بسم الله الرحمن الرحيم

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Implementation of Fuzzy Logic Controller in Environmental Control System

(Cabin Temperature Control)

—Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science. (BSc Honor)

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بسم الله الرحمن الرحيم

قــال اللهُ سبحانه و تعالى :

{ أَلَمْ تَرَ أَنَّ اللَّهَ يُسَبِّحُ لَهُ مَنْ فِي السَّمَاوَاتِ وَالْأَرْضِ وَالطَّيْرُ صَافَّاتٍ ۖ كُلٌّ قَدْ عَلِمَ صَلَاتَهُ وَتَسْبِيحَهُ ۗ وَاللَّهُ عَلِيمٌ بِمَا يَفْعَلُونَ (٤١) } .

صَدَقَ اللهُ العظيم .

سورة النور . الآية ٤١ .

Abstract

The environmental control system (ECS) of an aircraft is responsible for many important functions such as pressurizing the cabin, controlling temperature, providing breathing air, regulating humidity and other factions those keep the aircraft fully operational. ECS is a complex system consisting of many subsystems which makes design of one controller for the whole system very difficult. In this work Fuzzy logic controller is proposed for Cabin temperature control, data has been collected for specified aircraft and utilized to design, simulate and tune the fuzzy logic controller using Matlab (FLC toolbox). Simulation results has been recorded then tuned with different tuning methods. At the end of the work it has been cleared that the fuzzy logic controller is easy to design, simulate and tuned specially when using Matlab .FLC can be considered as a better choice for complex systems than other control techniques, so it can be applied to environmental control system.

التجريد

الطائرة عبارة عن هيكل شبه مغلق ، مما يزيد تعقيد تأثيرات الهواء ، وذلك يرجع إلى التداخل بين هذه العوامل مما يؤدّي إلى زيادة الحوجة إلى تطوير نظام التحكم في تكييف مقصورات الطائرةenvironmental control system . استُخدمت نظم الذكاء الإصطناعي لفعاليتها في التعامل مع هذه التعقيدات واخُتير نظام المنطق الضبابي كمثال لهذه النظم الذكية.

يتكون نظام تكيف مقصورات الطائرة من عدة نظم فرعية كنظام تكييف الهواء في مقصورات الطائرةaircraft air-condition system و نظام ضبط الضغط ونظام ضبط الرطوبة.

في هذه الأطروحة ، تم اختيار درجه الحرارة ، وتم عمل محاكاة باستخدام الأداة الخاصة بتطبيق المنطق الضبابي في برنامج ماتلاب Matlab ، بعد ذلك أُخِذَتِ النتائج وتم تحليلها ومِن ثَمَّ تم ضبطها باستخدام عدة طرق ضبط مختلفة . و في نهاية بحثنا ، اتضح أن المنطق الضبابي سهل التنفيذ وملائم لنظام تكييف كابينة الطائرة .

Dedication

We present our humble research to our parents , teachers , friends and to every student who wants get education .

Acknowledgement

First of all we thank Allah, then we thank our teachers who supervised this research to be a good and benefited lecturer. Donia Salih for her hard work and expensive time which she spent to help us in our research.

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Abbreviations

APU	Auxiliary Power Unit
ECS	Environmental Control System
EPS	Environmental protection System
FIS	Fuzzy Interface System
FLC	Fuzzy Logic System
MF	Membership Function
MISO	Multi-Input Single Output

Symbols:

E	Error
ΔE	Rate of change of error
k	sample
u	Control signal
Δu	Rate of change of error

1 Chapter One: Introduction

1.1 Overview

The environmental control system (ECS) of an aircraft is essential system for the crew and passengers. Its importance is not only for the comfort and safety of the crew and passengers but also for the aircraft to perform missions successfully. Environmental control system ECS refers to the system responsible of maintaining a comfortable close environment for a given payload, it pressurizes the cabin, keeps temperature within acceptable range, provides breathing air and regulates humidity. Furthermore, ECS is responsible for many other important functions that keep the aircraft fully operational.

Fuzzy logic control is a technique based on human thinking, in a way that deals with reasoning with uncertain or vagueness to make a decision or to support in making a decision, in this work it used to as controller design tool for ECS

1.2 Aim and objective

1.2.1 Aim

Design fuzzy logic controller for air-condition system of aircraft cabin.

1.2.2 Objective

1. Study the ECS focusing on:
   - General System configuration, and
   - Addressing the Complexity of system
2. Design a Fuzzy logic Controller.
3. Simulate and tune the fuzzy logic controller by using Matlab software.

1.3 Problem statement

ECS is the system in charge of maintaining cabin climate within wide change in altitude during flight; as consequence the parameters that affect cabin climate change, as well as ECS is a very complex system which comprises lots of components to maintain desired cabin condition.

1.4 Proposed solution

Fuzzy logic control FLC system for cabin temperature control.

1.5 Scope of work

The work focuses on:

- Cabin temperature as environmental parameters.
- MATLAB as simulation software.

1.6 Methodology

In the beginning both environmental control system (ECS) and fuzzy logic control (FLC) have been studied, then one subsystem of the (ECS) systems has been selected as the base of the work. Data about cabin temperature has been collected (from previous studies) and used to design, simulate and tune the controller using Matlab.

1.7 Outline

The work is arranged and presented in five Chapters as follows:

Chapter One: includes statement of the problem under investigation, scope of the work, proposed solution and the methodology adopted to achieve the objectives.

Chapter Two: surveys the studies of Environmental control System, addresses the system configuration in different aircrafts as well as focusing on the points regarding the complexity of the system, the chapter also contains literature related to fuzzy logic control.

Chapter Three: Describes the method used to achieve the main objective related to design of FLC for cabin temperature control and simulate it using MATLAB Simulink (FLC tool box).

Chapter Four: shows the results and the analysis obtained through the work

Chapter Five: through this chapter the conclusion of whole work is presented

2 Chapter Two: Literature Review

2.1 Introduction

This chapter consists of two parts, firstly literature about both environmental control system (ECS) and the environmental protection system (EPS), as well as the difference between various environmental control systems. The second part presents fuzzy logic control concept.

2.2 Environmental Control System vs. Environmental protection system

Environmental Control System is necessary to be used in hostile environments such as submarines, aircraft and spacecraft, it is usually related to the inside part of the vehicle. While the environmental control of the outer side is usually called environmental protection system (EPS).

Environmental control system for an aircraft is related to Cabin air conditioning, parameters such as pressure, temperature, ventilation, and humidity have to be monitored and controlled via this system, other parameters such fire protection, Water and sanitation, Food and solid waste, fuel tank initiation, cabin furniture ergonomics, noise (70 dB typical in a cruising airliner), lighting, and entertainment are also included in the Environmental control system

Environmental protection system used against high temperatures, high winds or turbulences, against water, ice, radiations, electrical shocks, and others such as biological attack (from micro-organisms to beasts) either through openings or by impact in flight. [1]

2.3 Environmental control system for aircrafts

The environmental control system (ECS) on an aircraft should assure aircrew and passenger survival in all aircraft operating conditions, i.e. from ground parking to high altitude flight. During flight, the cabin conditions (temperature, pressure and humidity) must be adjusted within tolerable limits to provide comfort ambiance for the passengers and crew. [2, 3]

Human comfort conditions are obtained in the following ranges:

• Pressure: higher than 750 mb (normal pressure at 8000 ft., or 2400 m, altitude);

• Temperature: between 18 and 23 °C;

• Relative humidity: between 20 and 70%;

• CO_2 volume concentration lower than 0.5%;

• CO volume concentration lower than 0.005%;

• O_3 volume concentration lower than 0.25 parts per million. "[2]

The aircraft environmental requirements can be accomplished by combining propulsion system, which is the source of pressurized air, and the pneumatic system, which processes and distributes the pressurized air. The environmental system varies from aircraft to another depending on the aircraft propulsion system (engine type). [4]

2.4 Bleed air systems in different aircrafts

The bleed-air serves as a supply of hot and pressurized air which is used to power the ECS to achieved cabin pressurization, cabin heating, cabin-cooling, and cabin-humidity control. In the earlier piston-engine aircraft, engine driven compressors were used to power aircraft ECS, these compressors serve as a source of hot and pressurized air which is used for the ECS functions.

In running jet-engine powered aircraft, the environmental control systems are powered by engine bleed-air: that is, air taken from different stages of the main engine's compressor (APU or engine 5th stage and if necessary 9th stage). While engine-driven compressors eliminate the need of engine bleed for the ECS, they have many disadvantages, including the following:

The compressors must be built to resist the torsional-vibrations and other hostile environments of the engine, the compressors are heavy and need much space, the compressors require mechanical disconnects, to protect the engine drive against mechanical-failures, significant ducting must reside in the engine power plant area and must be brought out of the power plant into the aircraft, the transit of the ducting from the power plant, through the pylons, through the wings, etc., that means problems of weight, customized duct-installation, high labor costs, and high material costs, engine driven compressors do not have viability and flexibility of operation, engine-driven compressors require an external air-source, if the (onboard) auxiliary power unit (APU) cannot be run for long periods of time.[5]

As a consequence of all these disadvantages a new technology has been introduced to improve performance, this technology is used in Boeing 747-8; this airplane is powered by General Electric GENX-2B engines, the bleed systems supply air from the engine compressor. There are four engine bleed systems per airplane with independent control.

Technological advancements allow Boeing to make several improvements to the bleed system on Boeing 747-8. These improvements include:

- New digital bleed: in this system there are no mechanical position switches and reduced use and integration of sensors.
- No remote valve controllers: in the design of the valve the torque motor and solenoid are built into the valve, allowing for easier troubleshooting and improved fault isolation.
- Fewer servo/sense ,lines: This improve system reliability.[6]

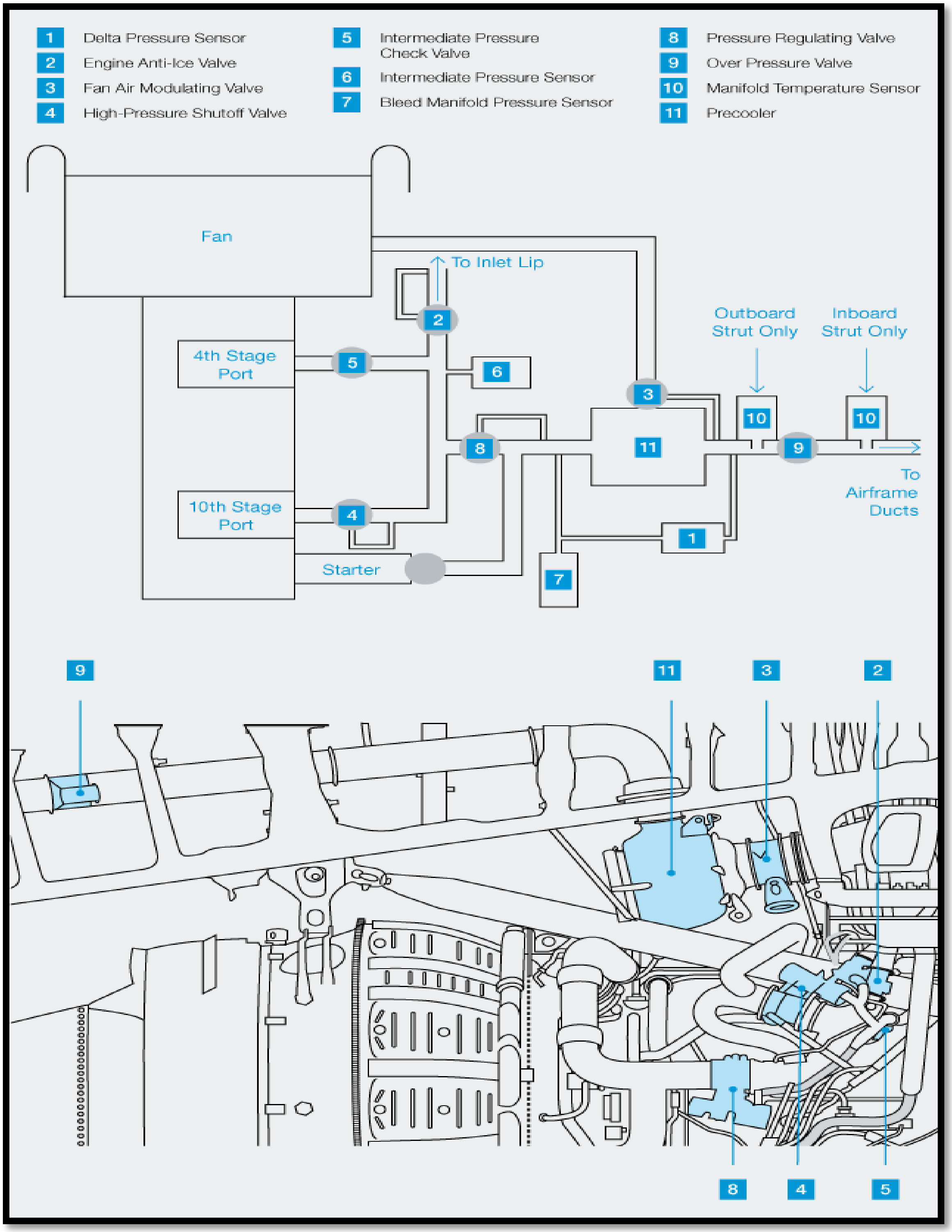

Figure 2-1 747-8 engine bleed system

Recently the technology tends to all electric environmental control system; this technology is applied in Boeing 787. The ECS of this aircraft takes its main power from at least one electric motor-driven compressor. The motor-driven compressor operates in conjugation with either a vapor-cycle cooling or an expansion-cooling system. The all-electric environmental control systems are useful for installation in advanced transport aircraft and are adjusted to provide pressurized conditioned air to the aircraft cabin .[5]

2.5 Environmental control system configuration

2.5.1 Cabin air conditioning

Cabin air conditioning should provide comfort conditions within the cabin, under all expect situation i.e. it must provide ventilation, pressurization, heating, cooling, humidification, dehumidification, and disinfection. One may divide air conditioning factors into: physical, chemical, and biological. As well as cabin air monitoring provides smoke detection means for fire warning. [1]

Conditioned air enters the cabin from distribution pipes by wall-floor and ceiling grilles and directional outlets over the seats, and goes out through other grilles and collecting pipes .About half of this outgoing air is exhausted from the airplane over an outflow valve in the underside, while the other half is drawn by fans through filters (for trapping microscopic, particles viruses and bacteria) and then recirculated. There is no recirculation on some flight decks, to have more margins for avionics cooling. There are two types of air conditioning systems generally used on aircraft:

2.5.1.1 Air Cycle Air Conditioning

Air cycle conditioning is usually used on most turbine-powered aircraft. It uses engine bleed air or APU pneumatic air during the conditioning process. Air cycle conditioning prepares engine bleed air to pressurize the aircraft cabin. The quantity and temperature of the air must be controlled to provide a comfortable cabin environment at all altitudes and on the ground. The air cycle system is usually called the air conditioning package or pack. It is usually located in the lower half of the fuselage otherwise it can be located in the tail of turbine-powered aircraft.[7]

Even if a temperature experienced is frigid at high altitudes, bleed air is very hot to be used in a cabin without being cooled. It is let into the air cycle system and routed through a heat exchanger where the bleed air cooled by the ram air. This cooled bleed air is directed to an air cycle machine. There, it is compressed before spurting through a secondary heat exchanger that cools the air with ram air again. After that the bleed air flows back into an air cycle machine where it drives an expansion turbine and cools the air even further. Water is removed and the air is mixed with bypassed air for final temperature adjustment. Finally it is sent to the cabin through air distribution system.[7]

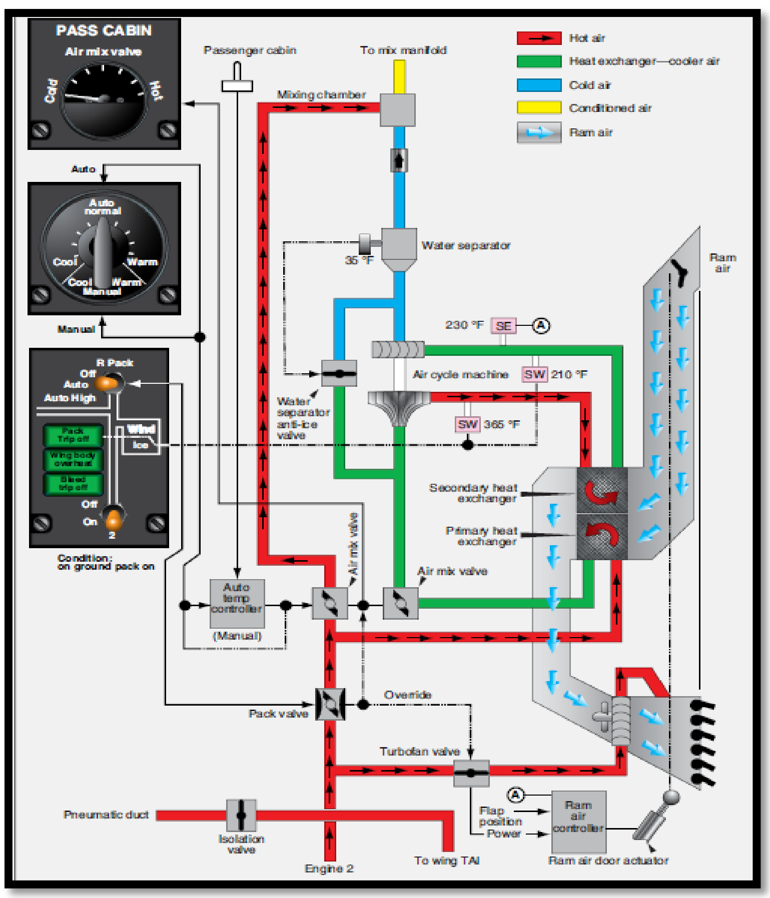

Figure 2-2 the air cycle air conditioning system

2.5.1.2 Vapor Cycle Air Conditioning

Vapor cycle air conditioning systems are commonly used on reciprocating aircraft, this type of system is similar to that found in automobiles and homes. As well as some turbine-powered aircraft use vapor cycle air conditioning. There is no bleed air source on reciprocating engine aircraft which makes the use of an air cycle system not suitable for conditioning cabin air .Hence vapor cycle air conditioning is used on most non turbine aircraft which equipped with air conditioning. However, it is not a source of pressurizing air it is only cools the cabin.[7]

Vapor cycle air conditioning system purpose is to remove heat from the aircraft cabin. It is a closed system in it a refrigerant is circulated through tubing and a diversity of components. During circulating, the refrigerant changes state. By handling the latent heat required to do so changing, hot air is replaced with the cool air in the aircraft cabin. The basic system on piston engine aircrafts consists of an air heating circuit that uses a heat exchanger with the engine exhaust gases. This process can work on non-pressurized aircraft and within a restricted range of flight environments. [2, 7]

The theory of the refrigerant is: "Energy can be neither created nor destroyed; however, it can be transformed and moved. This is what occurs during vapor cycle air conditioning. Heat energy is moved from the cabin air into a liquid refrigerant. Due to the additional energy, the liquid changes into a vapor. The vapor is compressed and becomes very hot. It is removed from the cabin where the very hot vapor refrigerant transfers its heat energy to the outside air. In doing so, the refrigerant cools and condenses back into a liquid. The refrigerant returns to the cabin to repeat the cycle of energy transfer as shown in figure."[7]

