Reactant Flow Control of Pem Fuel Cell System For Its Optimal Performance", International Journal of Engineering Research and Modern Education, Volume 2, Issue 1, Page Number 1-7, 2017.

Abstract:

In this project, a Proton Exchange Membrane Fuel cell (PEMFC) system which works on hybrid approach employing Maximum Power Point Tracking (MPPT) and fuel flow control to trim down fuel wastage is presented. In the proposed system both Perturb & Observe (P&O) MPPT algorithm and fuzzy logic based MPPT algorithm are implemented for various input conditions like different temperature and different membrane water content of the fuel cell and compared. Simulations show the output power of fuzzy logic based MPPT technique model provides better performance than the conventional P&O algorithm based model. Also the fuel controller is implemented for the fuzzy logic based model and the required amount of input fuel to the fuel cell is obtained. All the simulations are done using Sim Power System blocks of MATLAB SIMULINK software.

Index Terms: PEM Fuel Cell, MPPT, Fuel Flow Control, P&O Algorithm & Fuzzy Logic

1. Introduction:

Hydrogen is an emerging green energy resource and it is one of the most abundant elements in the universe. Hydrogen is widely accepted as a potentially viable energy source via fuel cells. Fuel cells which convert the chemical energy of a gaseous fuel into electrical energy [2] will produce electricity as long as fuel is supplied. Fuel cell consists of two electrodes called anode (negative terminal) and cathode (positive terminal) on either side of an electrolyte. Hydrogen and oxygen go by each of the electrodes. Therein, electricity, heat and water are produced by means of a chemical reaction. Hydrogen is supplied to the anode of the fuel cell and oxygen is supplied to its cathode. Hydrogen is splitted into an electron and a proton through a chemical reaction each of which takes a different path to the cathode [15]. The electrons which can take a path other than through the electrolyte, when controlled correctly can produce electricity for a given load. At the cathode, these electrons are then reunited with the protons which also passed through the electrolyte. The electron, proton and oxygen thus by combining, results in the formation of harmless by-product of water [4]. The problem of extracting the maximum power from renewable energy sources was first done for processes like Photovoltaic panels (PV) and wind turbines [3]. The plan consists of orienting the processing such a way that the produced power is optimized. More recently, the problem of extracting the maximum power from a FC has attracted the interest of certain authors and different methodologies have been proposed. In general, the challenge is the tracking of the maximum power point (MPP) of any FC type by controlling the gas flow, the pressure or the power converter [16]. When an external load is directly connected, the output power of FC depends on both the internal electro-chemical reaction and the external load impedance [7]. The system's operating point is at the intersection of the load line and fuel cells I–P curve. Maximum power point (MPP) is the unique operating point, at which the fuel cell produces its maximum power [8]. According to the maximum power transfer theory, the power delivered from the fuel cell to the load is maximized when its internal impedance is equal to the load impedance. In most cases, it is actually undesirable to operate at the maximum power, since the corresponding fuel efficiency is at best 50% [5]. It is necessary to track the maximum power point that adapts to changing operation conditions in the fuel cell system. This can avoid overfull fuel consumption and low efficiency operation. Various MPPT techniques were implemented for tracking the maximum power from the fuel cell system [1]. As a clean energy conversion technology, fuel cells are a promising alternative to the power generation using conventional resources of energy. On the note of its low operating temperature, high power density and fast start up, the PEM fuel cell power plant is a promising candidate for residential and vehicular applications [14].

2. Need for the Optimal Operation of Fuel Cell:

Fuel cells call for large amount of investment. To minimize the overall cost of the system, the ability to extract the maximal power from a fuel cell is a critical issue that must be considered for the optimal design of a fuel cell powered system. Since various MPPT techniques were implemented for tracking maximum power from fuel cell system, recently fuzzy logic controllers have been introduced in the tracking of the MPP in renewable energy systems [9]. They have the advantage of being robust and simple to design since because they do not require the knowledge of the exact model. In addition, the fuzzy parameters can also be changed by fuzzy logic controllers for improving the control system. Along with this fuzzy based MPPT technique, the fuel controller is also implemented to reduce the fuel wastage [6]. Thus a PEM fuel cell system which works on hybrid approach employing MPPT and fuel flow control to trim down fuel wastage is developed in the proposed system which makes the system to give optimal performance.

