DESIGN, IMPLEMENTATION AND EVALUATION OF FUZZY LOGIC AND PID CONTROLLERS FOR FUEL CELL SYSTEM

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DEPARTMENT OF
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I certify that in my opinion the thesis submitted by Abdulbari Ali Mohamed FREI titled "DESIGN, EVALUATION AND IMPLEMENTATION OF FUZZY LOGIC AND PID CONTROLLERS FOR FUEL CELL SYSTEM" is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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The degree of Master of Science by the thesis submitted is approved by the Administrative Board of the Graduate School of Natural and Applied Sciences, Karabük University.

Prof. Dr. Nevin AYTEMİZ ....
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“I declare that all the information within this thesis has been gathered and presented in accordance with academic regulations and ethical principles and I have according to the requirements of these regulations and principles cited all those which do not originate in this work as well.”

Abdulbari Ali Mohamed FREI

ABSTRACT

M. Sc. Thesis

DESIGN, IMPLEMENTATION AND EVALUATION OF FUZZY LOGIC AND PID CONTROLLERS FOR FUEL CELL SYSTEM

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In this thesis, fuel cell control is investigated in addition to the use of fuzzy logic to control fuel cells. For fuzzy rules, the maximum power point tracking algorithm is used. Additionally, PID control is used and tested in this thesis. As simulation results show, the performance of fuzzy logic is better than PID control. In general, for fuel cell systems, humidification is required for the air or the hydrogen, or both the air and hydrogen at the fuel cell inlets. Moreover, water content is very important for the protonic conductivity in the proton exchange membranes. If membrane dehydration or drying occurs, electrical performance decreases due to significant ohmic losses.

Key Word **:** Fuel cell, fuzzy logic, PID controller, MPPT.
Science Code : 701.3.019

ÖZET

Yüksek Lisans Tezi

YAKIT HÜCRELERİ SİSTEMİ İÇİN FUZZY LOJİK VE PID KONTROLCÜLERİNİN TASARIMI, GERÇEKLEŞTİRİLMESİ VE DEĞERLENDİRİLMESİ

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Bu tezde, yakıt hücresi kontrolü yakıt hücrelerini kontrol etmek için bulanık mantık kullanımına ek olarak incelenmiştir. Bulanık kuralları için, maksimum güç noktası izleme algoritması kullanılır. Ayrıca, PID kontrolü kullanılır ve bu tezde test edilir. Simülasyon sonuçlarının gösterdiği gibi, bulanık mantık performansı PID kontrolünden daha iyidir. Genel olarak, yakıt hücresi sistemleri için, nemlendirme yakıt hücresi girişlerinde hava ya da hidrojen ya da her ikisi için gereklidir. Ayrıca, su içeriği proton değişimi zarlarındaki protonik iletkenlik için çok önemlidir. Zar dehidrasyonu veya kuruma oluşursa, elektrik performansı önemli omik kayıpları nedeniyle azalır.

Anahtar Sözcükler : Yakıt hücresi, bulanık mantık, PID kontrolörü, MPPT.
Bilim Kodu **:** 701.3.019

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SYMBOLS AND ABBREVITIONS INDEX

SYMBOLS

H_2o : Water

H_2 : Hidrojen

He : Helyum

O_2 : Oxygen

CO_2 : Carbon Dioxide

K_2CO_3 : Potassium Carbonate

Y_2O_3 : Yttrium Oxide

ABBREVIATIONS

FC : Fuel Cell
AFC : Alkaline Fuel Cells
PAFC : Phosphoric Acid Fuel Cells
MCFC : Molten Carbonate Fuel Cells
SOFC : Solid Oxide Fuel Cells
PEFC : Polymer Electrolyte Fuel Cells
MPPT : Maximum Power Point Tracking
PID : Proportional Integrator Derivative
Ki : Integrator Coefficient
Kd : Derivative Coefficient
Kp : Proportional Coefficient
WG : Wind Generator
IC : Increasing Conductivity

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

Energy has been predicted as one of the main problem that humanity must face in the future. Nowadays, primary energy sources in the world consist of fossil fuels including petroleum, coal and natural gas. However, there are some problems with continued use of fossil fuels. They are limited in amount and someday will be depleted. They are causing serious environmental problems, such as global warming, climate changes, acid rains, air pollution, ozone layer depletion, and so on. For these reasons, alternative energy sources are needed. In these sense combined with fuel cells hydrogen energy systems is a good alternative [1].

Hydrogen is a perfect energy carrier with many unique properties. Together with hydrogen, fuel cells have been getting a lot of attention because they directly and efficiently convert chemical energy of reactants into electrical energy.

Fuel cell is an electrochemical device that converts chemical reaction energy directly into electrical energy by combining hydrogen with oxygen. In these chemical reactions, only byproducts are heat and water. Fuel cells have many advantages over conventional systems that produce electricity. They have higher efficiency than conventional system.

Within many types of fuel cells, proton exchange membrane (PEM) fuel cells are spectacular because of its compactness, light weight, high power and low cost [1]. They have been noticed as the most promising power generating device candidates in portable electronic, automotive and distributed power generation applications in future [2].

In recent years, research and development activities in fuel cells have been accelerated. Although, there are significant improvements in the technology of proton exchange membrane, the performance, stability, and reliability is not sufficient to replace internal combustion engines and the cost of fuel cell systems is still too high to become acceptable commercial products. The most important problems to be overcome are improvement of their performance and reduction of their cost [3].

In PEM fuel cells, hydrogen and air humidification may be required in order to prevent the fuel cell membrane from dehydration. At high current flow, there is ohmic heating causing drying problems in the polymer membrane and slows ionic transport through the membrane. Because of water generation at the air side, in some fuel cell stacks, humidification is not required. In general fuel cell systems, humidification is required for either the air or hydrogen or both the air and hydrogen at the fuel cell inlets. Water content is very important for the protonic conductivity in proton exchange membranes. If membrane dehydration or drying occurs, the electrical performance decreases due to significant ohmic losses [4].

In this thesis the fuel cell control is investigated and for control of fuel cell the fuzzy logic is used. For fuzzy roles the maximum power point tracking algorithm is used. Also in this thesis the PID control is used and tested. As simulation result shows the performance of fuzzy is better than the PID control.

1.2. LITERATURE REVIEW

Due to the fuel cell non-linear property of P-I, maximum power point tracking (MPPT) controller for practical applications is very important to apply. Junsheng et al., proposed a Fuel cell and converting, using sliding mode control based on a mathematical model and a new approach to MPPT. In their method DC-DC converter to change the duty cycle of reinforcement Control is applied. The features of the controller is confirmed by simulations. The performance of the method of its good transient response, low tracking error and operational temperature, water content and load changes are very rapid system response. They proofed that their method can be applied effectively and economically [9].

Output power of a fuel cell depends on the current or voltage is applied on non-linear and unique maximum power point (MPP) is available. This trail is an extreme MPPs by requesting paper controller reports a first attempt. MPPs working conditions of the focus of fuel cell varies linearly with no unforeseen changes. Thus, the maximum power point tracking (MPPT) controller changes in operating conditions is required to ensure the highest possible power continuous load occurs. Two loop cascade control unit with an intermediate converter is designed to operate from their MPPs fuel cell power plants. The outer loop uses an adaptive algorithm to estimate the MPP extremum who want real-time data and then estimate the value of the inner loop set-point force as the inner loop to operate fuel cell. Recommended MPPT control system, the fuel cell can continue to operate without real-time MPPs provides a simple and robust control law. Simulation of this control approach, the fuel cell shows satisfactory results in terms of stability towards the operating conditions change [10].

They obtained a DC step-up gain that can make microbial fuel cells (MFC) an energy aware power management unit aimed arrays (EA-PMU) for a inductor less DC-DC (I-DCDC) converter introduces efficient maximum power point tracking (MPPT). Because of identifying and selecting the best point of harvest time MFC MFC's changing power profile, increase the efficiency and overall power distribution. Currently, MFC series or reverse voltage current issues with MFC application is limited due to parallel connections; this is a more reliable approach harvest time multiplexing. However, each time leaving a new MFC harvest time, a new maximum power point (MPP) is required. Recommended converter, converts maximize efficiency as well as obtain dynamic MPP adapts to adjust their power consumption. Converters are designed and manufactured in 0.18 micron CMOS process and had input power of 1.6 mW shows 65% for maximum efficiency [11].

There is no resource for energy storage and play an important role in renewable energy systems. Fuel Cell (FC) is one of these technologies [12]. Power optimization methods Maximum Power Point Tracking (MPPT) is applied to these cells using the systems. Perturb and observe (P & O) and increasing conductivity (IC) method for simulating and is good for the FC system applications are compared to determine which one [12].

They proposed a method for wind generator (WG) maximum power point tracking (MPPT) system, DC / DC converter and MPPT functions for control unit. The load impedance is matched with the impedance of the source under a given wind speed wind energy conversion system can provide maximum strength. Because the load and dynamically changing wind speed, maximum power point tracking (MPPT) becomes more complex. The advantages of wind speed MPPT method WGA optimal power characteristic or measurement that there is no information required and operates at variable speeds WGA. Thus, the system of high reliability, low complexity, and less mechanical stress WG. In this paper a hybrid algorithm is used for maximum power point tracking. In their method, the electrical variation, the duty cycle of the inverter output voltage is adjusted in accordance with various embodiments [13].

Fuel cell (FC), low pollution, characterized by low noise and high efficiency. However, the FC voltage-current response to a single operating point of the working conditions that maximize the output power given a certain set of result, it is non-linear. Accordingly, a maximum power point tracking extension theory based on existing studies (MPPT) control scheme proposes an FC output stabilized at maximum power point. The simulation results of temperature, hydrogen confirms the ability of the controller to compensate for the output power at the maximum power point, despite the sudden changes Pressure until the membrane water content. Furthermore, the transient response time of the proposed controller, the faster (ES) seeking sliding mode controller (SM) and the end has been shown to be present [14].

They proposed a novel control strategy to maximize the level the fuel cell power generation efficiency. Maximum efficiency point tracking (MEPT) controller is designed based on the extremum seeking control algorithm. This closed-loop, can do real-time and non-model-based control methodology extreme perturbation, such as unacceptable by traditional optimization methods, such as the rapidly changing working conditions, obtained under the guarantee and observe the algorithm [15].

The ability of the system as a fuel to generate power is limited. So (MPP) is required to force to work in exchange for fuel cell maximum power point system requirements. Fuel cells MPP is unique and fixed point operations, load power requirements will vary with load resistance and output voltage variations are not taken into account. Battery Fuel CEO with the necessary controls have been proposed new configuration for hybrid power system and analyzed [16]. This fuel cell system operates its own MPP and the output voltage is kept constant, the way it works. The proposed system is simulated and the results indicate that the system is functioning within acceptable operating under different conditions.

A new flow-based maximum power point tracking (CMPPT) method is recommended for single-phase photovoltaic power conditioning system and will be available based MPPT changes the method of increasing the conductivity [17]. The current method based MPPT power conditioning system makes it all simple control structure and characteristics of solar cell uses the natural flow of the directory source. Therefore, durable and shows a quick response under fast changing environment. In addition, the digital phase locked loop using all-pass filter is added to detect the phase and peak voltage of the mains voltage. DC/DC boost converter, DC-bus voltage, DC/AC inverter controller is designed to work on coordination. It is also used for synchronous conversion PI current control using a fake unity power factor and current control grid. 3kW photovoltaic power conditioning system prototype has been built and experimental results are given to verify the effectiveness of the proposed control program.

Solar energy is clean, renewable and scattered low-density character of the region's population would be decentralized as appropriate. The cost of electricity from solar array system more expensive than grid electricity. So, it is necessary for any environmental condition to follow the maximum power point of a PV system to work at maximum efficiency. The neural network back propagation algorithm is used to control the operation of PV to achieve maximum power [18]. Two error functions are used. , The first classic error function and error function, the second amended it takes into account the derivative of the error function. The results are compared and discussed.

CHAPTER 2

FUEL CELLS

2.1. BACKGROUND

A fuel cell is the space in which electricity produced without combustion. The difference between the fuel cell and the battery is that fuel cells are infinite, while batteries are finite because, fuel cells are energy converters but batteries are energy sources. Generally, pure hydrogen or other hydrogen containing compounds such as hydrocarbons, ammonia are used as a fuel for these cells [5]. There are three main parts of a fuel cell: Anode, Cathode and Electrolyte. Typically, hydrogen molecules are inserted in the anode and it separates hydrogen ions and free electrons. Hydrogen ions go through the cathode and meet oxygen molecules. At the same time, free electrons move from anode to cathode by different path called electrical current. At cathode, chemical reaction is completed. Hydrogen atoms, oxygen molecules and free electrons combined together and water is made [6]. In Figure 2.1 the operation of fuel cell is illustrated.