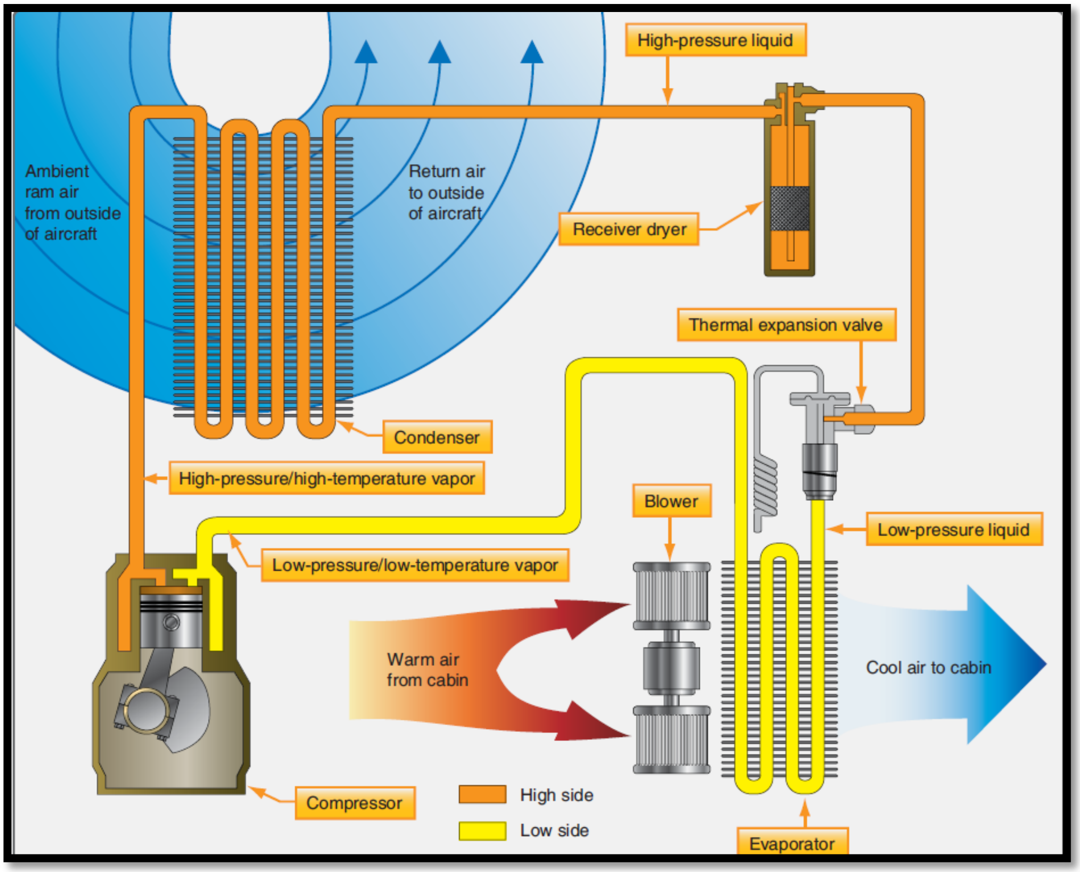

Figure 2-3 the vapor cycle air conditioning system

2.5.2 Aircraft Heaters

2.5.2.1 Bleed Air Systems

The aircraft operate at high altitudes where the Temperatures can reach below 0 °F. Combined with seasonally cold temperatures, this makes heating of the cabin an essentially issue. Pressurized aircraft which use air cycle conditioning systems mix bleed air with cold air provide by the air cycle machine expansion turbine which obtain warm air for the cabin.[7]

2.5.2.2 Electric Heating Systems

Sometimes, an electric heating instrument is used to heat the aircraft. When Electricity flowing through a heating element it makes the element warm. A fan to blow the air over the component and into the cabin that used to transfer the heat. Other floor or sidewall component simply radiate heat to warm the cabin.[7]

2.5.2.3 Exhaust Shroud Heaters

Large number of single-engine light aircraft depend on exhaust shroud heating systems to heat the cabin. Surround air is directed into a metal shroud, or jacket, which cover part of the engine's exhaust system. The exhaust warm the air and directed through a firewall heater valve into the cabin.[7]

2.5.2.4 Combustion Heaters

Combustion heater is used on many small and medium sized of aircraft. The aircraft's engine(s), is not the source of the heat, also it does use aircraft's main fuel systems as a source of the fuel. Combustion heaters are manufactured by a many few different companies that supply the aviation industry.[7]

2.5.3 Ventilating Air System

Ventilating air is the air that is warmed and sent into the aircraft cabin. Ordinarily, this air comes into the combustion heater through the ram air intake. Once the aircraft is on the ground, the fan of the ventilating air controlled by a landing gear squat switch operates in order to draw in the air.[7]

2.5.4 Humidity

Humidity in the aircraft is controlled both for aircraft safety and for human comfort. The two needs are sometime compliant, sometime in conflict. High humidity in the air of the cabin (e.., greater than 70% relative humidity), notably when accompanied by a high temperature leads to discomfort for passengers. High humidity can also lead to dripping, condensation, and freezing of moisture on the inside of the shell of the aircraft, which can lead to a number of safety problems, involves corrosion on the shell. The environmental control system must be able to prevent excessive humidity in the air of the cabin by removing the moisture from the outside before it is provided to the cabin.[4]

At cruise altitudes, the outside air contains a very little moisture. The main sources of humidity in the cabin air are evaporation from the skin of occupants and reparation , the study of supply of dry outside air is more than adequate to flush the human-generated moisture from cabin and sustain a low moisture contain in the air, typically 10 to 20% relative humidity at cruise altitudes. The low humidity can be averted to some extend by using the lowest operable flow rate of outside air at the cruise altitudes. There is an inherent conflict between contaminate control and humidity control: increasing the flow of outside air to decrease contaminates concentrations in the cabin decreases the humidity level, and reducing the flow of outside air to increase the humidity rise contaminate concentration. There are three main humidification principles have been develop for the aircrafts, which based on humidifying the dry air by:

- Atomized water spray.
- Steam boiler in devices.
- Water surface evaporation. [4]

2.5.5 Pressurization and oxygen control

Atmosphere pressure: The gases of the atmosphere (air), although invisible, have weight. A one square inch column of air stretching from sea level into space weighs 14.7 pounds. Therefore, it can be stated that the pressure of the atmosphere, or atmospheric pressure, at sea level is 14.7 psi. Atmospheric pressure decreases with increasing altitude, the decrease in pressure is a rapid one and, at 50,000 feet, the atmospheric pressure has dropped to almost one-tenth of the sea level value.

"Before cabin pressurization in the 1950s, ventilation was by infiltration as for buildings. Pilots used oxygen mask since WWWI reconnaissance flights (pressure suits were developed in the 1930s). Early jet liners (in the 1940s) pressurized the cabin with 10

L(s·pax) of fresh air, but modern jets (since 1970) only supply and renew 5 L/(s·pax), forcing another 5 L/(s·pax) of cabin air recirculation (otherwise, the primary jet engine would deteriorate too much in large bypass turbofans."[1]

Emergency oxygen can be supplied from: Gas bottled at 15 MPa, Liquid cryogens at cabin pressure, Solid of lithium perchlorate ($LiClO_4=LiCl+2O_2$) that releases O_2 when 'ignited' (heating above 400 ºC) by pulling a pin on the cartridge, and Gas separation from ambient air in a molecular sieve.[1]

The concentration of Air oxygen in volume is about 21%, it has little variation with altitude; this means the oxygen partial pressure is 21% of the surrounding partial pressure. Then the partial pressure of 10.7 kPa, indispensable for suitable respiration, corresponds to overall air pressure of 51 kPa, which relatively to the standard atmosphere is found at an altitude of 18000 ft (5500 m). Above this limit, the danger of hypoxia is rising and attend easily to collapse and unconsciousness. Due to flying the aircraft at higher altitudes, to provide comfortable conditions there are two possibilities: Oxygen partial pressure Increase, and Air total pressure Increase.[2]

The first choice, commonly used on spacecraft, is insufficient for most aircraft in normal operating conditions, because it should require a transport of oxygen with continuous increase of weight and decrease the safety. The general practice is then to pressurize the cabin to provide a comfortable value, far from any danger for the passengers.[2]

To have pressurized air on board is not an issue, because it is bled from the pneumatic system and then processed using the air conditioning packs. The air is then entered into the cabin and both the flow rate and pressure are controlled by altering outflow valves and then bleeding from the pneumatic system. The system is attended on current aircraft, controlled by a computer to match with the needs, limiting rate of change and the cabin pressure altitude. Normally the pilot enters the values for the cabin altitude and its rate of change and the cabin altimeter allows a suitable constant monitoring of the cabin internal conditions. Monitoring valves along the pneumatic line allow to seal the system in state of bleed air error, by closing the outflow valves and then giving the pilot it's time for descending.[2]

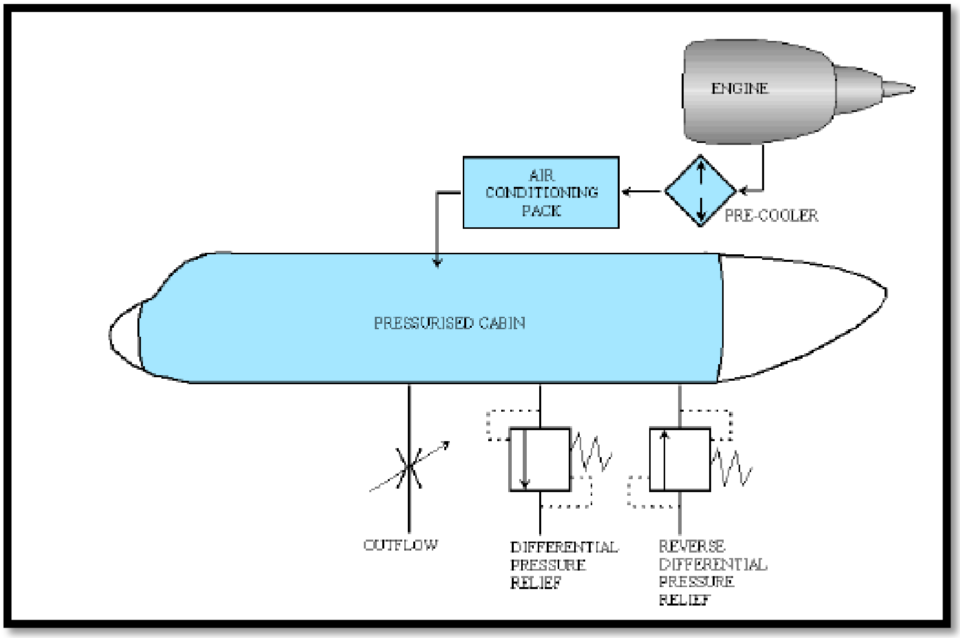

Figure 2-4 Pressurization system layout

2.5.5.1 Cabin air distribution

The air distribution system has the function of generating standardized temperature conditions, contaminant removal throughout the cabin and the ventilation. This is accomplished by ducts that provide the air to the cabin along its length and through diffusers, calibrated to ensure uniform distribution of the air. The air distribution system in transport aircraft is commonly located in the center of the ceiling of the corridors or along the overhead baggage compartments. Exhausted air is partly exacted from the cabin in the floor-side area, occasionally through the ceiling; part of it is filtered, sent to middle mixing manifolds, mixed with air equipping by the air conditioning packs and then re-introduced to inside the cabin. Usually a variable portion of 0 to 55% of air is recirculated.[2]

Temperature control is acquired by mixing hot trim air with that coming from the central of the manifolds, which is normally at a low temperature. On broader aircraft and for each zone there is a separate trim airflow valve, controlled by a local thermostat, for a more regular temperature control.[2]

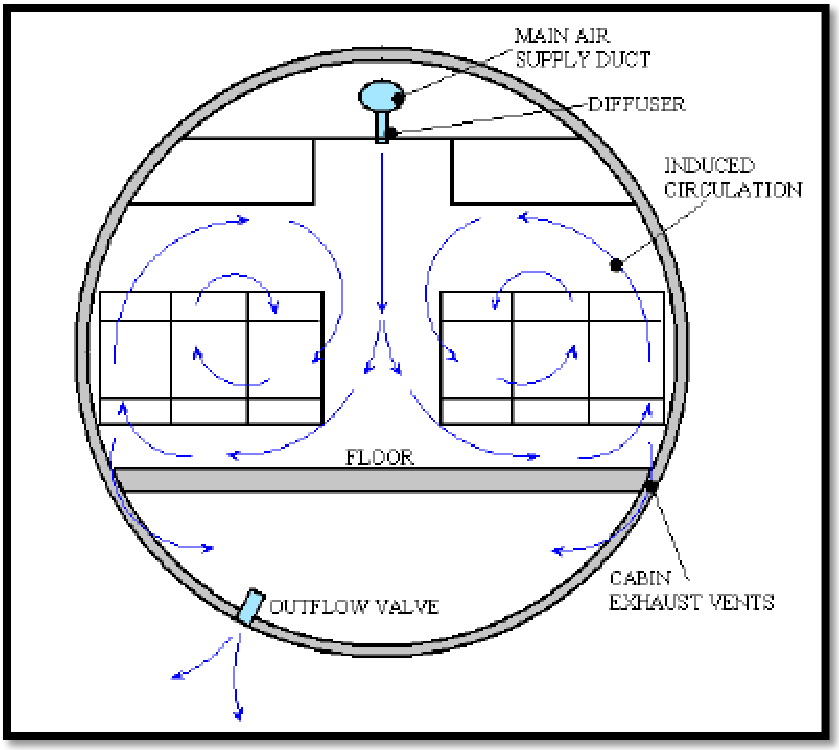

Figure 2-5 Air distribution and circulation

2.5.5.2 Air source (bleed air circuit)

The air source in aircraft ECS is ultimately outside air (in spacecraft it must be produced). Most ECS, up to now, take compressed air from main engines (before the combustion chambers, of course), instead of having dedicated compressors to pump outside air (but B787 is based on no bleed air technique). Bleed air systems should bleed at compressor interfaces (HP, LP-HP or LP-MP-HP) because bleeding at intermediate stages may cause unwanted flow deflections.[1]

The source of air to pressurize an aircraft varies mainly with engine type. Reciprocating Engine Aircraft there are three regular sources of air used to pressurize reciprocating aircraft: Supercharger, turbocharger, and engine-driven compressor. Turbochargers and Superchargers are installed on reciprocating engines to allow better performance at high altitudes by rising the pressure and quantity of the air in the induction system. A supercharger is mechanically driven by the engine. In spite of engine performance increases due to higher induction system pressure, number of the engines output are utilized by the supercharger. Furthermore, superchargers have finite capability to improve engine performance.as well as turbine Engine Aircraft the main concept of operation of a turbine engine includes the compression of large amounts of air to be blended with fuel and burned. The Bleed air from the compressor section is relatively free of contaminants. As well as, it is a great source of air for cabin pressurization. New large-cabin turbofan engine aircraft include recirculation fans to reuse up to 50 % of the air in the cabin, ensuring high engine output.

"There are different ways hot, high-pressure bleed air can be exploited. Smaller turbine aircraft, or sections of a large aircraft, may make use of a jet pump flow multiplier. Another method of pressurizing an aircraft using turbine engine compressor bleed air is to have the bleed air drive a separate compressor that has an ambient air intake. The most common method of pressurizing turbine-powered aircraft is with an air cycle air conditioning and pressurization system. Bleed air is used, and through an elaborate system including heat exchangers, a compressor, and an expansion turbine, cabin pressurization and the temperature of the pressurizing air are precisely controlled."[4, 7]

2.5.5.3 Control of Cabin Pressure

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Firstly Pressurization Modes Aircraft cabin pressurization can be controlled through two different modes of operation. The first one is the isobaric mode, which tries to maintain cabin altitude at a single pressure in spite of the changing altitude of the aircraft. The second one is the constant differential mode, which works to control cabin pressure to ensure a constant pressure difference between the pressure of air inside the cabin and the air pressure outside the cabin, regardless of aircraft altitude changes. As well as Cabin Pressure Controller: The cabin pressure controller is the instrument used to control the cabin air pressure. In Older aircraft strictly pneumatic means used for controlling cabin pressure. Chosen for the desired cabin altitude, rate of cabin altitude variation, and barometric pressure setting are all made directly to the cabin pressure controller from pressurization panel in the cockpit.[7]

Modern aircraft often combine pneumatic, electronic and, electric control of pressurization. The Cabin altitude, barometric setting and cabin rate of change, are made on the cabin pressure selector of the pressurization panel in the cockpit. The selector sent Electric signals to the cabin pressure controller, which functions as the pressure adapter. It is remotely located near the cockpit but inside the pressurized portion of the aircraft. The controller used the signals after it converted from electric to digital.[7]

The airplane is pressurized by bleed air supplied to the packs which controlled by outflow valves, which combine the use of both electricity and pneumatic operation have all-pneumatic standby and manual mode.[7, 8]

The auto system will fail in case of: Cabin altitude more than 13,875ft CPCS; 15,800ft DCPCS. Cabin rate of climb or descent more than 1890 sea level fpm CPCS; 2000 sea level fpm DCPCS. Loss of AC power. Differential pressure more than 8.3 psi CPCS, 8.75 psi DCPCS, and Any Other fault in pressurization controller.[8]

2.5.5.4 Cabin Air Pressure Regulator and Outflow Valve

Controlling cabin pressurization is accomplished through adapting the amount of air that flows out of the cabin. The cabin outflow valve opens, closes, or justice to establish the amount of air pressure maintained in the cabin.[7]

2.6 Fuzzy logic

2.6.1 Introduction

Fuzzy logic can be defined as a part of artificial intelligence, which is based on human thinking, in a way that deal with reasoning with uncertain or vagueness to make a decision or to support in making a decision.

Fuzzy logic can be thought as a gray logic, which mean that a fuzzy logic data can be any real value between 0and1. In state of classic logic (crisp logic) data take value of 0 or 1.

First of all knowledge is required to build reason based on it. The source of knowledge is an expert [person who know process or machine].

As an example if we take a temperature in a temperature regulated batch, if temperature rise, the expert may order to turn the steam valve in clock wise “little bit”. The fuzzy system may translate “little bit” as 15 degree clockwise rotation. So the expression “little bit” can take place in fuzzy system, but does not as definite value. [9-11]

2.6.2 Brief history

“Fuzzy theory was initiated by Lotfi A. Zadeh in 1965 with his seminal paper on “fuzzy Sets" (Zadeh [1965]). Before working on fuzzy theory, Zadeh was a well-respected scholar in control theory. He developed the concept of "state," which forms the basis for modern control theory. In the early '60s, he thought that classical control theory had put too much emphasis on precision and therefore could not handle the complex systems. As early as 1962, he wrote that to handle biological systems "we need a radically different kind of mathematics, the mathematics of fuzzy or cloudy quantities which are not describable in terms of probability distributions" (Zadeh [1962]). Later, he formalized the ideas into the paper "fuzzy sets.”

Since its birth, fuzzy theory has been sparking /controversy. Some scholars, like Richard Bellman, endorsed the idea and began to work in this new field. Other scholars objected to the idea and viewed "fuzzification" as against basic scientific principles. The biggest challenge, however, came from mathematicians in statistics and probability who claimed that probability is sufficient to characterize uncertainty and any problems that fuzzy theory can solve can be solved equally well or better by probability theory**.** Because there were no real practical applications of fuzzy theory in the beginning, it was difficult to defend the field from a purely philosophical point of view. Almost all major research institutes in the world failed to view fuzzy theory as a serious research field.

Although fuzzy theory did not fall into the mainstream, there were still many researchers around the world dedicating themselves to this new field. In the late

1960s, many new fuzzy methods like fuzzy algorithms, fuzzy decision making, etc. Were proposed."[12]

2.6.3 Reasons of using fuzzy logic

Fuzzy Logic can "Represent vague language naturally. Enrich and not replace crisp sets. Allow flexible engineering design. Improve model performance. Are simple to implement, very robust, can be easy modify, And best of all they often work."[10, 13]

2.6.4 Fuzzy logic in real application

The Success of Fuzzy Logic is mainly due it's introduce into Consumer Products, early applications started in Japan since 1980s, and some examples are:

Temperature Controlled in Showers, Air Conditioner, Sendai Subway System, as facial pattern recognition, air conditioners, washing machines, vacuum cleaners, antiskid braking systems, transmission systems, control of subway systems and unmanned helicopters, knowledge-based systems for multi-objective optimization of power systems, weather forecasting systems, models for new product pricing or project risk assessment, medical diagnosis and treatment plans, and stock trading. Fuzzy logic has been successfully used in numerous fields such as control systems engineering, image processing, power engineering, industrial automation, robotics, consumer electronics, and optimization. This branch of mathematics has instilled new life into scientific fields that have been dormant for a long time.[13]

2.6.5 Fuzzy logic algorithm

The figure (2-6) shows the fuzzy logic control begin with the fuzzy input which is the output of the process, which is interface to the system by using input interfaces. If we take a temperature application as an example it will interface to the system by using analog input module.[11]

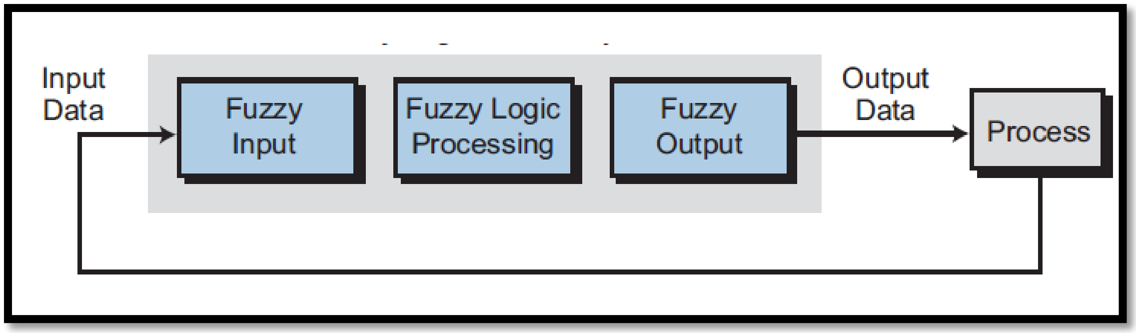

Figure 2-6 fuzzy logic control system

The output of the fuzzy input will go to the fuzzy logic process, here the data would be analyzed, and to provide an output, also rule would be executed, which is based on the input condition. The input data can be represent as error(50%),or as count value(0-4095) as shown in figure(2-7).[11]