3. Proposed System:

PEM Fuel cell system which works on hybrid approach employing MPPT and fuel flow control to trim down fuel wastage is described. The MPPT controller uses the fuel cell voltage, current, and subsequently its power to find the MPP and then generates control instructions for the boost converter. The fuel controller uses the fuel cell current and generates the exact amount of fuel which is given to the fuel cell input.

A. Block Diagram of Proposed System: The block diagram consists of a fuel cell, MPPT controller, fuel controller, DC to Dc converter and load. The voltage and current from the fuel cell mathematical model is given to the MPPT controller. The MPPT controller determines the duty cycle to make the fuel cell to operate at Maximum Power Point. This duty cycle is given to the boost converter, through which the load is connected. The current from the fuel cell model is give to the fuel controller. The fuel controller calculates the input fuel (Hydrogen) in lpm which is proportional to current.

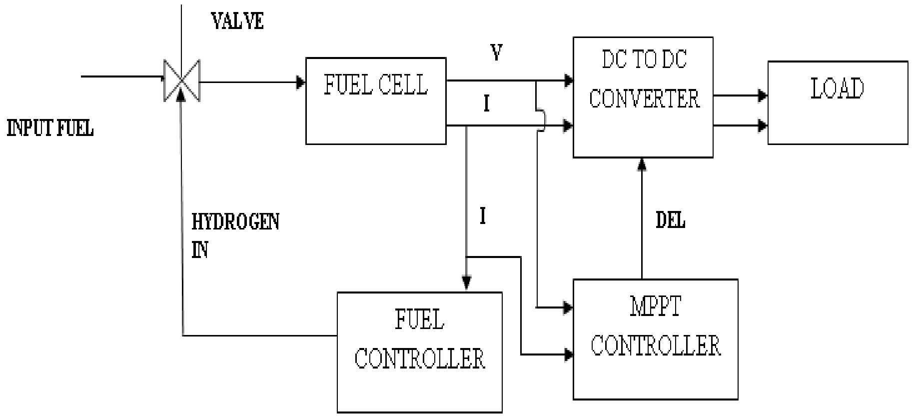

Figure 1: Block diagram of Proposed System

4. Mathematical Modeling of PEM Fuel Cell:

In this section the mathematical modeling of a PEM fuel cell is developed by using PEM fuel cell voltage equation.

A. Operating Voltage of PEM Fuel Cell: A FC converts the chemical energy of a fuel and an oxidant into a direct electrical current, associated with nonlinear and complicated voltage-current characteristics [13]. A polarization curve shows the nonlinear relationship between the current dencity and voltage of a fuel cell. In the steady state, the fuel cell output voltage is a function of current density and it is influenced by operating conditions, including cell temperature, air pressure, oxygen partial pressure, and membrane water content. In the case of PEMFC, hydrogen (H_2) is the fuel and oxygen (O_2) is the oxidant. The total fuel reaction is

$$H_2 + 1/2\ O_2 \longrightarrow H_2O + \text{electricity} + \text{heat}$$

When the FC operates, the actual voltage of the cell, V_{FC}, is less than the value calculated by. The voltage difference is the result of losses or irreversibility. FC output voltage is the difference between its internal voltage drops its reversible open circuit voltage, namely the activation, Ohmic, and concentration voltage drops [11]. These voltage drops are nonlinear functions of the FC current, the temperature, and the chemical reactions. The basic expression for the PEMFC voltage is

$$V_{FC} = E_{Nernst} - V_{act} - V_{ohm} - V_{conc} \quad (1)$$

Where,

V_{FC} - FC output voltage,
E_{Nernst} - reversible cell voltage,
V_{act} - losses in activation,
V_{ohm} - ohmic losses,
V_{conc} - losses in concentration