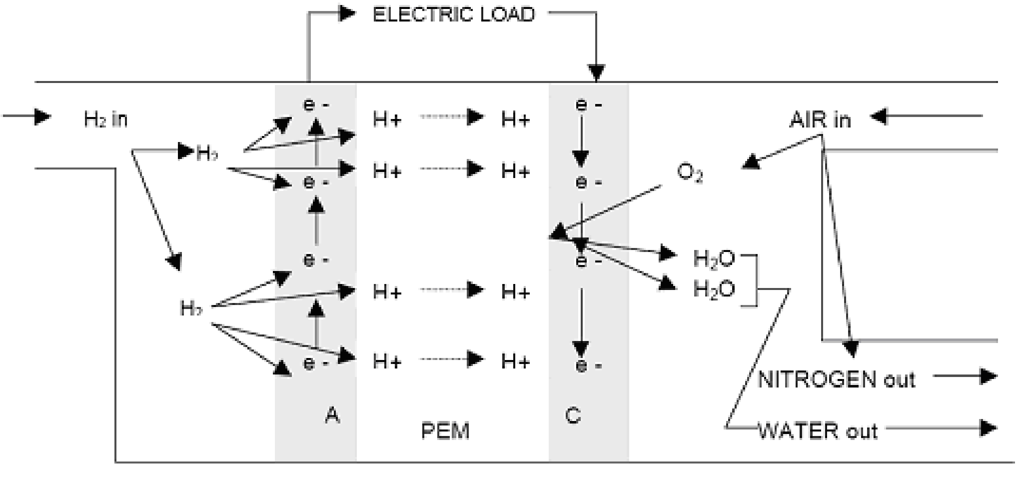


Figure 2.1. Fuel cell operation.

$2H_2 \rightarrow 4H^+ + 4e^-$ Anode Reaction (2.1)

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ Cathode Reaction (2.2)

$2H_2 + O_2 \rightarrow 2H_2O$ + Electricity + Heat Cell Reaction (2.3)

Sir William Grove, who was called “Father of The Fuel Cell”, discovered fundamentals of fuel cell in Britain in 1839. He found the idea of producing electricity by using oxidation and reduction reactions but, later, fuel cells hadn’t been being used over a hundred years except space projects like the Apollo or Gemini. The reason is simple; material costs were very expensive. However, automotive industry has been using fuel cells since mid 1960’s [5].

2.2. FUEL CELL PERFORMANCE

The rate of change of Gibbs free energy constant defines optimum electrical work under constant temperature and pressure conditions.

$$W_{ei} = \Delta G = -n.F.E \tag{2.4}$$

n : is the electron number in reaction, F is faraday constant, E is optimum potential of the cell Below formula also calculates The Gibbs Free Energy Constant

$$\Delta G = \Delta H - T.\Delta S \tag{2.5}$$

ΔH is enthalpy change and ΔS is entropy change
T.ΔS is waste or useless energy due to varying entropy. If reaction generates heat this means negative entropy, if reaction needs heat this means positive entropy. Efficiency of the fuel cell is

$$\eta = \frac{Beneficial\,.Energy}{\Delta \mathrm{H}} \tag{2.6}$$

$$\eta_{ideal} = \frac{\Delta G}{\Delta \mathrm{H}} \tag{2.7}$$

Basic reaction:

$$H_2 + {}^{1}\!/_{2} O_2 \rightarrow H_2O + \text{Electrical.Energy + Heat} \tag{2.8}$$

At normal conditions, 25^{o}C and 1 atm, ΔH 285,8 H kJ/mole and ΔG 237,1 G kJ/mole

So ideal efficiency

$$\eta_{ideal} = 0{,}83 \tag{2.9}$$

$$\eta = \frac{Beneficial\ .Energy}{\Delta \mathrm{H}} = \frac{Beneficial\ .Energy}{\left(\dfrac{\Delta G}{0{,}83}\right)} = \frac{V_{real} x I_{real}}{\left(\dfrac{V_{ideal} x I_{real}}{0{,}83}\right)} = \frac{0{,}83 x V_{real}}{E_{ideal}} \tag{2.10}$$

If hydrogen and oxygen accepted 100% pure and pressure is 1 atm and temperature is 25^{o}C, ideal potential E equals 1.229 V for liquid form and 1.18 for gas form of output water. So, equation becomes:

$$\eta = 0{,}675 x V_{real(cell)} \tag{2.11}$$

There is a difference between ideal potential because different conditions of water results in gibbs free energy change due to vaporization. The effect of temperature on ideal potential is seen on Figure 2.2 graphic [6].

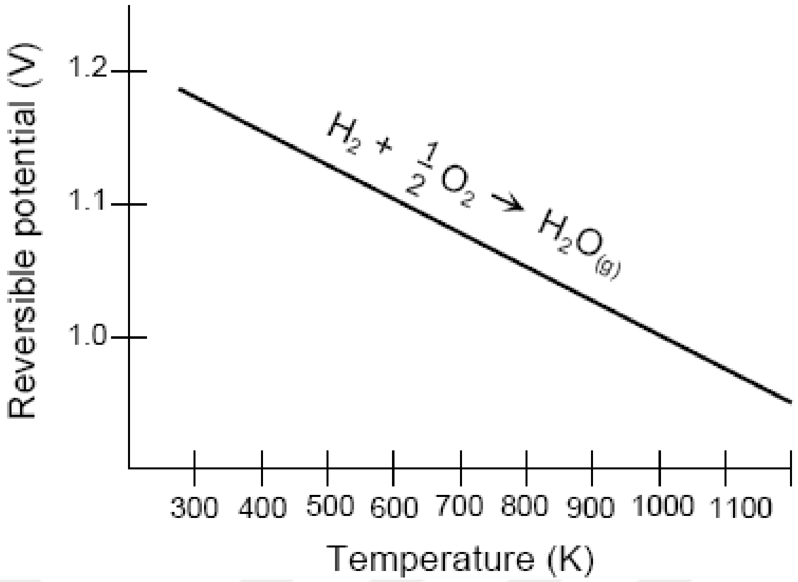


Figure 2.2. The effect of temperature on fuel cell.

The cause of difference between ideal and real is non-reversible losses such as reaction rate losses, ohmic losses due to electrolyte resistance to ion flow and electrode resistance to electron and the last one gas transport losses.

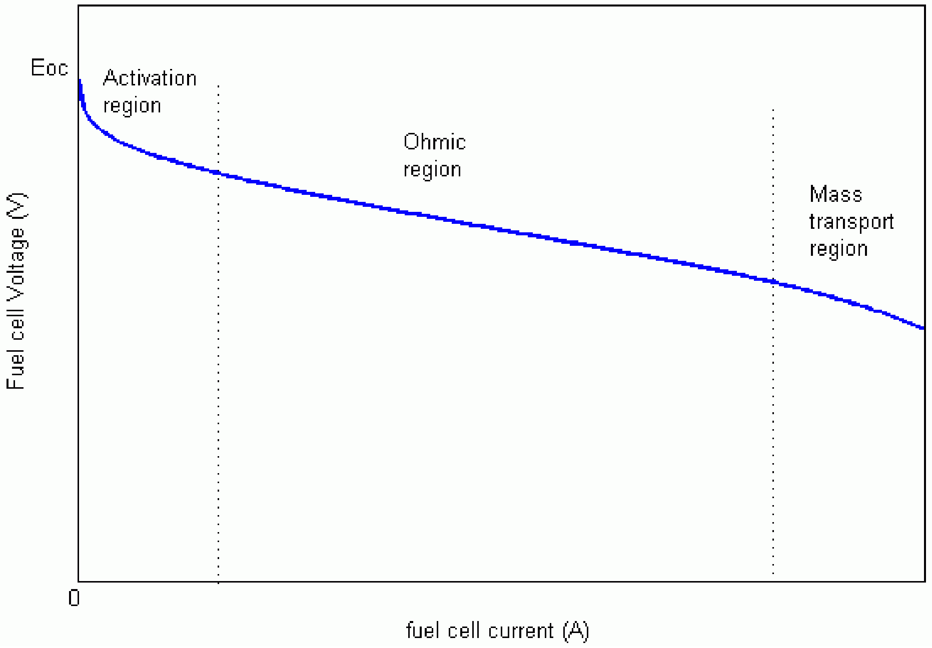


Figure 2.3. Loss division for fuel cell.

Current density is an important coefficient, which affects fuel cell performance seriously. At the beginning of the reaction, start-up current flows but reaction speed is low and voltage decreases. During normal operation, electrode and electrolyte resistances cause voltage drop. At high current ratios, necessary reactant cannot pass cathode side as a result of voltage decreases. Figure 2.4 shows the relation of voltage-current and power-current. Minimum power means maximum voltage and lower current density. On the other hand, maximum power means minimum voltage and minimum cell efficiency so optimization must be handled.

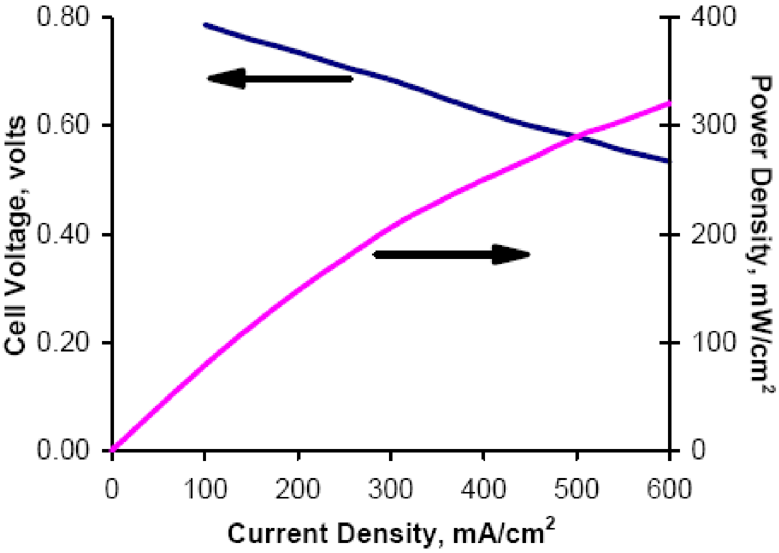


Figure 2.4. Performance of fuel cell.

Temperature is another critical factor, which determines cell performance with pressure. As H_2 and O_2 reaction is exothermic, any increase in temperature will decrease (0.84mV/°C) potential of the fuel cell. Furthermore, positive pressure change improves performance and rises up potential voltage. Nevertheless, temperature has other effects. For example, higher temperature enhances electrode reactions. Secondly, on the contrary to normal conductive materials, any increase in temperature, declines ohmic resistance and promotes reaction.

2.3. FUEL CELL TYPES

2.3.1. Alkaline Fuel Cells (AFC)

There are two kinds of KOH electrolyte concentration one of them is about %85 and the other one is about %40 percent while higher one operating temperature is 250°C and lower one is less than 120°C. Only hydrogen is usable as a fuel supply because for example CO_2 is harmful as it tends to react with KOH to create K_2CO_3. Development of AFC had started in 1960, which was a famous project, The Apollo Space Vehicle. The AFC was used to supply electrical energy for Apollo. Despite being successful, the AFC had some difficulties especially CO_2 sensivity. There are two important advantages of the AFC: many kinds of electro-catalysts are usable and its electro kinetic is very active so these make the AFC's performance admirable. On the other hand, the AFC requires high ratio of purity for H_2, it means that CO and CO_2 purification system must be well-designed at high efficiency. Overall, the cost is getting more expensive, the construction is getting more complex and the size is getting bigger [6]. Fundamental reactions and general fuel reaction:

$$H_2 + 2OH^- \rightarrow 2H_2O + 2e^- \qquad \text{Anode Reaction (2.12)}$$

$$\tfrac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^- \qquad \text{Cathode Reaction (2.13)}$$

$$H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O + \text{Electrical.Energy + Heat} \qquad \text{Cell Reaction (2.14)}$$

KOH is selected for electrolyte because it is the best of alkaline hydroxides when compared by conductance.

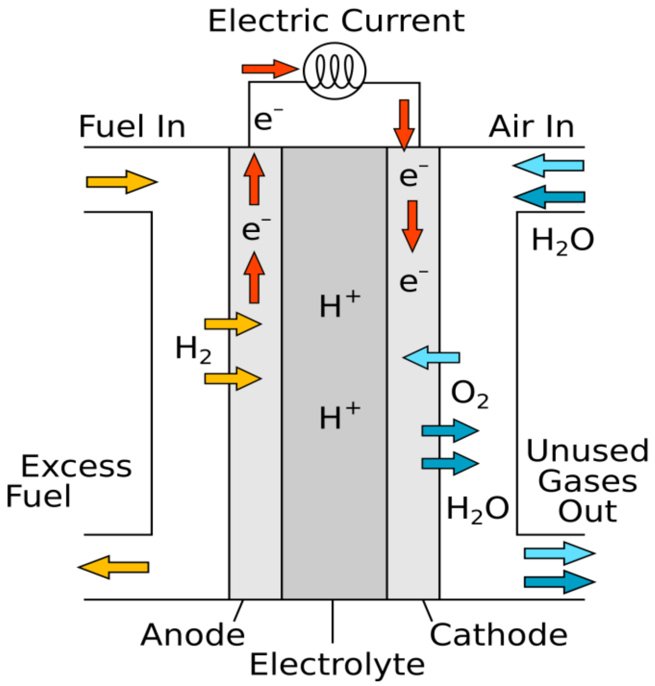


Figure 2.5. Basic scheme of AFC.