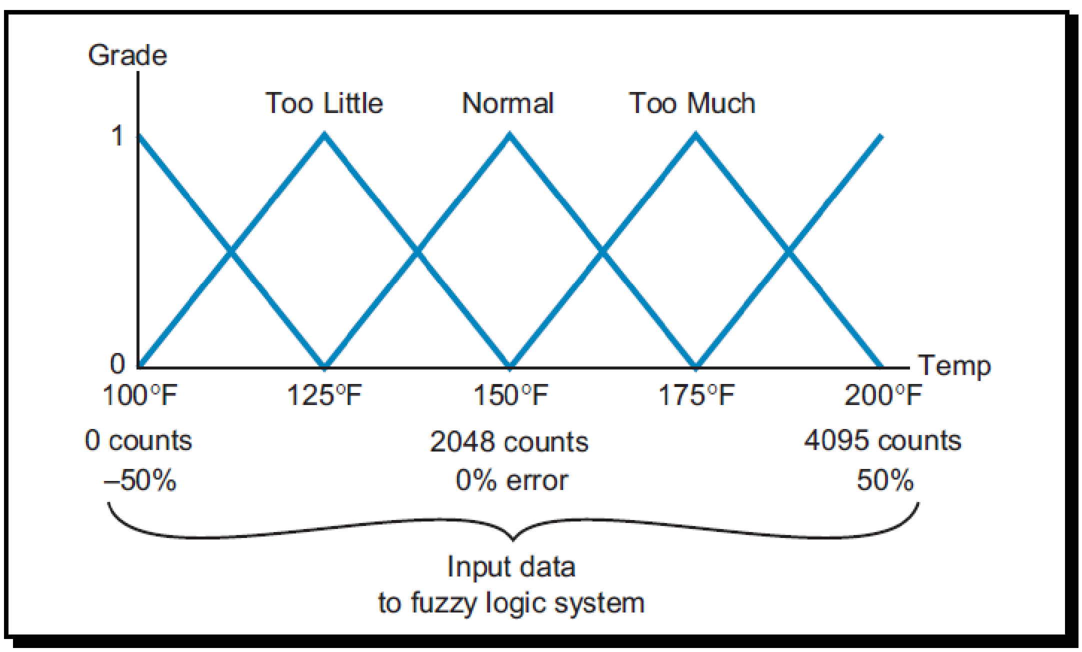

Figure 2-7 input data to fuzzy logic system represented as counts and percentages

Lastly the output of the fuzzy logic processing will go through the fuzzy output, which also can be represented as grade or count value as shown in figure (2-8).[11]

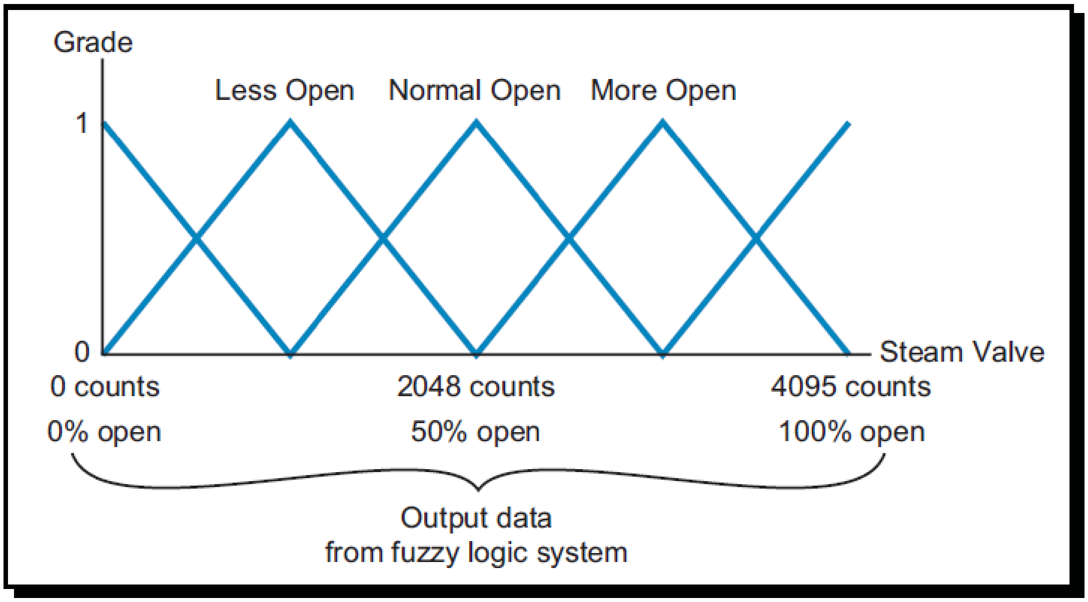

Figure 2-8 output data from a fuzzy logic system represented as counts and percentages

2.6.6 Fuzzy logic control components

The main actions performed by a fuzzy logic controller are: the first one is the fuzzification which mean the translation from a crisp form into fuzzy form. The second action is the fuzzy processing, in it the IF…THEN rules is used to evaluate the input information, which established by the user. The last action is the defuzzification. In it the output conclusion convert into real data [crisp value].then this real data will go to the process by using the output module interface.[11]

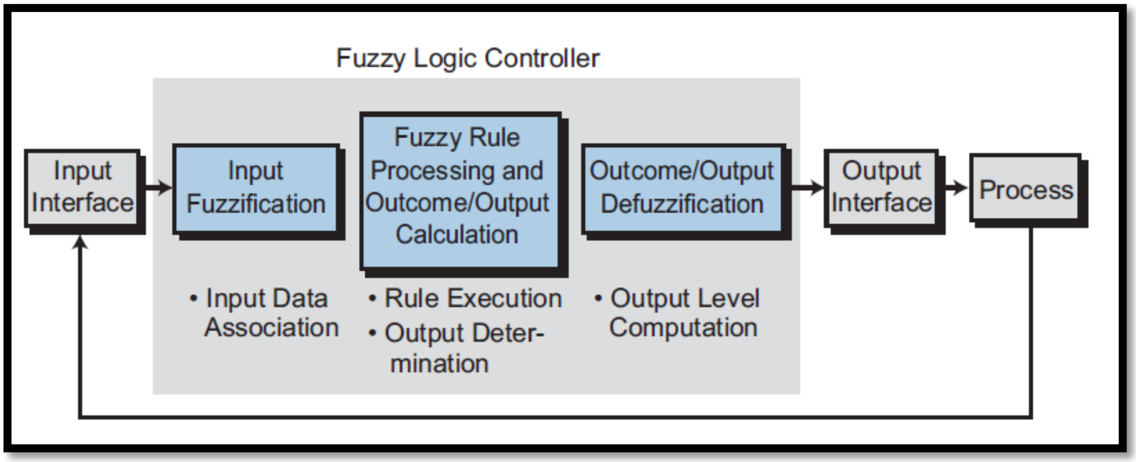

Figure 2-9 fuzzy logic controller operation

2.6.6.1 Fuzzification components

It has two main component, the first one is the membership function, which is a user defined chart used to analyze the input data. This membership function is divided into **sets.** There are various type of member ship function but the famous one are: S, Z, Λ, π , Gaussian, and trapezoidal shapes.

The second component is the labeling, which is the name that define the membership function. For example, if a membership function is divided into three sets, each set would have it is own label that define the certain set.[11]

2.6.6.2 Fuzzy processing components

The processor perform tow action. The first one is the rule evaluation.in rule evaluation a reasoning or inference is used .process here consist of IF…THEN rules, each rule provide an outcome or a response.

The rules is trigged if the condition part satisfied by the input and the output based on the THEN pat, as shown in figure(2-10).[11]

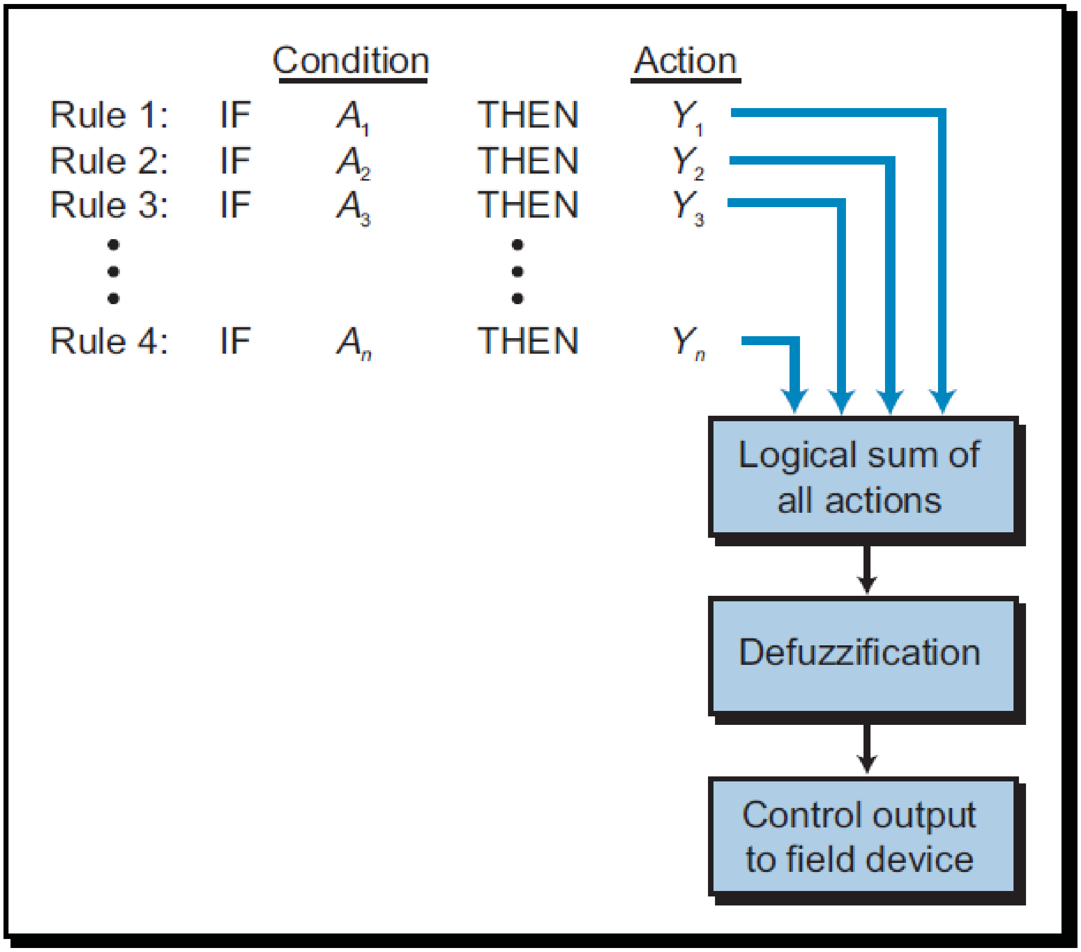

Figure 2-10 multiple rules in a fuzzy system

Note: in fuzzy logic there is flexibility to have more than one IF condition, which logically linked by AND or OR relationship, as shown in figure (2-11).[11]

		Condition		Action
Rule 1:	IF	A_1 AND B_1 AND C_1	THEN	Y_1
Rule 2:	IF	A_2 OR B_2	THEN	Y_2
Rule 3:	IF	(A_3 AND B_3) OR C_3	THEN	Y_3

Figure 2-11 rules with multiple input conditions linked in AND and OR relationships

The output outcome would be generated when the input data that belongs to a membership function is satisfied IF statement. This fuzzy output will composed with membership function and labeling.[11]

2.6.6.3 Defuzzification components

The final output value from the fuzzy controller relies on the defuzzification method used to compute the output outcome values corresponding to each label.

There are different defuzzification methods, but all are based on mathematical algorithms.

i. .Max membership method:

This method is limited to peaked output functions which is given by the algebraic expression:

$\mu z (z^*) \geq \mu z (z)$ for all $z \in Z$

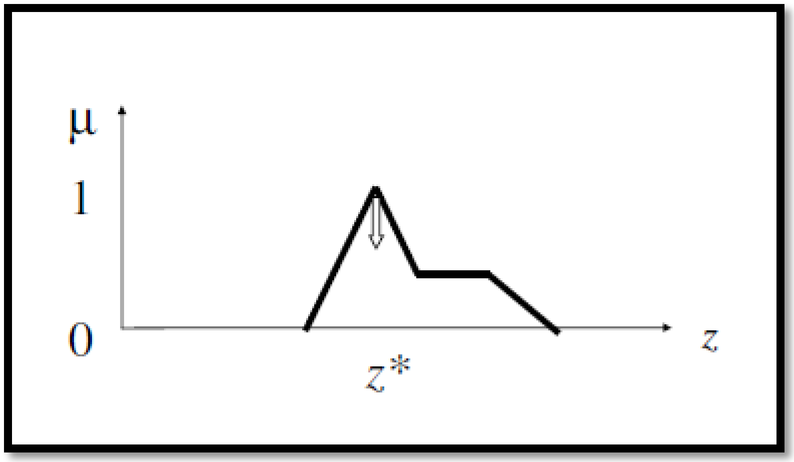

Figure 2-12 maximum membership method

ii. Center of gravity method:

This procedure is the most predominate and physically restarting of all the defuzzification methods. It is given by the algebraic expression:

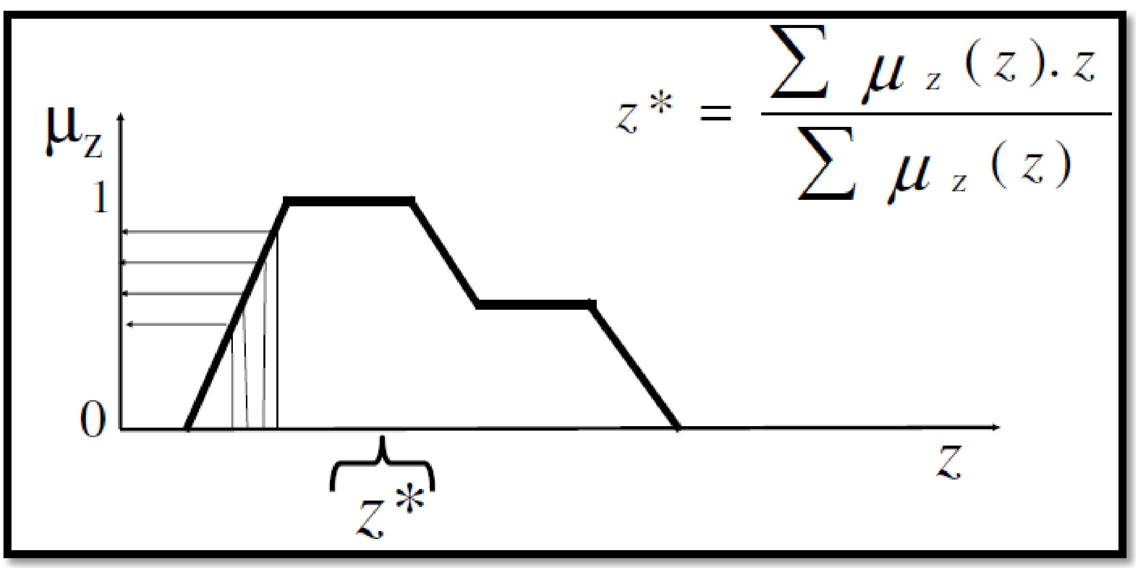

Figure 2-13 center of gravity method

iii. Weight average method

This method is only possible for symmetrical output membership functions. This method is formed by weighting each membership function in the output by its respective maximum membership value, z .It is given by the algebraic expression:

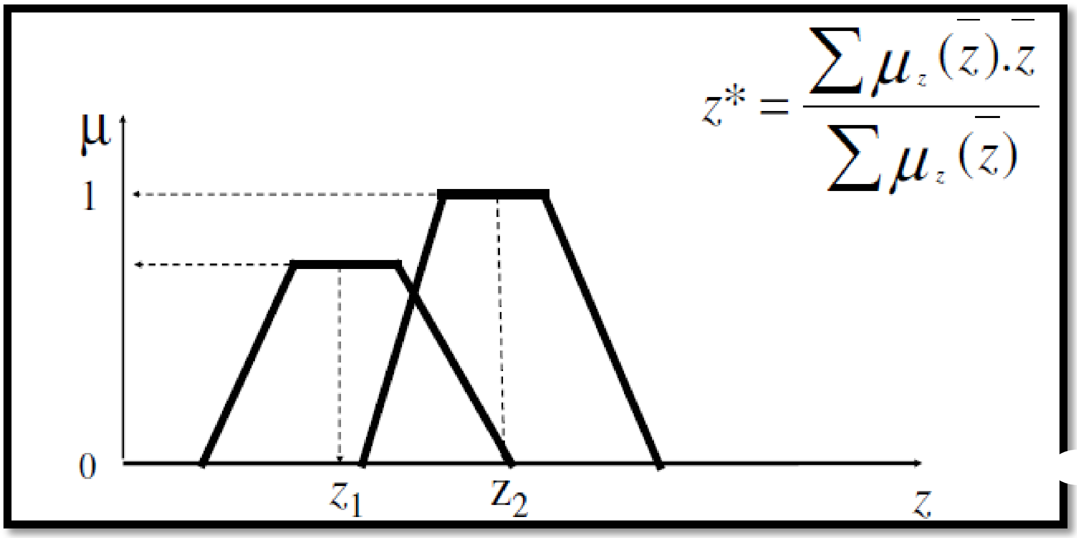

Figure 2-14weight average method

(iv) Mean-max membership method:

• This scheme is closely related to the first method, except that the locations of the maximum membership can be non-unique. This method is given by the expression:

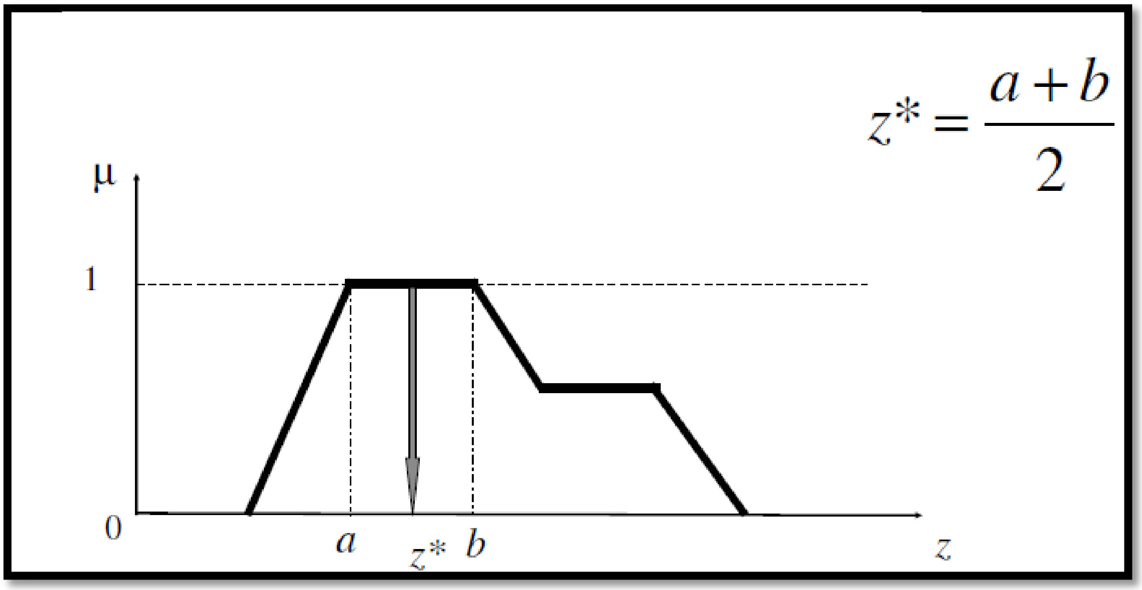

Figure 2-15 mean- max membership method

All these type of defuzzification methods used depends on application where the controller is used. [13]

There are various type of fuzzy controller, the one that chosen here is Mamdani controller

Mamdani controller:

The main idea of the Mamdani controller is to describe the process state by means of linguistic variables and to use these variable as inputs to control rules. The definition of linguistic variables and rules are the main design steps when implementing a Mamdani controller. The computational core can be described as a three-step process consisting of

1- Determination of the degree of membership of the input in the rule antecedent by employing the minimum –operator as model for the “and”.
2- Computation of the rule consequences by aggregation of all consequences using the maximum –operator.
3- Aggregation of rule consequences to the fuzzy sets control action.[14]

2.7 Related work

A need of having an alternative technique that immunized computational system, by combine the knowledge of an expert with the capability of adaption with the work environment to have an enhancement and a powerful ,reliably, intelligent systems.

To achieve the goal, a study of various level of intelligent control is done, and then related these intelligent control to similar function in human immune system. A technique is used to implement these new system adaptive critic. After that a technique applied to a flight path generator for level to, non-linear, full-envelope, intelligent aircraft control problem.