5. MPPT Controller:

Maximum Power Point Tracking (MPPT) refers to the process of maintaining the maximum power output of an energy source, when its power output changes in time. Among a number of MPPT methods that have been proposed in photovoltaic power applications, the perturbation and observe (P&O) algorithm, is by far the most commonly used in practice because of its simplicity in algorithm and ease of implementation. Fuel cells have nonlinear voltage-current characteristic, and there exists only one unique operating point for a fuel cell system with a maximum output under a particular condition. In fact, the stack current and fuel flow are controlled in the MPPT algorithm, under various operating conditions to optimize fuel consumption and the extract maximal power of the fuel cell. In the proposed system both P&O algorithm based MPPT controller and fuzzy logic based MPPT controller are implemented for various input conditions like different temperature and different membrane water content of the fuel cell. These MPPT controllers give the duty cycle to the boost converter which is connected to the fuel cell to make it operate at maximum power. The output power of both the controllers is compared.

A. P&O Algorithm Based Controller: Resulting change of power, Δ P, is observed when the operating current of the fuel cell is perturbed by a small constant increment. If ΔP is positive, then it is supposed that it has moved the operating point closer to the MPP and further current perturbations in the same direction will move the operating point toward the MPP. If ΔP is negative, then the operating point has moved away from the MPP, and the direction of perturbation should be reversed to move back toward the MPP.

In order to find the direction of change for maximizing the power, the P&O method periodically perturbs the operation point of the system. If the sign of power derivative ΔP and that of voltage derivative ΔI are the same, the reference current should be further increased, and vice versa. For efficiency and simplicity reasons, and in order to focus on the main issue of extracting maximum power at optimum flow, the traditional P&O is used to drive the FC to its maximum power.

P&O Pseudocode: The pseudo code which is implemented in the P&O controller of the proposed system is given as below,

```
        if fuel cell Power > fuel cell previous Power
        if fuel cell voltage > fuel cell previous voltage
        Duty = Duty – change;
        else
        Duty = Duty + change;
        else
if fuel cell voltage > fuel cell previous voltage
        Duty = Duty + change;
        else
        Duty = Duty – change;
        End
```

A major problem of the P&O based MPP control method is that they are lacking in solid theoretical support. As a result, their stability and robustness is hard to analyze and may deteriorate in some unfavorable environments. The drawback of P&O is the oscillation around the MPP. For this the fuzzy logic based MPPT controller is implemented for the fuel cell model.

B. Fuzzy Logic Based Controller: Recently fuzzy logic controllers have been introduced in the tracking of the MPP in renewable energy systems. They have the advantage to being robust and relatively simple to design as they do not require the knowledge of the exact model [12]. In addition, fuzzy logic controllers can also change the fuzzy parameter for improving the control system. A fuzzy logic controller basically includes- Fuzzification, Rule base, Inference method and Defuzzification method [10].

1) Fuzzication: Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big). The value of input error (e) and change of error (de) are normalized by an input scaling factor.

2) Inference Model: The composition operation is the method by which a control output is generated. Several composition methods such as Max–Min and Max-Dot have been proposed. The commonly used method, Max–Min, is used in the proposed system. The output membership function of each rule is given by the Min (minimum) operator and Max (maximum) operator. Table I shows rule base of the FLC.

3) Defuzzication: As a plant usually requires a nonfuzzy value of control, a defuzzification stage is needed. Defuzzificaion for this system is the height method which is both simple and fast. The output of FLC is used to modify control output. Then, control output is compared with the reference waveform to generate a pulse for controllable switch (SB) of the boost converter. The fuel cell voltage and current is given to the fuzzy logic controller. In fuzzy logic controller these 49 rules have been implemented, which makes the fuel cell to operate at maximum power. The controller gives the duty cycle to the boost converter which is connected to the fuel cell model. This makes the system to operate at maximum power. Compared with P&O controller, fuzzy logic based controller will give better performance and stability.