2.3.2. Phosphoric Acid Fuel Cells (PAFC)

Typical PAFC concentration is %100 phosphoric and operation temperature is between 150 °C and 220 °C because higher temperature increases conductance and does not allow CO to harm Pt catalyst [6]. When compared to general margins of acids, operating temperature of concentrated phosphoric acid is lower because of its higher relative durability as a consequence pressure of water vapor decreases and this makes water treatment simple. Silicon carbide is applied to keep acid healthy and Pt is used in anode and also cathode.

PAFCs are feasible for settled systems because they were designed and dedicated to be compatible for these systems. It is simple and possible to find advanced PAFCs in USA or Japan however recent developments on PEFC decreasing popularity of PAFCs due to better performance and better cost [7]. CO sensivity of PEFCs and AFCs are higher than PAFCs. General components are applicable for framework due to the fact that operation temperature is lower. This also simplifies design and construction of systems to export heat from Fuel Cell. Overall system efficiency is better than PEFCs on the other hand worse than SOFCs and MCFCs [6]. Platinum catalyst is necessity and also reduction reactions are not as fast as AFCs. A sophisticated fuel operation system is an essential requirement by the way performance will be upgraded. Since corrosion tendency of phosphoric acid is high, stack equipment must be complex as a result stack cost becomes higher [6].

$H_2 \rightarrow 2H^+ + 2e^-$ Anode Reaction (2.15)

${}^1\!/_2 O_2 + 2H^+ + 2e^- \rightarrow H_2O$ Cathode Reaction (2.16)

${}^1\!/_2 O_2 + 2H^+ + 2e^- \rightarrow H_2O$ Cell Reaction (2.17)

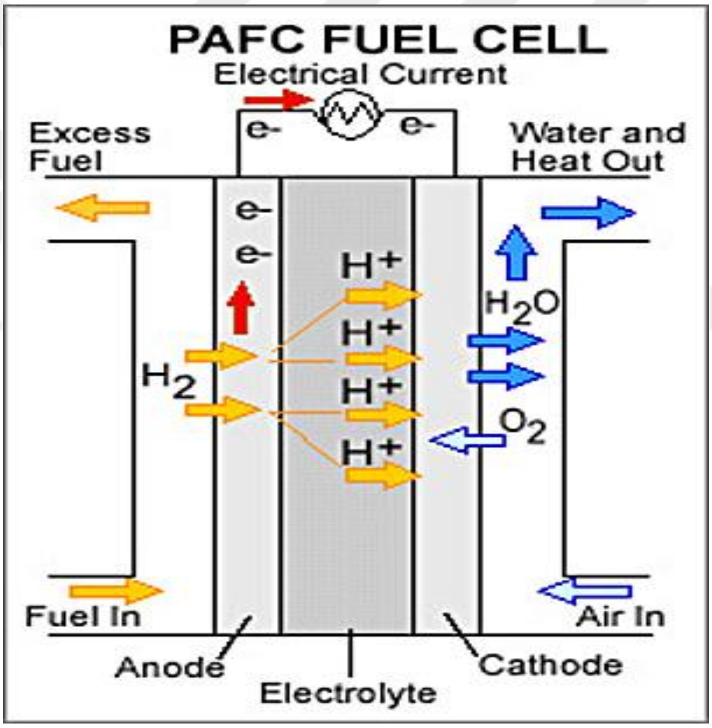


Figure 2.6. Basic scheme of PAFC.

2.3.3. Molten Carbonate Fuel Cells (MCFC)

The nominal operating temperature is between 600 °C and 700 °C because electrolyte is consist of alkali carbonates and they build up good conductive environment by carbonate ions. High temperature also enables to use Nickel as an anode and Nickel oxide as a cathode so there is no need to noble metals to increase chemical activation [7].

Settled systems and marine industry are the main interest area of MCFCs because bigger volumes and longer start-up time could be tolerated. High cost electro catalysts are not required due to the fact that working temperature reaches 650-700 °C and also MCFC systems has ability to use CO or hydrocarbons as a fuel this raises system efficiency up to middle fifties. Besides construction will be simple since CO management is not necessary. However, high temperature must be outsourced for automotive applications this means additional cost, weight and volume [6]. Another disadvantage is electrolyte which tends to corrode other equipments as a result high-quality stainless steel must be used for cell hardware resulting high cost.

$H_2 + CO_3^{-2} \rightarrow H_2O + CO_2 + 2e^-$ Anode Reaction (2.18)

${}^{1}\!/_{2} O_2 + CO_2 + 2e^- \rightarrow CO_3^{-2}$ Cathode Reaction (2.19)

$H_2 + CO_2 + {}^{1}\!/_{2} O_2 \rightarrow H_2O + CO_2$ Cell Reaction (2.20)

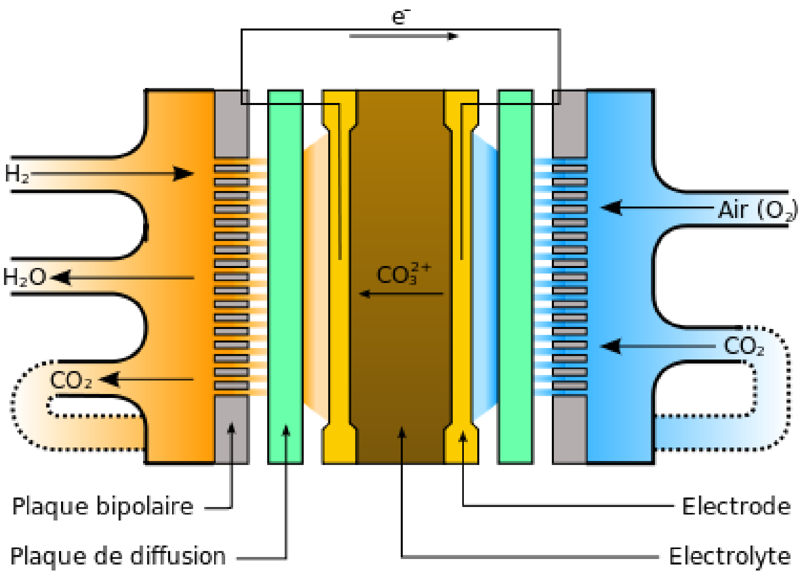


Figure 2.7. Block scheme of MCFC.

2.3.4. Solid Oxide Fuel Cells (SOFC)

The electrolyte of SOFC is solid generally made of Y_2O_3 material. The electrolyte is not liquid it takes same advantages such as electrolyte management and limited corrosive effect. Another advantage is CO can be used as a fuel. Although the performance is good and suitable for fast working conditions, nominal operating temperature is very high about 1000 °C which could be solved by additional equipment as a consequence the cost increases, the volume gets bigger. If these problems are solved SOFC will be used in mobile applications however the load applied SOFC must be a little bit steady because excessive load changes damage the unity of stack [6].

2.3.5. Polymer Electrolyte Fuel Cells (PEFC)

Short start-up and response times, lower operating temperatures and higher voltage current capacities make PEFCs the most appropriate option for new hydrogen based energy conversion systems [7]. A PEFC is also called Proton Exchange Membrane Fuel Cell (PEMFC) consists of four mother parts. First part is ion exchange membrane, which separates H+ and e-, is the conductive path. Second part is porous layer which works as a gas diffuser, mechanical support, pathway for electrons, channel for exhaust water from the electrodes. Thirdly, electrodes are contacts between layer and membrane.

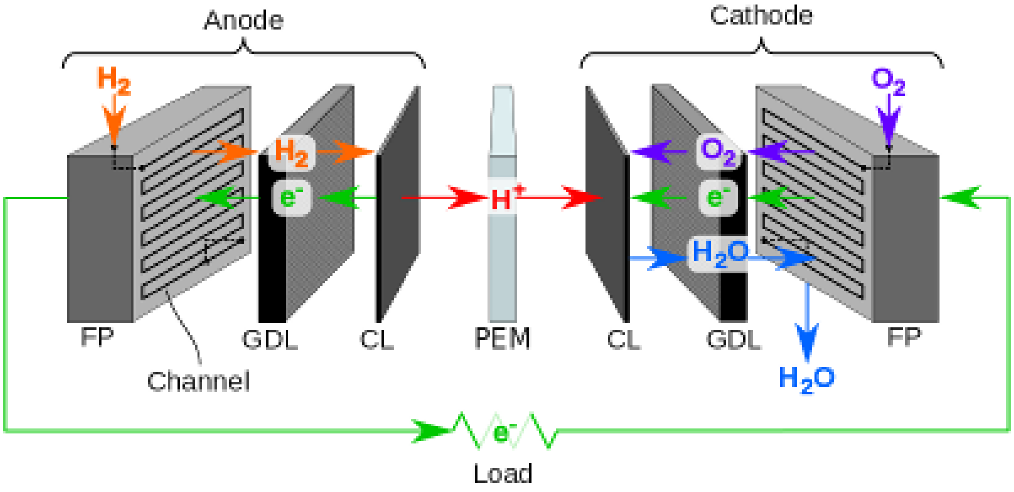


Figure 2.8. Layers of PEFC.

Hydrogen oxidized H+ and e- at anode. At anode side, hydrogen oxidation potential and at cathode side, oxygen reduction potential create 1V, which pulls H+ ions from anode to cathode.

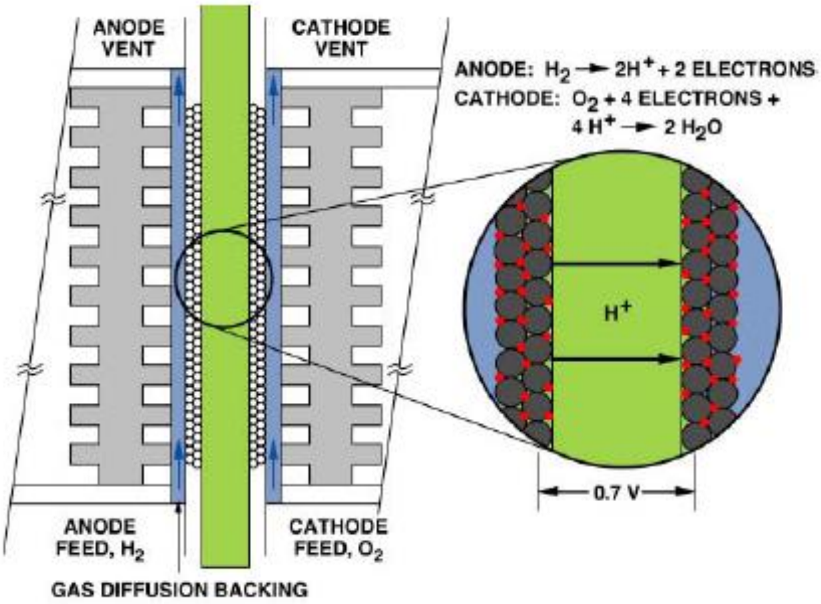


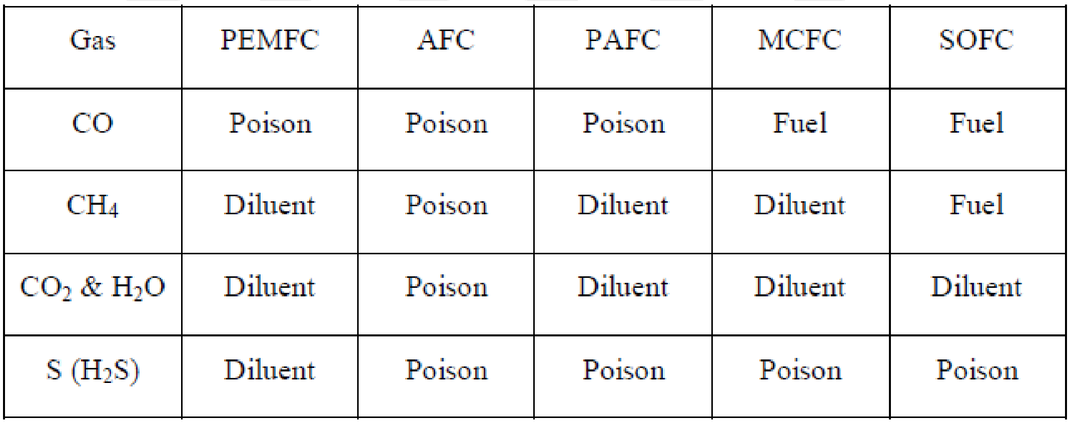
Figure 2.9. Anode-Cathode reaction of PEFC.

Theoretical operating temperature of PEMFC is between 0-90 °C but in practical a PEMFC works around 60-80 °C. PEMFCs have ability to start up fast from normal conditions because of low working temperature. However, low temperature causes CO poisoning, because CO is harmful for platinum catalyst at especially lower temperatures. Very low quantities of CO, like 2-3 ppm is allowed at 60-80 °C but at high temperatures greater than 120 °C just adequate to stop CO poisoning. Typical membrane is made of nafion (per fluorinated sulfonic acid polymer) and it cannot work properly at these temperatures since it dehydrates unless high pressure supplied [7,8].