This technique is used by K.K Kalmanje and Neidhoefer in their paper immunized adaptive critic for autonomous aircraft control application. In doing this technique a care should be taken about the knowledge between hands, and also the complexity of work is another disadvantage of having adaptive immunized system.[15]

A pleasant surrounding atmosphere is one of the important criterion in the modern passenger aircraft to be a successful flight operator. In order to provide accurate controlling for aircraft cabin temperature, the cabin must be divided into plurality.
A passenger aircraft consist of a cabin subdivided into a plurality of cabin zones which supplied with feed air from it special supply lines, a plurality of temperature sensors, and an electronic control unit in addition to the plurality of temperature sensors. The plurality of temperature sensors determine a plurality of individual surrounding temperature values related with different locations in at least one of the plurality of cabin zones. The electronic control unit derives surrounding temperature value form one cabin zone at least from the plurality of individual surrounding temperature values. Then the electronic control unit controls a temperature of the feed air delivers to the at least one cabin zone according to the difference between the derived surrounding temperature value and a room temperature wanted value for the at least one cabin zone. Although the system is accurate, the system has more weight due to the number of sensors and hence high cost, it

price pay to get high accuracy. This method has been used in the report controlling the fed air temperature for a passenger aircraft.[16]

A cabin pressure control system for aircraft include a controller for receiving and comparing reference value and actual values for an airplane cabin pressure. The triggering of the valve is joined with air outlet valve with is driven via A speed-controlled for controlling the triggering of the valve as a function of the comparison. Regarding a newly established actual cabin pressure, a remote indication is issued to the controller solely, without a remote position indication from the valve.

The overall result is consequently a cabin pressure control system that is structure at reduced expense and yet operates as a function of pre-established control parameters to insure reliable and optionally plus control of the cabin pressure the altitude of the aircraft change. The main disadvantage of this system is the ability of Decompression which is define as the failure of the aircraft's pressurization system to keep its designed pressure schedule. Decompression maybe caused by structural damage to the aircraft or by a malfunction of the system itself. Explosive decompression could cause structural damage with ability of catastrophic outcome, but the events of such nature are extremely rare. In the case of decompression there are two sets of immediate risk: Physical hazards such as noise, extraction, debris and cooling are well recognized, but in most decompressions there is very little risk of mechanical wound. Physiological Hazards like Hypoxia Gas Expansion, Hypothermia, Decompression sickness and impaired human performance. This method has been used in the report of method for of aircraft cabin pressure control system.[17]

2.8 Summary

Designing a fuzzy controller can be done with several different computer based tools, the tool we will be using is the Fuzzy Logic Toolbox in MATLAB with Simulink. This toolbox provides a GUI for defining membership functions and inference rules and can be integrated with Simulink.

In this work the temperature has been selected as environmental control system parameter for FLC design, simulation and tuning levels.

3 Chapter Three: Methodology

3.1 Introduction

In this chapter fuzzy logic controller FLC for an aircraft cabin temperature has been designed based on temperature Profile of test a flight for Airbus A340-600 recorded for 23735 seconds. The controller simulated by using MATLAB fuzzy logic toolbox then tuned to elaborate the effect of fuzzy controller parameters in final results.

3.2 Fuzzy logic designer

3.2.1 Overview

Fuzzy Logic Designer allows to utilize the highest level features of the fuzzy inference system, such as the number of input and output variables, fuzzy implication and fuzzy inference as well as defuzzification. This interface provides convenient access to all other editors with an emphasis on maximum flexibility for interaction with the fuzzy system.

3.2.2 Fuzzy Logic Control Design

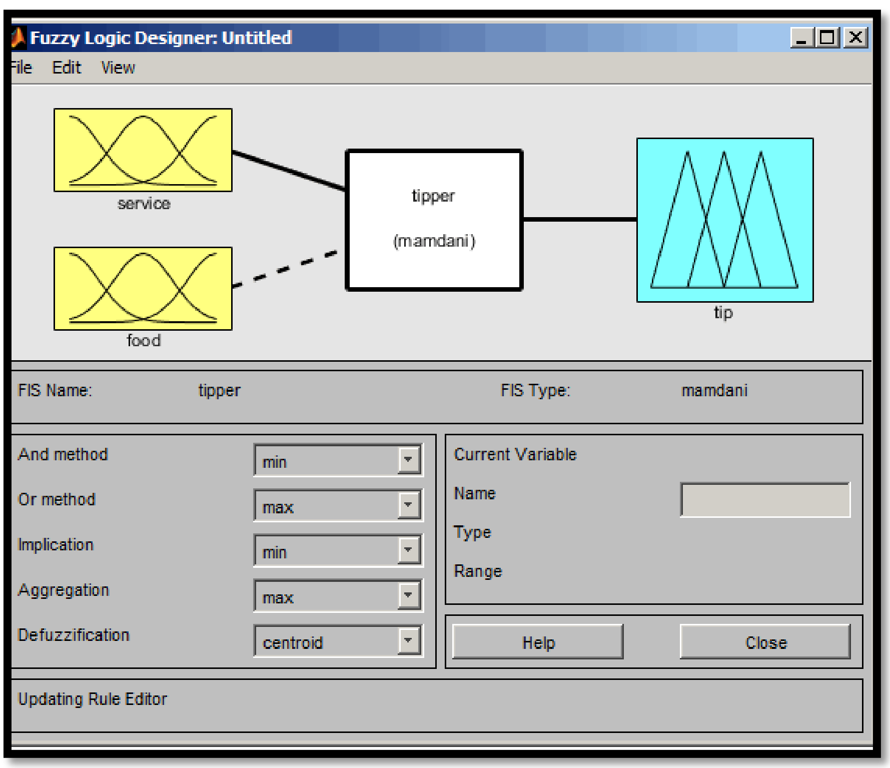

Figure 3-1 fuzzy logic designer interface

The Fuzzy Logic Designer shows the inputs, outputs, and a central fuzzy rule processor. The variables can be edited by Clicking on variables boxes, another clicking opens the Membership Function Editor. Rules can be edited through rules editor dialogue box if a variable exists but is not mentioned in the rule base, it is connected to the rule processor block with a dashed line.

The number of inputs of Fuzzy Logic Toolbox may be limited by the available memory of running machine, also the large number is difficult to be analyzed by the FIS.

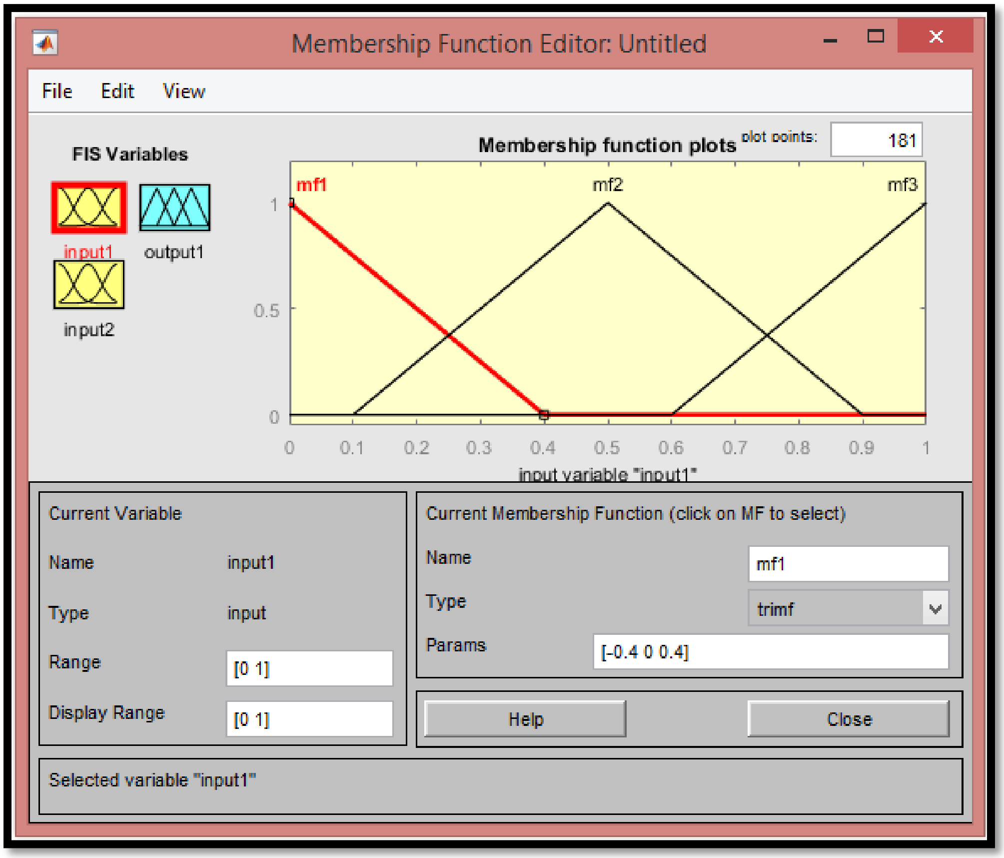

Figure 3-2 member function editor

To define the shapes of all the membership functions associated with each variable.

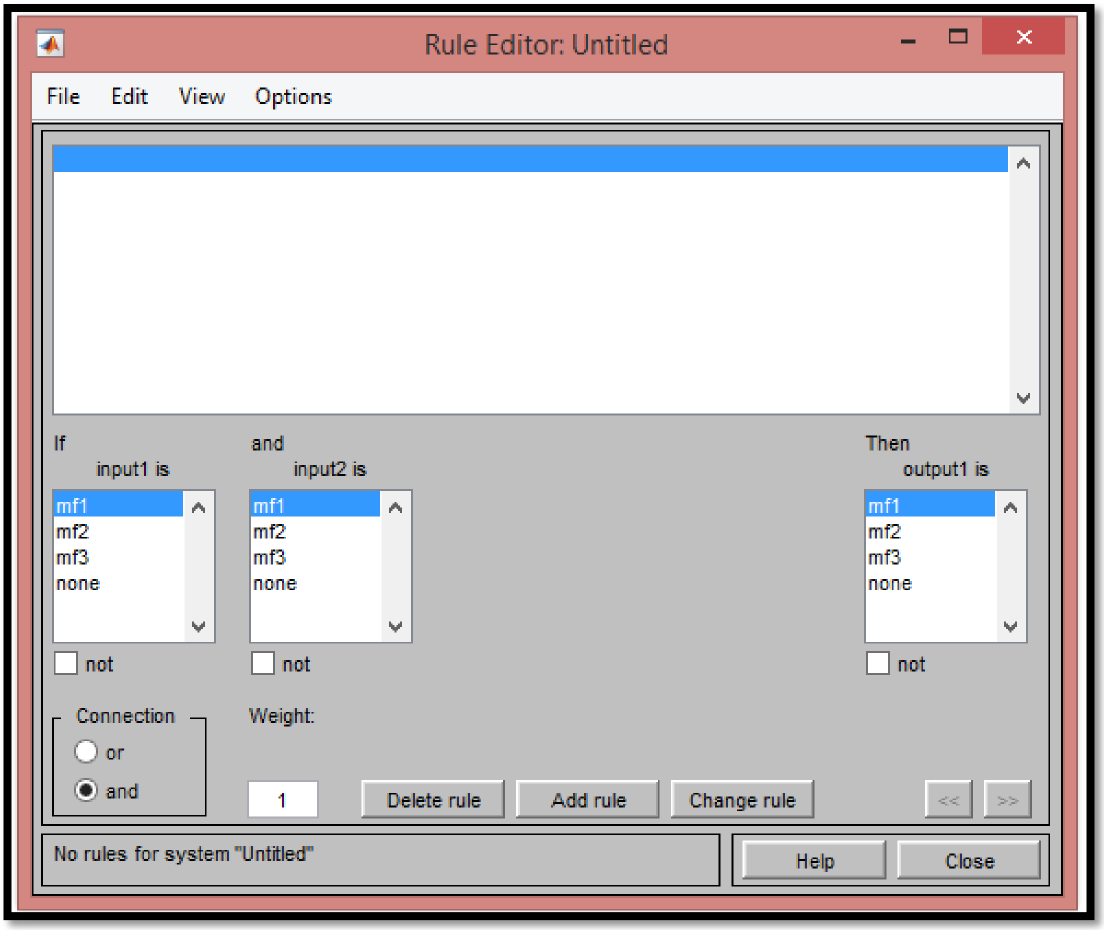

Figure 3-3 rule editor

To edit the list of rules that defines the behavior of the system.

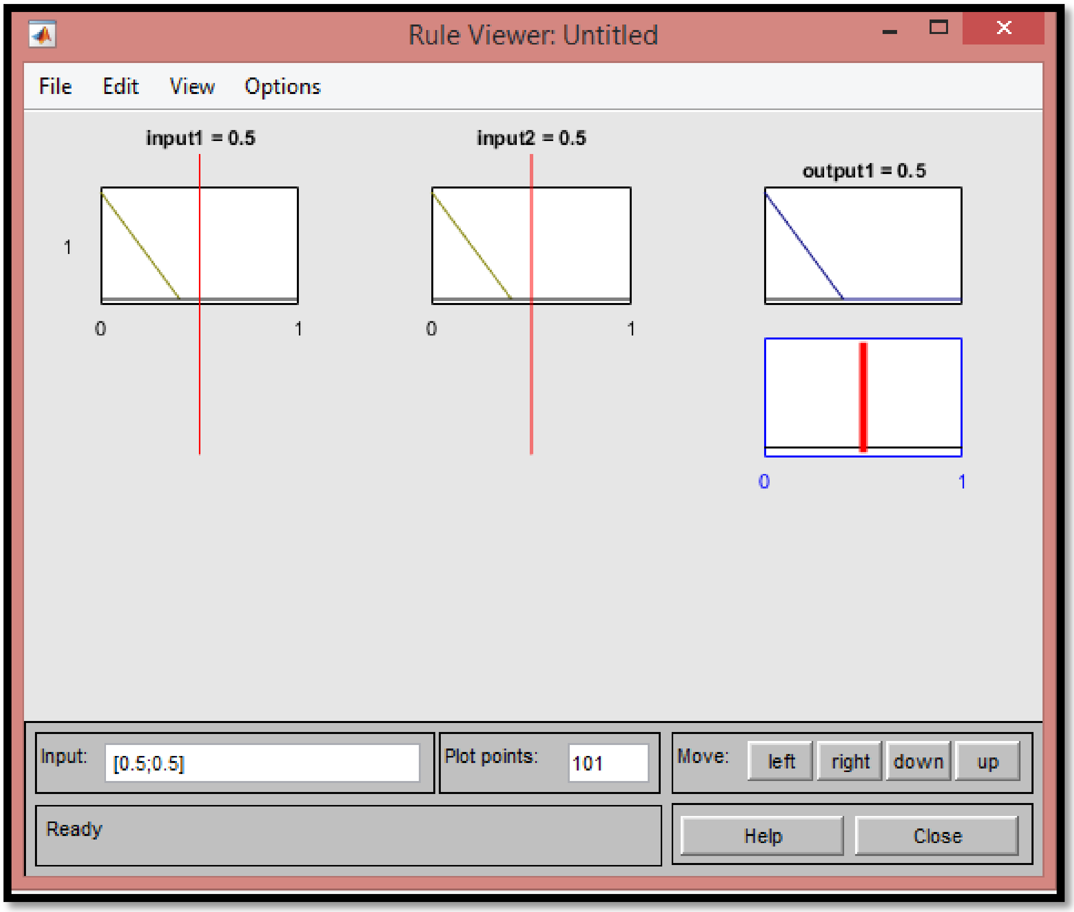

Figure 3-4 rule viewer

This window views the fuzzy inference diagram. This viewer is considered as a diagnostic to see which rules are active, or how individual membership function shapes influence the results.

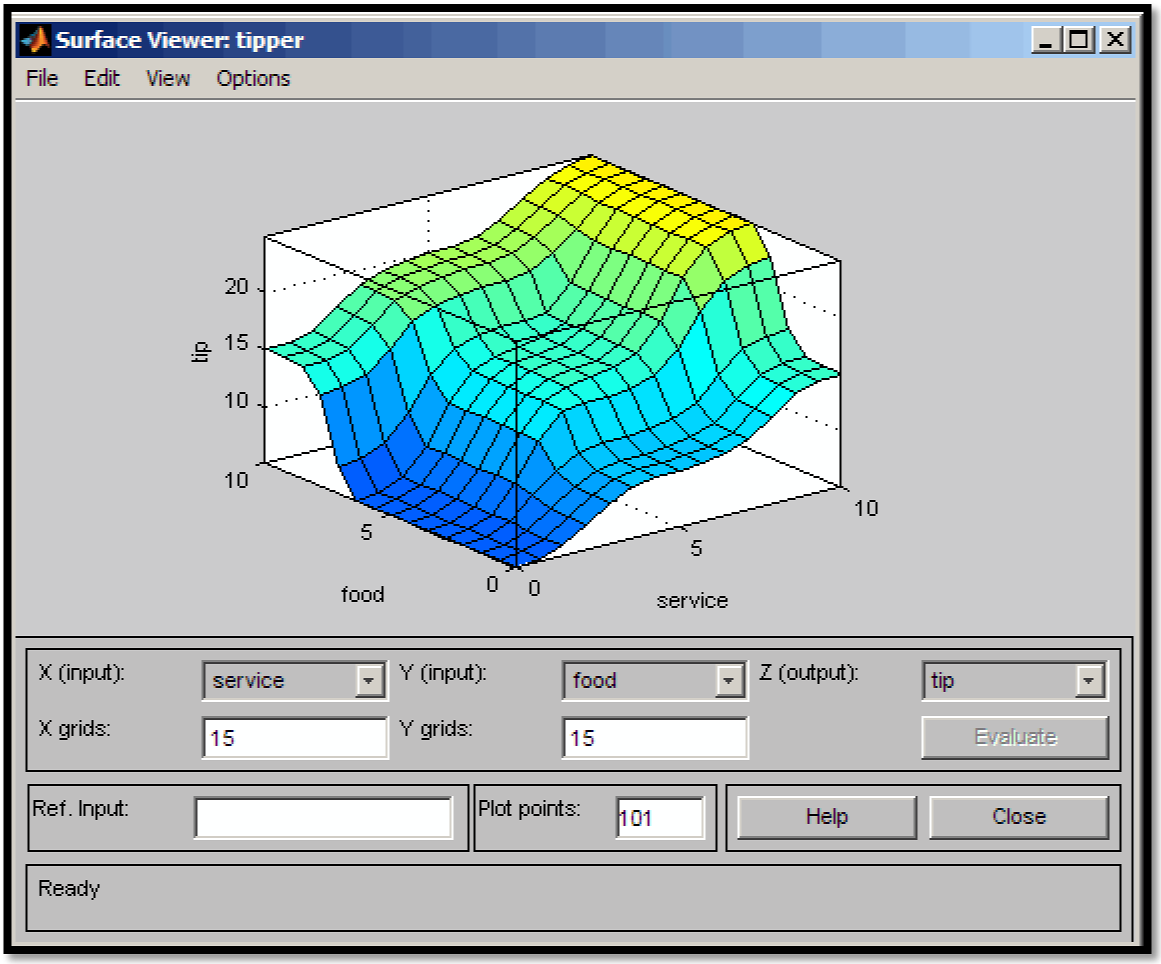

Figure 3-5 surface viewer

Upon opening the Surface Viewer, a three-dimensional the curve is shown which represents a two-input one-output case, the entire mapping is illustrated in one plot.

3.3 Objectives through using FLC design tool

- Study and analyze the pre collected data to define its problems to be tackled with FLC tool
- Tune the FLC Using different method and make a comparison for results obtained from each tuning method.
- Deduce which method has better effect on final response.

3.4 Design and Simulation of the cabin temperature control

As stated in the previous chapter the complexity of ECS make whole control is complicated thus each subsystems is controlled separately. Air-condition system has been selected as the system under investigation and the temperature as the key variable.

The fuzzy logic control needs at least two input and one output (MISO), therefore the error in temperature and the derivative of error are taken as the two fuzzy input variables where change in the control signal is the output of the controller. The fuzzy rules are then formulated on the bases of condition of error (E) and rate of change of error (derivative of error (ΔE)) and the output is the change in the control signal (Δu).

3.4.1 Controller variables calculations

These calculations based on sampled data of temperature Profile of test a flight for Airbus A340-600 recorded for 23735 seconds shown in figure (3.1).