Table 1: Rule Base of Fuzzy Logic Controller

		CHANGE IN ERROR						
ERROR		**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
	NB	NB	NB	NB	NB	NM	NS	ZE
	NM	NB	NB	NB	NM	NS	ZE	PS
	NS	NB	NB	NM	NS	ZE	PS	PM
	ZE	NB	NM	NS	ZE	PS	PM	PB
	PS	NM	NS	ZE	PS	PM	PB	PB

	PM	NS	ZE	PS	PM	PB	PB	PB
	PB	ZE	PS	PM	PB	PB	PB	PB

6. Fuel Controller:

The primary control loop avoids the underused or overused fuel. The real output current is proportional to the fuel input of the FC stack with a constant utilization factor in the steady state. The equation shows that,

$N_f = (K_r I_{FC} / Us)$

Where Us is the utilization factor in steady state. The relationship between a small change of stack current ΔIfc and a small change in hydrogen input $qH_{2\text{-}in}$ fed to the FC stack can be derived as,

$$I_{FC}=(u * qH_{2\text{—}in})/2K_r \qquad (2)$$

The fuel controller optimizes of the fuel consumption in the fuel cell. It also reduces the fuel wastage. Only the exact amount of the fuel needed at the input of the fuel cell will be delivered. The fuel cell current is given as the input to the fuel controller and the fuel input is calculated from the controller. It also protects the mechanical structure of the membrane and increases the fuel cell lifetime. The proposed system consists of both MPPT controller and fuel controller. The MPPT controller facilitates the load to extract maximum power from the fuel cell. The fuel wastage can be reduced by using fuel controller.

7. Simulation and Results:

A. Simulation of P&O based System:

P&O based system consists of a fuel cell model with P&O controller, boost converter. The fuel cell voltage and current is given to the P&O algorithm based MPPT controller. This controller gives the duty cycle to the boost converter to operate at maximum power. The current input to the fuel cell is feedback from the converter output. The input power and output power are compared in the proposed system. Figure 2 shows the output power of P&O controller at different temperature. Similarly the simulation is carried out by keeping the temperature constant. Figure 3 shows the output power of P&O controller at different membrane water content.