Hence working pressure equal ambient pressure and operating temperature is below 100 °C, output water is liquid. Water concentration is important for conduction ability of electrolyte. Water treatment is a key issue for PEMFC it depends on working conditions, membrane and electrode features. Keeping working temperature stable is also a critical topic which is generally achieved by cooling water to hold temperature difference below 10 °C.

CO and S are the most effective contaminants while CO_2 and hydrocarbon fuels have relatively low effect on PEMFCs. Sulfur compounds are most damaging to the fuel cell because they adsorb onto the Pt catalyst and reduce the number of available reactivity sites for the oxygen reduction reaction. There are also some harmful chemicals for example ammonia causes membrane deterioration, alkali metals and hydrocarbons harm catalyst. They must be filtered out of the incoming air in order to prevent damage and performance loss of the fuel cell. Like the internal combustion engine, dust must be filtered out since the intake system, as well as the fuel cell, is composed of many components that are sensitive to this impurity. Aside from dust and other particulates, some harmful chemical substances must also be removed.

Table 2.1. Effects of main toxics on different types of fuel cells.



Gas	PEMFC	AFC	PAFC	MCFC	SOFC
CO	Poison	Poison	Poison	Fuel	Fuel
CH_4	Diluent	Poison	Diluent	Diluent	Fuel
CO_2 & H_2O	Diluent	Poison	Diluent	Diluent	Diluent
S (H_2S)	Diluent	Poison	Poison	Poison	Poison

Hydrogen and oxygen are two input of PEMFC. As mentioned hydrogen is supplied from hydrogen storage system but oxygen, generally is sourced from ambient atmosphere by an air intake system which is preferred to get maximum performance and efficiency from a PEMFC. The specifications of absorbed air have an emphasis on PEMFC performance such as pressure, flow-rate, humidity, temperature and purity [8]. Oxygen is one of the two inputs of fuel cell so physical condition of oxygen determines performance of the fuel cell. Likely, oxygen pressure have positive effect on performance. For example [6] reported that at 93 °C, fuel cell performance increased 42 mV and 215 mA/cm^2 by changing oxygen pressure from 3 bar to 10 bar. Another example, when oxygen pressure is increased from 1 bar to 5 bar, at 50 °C, 500 mA/cm^2 and 83 mV is gained. The last example, current density of a PEMFC is increased 431 mA/cm^2 and voltage rised up 22 mV by only 1 bar changing at 80 °C. This is certain that increased oxygen pressure improves PEMFC performance but compressing of oxygen is still work and some amount of power is consumed. This means that a good optimization is needed. The additional work to compress oxygen mustn’t be greater than extra work which is gained at fuel cell side [6].

Typical PEMFC current density is 200 mA/cm^2, providing 0.78 V at 80 °C. Since mentioned above higher temperatures improve fuel cell performance for example 1,1-2,5 mV per each degree. The reason is that higher temperature decreases ohmic resistance of electrolyte and rises up reaction kinetics. Although, temperature has positive effect on fuel cell performance, too much temperature rise would cause dehydrogenation and it could decelerate ionic conductivity. So, extra heat must be removed by thermal management system for which generally air/water is preferred to keep PEMC on optimum temperature. Cooling with air or water are preferred solutions. At the same temperature pure oxygen performance is better than air and when the same air is used, higher temperature causes higher performance [8].

Direct use of H_2 for PEMFC needs R&D work specifically on heat exchangers, humidifier and condenser. Existing automotive industry standards limit engine temperature at maximum 60 °C [6]. Therefore, there is a critical problem, which requires advanced water and heat treatment systems especially for very hot areas because the temperature difference will be very small. Despite CO sensibility and thermal characteristic, PEMFCs seems as the most suitable fuel cell system for mobile applications because working temperature is low and they can easily match up with instantaneous changes in automobile applications by having quick start up/response abilities. According to [8] PEMFCs also have the best current/voltage capacities but there are some problems wait for to be solved. Firstly, volume and weight must be reduced. Secondly, life and reliability features must be improved.

Thirdly, they must be robust to run in different working conditions. Because people travel by their own vehicles and they could move from a hot city on sea level to cold city at 1000 meters. Fourthly, cost of fuel cell and related systems must be declined to be competitive of traditional gasoline engine systems. Lastly, since their fuel is hydrogen, hydrogen related systems mainly storage systems and technical foundation must be built, standards must be published [8].

Now, only 100 hydrogen-refueling stations have been being settled in the world. Expectations say this number will increase in a short time. Still, fuel cell systems are more expensive than traditional combustion engine and cooling mechanisms also increase fuel cell stack cost but these problems are not only PEMFC’s problems. These are general problems of new developed technologies.

CHAPTER 3

METHODOLOGY

3.1. THE PID CONTROLLER

This controller replaces the amplifier in the forward path of our closed-loop control system. One example of PID controller is shown in Figure 3.1.

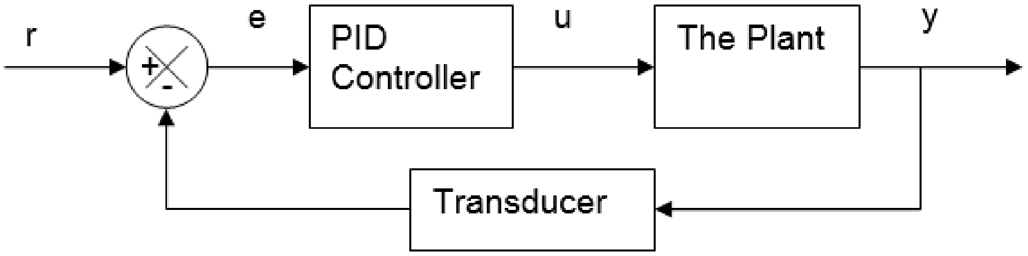


Figure 3.1. PID controller.

"The Plant" just means the equipment whose output is being controlled.

In this Figure ***r*** is the reference input. Telling the system that we want the output y to settle at a value which will make the transducer output equal to y. ***e*** is the error. ***u*** is the controller output or controller action. ***y*** is the plant output.
We began our studies of such systems by just using an amplifier instead of the PID controller.

The PID controller (also called a Three-Term Controller) actually incorporates what is effectively an amplifier. The output u of the PID controller is:

$$u = P \times e + I \times \int edt + D \times \frac{de}{dt} \tag{3.1}$$

where P, I and D are the Proportional, Integral and Derivative gains respectively. If I and D are both zero, the controller is just an amplifier with a gain P.

3.1.1. Modeling The System With Equations

A discrete PI controller is used as the fuel cell controller based on the following equation:

$$y(k) = y_p(k) + y_i(k) \tag{3.2}$$

where

$$\begin{aligned} &y_p(k) = K_p e(k) \\ &y_i(k) = y_i(k-1) + K_i T_s e(k) \\ &-1 \le y_i(k) \le 1 \end{aligned} \tag{3.3}$$

y(*k*) — Controller output
e(*k*) — Error (difference between desired output and actual output)
T_s — Sample time
K_p — Proportional gain
K_i — Integral gain

The Backward Euler method (a numerical integration approximation) is used to solve the integrator equation from above. This is why the integrator equation goes from $y_i(k\text{-}1)$ to $y_i(k)$.

The output of the integrator equation must fall between -1 and 1. This range is required as an antiwindup measure, or to prevent windup in the system. Windup refers to the condition when the controller is ineffective at reducing the system error, and so the integral state ($y_i(k)$) becomes very large.

4.1.2. Building A Block Diagram Model Of The System

To build a block diagram model of the system,

1. Use a step function as the system input (*e(k)*).
2. Build the integrator equation using the method discussed earlier in this homework.

3. Limit the output of the y_i integration to fall within the limits defined below.
4. Define an initial condition of 0 for y_i (this can be done by setting an initial condition in the Unit Delay block).
5. View both the input and output on the same scope.
6. Use variable names to define block parameters.
7. Label the signals and annotate the diagram.

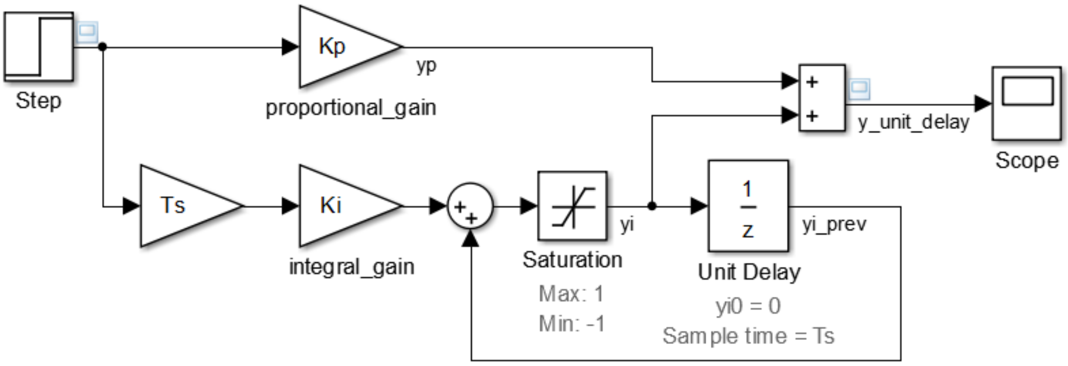


Figure 3.2. PID controller in SIMULINK.

In this thesis we used PID controller for controlling of Fuel cell stack. The output of continues PID controller is the sum of three individual controller outputs — proportional, integral, and derivative controls:

$$y(k) = y_p(k) + y_i(k) + y_d(k) \tag{4.4}$$

where

$$\begin{aligned} y_p(k) &= K_p e(k) \\ y_i(k) &= y_i(k-1) + K_i T_s e(k) \\ y_d(k) &= \frac{K_d}{T_s}\left[e(k) - e(k-1)\right] \end{aligned} \tag{4.5}$$

Table 3.1. The parameter used in this project is as below.

Parameter	Ki	Kd	Kp
Description	Integrator Coefficient	Derivative Coefficient	Proportional Coefficient
Value	100	0.1	30

3.2. FUZZY LOGIC

Fuzzy logic is a theory which colloquial especially for the modeling of uncertainty and vagueness of descriptions have been developed. It is a generalization of the divalent Boolean logic. For example, so called fuzziness of information is "very" captured in mathematical models as "a bit", "pretty", "strong" or. Fuzzy logic is based on fuzzy sets (fuzzy sets) and so-called membership functions that represent objects on fuzzy sets and matching logic operations on these quantities and their inference. For technical applications also methods for fuzzification and defuzzification must be considered, that is, methods for the conversion of information and relationships in fuzzy logic and back again, for example as a control value for a heater as a result. In Figure 3.3 the fuzzy system is illustrated for weather state.

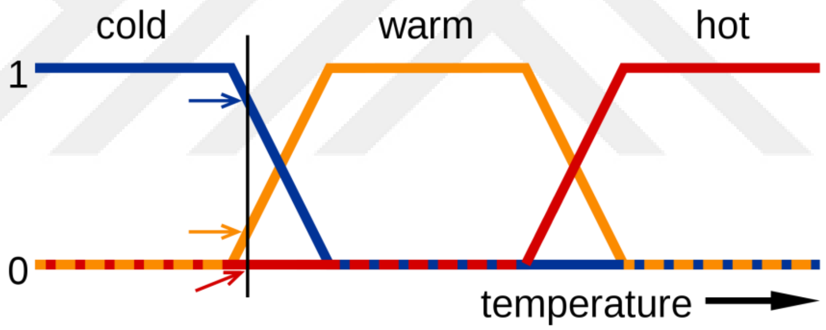


Figure 3.3. fuzzy logic for weather state.

This figure shows only for three state. The other state is shown in Figure 3.4.

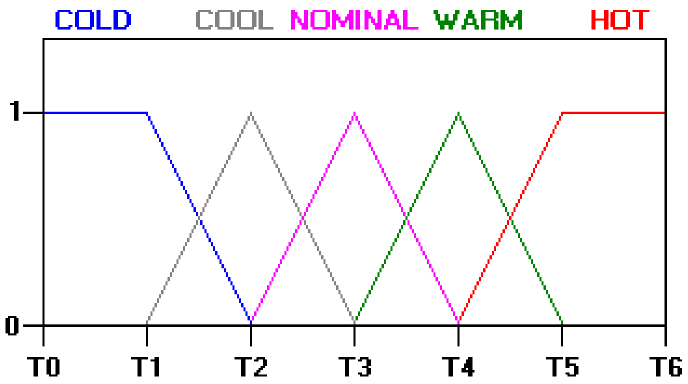


Figure 3.4. Fuzzy system for mult state for weather.

3.2.1. Historical Development

The reflections on a logic of between date back to ancient Greece. Already the philosopher Plato postulated that true and false lies a third region. This stood in stark contrast to his contemporary Aristotle, who founded the precision of mathematics that a statement can only be true or false either.