- **Error Calculation:**

$\boldsymbol{E\ (k) = r\ (k) - y\ (k)}$ ... ... **(3.1)** [13]

E (k)≡ error

r (k)≡ max output

y (k)≡ set point.

k ≡ sample interval

- **Calculation of Rate of change**:

$\boldsymbol{\Delta E(k) = E(k) - E(k-1)}$ .... **(3.2)**[13]

$\boldsymbol{\Delta E(k)}$ ≡ Rate of change of error

- **Calculation of Rate of change of control signal:**

  $\boldsymbol{u\ (k+1) = u(k) + \Delta u(k)}$............**(3.3)**[13]

$\boldsymbol{u(k)}$ ≡ Control signal

$\Delta \boldsymbol{u}(\boldsymbol{k}) \equiv$ rate of change of control signal

3.5 System simulation

3.5.1 Range estimation

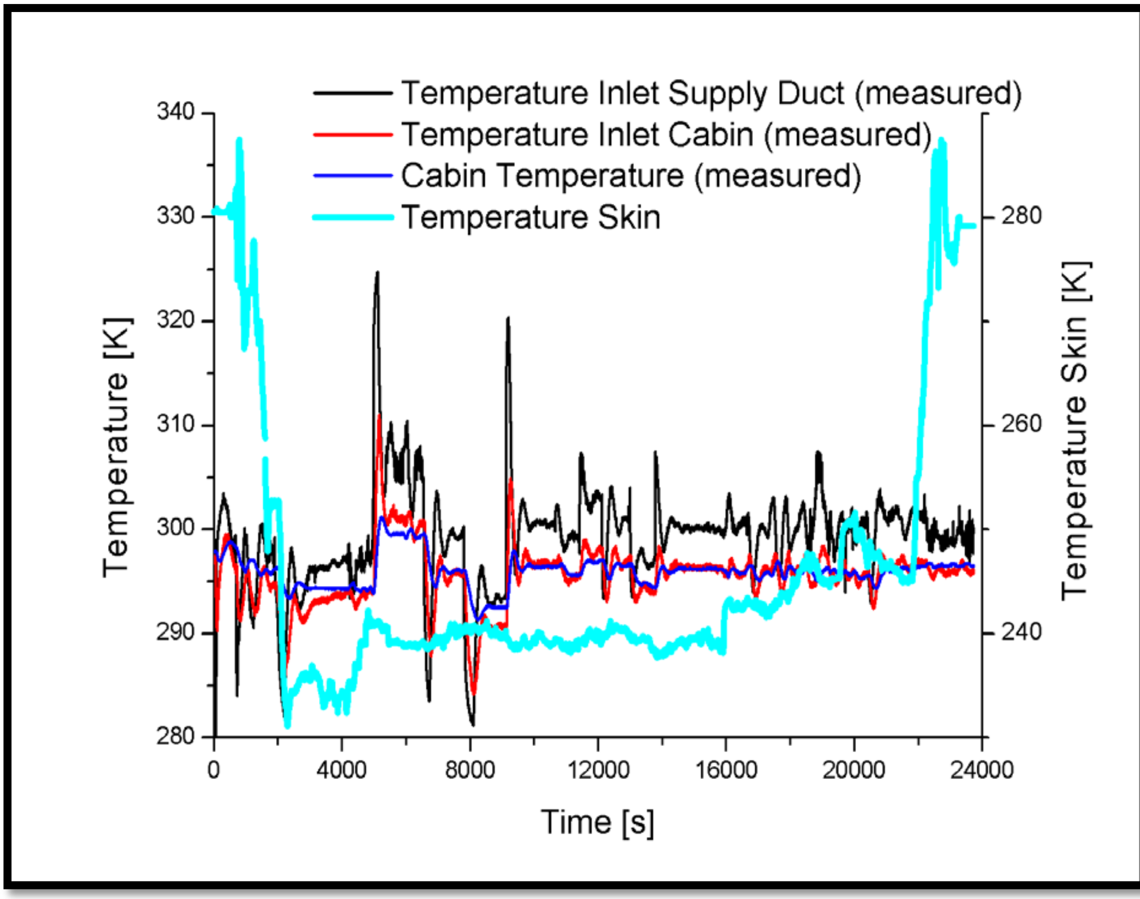

Figure 3-1 the cabin temperature profile of A340-600 source [18]

The selected set point is 22°C (295 K) according to cabin temperature (measured) curve in the figure (3-1) complying with the predefined values for human comfort .equation(3.1),(3.2),and(3.3) are used to drive different values for fuzzy inputs and outputs. The universe of discourse of error and universe of discourse of derivative of error as well as the universe of discourse range of the rate of change of control signal have been set in order to fuzzify the inputs as follow:

Two input variables:

Error in temperature:

$\boldsymbol{E}\ (\boldsymbol{k})\ = \boldsymbol{r}\ (\boldsymbol{k}) - \boldsymbol{y}\ (\boldsymbol{k})$

= 301- 295

= 6

Since the range of universe of discourse of error is $(\pm\mathbf{6})$

Rate of change of error:

$\Delta\boldsymbol{E} = \boldsymbol{E}(\boldsymbol{k}) - \boldsymbol{E}(\boldsymbol{k} - 1)$

$\boldsymbol{E}(\boldsymbol{k} - 1)$ = 294-295

= -1

$\Delta\boldsymbol{E} = \mathbf{6} - (-\mathbf{1})$

=7

The range of universe of discourse of rate of change of error is $(\pm\mathbf{7})$.

Rate of change of control signal:

$\boldsymbol{u}\ (\boldsymbol{k} + \mathbf{1})\ = \boldsymbol{u}(\boldsymbol{k}) + \Delta\boldsymbol{u}(\boldsymbol{k})$

$\Delta\boldsymbol{u}(\boldsymbol{k}) = \boldsymbol{u}\ (\boldsymbol{k} + \mathbf{1}) - \boldsymbol{u}\ (\boldsymbol{k})$

u (k) = 301-294

= 7

u (k+1) = 301 – 299

= 2

Δu (k) = 2-7

= 5

The range of universe of discourse of rate of change of control signal $(\pm \mathbf{5})$

Note:

The absolute value has been taken.

3.5.2 Linguistic Variables and Membership Functions

Inputs are taken and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. In the Fuzzy Logic Toolbox, the input is always a crisp numerical value limited to the universe of discourse of the input variable and the output is a fuzzy degree of membership in the qualifying linguistic set. The inputs must be fuzzified according to each of these linguistic sets before the rules can be evaluated. Each input is fuzzified over all the qualifying membership functions required by the rules in this manner.

The linguistic variables, together with the number of fuzzy sets that represent each of them have to be decided. This step is required for the successful implementation for the controller and will influence the number of rules to be considered since the number of terms is used to describe the universe of discourse of each input variable.

The universe of discourse of the output variable has been divided and tuned to enhance the capability of the controller to follow the reference set point.

3.5.2.1 Linguistic Variables

Introduction of linguistic variables:

• Input 1: "**error**": positive (P), zero (Z), negative (N)

• Input 2: "**error-det**": positive (P), zero (Z), negative (N)

• Output: positive (P): increase temperature, zero (Z): do nothing, negative (N): decrease temperature.

3.5.2.2 Membership function

The most important step is the generation of the membership functions which is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The input space is sometimes referred to as the universe of discourse.

The simplest membership functions are formed using straight lines of these, the simplest is the triangular membership function, and it has the function name trimf.

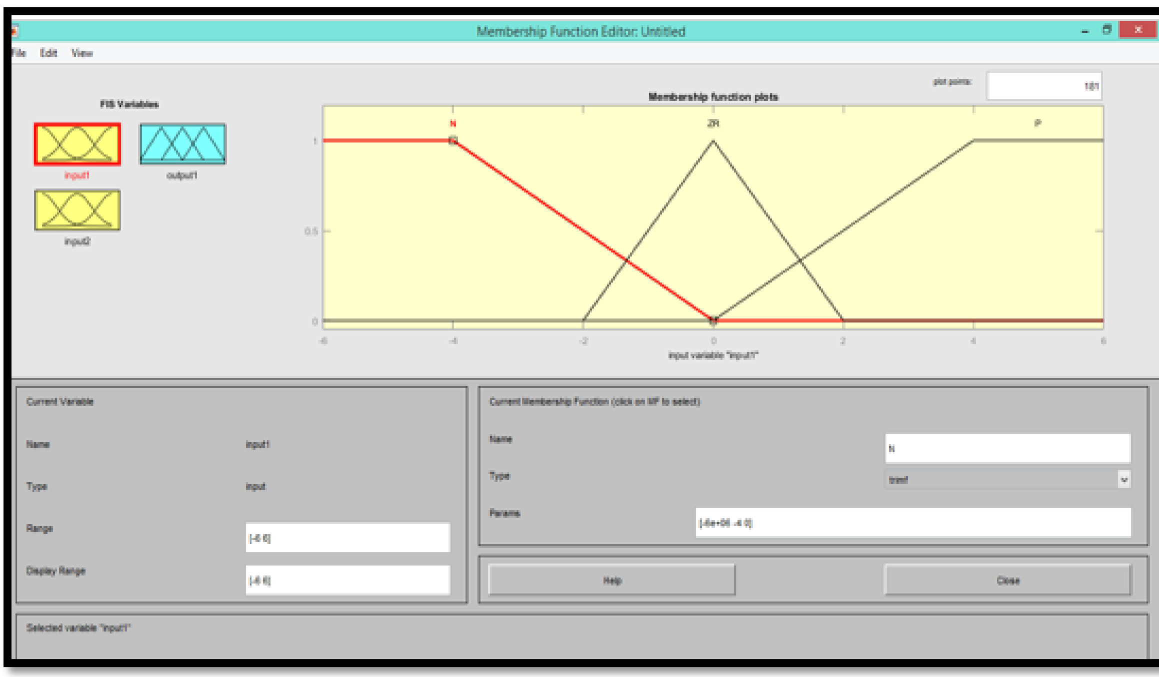

Figure 3-6 first input of triangular MF

The fuzzy set of triangular shape define by three points.The scale factor of temperature error is measured in order to determine the upper and lower limits of the range for the temperature error input variable, a scaling factor of 6 step in positive and negative has been determined . The range of the three fuzzy after calculations are finally set as follows:

N= [-6*10^6,-4, 0]

Z= [-2, 0, 2]

P= [0, 4, 6*10^6].

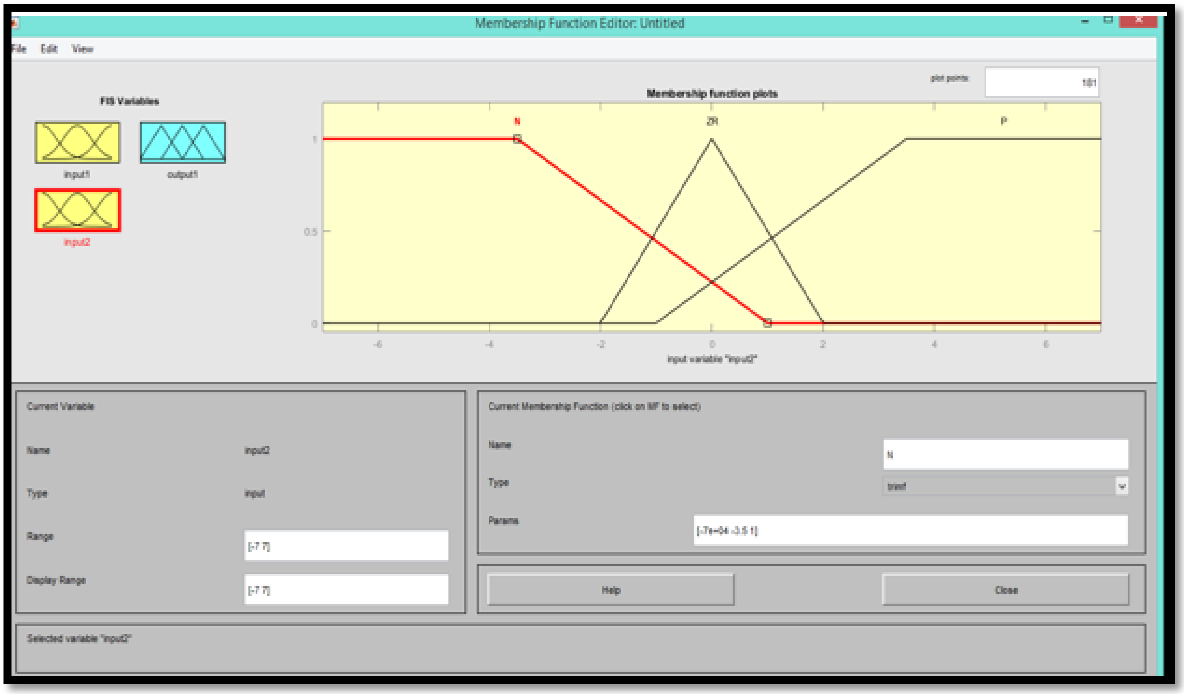

Figure 3-7 scond input of triangual MF

The universe of discousure of fuzzy sets for derivative of error has been set in same way as that of error setting, in order to determine the upper and lower limits of the range for the temperature derivative of error input variable, a scaling factor of 7 step in positive and negative has been used. The range of the three fuzzy sets are set as follows:

N= [-7*10^6, -3.5, 1]

Z= [-2, 0, 2]

p= [-1, 3.5, 7*10^6]

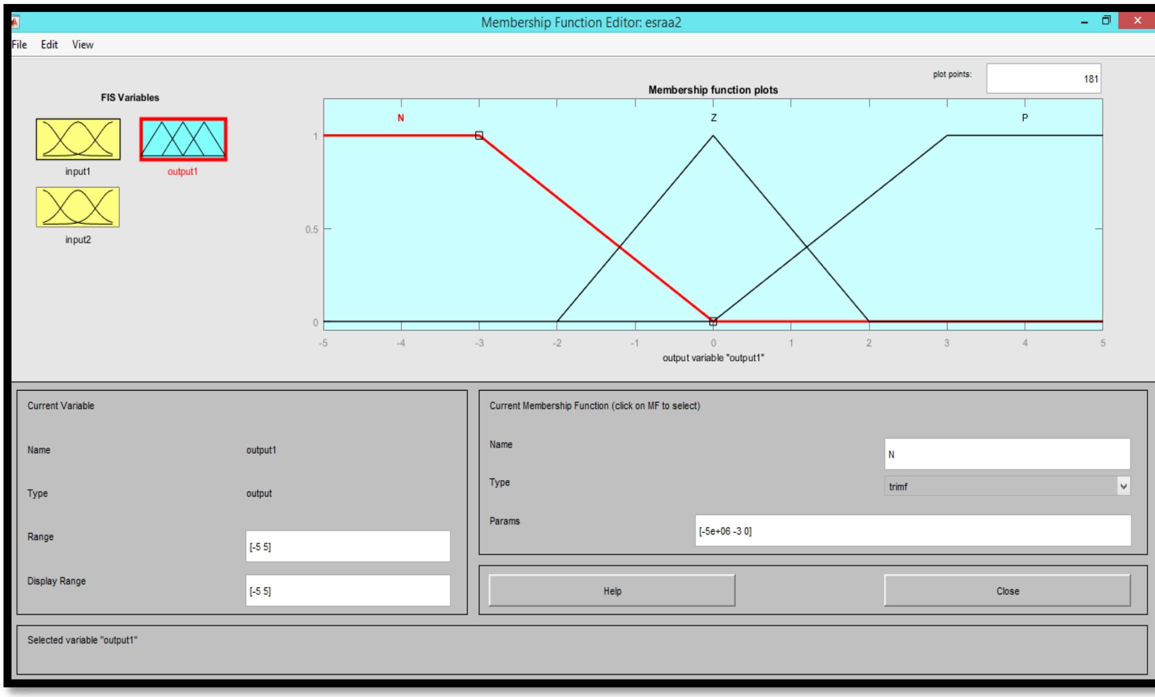

Figure 3-8 the output of triangular MF

Agin a scaling factor of 5step in positive and negative is used to determine the upper and lower limits of the range of control signal which is output variable .The range of the three fuzzy sets are:

N= [-5*10^6, -3, 0]

Z= [-2, 0, 2]

p= [0 3 5*10^-6]

3.5.3 Setting FLC rules

The next stage is rules definition after the membership functions and the linguistic variables of the system have being defined. The total number of rules is the product of the individual number of terms used for each input variable, since each and every combination of stands for a possible input space point. There are 3 linguistic variables for the error and 3 for derivative of error and this will result in 3*3 = 9 rules combination in this fuzzy inference system.

The rule base is formed by assigning the fuzzy relationships between the inputs' fuzzy subsets and the outputs' fuzzy subsets, thus forming the rule-base.

1. IF error P AND error det Z THEN delta u is P

2. IF error Z AND error det NTHEN delta u is N

3. IF error N AND error det Z THEN delta u is N

4. IF error Z AND error det P THEN delta u is P

5. IF error Z AND error det Z THEN delta u is Z

6. IF error P AND error det N THEN delta u is P

7. IF error N AND error det N THEN delta u is N

8. IF error N AND error det P THEN delta u is N

9. IF error P AND error det P THEN delta u is P

After applying rules to the rule editor, then the results is shown in the rule viewer as shown in figure (3-9).

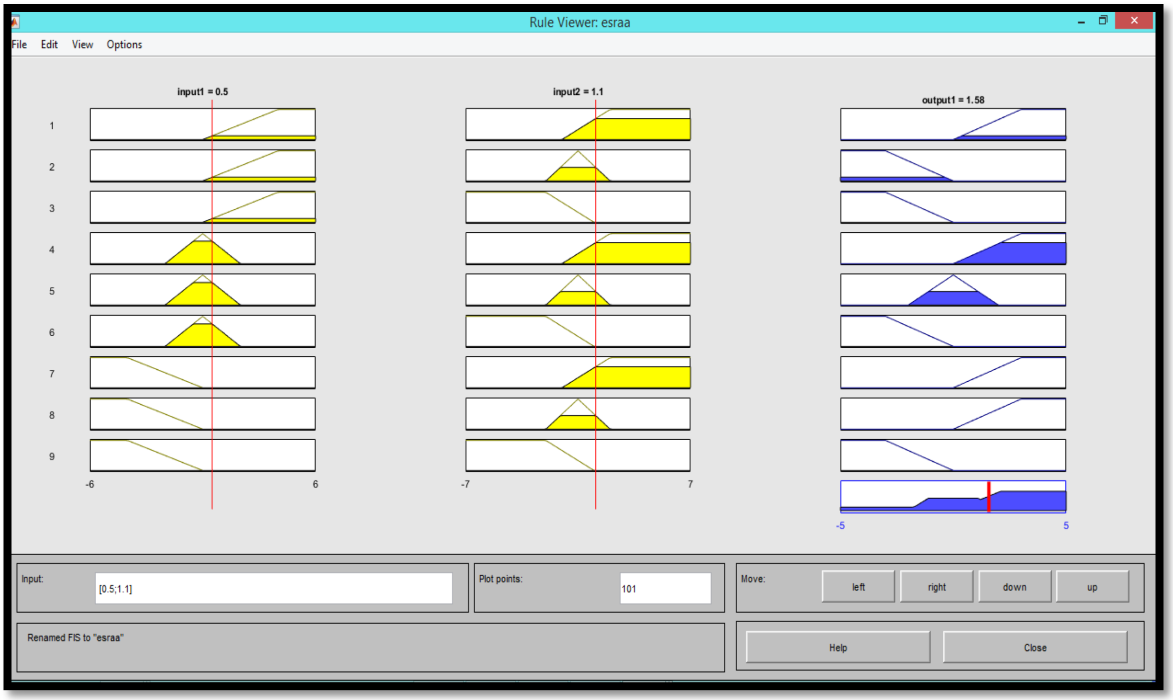

Figure 3-9 the rule viewer of triangular MF

In The rule viewer the output value is given according to the values of the two inputs. There are two ways to select the output either by using pointer or enter the inputs values.

3.5.4 Tuning FLC

To get better response tuning can be accomplish by:

- Changing the range of fuzzy sets.
- Changing the number of fuzzy sets.
- Changing the type membership function.

3.5.4.1 Case 1: Changing the range of fuzzy sets

The first method of tuning is changing the range of the fuzzy sets, in order to get better response.