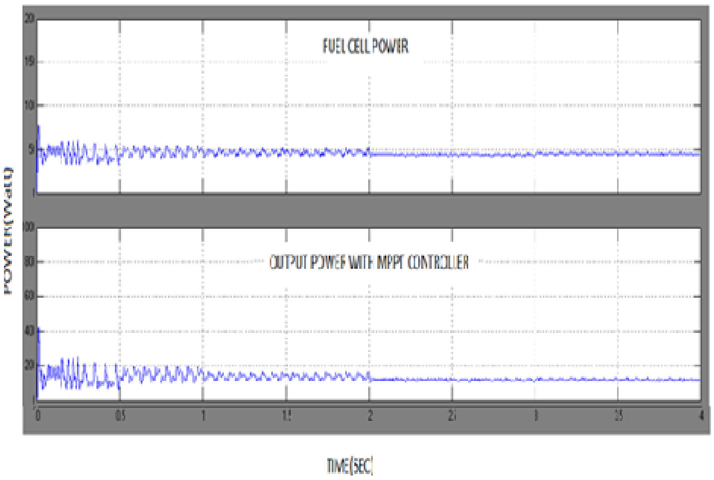

Figure 1: Output Power of P&O System at different Temperature

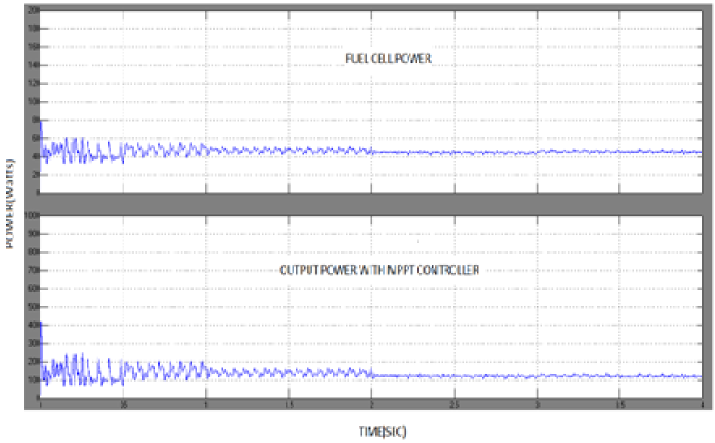

Figure 2: Output Power of P&O System at different Membrane Water Content

B. Simulation of Fuzzy Logic Based System: The fuzzy based system consists of a fuel cell model with fuzzy based MPPT controller, boost converter. The fuel cell voltage and current is given to the fuzzy logic based MPPT controller. This controller gives the duty cycle to the boost converter to operate at maximum power. The current input to the fuel cell is feedback from the converter output. The input power and output power are compared in the proposed system. Fig 4 shows the output power of fuzzy logic based controller at different temperature.

Similarly the simulation is carried out by keeping the temperature constant. Fig 5 shows the output power of fuzzy logic based controller at different membrane water content.

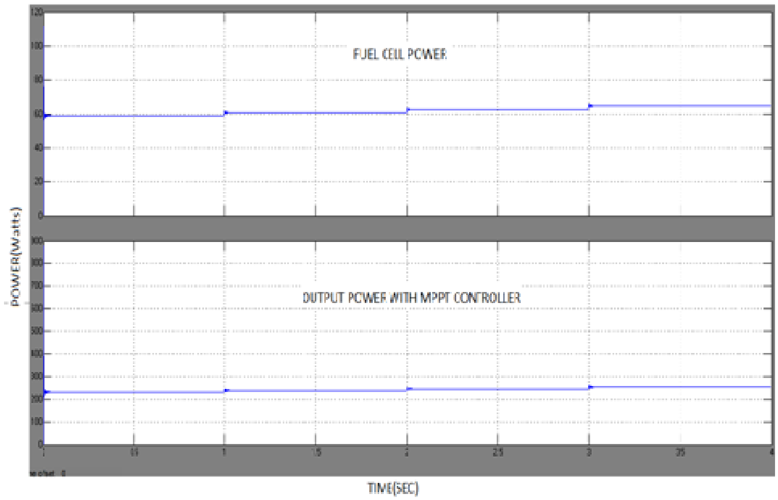

Figure 3: Output Power of Fuzzy based System at different Temperature

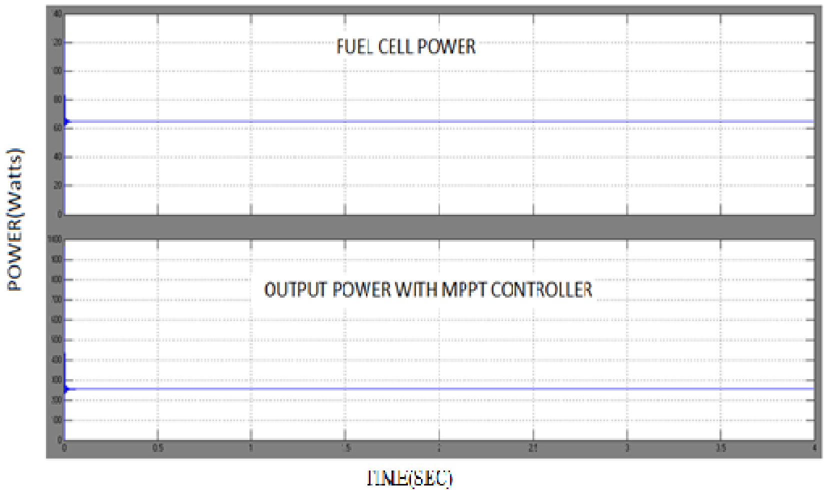

Figure 4: Output power of Fuzzy based System at different Membrane Water Content

C. Output Comparison of P&O and Fuzzy Based System: The output power of both P&O based system and fuzzy logic based system are compared for different temperatures and membrane water content. From the comparison it is found that fuzzy based MPPT system gives better performance and higher output power when compared with the P&O based MPPT system. Also the fuel controller is implemented for the fuzzy logic based system. The table II and III gives the comparison of output power for various temperature and membrane water content.