The fuzzy set theory, i.e., the fuzzy set theory, was developed in 1965 by Lotfi Zadeh at the University of California, Berkeley [19]. The fuzzy technology adopted in the 1980s, especially in Japan its rise to the so-called Japanese fuzzy Wave. A historical example is the regulation of fully automatic Sendai Subway, the first successful large-scale application of fuzzy logic in practice. Later, the fuzzy logic has been widely used in devices of entertainment electronics. The European fuzzy wave came only in the mid-1990s, when the policy discussion about the fuzzy logic subsided. Figure 3.5 show the rules and fuzzification for some application.

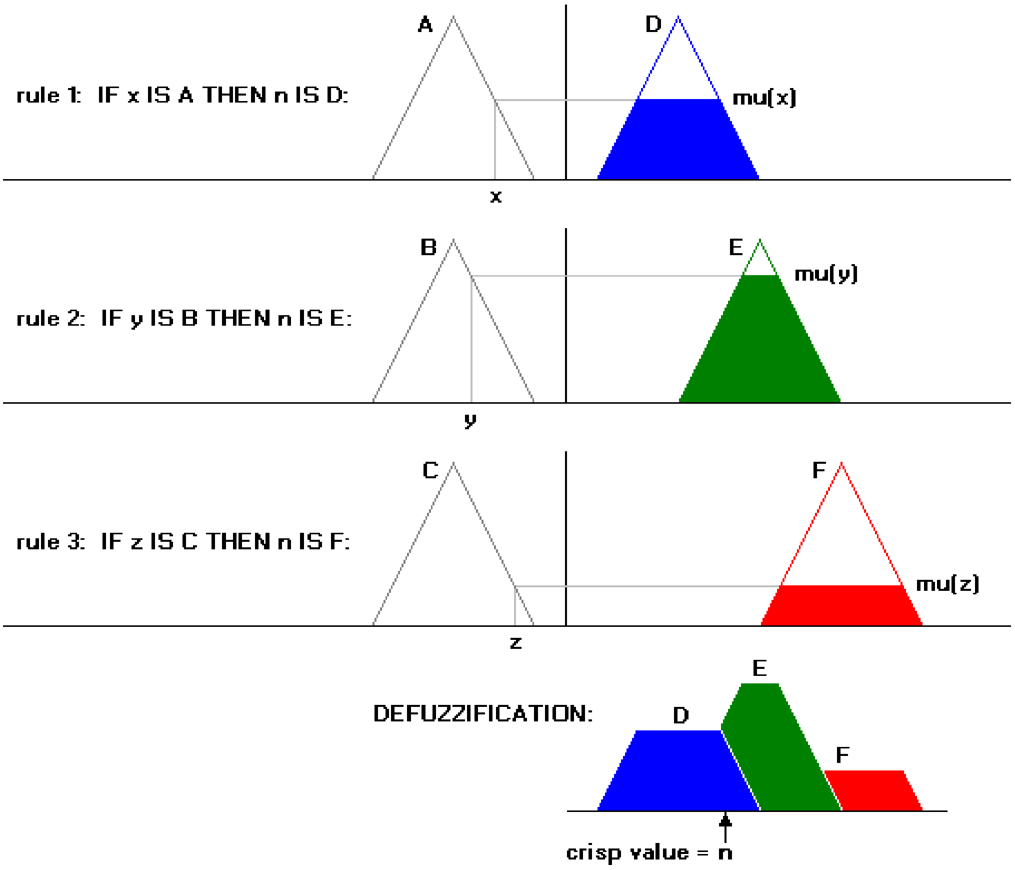


Figure 3.5. Fuzzy roles for de-fuzzification.

3.2.2. Fuzzy Set Theory

The fuzzy set theory is to be distinguished from the multivalent logic that described in the 1920s, the Polish logician Jan Łukasiewicz. In a narrower sense, the so-called fuzzy logic can be interpreted as a multi-valued logic though, and in this respect there is a certain proximity to the polyvalent logic, for their truth value of a logical statement figures from the real unit interval [0, 1] (the real numbers from 0 to 1) may be used. However, Lotfi Zadeh summarizes the fuzzy set theory as a formalization of indefinite extents in terms of referential semantics, which allows him to specify the fuzziness of the membership of objects as elements of definable amounts gradually over numerical values between 0 to 1. Thus a further, linguistic interpretation of the fuzzy set theory opened as the basis of a logic of blur. The concept of fuzzy logic was initially not in use by Zadeh, but later also by the teachers in Berkeley linguist George Lakoff after Joseph Goguen, a graduate student Zadeh, a logic fuzzy terms [20] had introduced. Comparisons in this context, the term coined by Hegel doubled middle.

3.2.3. Fuzzy Sets

Based fuzzy logic are the so-called fuzzy sets. Unlike traditional quantities (called in the context of fuzzy logic and sharp amounts) in which contain an element of a predetermined base amount of either or not, is a fuzzy (fuzzy) amount not defined by the objects that are elements of this set are (or are not), but about the level of their belonging to this set. This is done through membership functions uA: X → [0,1], assign each element of the definition set X is a number from the real-valued interval [0,1] of the target amount, which the membership degree uA (x) every element x to thus defined fuzzy set A indicates. Thus each element is the element of each fuzzy set, but each with a different, a certain subset defining membership degrees. Zadeh commented new set operations, which constitute the multi-valued fuzzy logic operations as a new logical calculus and identify them as a generalization of the bivalent, classical logic, which is included as a special case in her. These operations on fuzzy sets can be defined as sharp on quantities such. As the formation of intersection (AND), Union amounts (OR) and complement (NOT). To model the logical operators of the conjunction (AND), disjunction (OR) and the negation (NOT) use is made of functional classes of T standard and T-conform.

3.2.4. Negation

The negation in fuzzy logic is carried out by subtracting the input values of 1. So

NOT (A) =1-A

3.2.5. Non-Exclusive-OR Circuit

The adjunction is done by selecting the respective higher value of the input values. Thus

OR (A; B) =A if A>B
B if A<=B

This state illustrated in Figure 3.6.

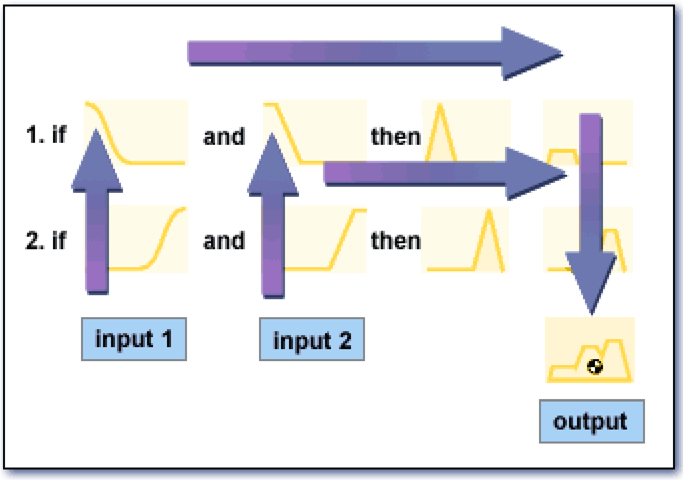


Figure 3.6. If then role.

3.2.6. AND Circuit

The conjunction is effected by choice of the lesser value of the input values. Thus

AND (A; B) =A if A<B
B if A>=B

3.2.7. Negative-OR Circuit

For the disjunction one complements the smaller of two values and selects the smaller of the two. For more than two input values is given to the result of the last operation recursively with the next input value. Simple: you take the difference of the less extreme of the extreme value opposite him. Thus

XOR (A; B) =A when A>B und A<= (1-B)
1-B if A>B and A>= (1-B)
B if B>A and B<= (1-A)
1-A if B>A and B>= (1-A)

3.2.8. Fuzzification

Summaries of individual membership functions give the fuzzy functions. An example of this is a fuzzy function of the age of a person. This could consist of several roof-shaped triangles, which in turn represent different ages and types representing membership functions of these different age types. Each triangle covers an area of several years in human age. A person with 35 years would have so the properties: young with the rating 0.75 (which is still quite a lot), mean age with an initial rating 0.25 (that's a bit) and none of the other functions. In other words, with 35 one is quite a bit young and a bit medium. The fuzzy function assigns each age value to a membership function characterizing him.

In many cases, fuzzy functions are created on tables from statistical surveys. This can also be raised by the application itself so far as feedback is given, as in the elevator control. Practically important is to have the experience and intuition of experts be included in the relevant field in a fuzzy function, especially when no statistical statements are present, for example, when it comes to a complete re-describing system.

This triangular shape, however, is by no means conclusive, generally the values of fuzzy functions can have any shape as long as the function values remain in the interval [0, 1]. In practice, such triangular functions are, however, often used because they are easy predictability. Relatively widespread are still Trapeze (not necessarily mirror symmetry), but also half circles can be found in some applications. Also, in principle, more than two portions of a fuzzy function overlap (in the example considered here, but that does not seem to make sense).

3.2.9. Example Of A Non-Linear Fuzzy Function

An example of a non-linear membership function forms the following sigmoidal function:

$$S(x,a,\delta)=\begin{cases}0 & x\le a-\delta\\ 2\left(\dfrac{x-a+\delta}{2\delta}\right)^2 & a-\delta<x\le a\\ 1-\left(\dfrac{x-a+\delta}{2\delta}\right)^2 & a<x\le a+\delta\\ 1 & x>a+\delta\end{cases} \tag{3.6}$$

The curve expresses the shape of the letter S, a rising membership of the quantity being described by a value in the range [0,1] from. Depending on the application can be a decreasing membership through an appropriate Z-curve express:

$$Z(x,a,\delta)=1-S(x,a,\delta) \tag{3.7}$$

The α parameter specifies in this case at the inflection point of the S-curve, the value δ determines the slope of the curve. The larger is chosen δ, the flatter the curve of the resulting function.

The age of a person can be defined by this curve as follows as fuzzy function represent.

The colloquial modifiers can be very, represented more or less and not much by simple modification of a given function:

The colloquial reinforcing modifier very can be represented in terms of increased exponents (in the example $S_0 = S_1^2$). The result is a steeper curve compared to the initial function.

The colloquial modifier more or less can be expressed by use of a lower exponent, or the square root of a given function ($S_3 = \sqrt{S_4}$) The result is a flatter curve in comparison to the initial function.

The negation of a colloquial expression can by a simple subtraction represent $(S_2 = 1 - S_0)$.

According to the applications, it is in this form of representation by linguistic variables. Ultimately, a single numerical value is calculated from the individual weighted statements, which can express the age in mathematical form. This value can then continue to work precisely. In this so-called Defuzzyfication many methods are possible, the most famous (but by no means always the best) is certainly the method Center-of-Gravity in which the value weighted by the mass of the geometric shape of the individual sections of the membership function is formed. Another possibility is to simply form a weighted average of the function values.

3.2.10. Application Examples

Fuzzy logic is used today in various areas: A significant application are fuzzy controller, e.g. in automation technology, medical technology, consumer electronics, automotive engineering and other fields of control engineering, in which competing fuzzy controller with conventional controllers. Application finds also in artificial intelligence, in Inference system, in speech recognition and other fields, such as in electrical safety (quantitative review) [21].

Availing the use of fuzzy logic, if no mathematical description of facts or problem exists, but only a verbal description. Even if - as almost always - is the existing knowledge gaps in or partially obsolete, the use of fuzzy logic offers to still arrive at a valid opinion about a current or future system state. Then a mathematical description is obtained from linguistically formulated principles and rules by means of fuzzy logic, which can be used in computer systems. The interesting thing is that with the fuzzy logic also controlled systems make sense (or regulated) may be, if a mathematical relationship between the input and output variables of a system cannot be represented - or could be done only with great effort, so that automation to would be realized expensive or not in real time.

Other applications include the control of subways, forecasting the future load on routers, gateways and cellular base stations, control of automatic transmissions in automobiles, alarm systems for anesthesia, intermediate frequency filter in radio, ABS for automobiles, fire alarm systems, the prognosis of energy consumption energy providers, AF-coupled multi-automatic exposure and AF predict in SLRs etc.
Also in business applications Fuzzy logic has successfully been introduced. One successful example is the Intelligent Claim Evaluation (ICE), protect against insurance fraud with the worldwide insurance companies.

3.2.11. Term Deferred

Not to be confused with the fuzzy logic is the fuzzy search, which enables a fuzzy search in databases, for example, when the exact spelling of a name or term is unknown. Even if the belongingness values from the interval [0, 1] look formal as probability values, so blur is something fundamentally different from probability. Above all, it should be noted that the sum of the values of two functions that the overlap does not have to be 1. You may be equal to 1, but higher or lower.

CHAPTER 4

SIMULATION RESULT

4.1. FUEL CELL STACK

The Fuel Cell Stack block implements a generic model parameterized to represent most popular types of fuel cell stacks fed with hydrogen and air.

The block represents two versions of the stack model: a simplified model and a detailed model. You can switch between the two models by selecting the level in the mask under Model detail level in the block dialog box.