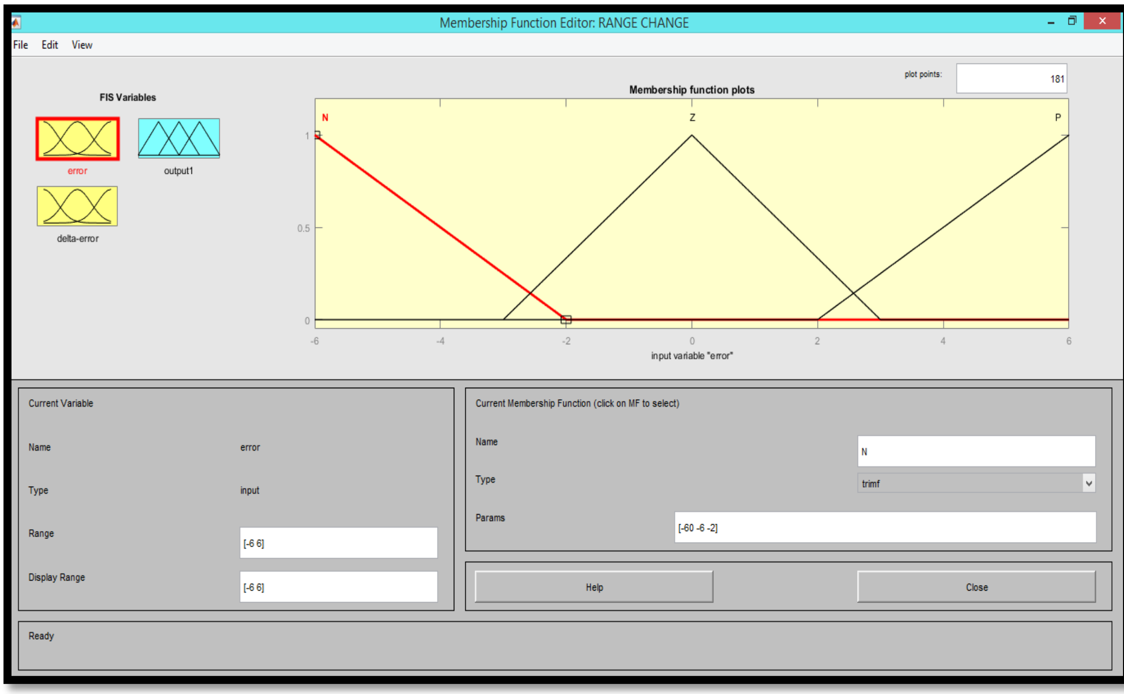

Figure 3-10 first input of the triangular range change of fuzzy sets tuning method

The range of the fuzzy sets of the first input variable (e) has been changed to:

N= [-60, -6, -2]

Z= [-3, 0, 3]

P= [2, 6, 60]

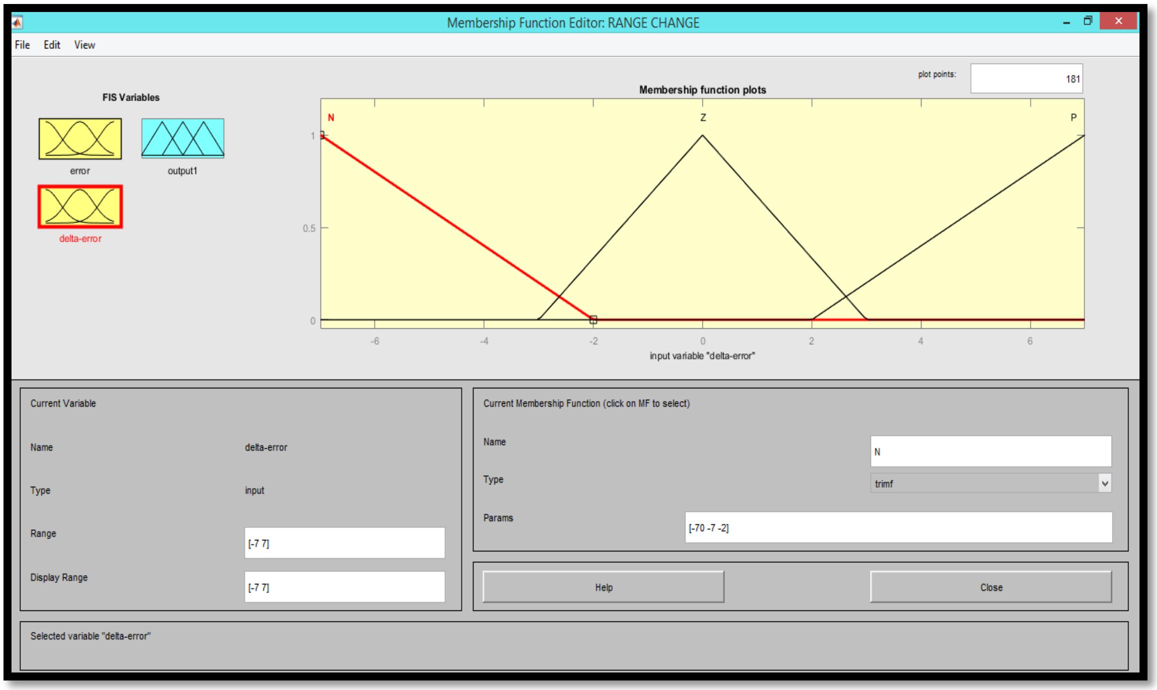

Figure 3-11 the results from changing fuzzy sets range triangular (e)

The range of the fuzzy sets of the second input has been changed to:

N = [-70,-7,-2]   Z= [-3, 0, 3] P= [2, 7, 70]

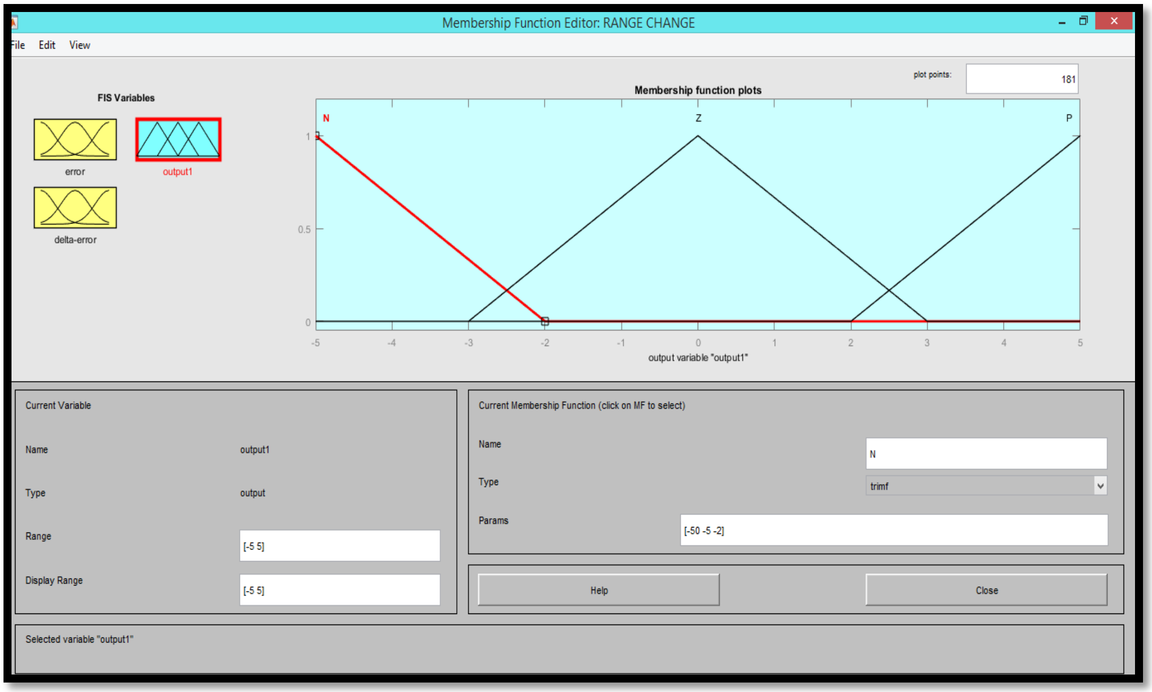

Figure 3-12 the results from changing fuzzy sets range triangular (delta e)

The range of the fuzzy sets of the output has been changed to:

N= [-50, -5, -2]

Z= [-3, 0, 3]

P= [2 5 50]

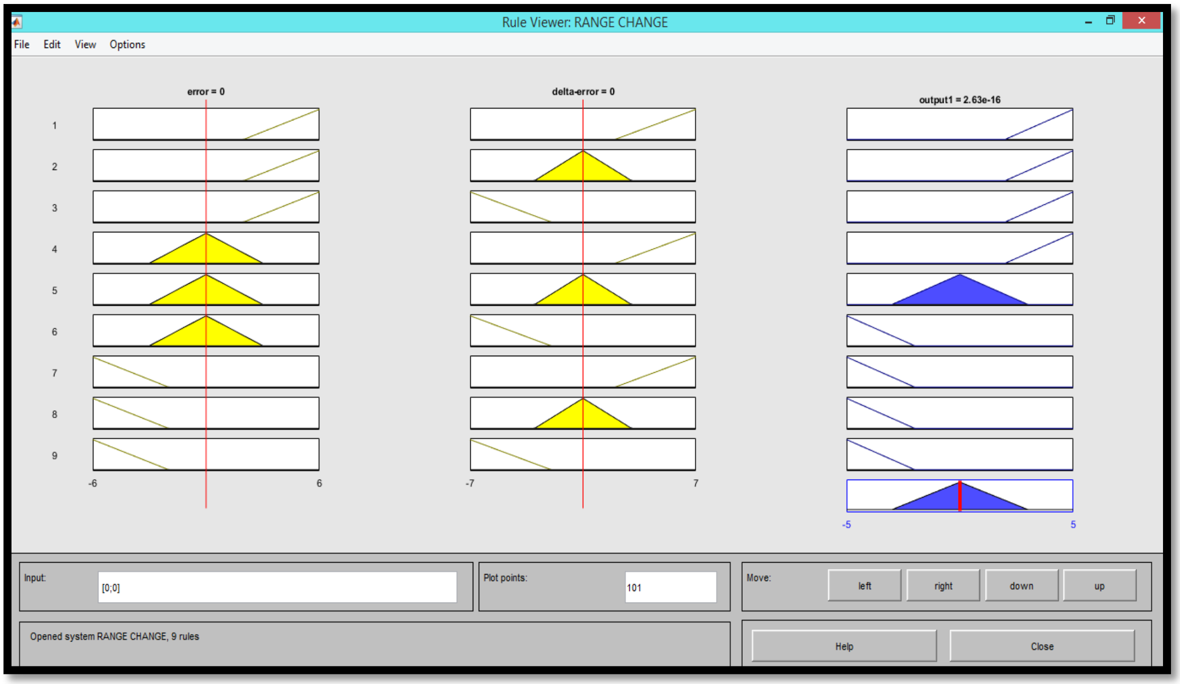

Figure 3-13 the results from changing fuzzy sets range triangular (delta u)

3.5.4.2 Case 2: Changing the number of fuzzy sets

The number of the fuzzy set can be even or odd, but odd is more popular, the fuzzy sets change in order to enhancement the response, in this study the number of fuzzy sets are changed from three sets to five sets labeled as follows:

LN (large negative)

N (negative)

Z (zero)

P (positive)

LP (large positive)

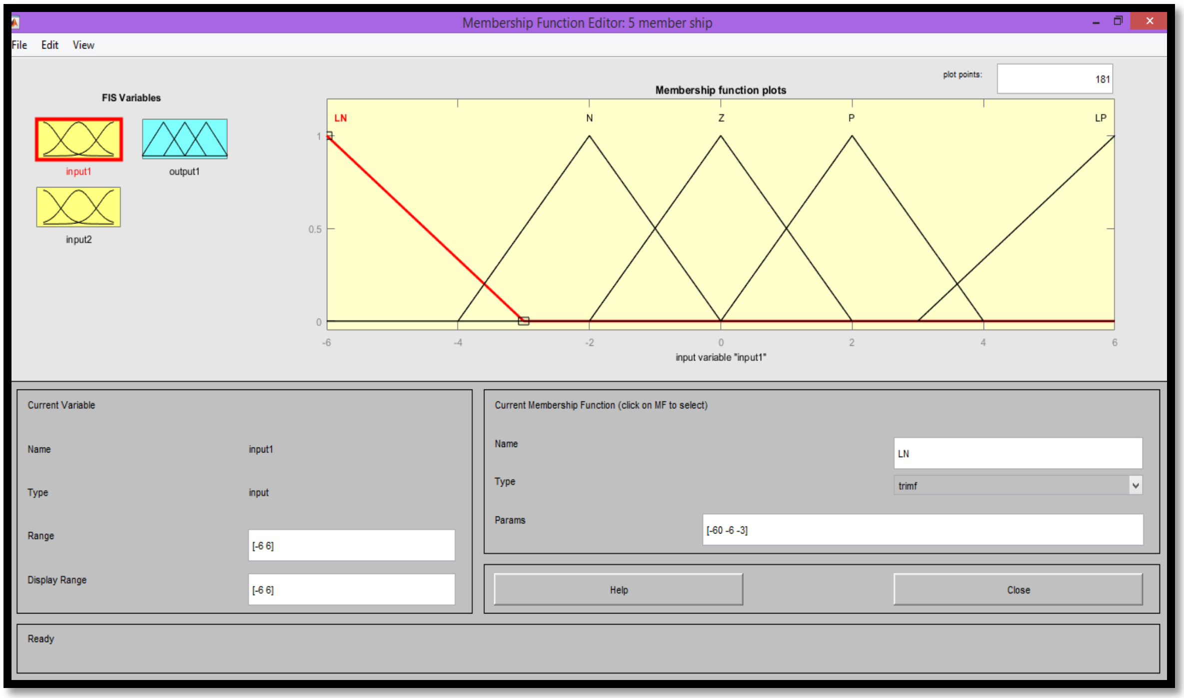

Figure 3-14 first input of the triangularfor five fuzzzy sets

Five fuzzy sets are assigned to each of the three variables. For each of the variables, 5 triangular shapes are spread across the range, the range of the five fuzzy sets are:

LN= [-60, -6, -3]

N= [-4,-2, 0]

Z= [-2, 0, 2]

P= [0, 2, 4]

LP= [3, 6, 60]

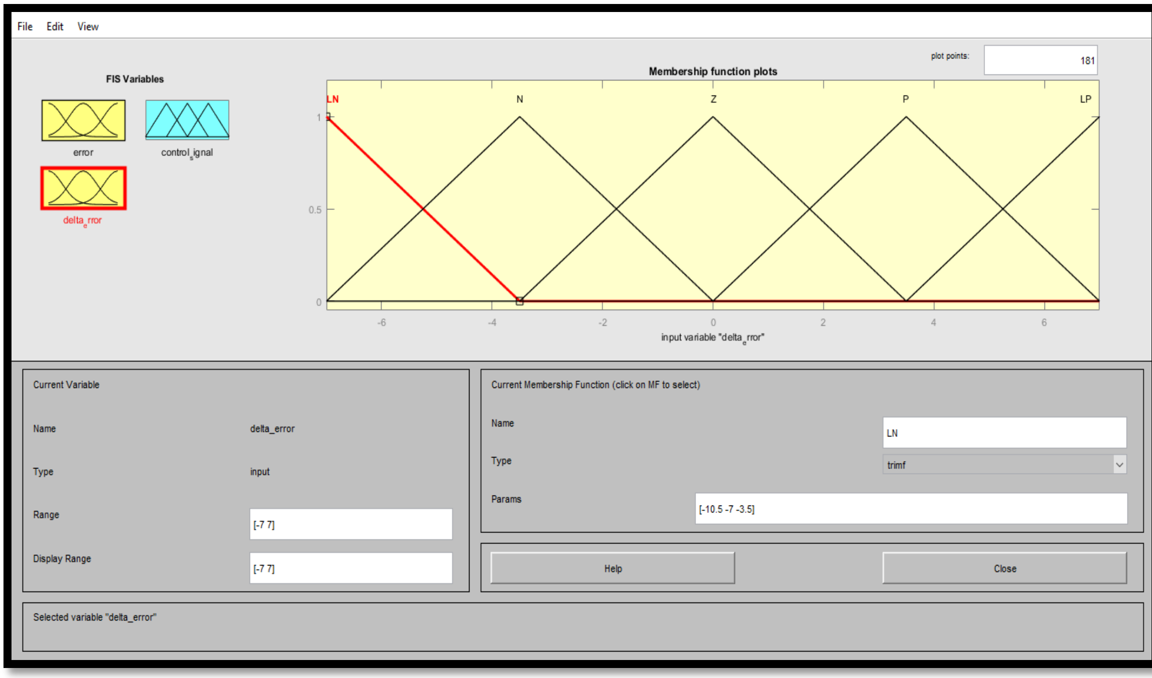

Figure 3-15 second input of the triangular five fuzzy stes

Five fuzzy sets are assigned to each of the three variables. For each of the variables, 5 triangular shapes are spread across the range. The range of the three fuzzy sets:

LN= [-10.5 -7 -3.5]

N= [-7 -3.5 0]

Z= [-3.5 0 3.5]

P= [0 3.5 7]

LP= [3.5 7 10.5]

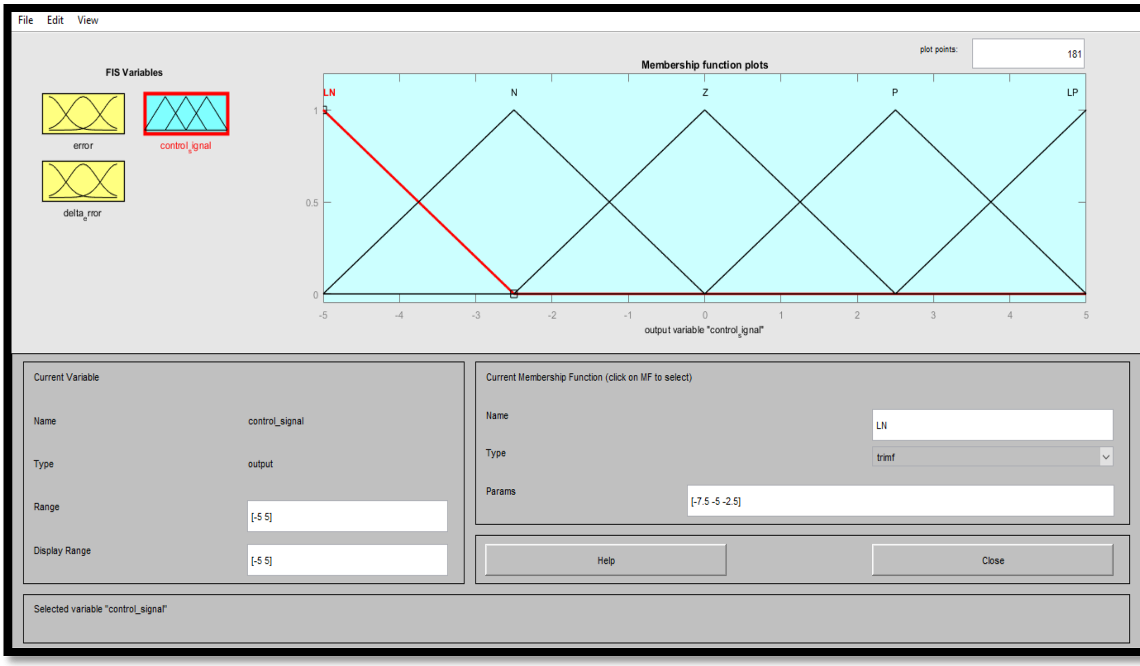

Figure 3-16 the output of the triangular five fuzzy sets tuning method

Five fuzzy sets are assigned to each of the three variables. For each of the variables, 5 triangular shapes are spread across the range .The range of the three fuzzy sets:

LN = [-7.5 -5 -2.5]

N= [-5 -2.5 0]

Z= [-2.5 0 2.5]

P= [0 2.5 5]

LP= [2.5 5 7.5]

- **Inference rules:**

There are five linguistic variables for error and 5 for derivative of error and thus ttoltal number of rules will be 5 × 5 = 25 rules combination in this fuzzy inference system.