Table 2: Output Power Variations for Different Temperature

Temperature(K)	Time period (sec)	Output power with P&O MPPT (Watts)	Output power with fuzzy MPPT (Watts)
313	1	164	231
323	2	149	238.2
333	3	117.9	245.3
345	4	119.8	254.2

Table 3: Output Power Variations for Different Membrane Water Content

Membrane water content	Time period (sec)	Output power with P&O MPPT (Watts)	Output power with fuzzy MPPT (Watts)
14	1	174	253
13	2	150	254
12	3	115.4	254
11	4	112.7	254

D. Fuel Controller:

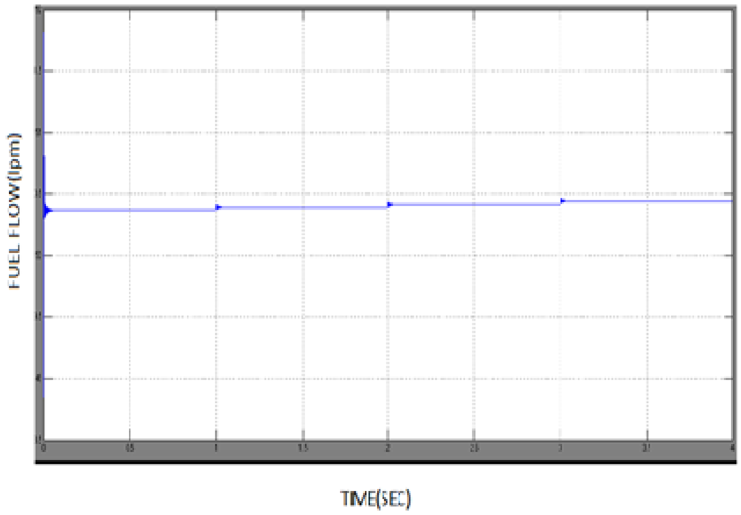

Figure 5: Fuel Flow for different Temperature

The simulation of fuel controller is done for fuzzy logic based system. The fuel cell current is given as the input to the fuel controller and the fuel input is calculated from the controller. The fuel controller optimizes of the fuel consumption in the fuel cell. It also reduces the fuel wastage. The exact amount of fuel which is given as input to fuel cell is shown in Fig 6 Also the Table IV gives the fuel variations for different temperature.

Table 4: Fuel Variations for different Temperature

Temperature(K)	Fuel Flow at Different Temperature (lpm)
313	50.37
323	50.39
333	50.42
345	50.45

8. Conclusion and Future Scope:

In this project, P&O and fuzzy logic based maximum power point tracking approach for PEM fuel cell is presented and its characteristics and performance is investigated via simulations. Besides, the performance of the fuzzy logic method is compared with the P&O approach. The results are indicative that the performance of fuzzy based controller is better that P&O based system. The MPPT controller facilitates the load to extract the maximum power from the fuel cell. Also the flow controller is implemented for the modelled fuel cell to reduce the fuel wastage. The proposed system has the advantages like reduction of fuel wastage, overheating of fuel cell, protection against short circuit and over current absorption. A unified controlling approach for extracting the maximum power and for optimizing the fuel consumption in a fuel cell system is developed .Thus by using the enhancement technique; the fuel cell can be made to operate optimally and can be used as one of the promising renewable energy resource. In future other enhancement technique like air flow control based on oxygen excess ratio, to overcome oxygen starvation or oxygen saturation problem can also be included to improve the fuel cell performance and make it more optimum.