4.2. PID AND FUZZY CONTROLLER

A proportional integral derivative controller (PID controller) is a control loop feedback mechanism (controller) commonly used in industrial control systems. A PID controller continuously calculates an error value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error over time by adjustment of a control variable, such as the position of a control valve, a damper, or the power supplied to a heating element, to a new value determined by a weighted sum:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \tag{4.1}$$

Where K_p, K_i, and K_d, all non-negative, denote the coefficients for the proportional, integral, and derivative terms, respectively (sometimes denoted P, I, and D). The architeckture of PID controller is shown in Figure 4.1.

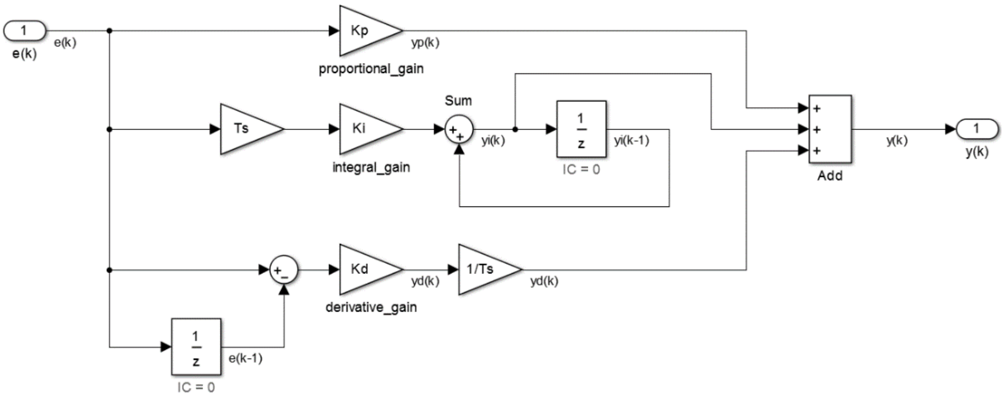


Figure 4.1. Architecture PID controller.

In this model,

1. P accounts for present values of the error (e.g. if the error is large and positive, the control variable will be large and negative),
2. I accounts for past values of the error (e.g. if the output is not sufficient to reduce the size of the error, the control variable will accumulate over time, causing the controller to apply a stronger action), and
3. D accounts for possible future values of the error, based on its current rate of change.

For PID controller we used 5.28 for K_i and K_d is equal to 1.32, also for K_p we select 5.28. These values was get experimentally. The Simulink model that we used in our project is shown in Figure 4.2.

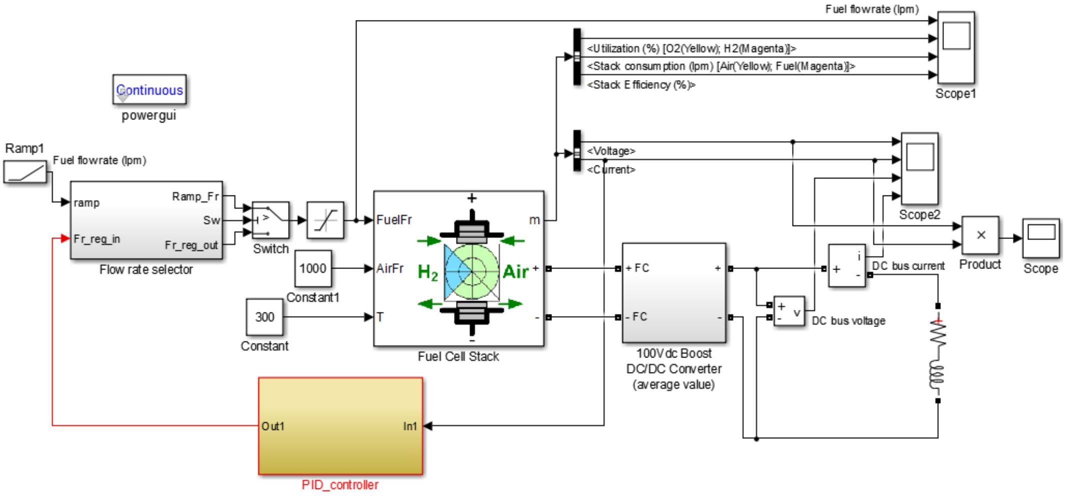


Figure 4.2. SIMULINK model with PID controller.

A DC-to-DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. It is a type of electric power converter. Power levels range from very low (small batteries) to very high (high-voltage power transmission). In this thesis the DC to DC converter that used is shown in Figure 4.3.

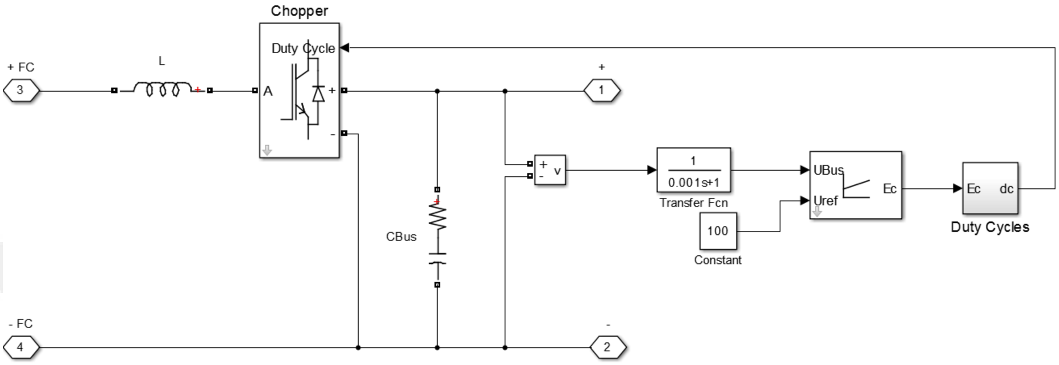


Figure 4.3. DC to DC convertor.

After simulation the result is get and this result is shown as Figure 4.4.

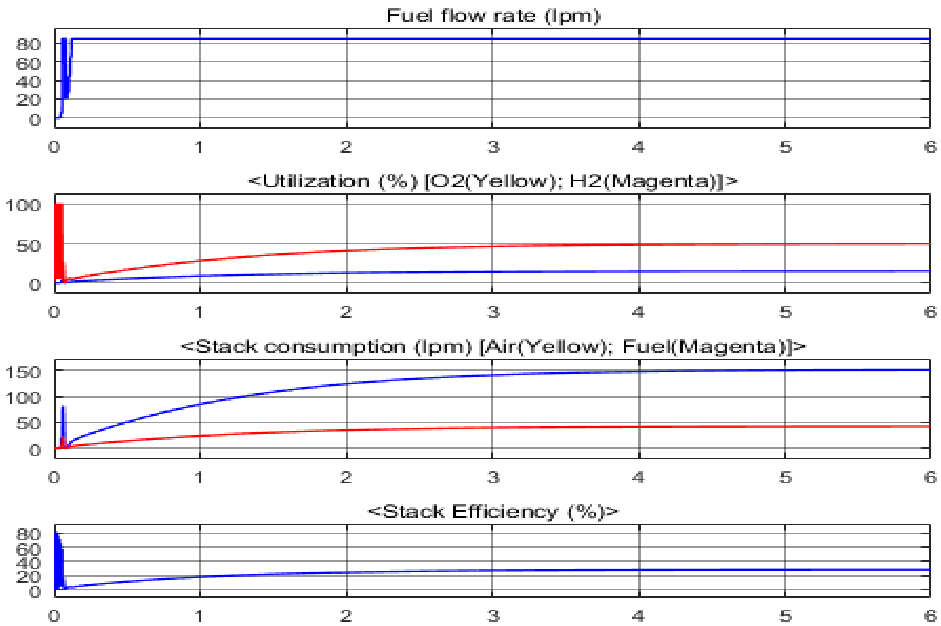


Figure 4.4. Simulation result for fuel flow rate and O_2, H_2 and fuel magnetant and stack efficiency.

In this Figure the X coordinate is Time (S) and Y coordinate is amplitude value for fuel flow rate, Oxidant and Hydrogen, Stack consumption and stack efficiency.

The output of stack is shown in Figure 4.6. In this figure the voltage, current, DC bus voltage and DC bus current is shown.

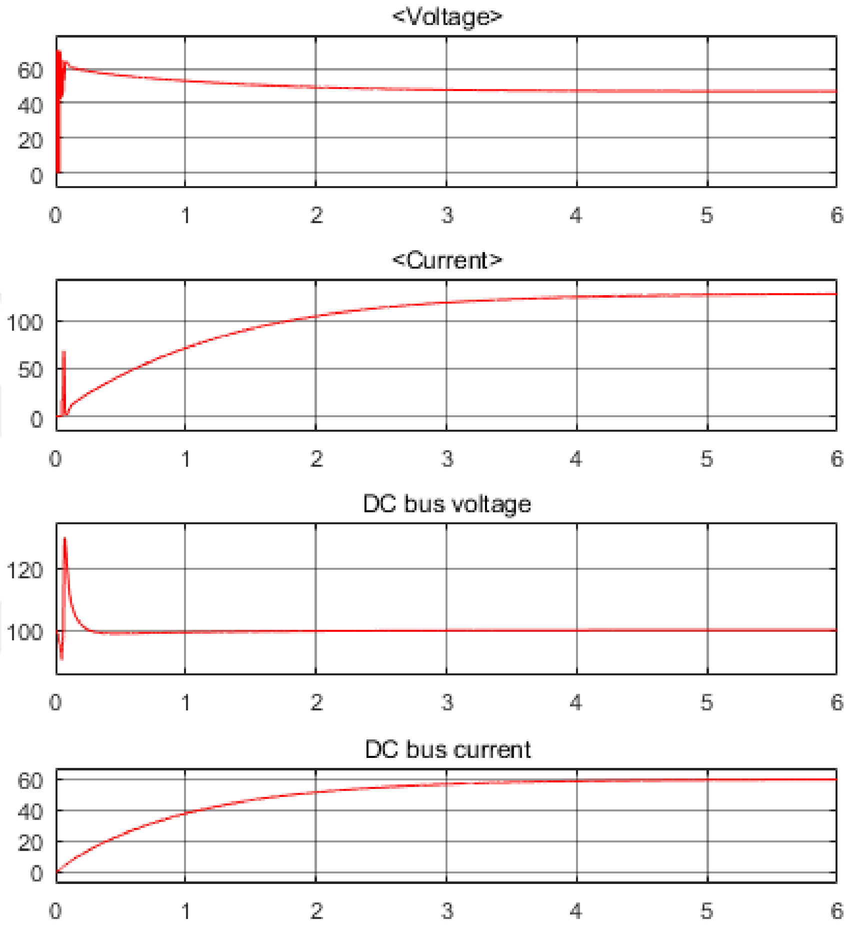


Figure 4.5. Simulation result for voltage and current and DC bus voltage and DC bus current.

In this figure the X coordinate is Time (S) and Y coordinate is Volt, Ampere, Volt and Ampere respectively.

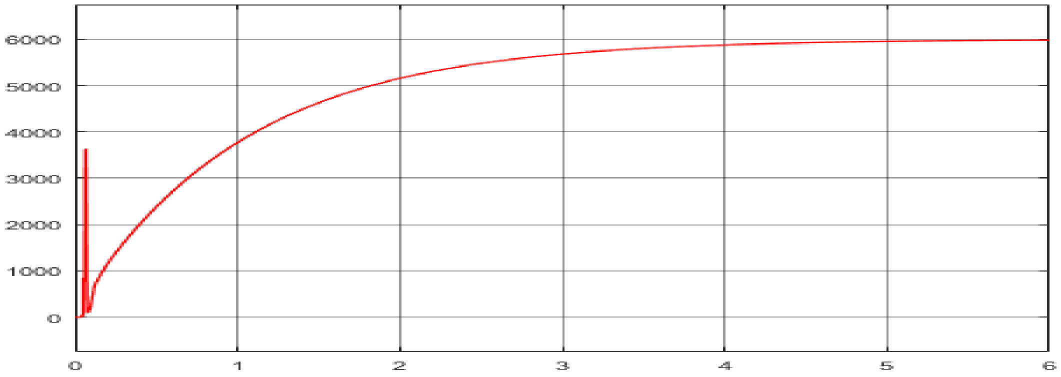


Figure 4.6. Simulation result for power.

As shown in this figure after 6 second the output is get. In this figure the X coordinate is Time (s) and Y coordinate is power (W).