IF error is PL AND error-det is PL THEN delta u is PL

IF error is PL AND error-det is P THEN delta u is P

IF error is PL AND error-det is Z THEN delta u is P

IF error is PL AND error-det is N THEN delta u is P

IF error is PL AND error-det is NL THEN delta u is P

IF error is P AND error-det is PL THEN delta u is P

IF error is P AND error-det is P THEN delta u is P

IF error is P AND error-det is Z THEN delta u is P

IF error is P AND error-det is N THEN delta u is N

IF error is PAND error-det is NL THEN delta u is P

IF error is Z AND error-det is PL THEN delta u is P

IF error is Z AND error-det is P THEN delta u is P

IF error is Z AND error-det is Z THEN delta u is Z

IF error is Z AND error-det is N THEN delta u is N

IF error is Z AND error-det is NL THEN delta u is N

IF error is N AND error-det is PL THEN delta u is P

IF error is N AND error-det is P THEN delta u is P

IF error is N AND error-det is Z THEN delta u is N

IF error is N AND error-det is N THEN delta u is N

IF error is N AND error-det is NL THEN delta u is NL

IF error is NL AND error-det is PL THEN delta u is P

IF error is NL AND error-det is P THEN delta u is N

IF error is NL AND error-det is Z THEN delta u is N

IF error is NL AND error-det is N THEN delta u is NL

IF error is NL AND error-det is NL THEN delta u is NL

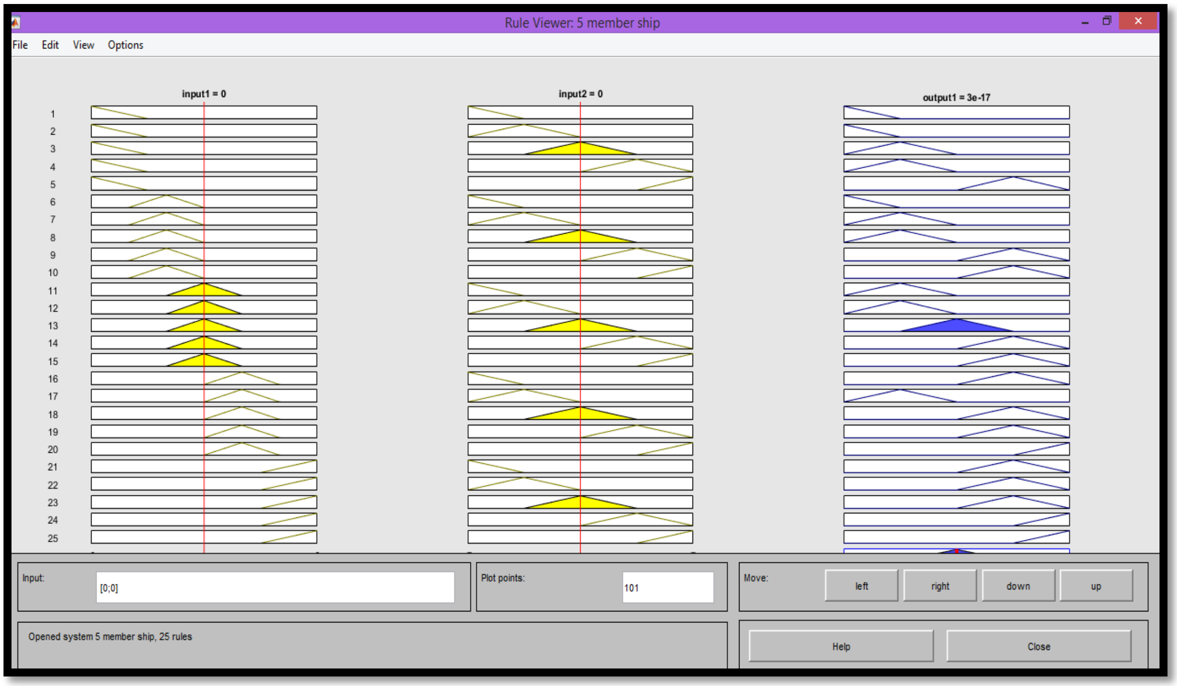

Figure 3-17 the results of the triangular for five fuzzy sets

3.5.4.3 Case 3: Changing the type of membership function

The membership function has been changed from triangular to trapezoidal .The *trapezoidal* membership function, (trapmf), has a flat top, and really is just a truncated triangle

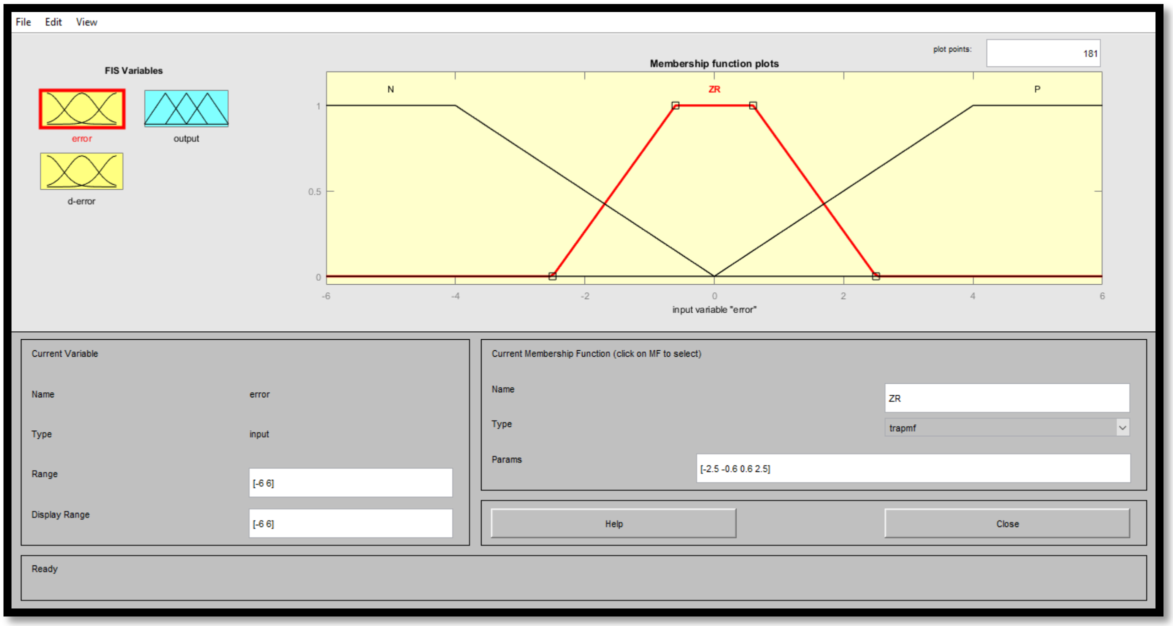

Figure 3-18 first input of the trapezoidal membership function

The membership function is defined by four points. The range of the three fuzzy sets:

N=[-11,-6,-4,0] ,

ZR=[-2.5 ,-0.6 ,0.6, 2.5] ,

P = [0,4,6,11]

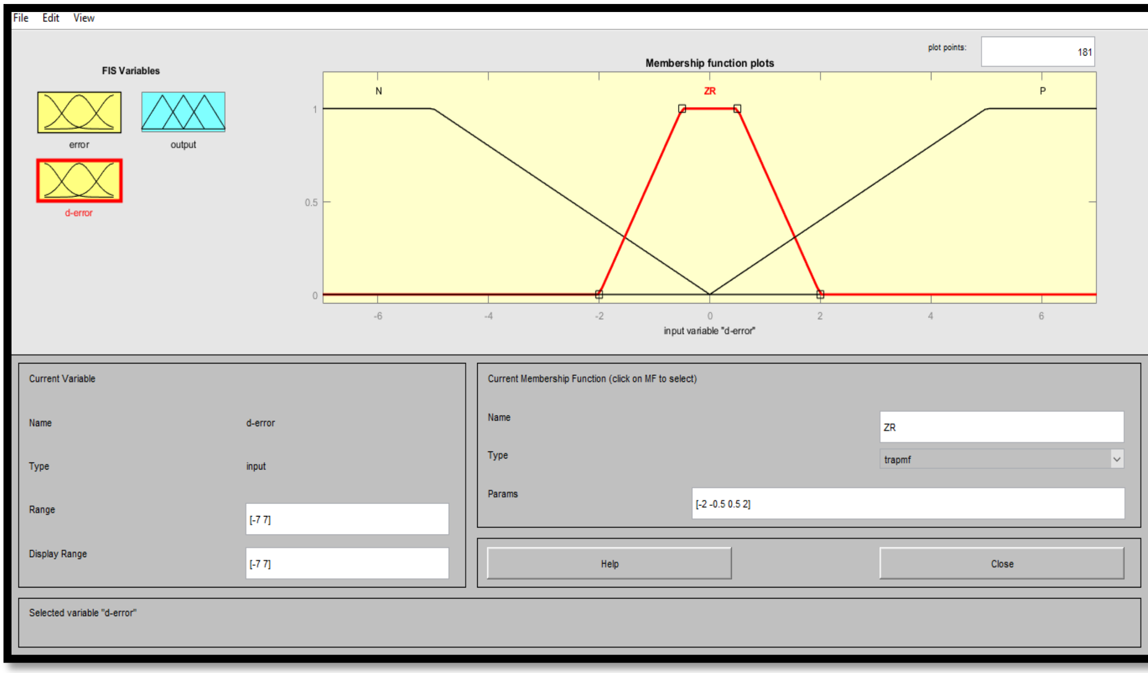

Figure 3-19 secondt input of the trapezoidal membership function

The membership function is defined by four points. The range of the three fuzzy sets are:

N=[-13 , -7 , -5 , 0]

ZR=[-2 , -0.5 , 0.5 ,2]

P = [0 , 5 , 7 , 13]

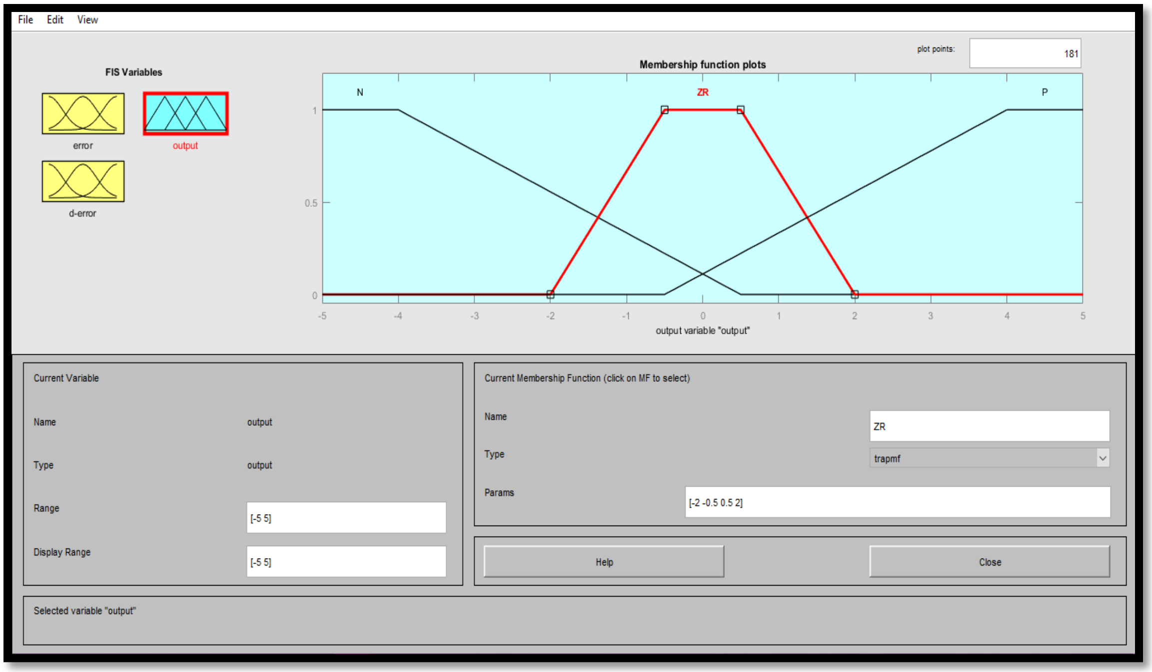

Figure 3-20 the output of the trapezoidal membership function

The membership function is defined by four points. The range of the three fuzzy sets:

N=[-9 , -5 , -4 , 0.5]

ZR = [-2 , -0.5 , 0.5 , 2]

P = [-0.5 , 4 , 5 , 9]

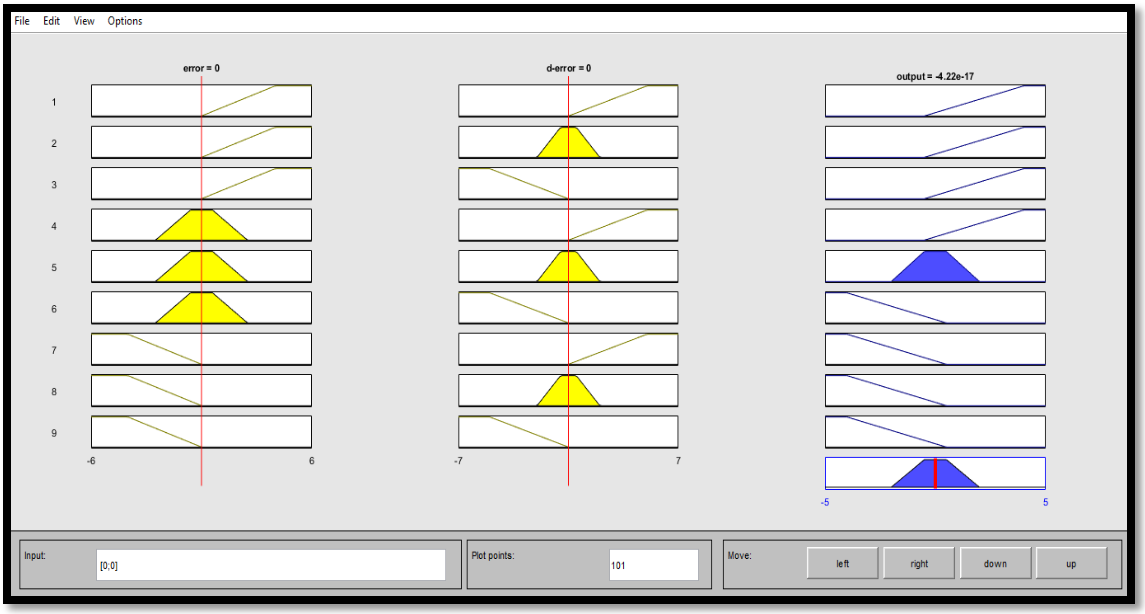

Figure 3-21 the result of the trapezoidal membership function

i. Changing the range of the fuzzy sets of trapezoidal MF:

In part of tuning method in a same way as that of triangular membership function ,the range of each fuzzy set have been changed.

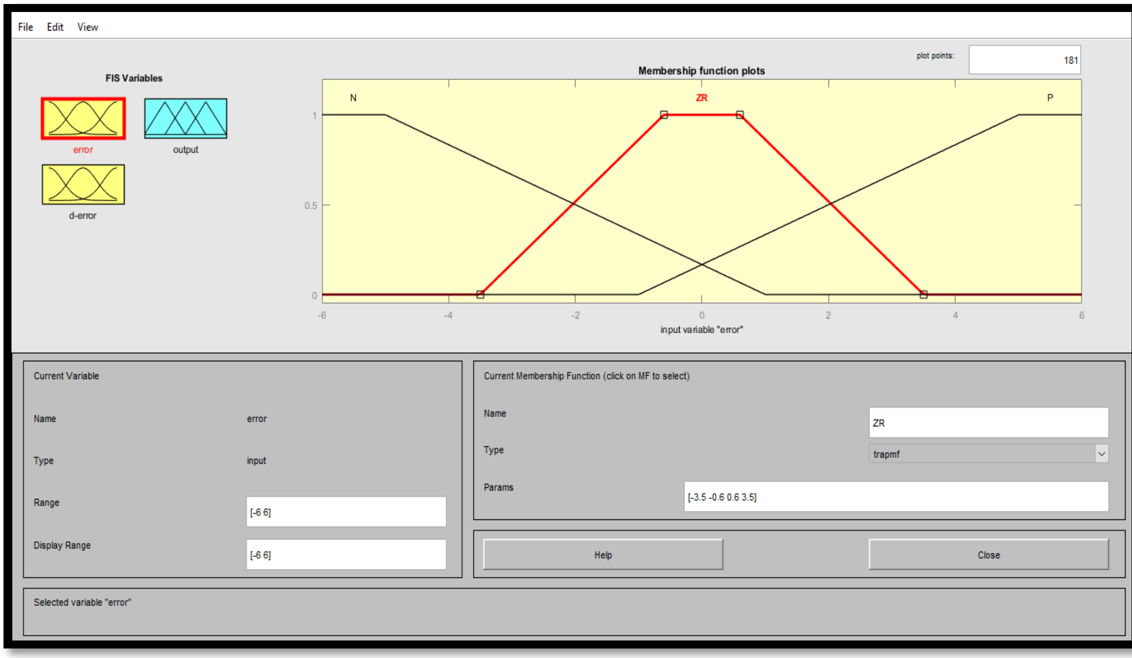

Figure 3-22 first input of the trapezoidal range change of the fuzzy sets

The range of the fuzzy sets of the first input variable (e) has been changed to:

N= [-11,-6,-5, 1], Z= [-3.5, -0.6, 0.6, 3.5] ,P= [-1, 5, 6, 11]

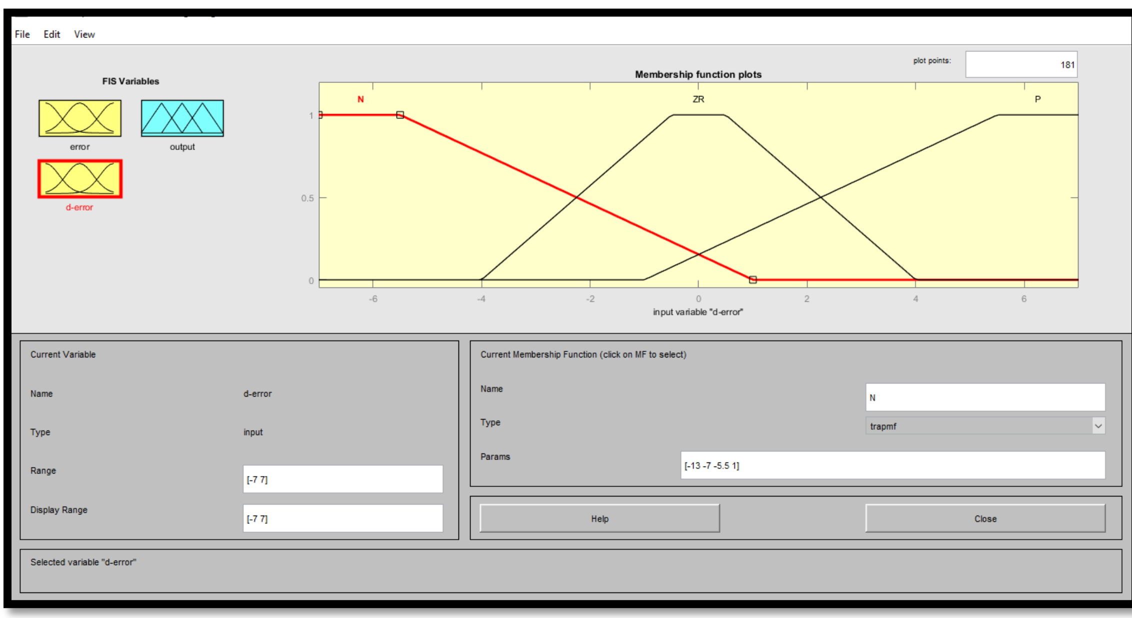

Figure 3-23 second input of the trapezoidal range change of the fuzzy sets

The range of the fuzzy sets of the second input has been changed to:

N = [-13,-7,-5.5, 1]   Z= [-4,-0.5, 0.5, 4] P= [-1, 5.5, 7, 13]

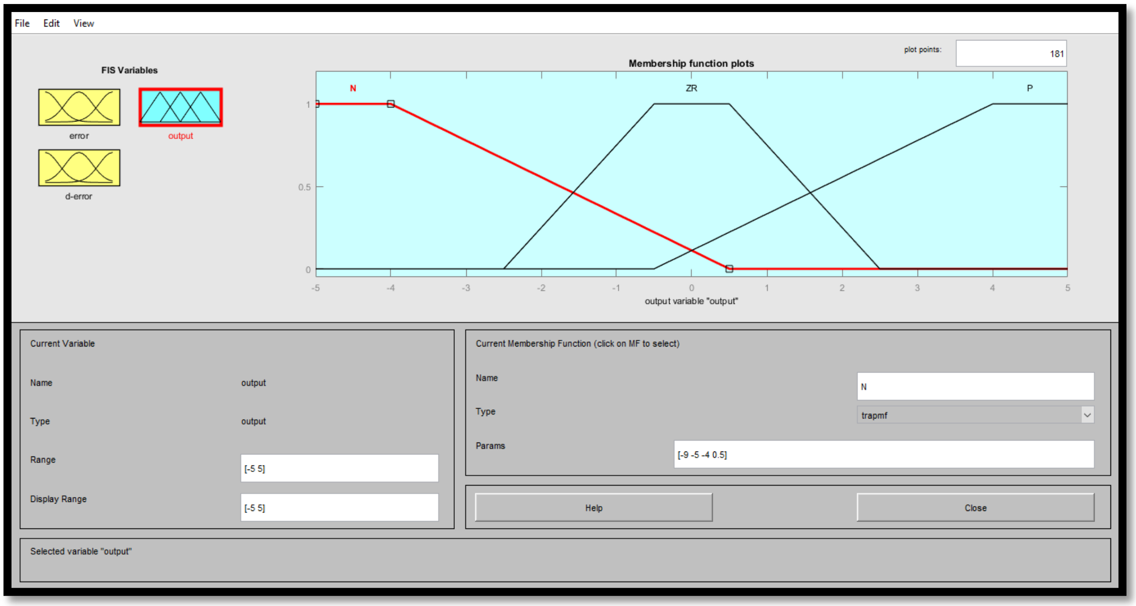

Figure 3-24 23 the output of the trapezoidal range change of the fuzzy sets

The range of the fuzzy sets of the output has been changed to:

N= [-9 , -5 , -4 , 0.5] Z= [-2.5 , -0.5 , 0.5 , 2.5] P=[-0.5 , 4 , 5 , 9]

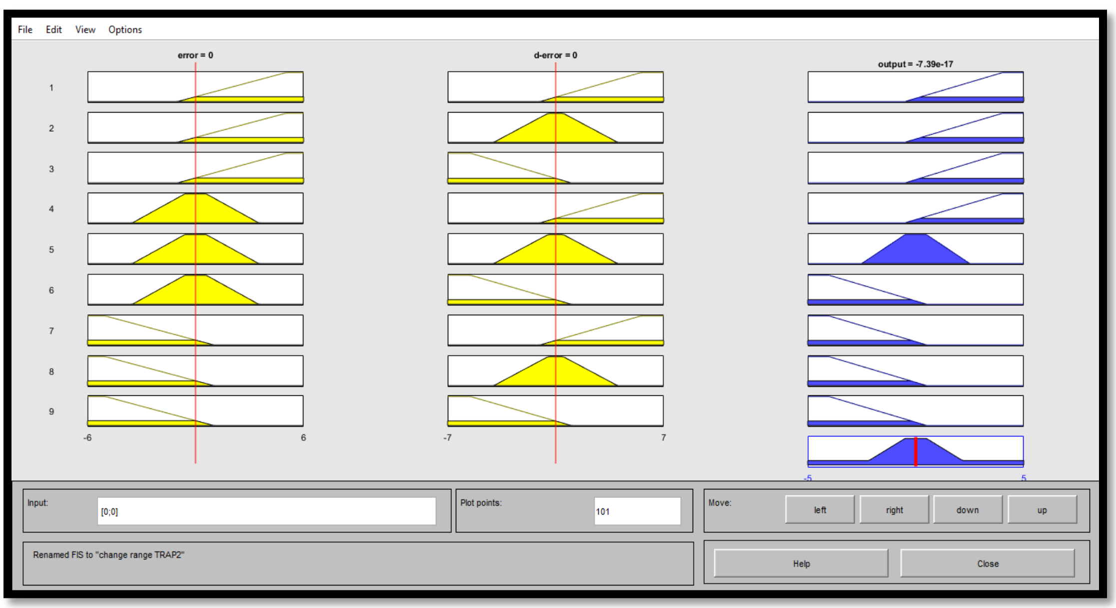

Figure 3-25 the results of the trapezoidal range change of the fuzzy sets

ii. changing the number of fuzzy sets of trapezoidal MF:

The number of fuzzy sets of trapezoidal MF are changed from three to five sets.