9. References:

1. Abdi Sh, K. Afshar, N. Bigdeli, and S. Ahmadi, “A Novel Approach for Robust Maximum Power Point Tracking of PEM Fuel Cell Generator Using Sliding Mode Control Approach,” International Journal of Electrochemical Science, vol. 7, 4192 – 4209, 2012.
2. Alessandro Giustiniani, Giovanni Petrone, Giovanni Spagnuolo, “Low frequency Current Oscillations and Maximum Power Point Tracking in Grid Connected Fuel-Cell-Based Systems,” IEEE Transactions on Industrial Electronics, vol. 57, no. 6, 2042-2053, Jun. 2010.
3. Aryuanto Soetedjo, Abraham Lomi, Yusuf Ismail Nakhoda, Awan Uji Krismanto, “Modeling of Maximum Power Point Tracking Controller for Solar Power System,” TELKOMNIKA, vol.10, pp. 419-430, No.3, July 2012.
4. Carlos Andres Ramos-Paja, Carlos Bordons, Alfonso Romero, Roberto Giraland, Luis Martinez-Salamero, “Minimum Fuel Consumption Strategy for PEM Fuel Cells,” IEEE Transactions on Industrial Electronics, vol. 56, no. 3, 685-696, Mar. 2009.
5. F. A. Coutelieris, S. Douvartzides, and P. Tsiakaras, “The importance of the fuel choice on the efficiency of a solid oxide fuel cell system,” Journal of Power Sources, Elsevier, 123, 200–205, 2003.
6. K. H. Hussein, Muta, Hoshino, and M. Osakada, “Maximum photovoltaic power tracking: an algorithm for rapidly changing atmospheric conditions,” IEE Proc.-Gener. Transm. Distrib., vol. 142, no. 1, 59-64, Jan. 1995.

7. Iman Soltani, Mohammad Sarvi, and Haniyeh Marefatjou, “An Intelligent, Fast and Robust Maximum Power Point Tracking for Proton Exchange Membrane Fuel Cell,” World Applied Programming, vol. 3, Issue. 7, 264-281, Jul. 2013.
8. Junsheng JIAO and Xueying CUI, “A Real-time Tracking Control of Fuel Cell Power Systems for Maximum Power Point,” Journal of Computational Information Systems 9: 5, 1933-1941, 2013.
9. Junsheng JIAO and Xueying CUI, “Adaptive Control of MPPT for Fuel Cell Power System,” Journal of Convergence Information Technology (JCIT), vol. 8, no. 4, Feb. 2013.
10. Kalyan Chatterjee, Ravi Shankar, and Amit Kumar, “Fuzzy Logic Based Controller for a Grid-Connected Solid Oxide Fuel Cell Power Plant,” Journal of Fuel Cell Science and Technology, vol. 11, no. 051005-1, Oct. 2014.
11. Karthik Murugesan and Vijayachitra Senniappan, “Investigation of Water Management Dynamics on the Performance of a Ballard-Mark-V Proton Exchange Membrane Fuel Cell Stack System,” International Journal of Electrochemical Science, vol. 8, 7885 – 7904, 2013.
12. Khaled mammar and Abdelkader chaker, “Fuzzy logic -based control of power of PEM fuel cell system for residential application,” Leonardo Journal of Sciences, Issue. 14, 147-166, Jan-Jun. 2009.
13. R. F. Mann, J. C. Amphlett, A. I. Michael, and Hooper, “Development and application of a generalised steady-state electrochemical model for a PEM fuel cell,” Journel of Power Sources, 86 (2000) 173–180.
14. S. Mekhilefa , R. Saidurb, and A. Safari, “Comparative study of different fuel cell technologies,” Elsevier, Renewable and Sustainable Energy Reviews 16, 981– 989, 2012.
15. Meng-Hui Wang, Her-Terng Yau, and Tai-Yuan Wang, “Extension Sliding Mode Controller for Maximum Power Point Tracking of Hydrogen Fuel Cells,” Abstract and Applied Analysis, Hindawi Publishing Corporation, 2013.
16. Nicu Bizon,“Energy harvesting from the FC stack that operates using the MPP tracking basedon modified extremum seeking control,” Applied Energy, Elsevier, 104, 326-336, 2013.
17. Zhong Zhi-dan, Huo Hai-bo, Zhu Xin-jian, Cao Guang-yi, Ren Yuan,“Adaptive maximum power point tracking control of fuel cell power plants”, Journal of Power Sources, Elsevier, 176, 259-269, 2008.