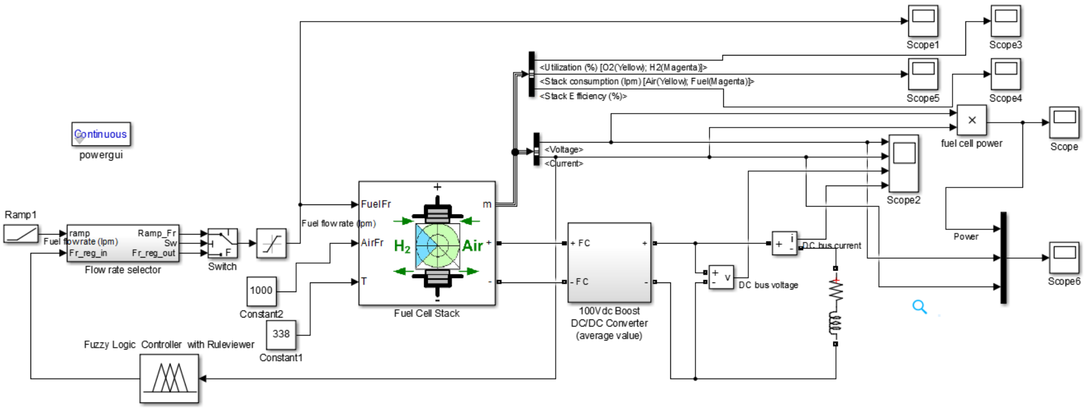


Figure 4.7. SIMULINK model used for fuzzy logic.

At t = 0 S, DC / DC converter 100VDC applied to the load R , L (initial flow of time is 0). Fuel used to adjust the nominal value of 99.56%. The current increase until the value 133. In order to keep fuel consumption nominal flow rate is automatically adjusted. DC bus voltage is well regulated by the converter view. The peak voltage of 122Vdc at the beginning of simulation voltage regulator is created by the interim government.

At t = 10 S, fuel flow rate of 50 liters per minute (LPM) to 85 LPM during the 3.5 hour decrease in doing so increased use of hydrogen. Nernst this moment causes an increase in cell voltage so that the current will be reduced. The stack consumption and efficiency will be reduced.

The flow rate of this stack is shown in Figure 4.9.

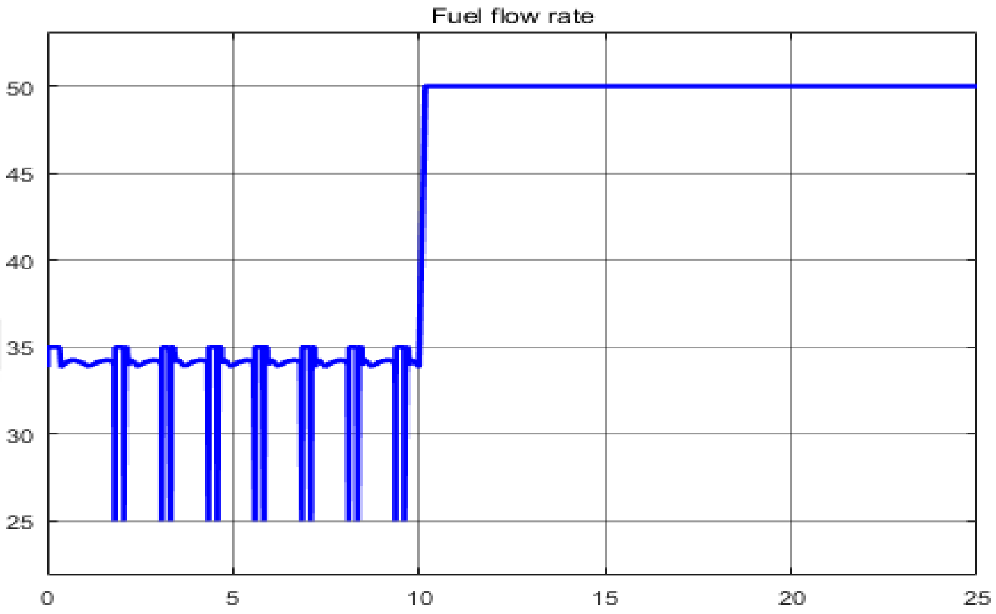


Figure 4.8. Flow rate of fuel cell stack.

In the saturation we put the maximum value 50 and minimum value is 25.

The fuel cell output power is shown in Figure 4.10.

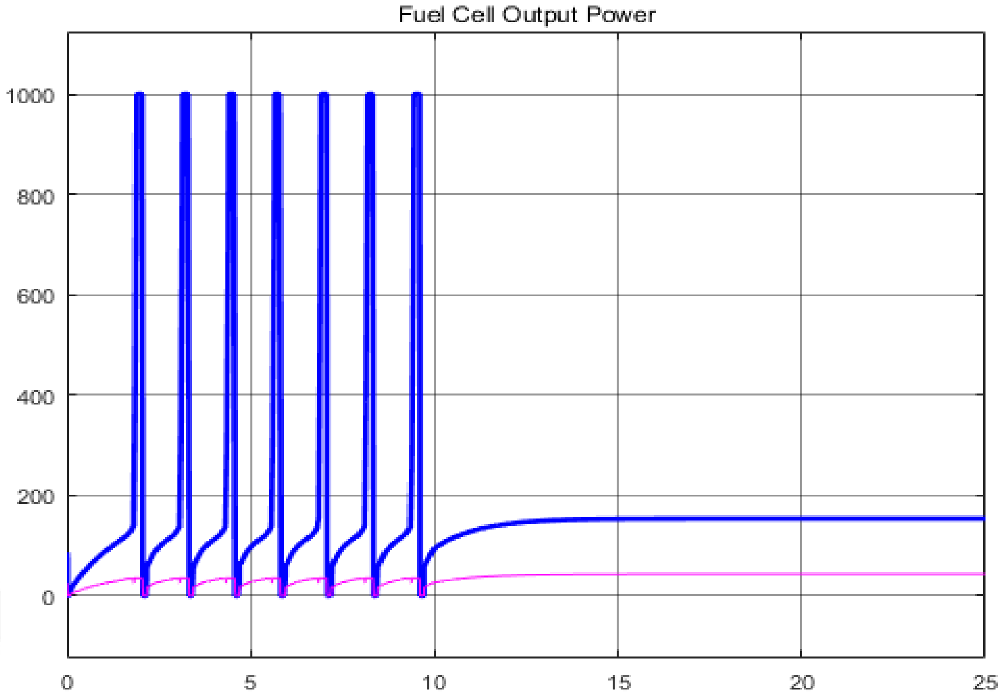


Figure 4.9. Fuel cell output power.

As seen in this figure after 12.5 second the output is stable and fixed in 150.

Figure 4.11 show the efficiency of system. In this system after middle of time (after 12.5 sec) the system is stable and 55 value is get.

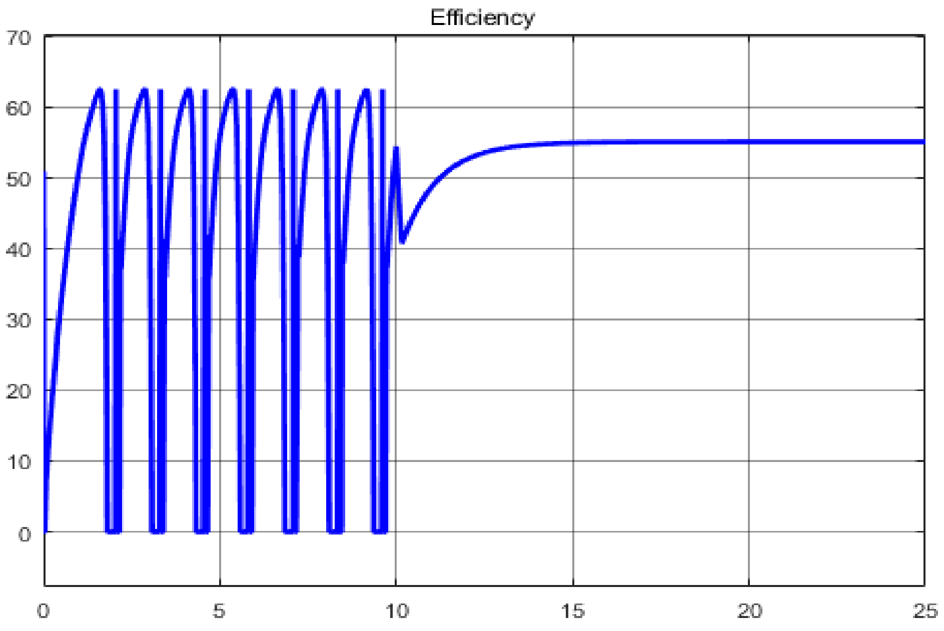


Figure 4.10. Efficiency of system.

The fuel cell output power is shown in F 4.12. as shown in this figure the system after 15 second the power is 6000 that we selected in the parameter of stack. With getting to this value we get the 6000 w.

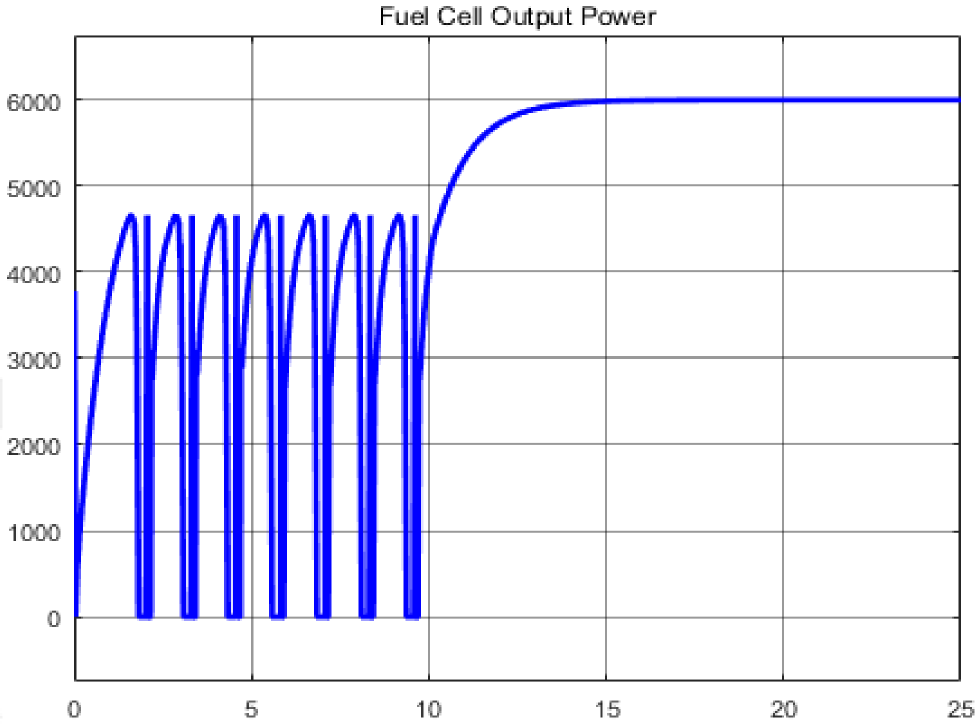


Figure 4.11. Fuel cell out put power 6000 Watt.

As shown in this figure after 13 second the final value for power is get and this value is 6000 Watt.

The voltage curve, current, DC bus voltage and DC bus current is shown in Figure 4.13. as shown in this figure the voltage after middle of simulation time is stable and this value is 55 volt. For cuurent this value is 0. Also in DC bus voltage this value is 100 volt. For DC bus current we get about 60 A.

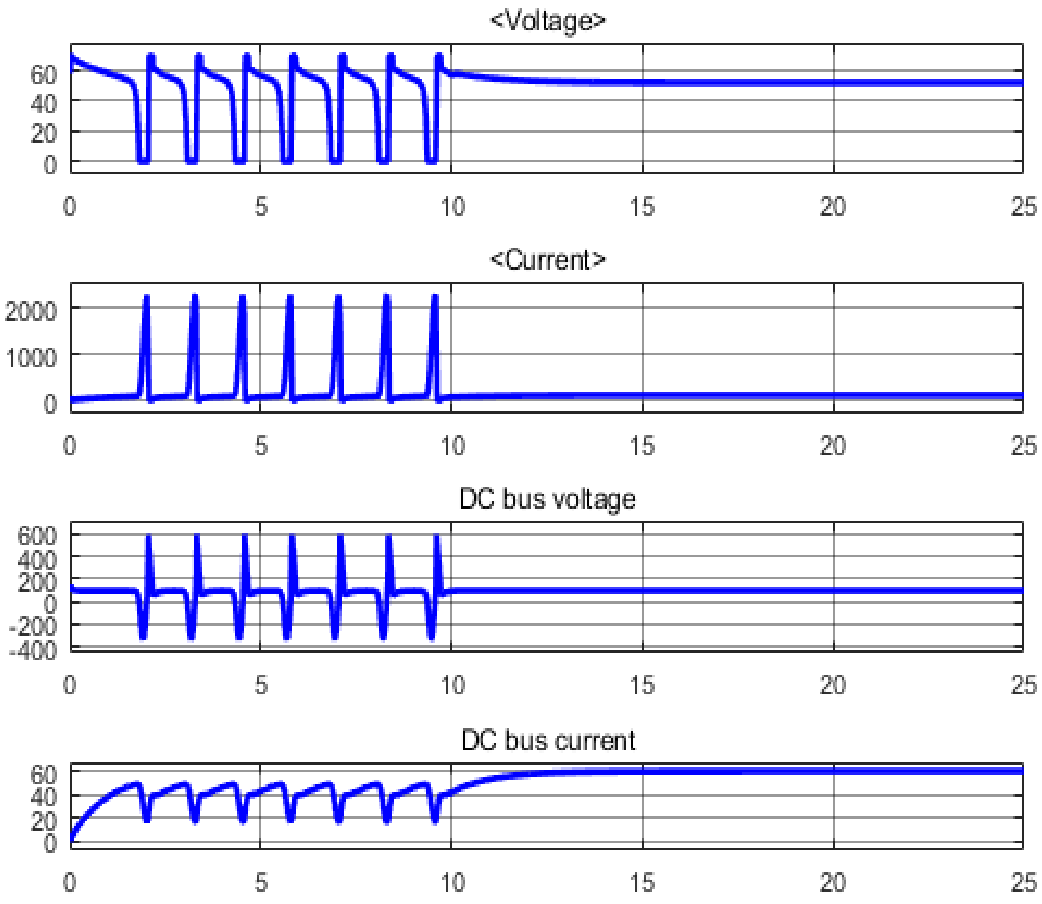


Figure 4.12. Simulation result for voltage and current and DC bus voltage and DC bus current.

The stack voltage vs current is shown in Figure 4.14. As shown in this figure this curve is represent the value of voltage vs current. This simulation is inside of stack. For every current from 0 value to 250 A the voltage is shown as below.

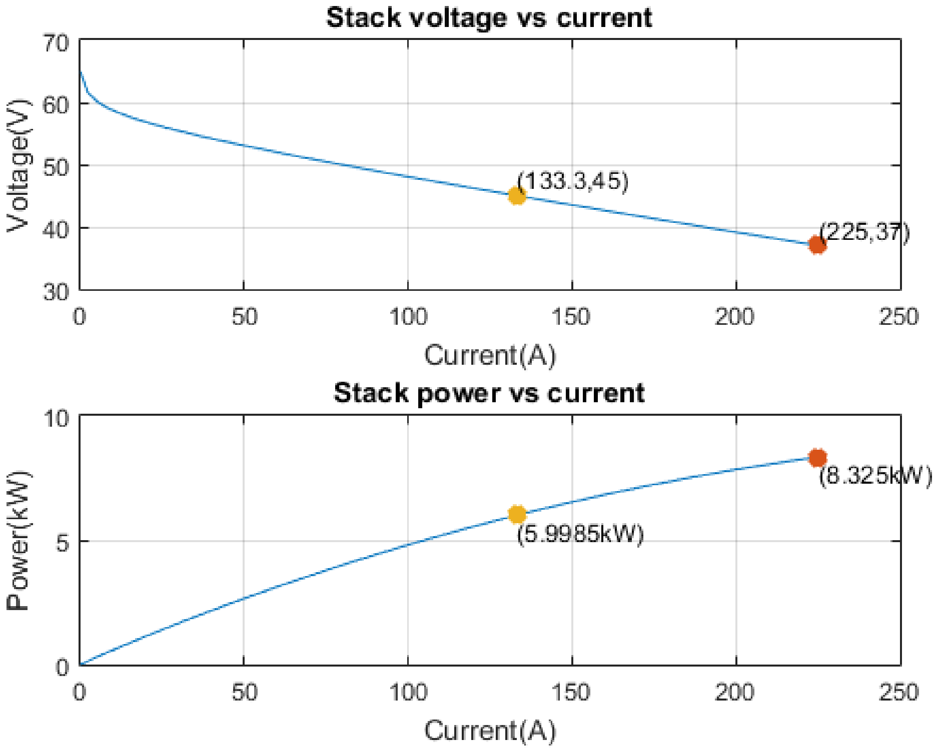


Figure 4.13. Stack voltage VS current and stack power VS current.

The lower figure show the stack power vs current. As seen in this figure the current is start from 0 up to 250 A. the maximum power is 8.325 KW.

The fuel cell nominal parameter is shown in Table 4.1 and 4.2.

Table 4.1. Fuel cell nominal parameters.

Stack power	Nominal (w)	5998.5
	Maximal (w)	8325
Fuel Cell Resistance (ohms)	0.07833	
Nerst voltage of one cell [En] (V)	1.1288	
Nominal Utilization	Hydrogen (H2)	99.56 %
	Oxidant (O2)	59.3%
Nominal Consumption	Fuel (Slpm)	60.38
	Air (slpm)	143.7
Exchange current (A)	0.29197	
Exchange Coefficient [alpha]	0.60645	

As shown in this figure the fuel cell resistance is 0.07833 0hm and the nerst voltage of one cell is 1.1288 volt.for nominal utilization there are two type of element and these two type is hydrogen and oxidant. Which the Hydrogen is take about 99.56 percent of material of fuel cell and the Oxidant take about 59.3 percent of this fuel cell. For nominal consumption there two element and this element is fuel and air. Exchange current is 0.29197 Ampere and also exchange coefficient (alpha) is 0.60645.

Table 4.2. Fuel cell signal variation parameters.

Fuel composition (%)	99.95	
Oxidant Composition (%)	21	
Fuel flow rate (lpm)	Nominal	50.06
	Maximum	84.5
Air Flow Rate (lpm)	Nominal	300
	Maximum	506.4
System temperature (K)	338	
Fuel Supply Pressure (bar)	1.5	
Air supply pressure (bar)	1	

In Table 5.2, The fuel composition is about 99.95 percent. This value for Oxidant composition is 21 percent. For fuel flow rate there are two type of application and this values is 50.06 for nominal and 84.5 for maximum. Also for system temperature is 338, for fuel supply pressure is used as 1.5 bar. Finally for air supply pressure 1 bar is used.

In this thesis also we compared the performance of fuzzy logic and PID controller. The Simulink model that we used in this thesis is shown as Figure 4.15.

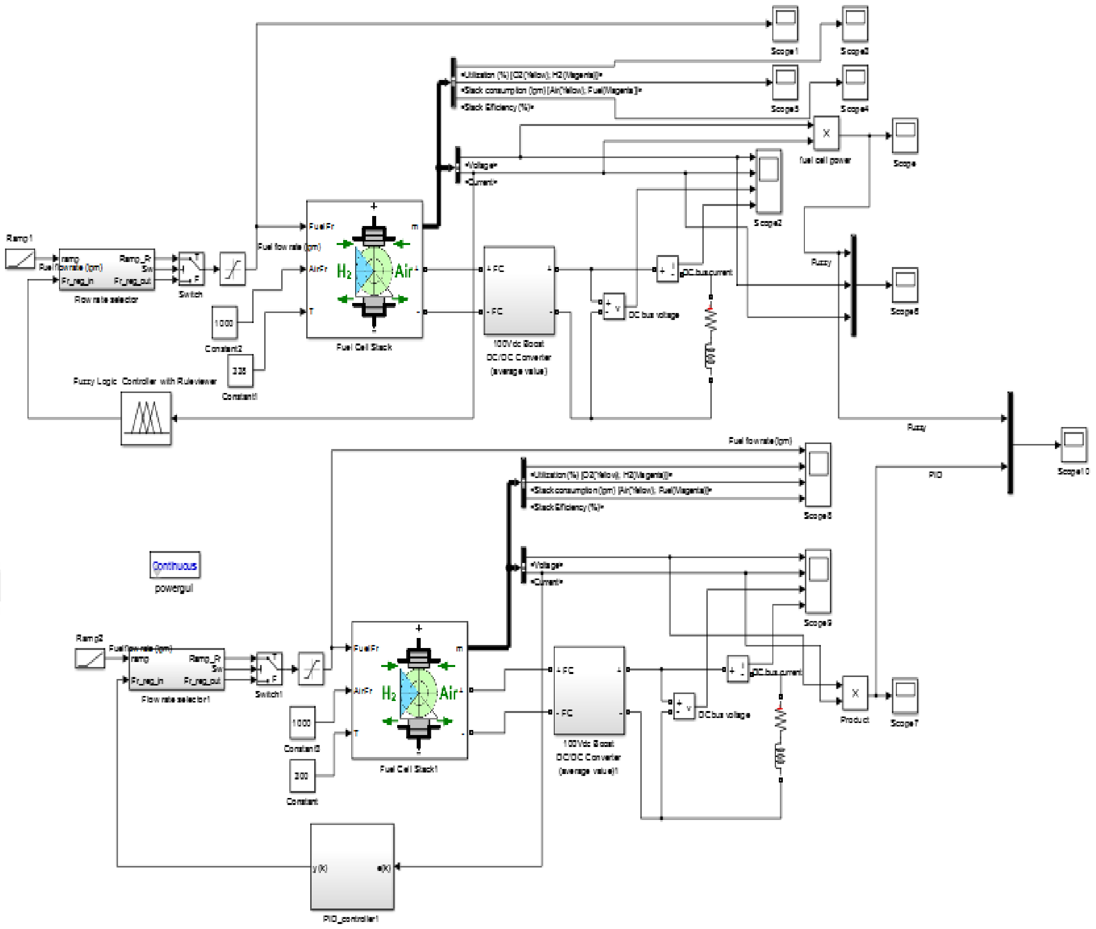


Figure 4.14. Comparison between fuzzy logic and PID controller model.

The result between fuzzy logic and PID controller as shown in Figure 4.16.

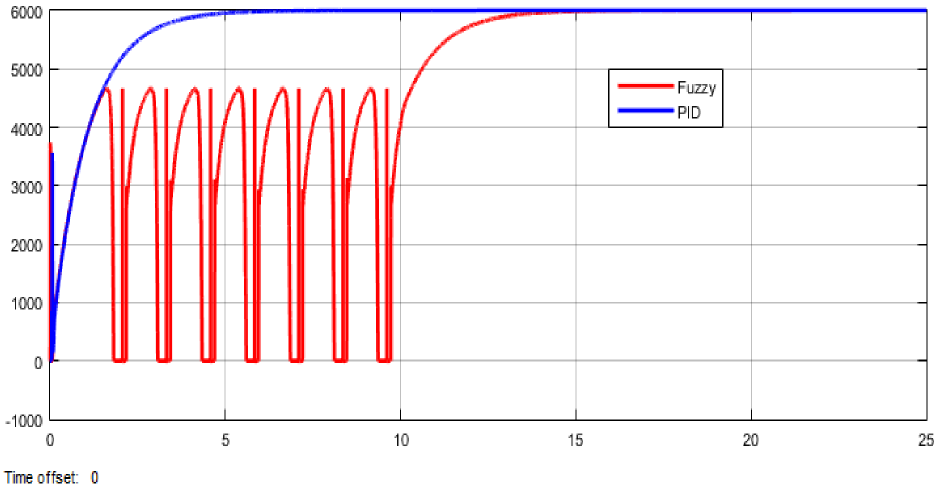


Figure 4.15. Comparison between Fuzzy logic and PID controller.

As shown in this figure PID controller after 5second is stable and Fuzzy after 13second is stable. Here PID is better than the Fuzzy logic. Because fuzzy logic is intelligent system and need for a lot of time for converging but PID just use 3 parameter for converging. The simulation time that we used in this thesis is 25 second and the final value for power is 6000 Watt. As shown in this figure this value is reached for Fuzzy and PID controller. The advantage of PID controller is simple and fast method, and the advantage of Fuzzy method is robustness method because Fuzzy use the intelligent system as if then role method and for application this method much better than the other method.

CHAPTER 5

CONCLUSION

In recent years, research and development activities in fuel cells have been accelerated. Although, there are significant improvements in the technology of proton exchange membrane, the performance, stability, and reliability is not sufficient to replace internal combustion engines and the cost of fuel cell systems is still too high to become acceptable commercial products. The most important problems to be overcome are improvement of their performance and reduction of their cost. In PEM fuel cells, hydrogen and air humidification may be required in order to prevent the fuel cell membrane from dehydration.

At high current flow, there is ohmic heating causing drying problems in the polymer membrane and slows ionic transport through the membrane. Because of water generation at the air side, in some fuel cell stacks, humidification is not required. In general fuel cell systems, humidification is required for either the air or hydrogen or both the air and hydrogen at the fuel cell inlets. Water content is very important for the protonic conductivity in proton exchange membranes.

If membrane dehydration or drying occurs, the electrical performance decreases due to significant ohmic losses. In this thesis the fuel cell control is investigated and for control of fuel cell the fuzzy logic is used. For fuzzy rules the maximum power point tracking algorithm is used. Also in this thesis the PID control is used and tested. As simulation result shows the performance of fuzzy is better than the PID control. In general fuel cell systems, humidification is required for either the air or hydrogen or both the air and hydrogen at the fuel cell inlets. Water content is very important for the protonic conductivity in proton exchange membranes. If membrane dehydration or drying occurs, the electrical performance decreases due to significant ohmic losses. In this thesis the fuel cell control is investigated and for control of fuel cell the fuzzy logic is used. For fuzzy rules the maximum power point tracking algorithm is used.

In future work, the proposed method will be test on Field Programmable Gate Array (FPGA). Also other controller can be used for getting the high accuracy of power point tracking algorithm. The hybrid controller like the fuzzy and PI together also can be use. The implementing of fuzzy and hybrid system in FPGA can be design, evaluate and implement for getting the high performance of this fuel cell systems.

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RESUME

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