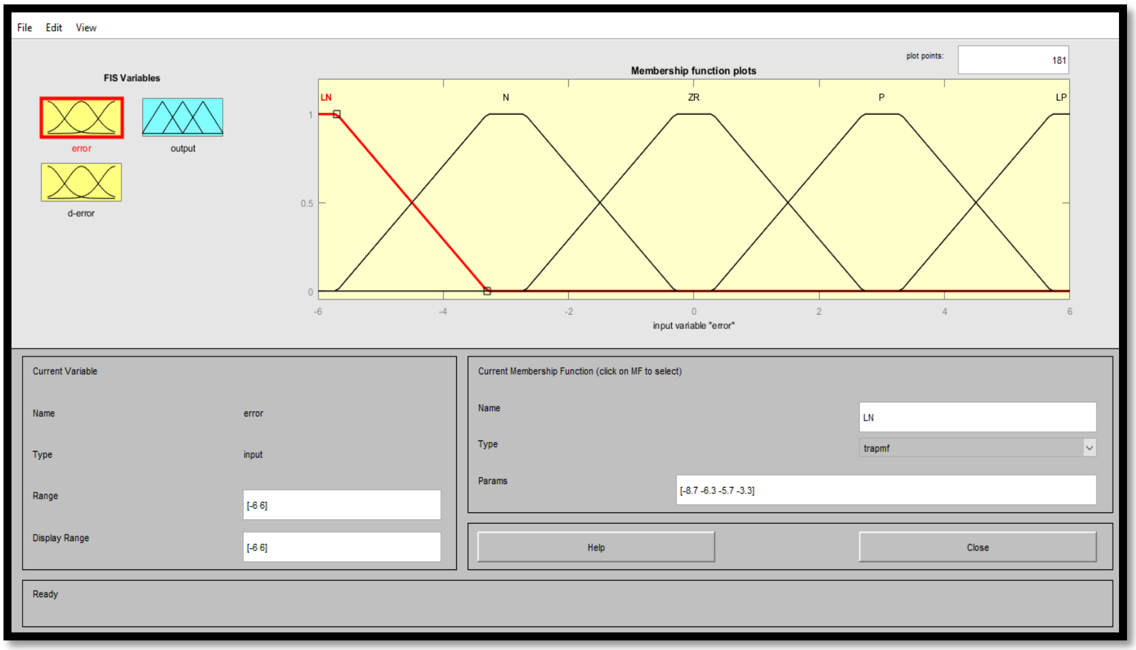

Figure 3-26 first input of the trapezoidal five fuzzy sets

Five fuzzy sets are assigned to each of the three variables. For each of the variables, 5 trapezoidal shapes are spread across the range. The range of the five fuzzy sets are:

LN= [-8.7, -6.3, -5.7, -3.3] N= [-5.7, -3.3, -2.7, -0.3] Z= [-2.7, -0.3, 0.3, 2.7]

P=[0.3,2.7,3.3,5.7]LP=[3.3,5.7,6.3,8.7]

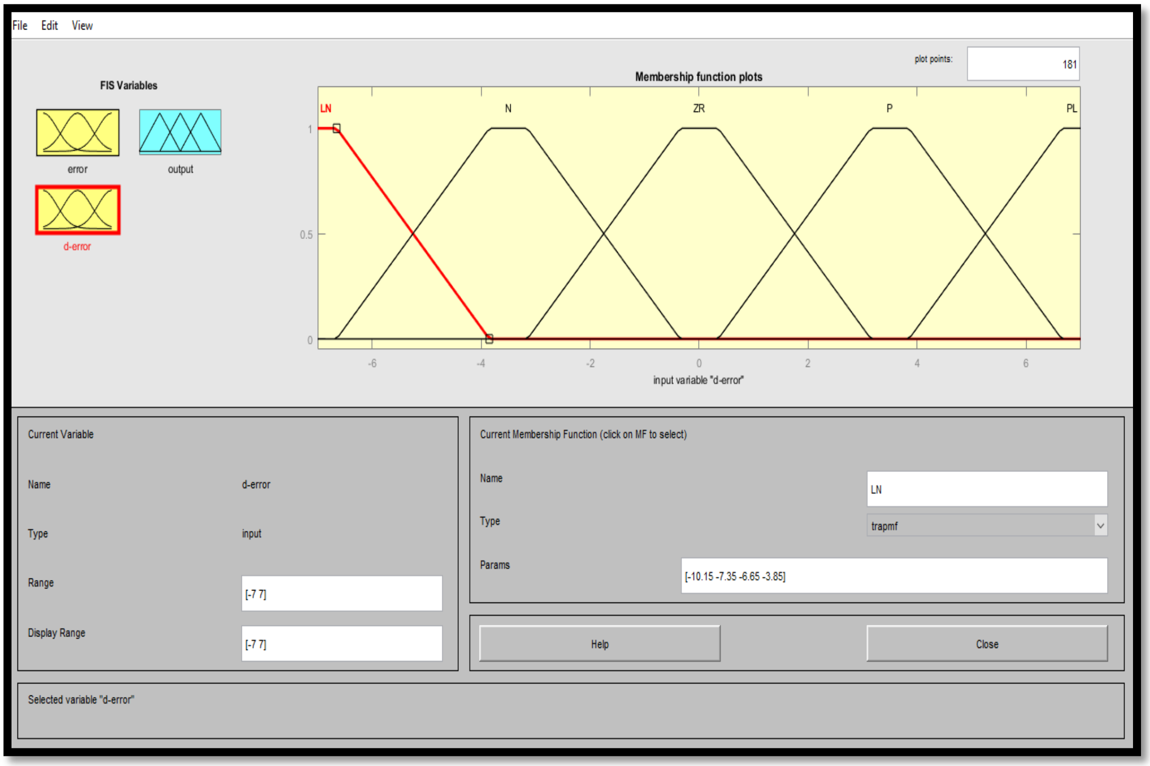

Figure 3-27 second input of the trapezoidal five fuzzy sets

Five fuzzy sets are assigned to each of the three variables. For each of the variables, 5 trapezoidal shapes are spread across the range. The range of the three fuzzy sets:

LN= [-10.15, -7.35, -6.65, -3.85] N= [-6.65, -3.85,-3.15, -0.35] Z= [-3.15, -3.5, 3.5, 3.15] P= [0.35, 3.15, 3.85, 6.65] LP= [3.85, 6.65, 7.35, 10.15]

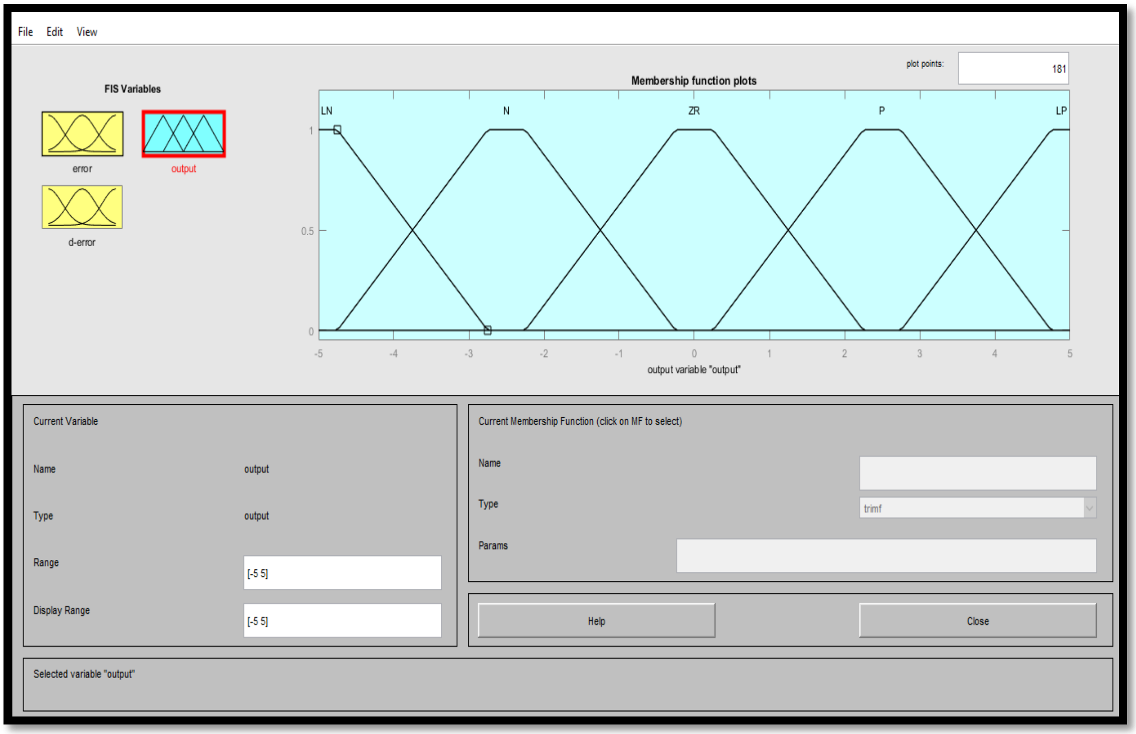

Figure 3-28 the output of the trapezoidal five fuzzy sets

Five fuzzy sets are assigned to each of the three variables. For each of the variables, 5 trapezoidal shapes are spread across the range .The range of the three fuzzy sets are:

LN = [-7.25, -5.25, -4.75, -2.75] N= [-4.75, -2.75, -2.25, -0.25] Z= [-2.25, -0.25, 0.25, 2.25]

P= [0.25, 2.25, 2.75, 4.75] LP= [2.75, 4.75, 5.25, 7.25]

There are total number of twenty five rules to be applied to the trapezoidal rule editor.

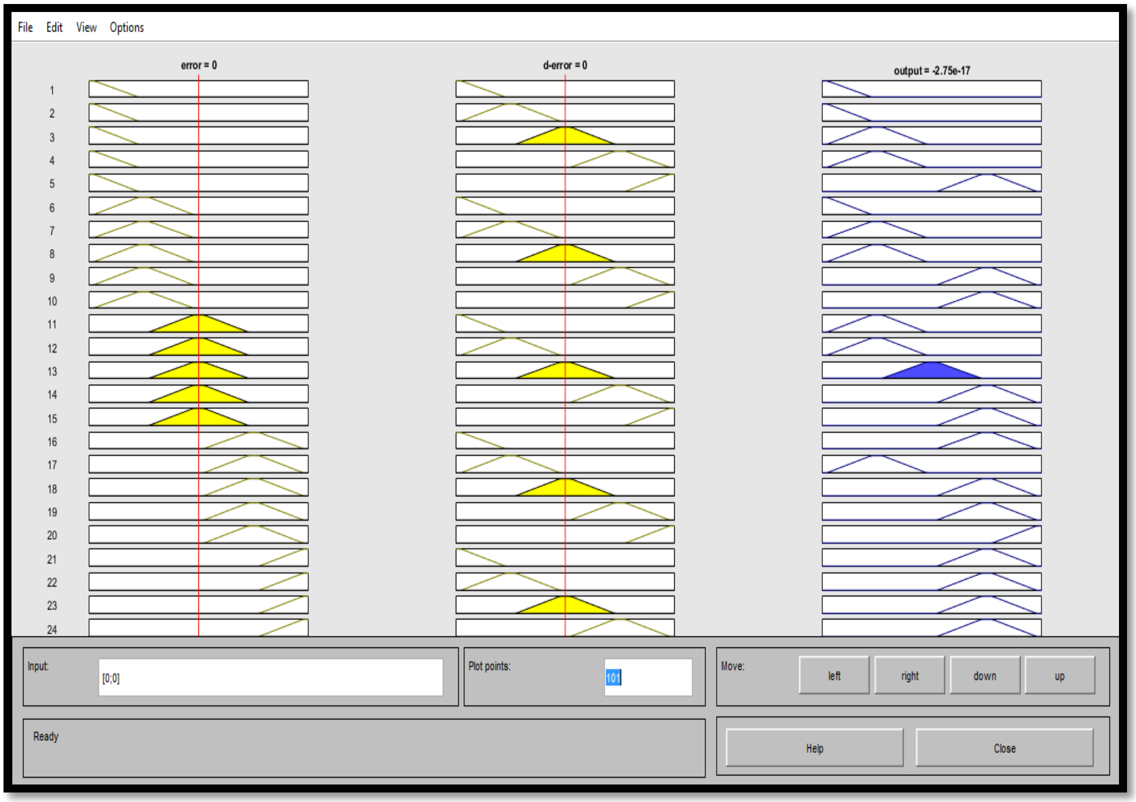

Figure 3-29 the results of the trapezoidal five fuzzy sets

3.6 Summary

In this chapter detailed steps of fuzzy logic controller design and tuning using Matlab FLC toolbox is presented.

4 Chapter 4: Results and Discussion

4.1 Surface viewers

Surface viewer which is a three-dimensional is commonly used represent a relation between two inputs and one output, the rule viewer provide animation showing how rules are fired during different simulation steps. The colures of the view change according to the output values. This is just like a temperature or elevation map that help to visually seen where the output values are low and where they are high.

4.1.1 FLC Simulation output analysis

The following sections will illustrate the results obtained from each tuning step presented in chapter three.

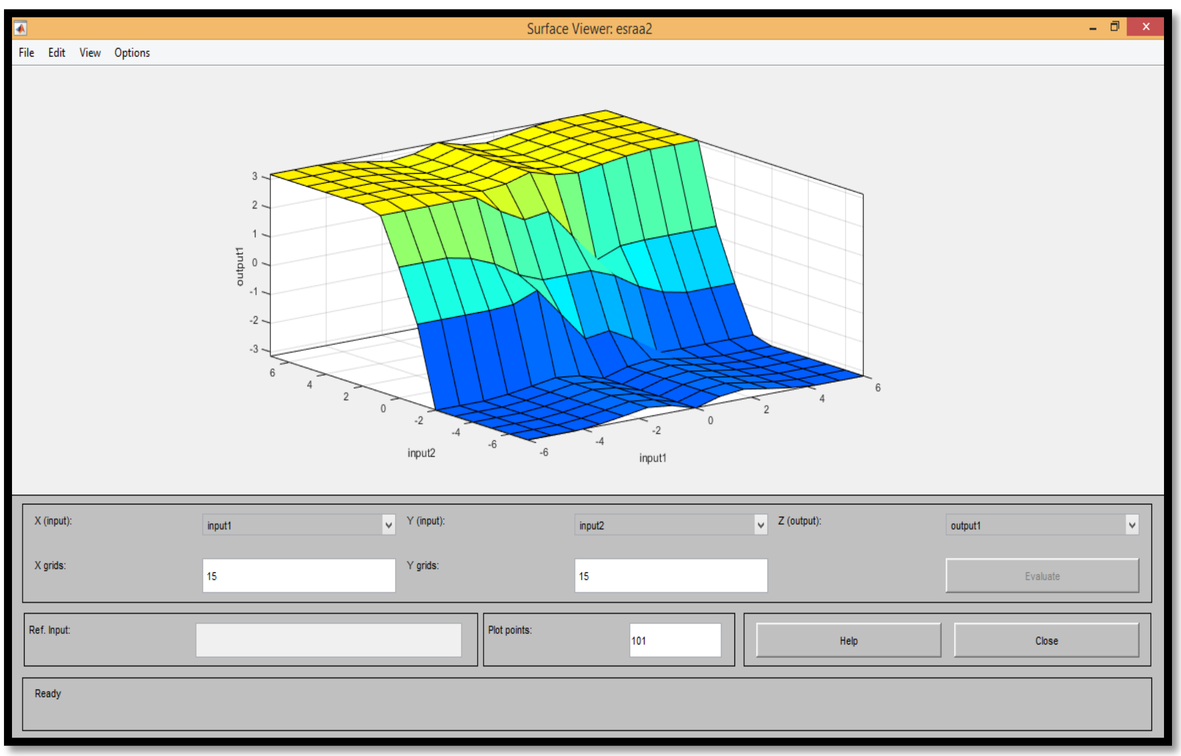

Figure 4-1: surface viewer of three set of triangular membership function.

From The figure (4-1) showing the output many problems with the response has been identified and stated below:

- There is no smooth transition of controller states.

- The output rest at the max value for numerous values of the inputs before it changes.
- The output (Δu) is highly effected by rate of change of error (Δe) than the error (e) and there are many odd values which make the response not smooth, due to previous problems tuning had been done to improve the response.

4.1.2 Result after changing the range of fuzzy sets

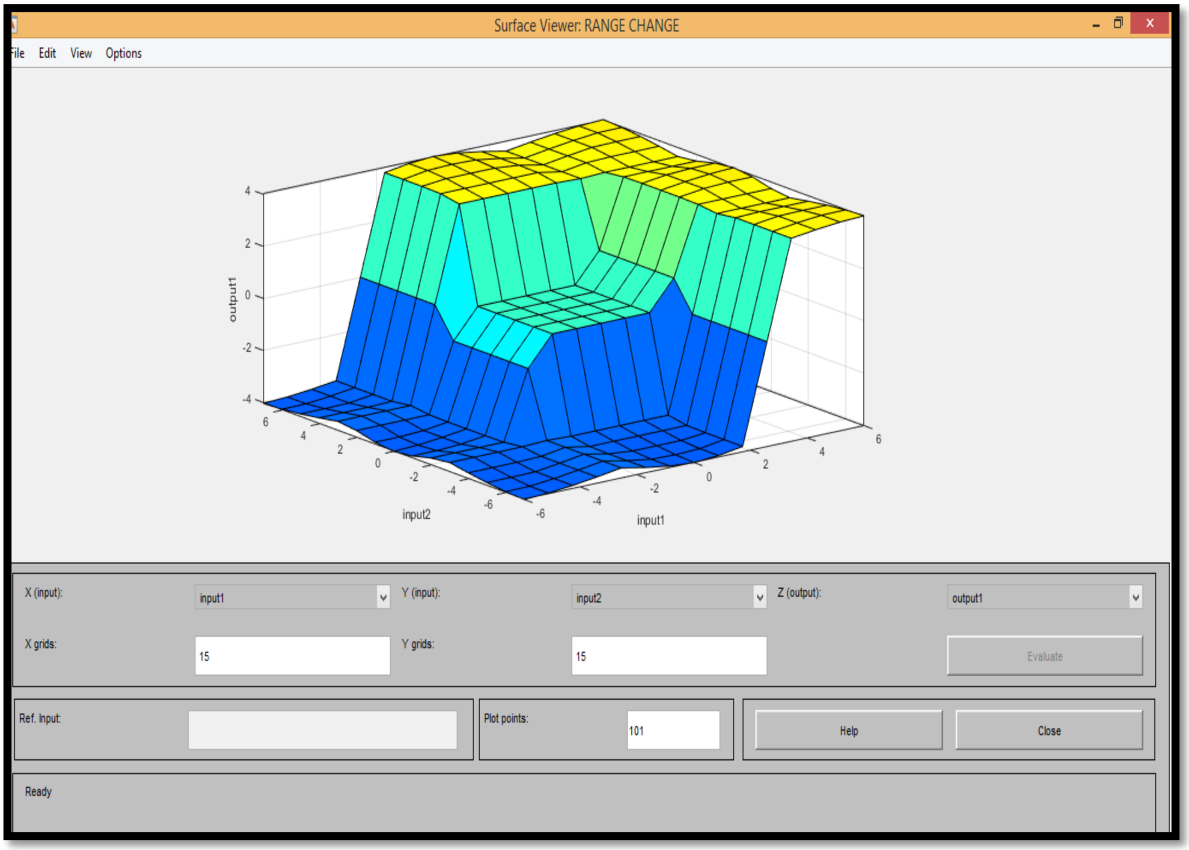

Figure 4-2 range change tuning method of triangular membership function

From Figure (4-3) it's clear the *max output range has been reduced,* that mean any variation in the inputs value effect the output value. Short come of this method is that zero has area in the surface instead of one point i.e. there are values of error and derivative of error (Δe) which has no effect on control signal (small value of error and derivative of error (Δe).

4.1.3 Results after changing the number of fuzzy sets

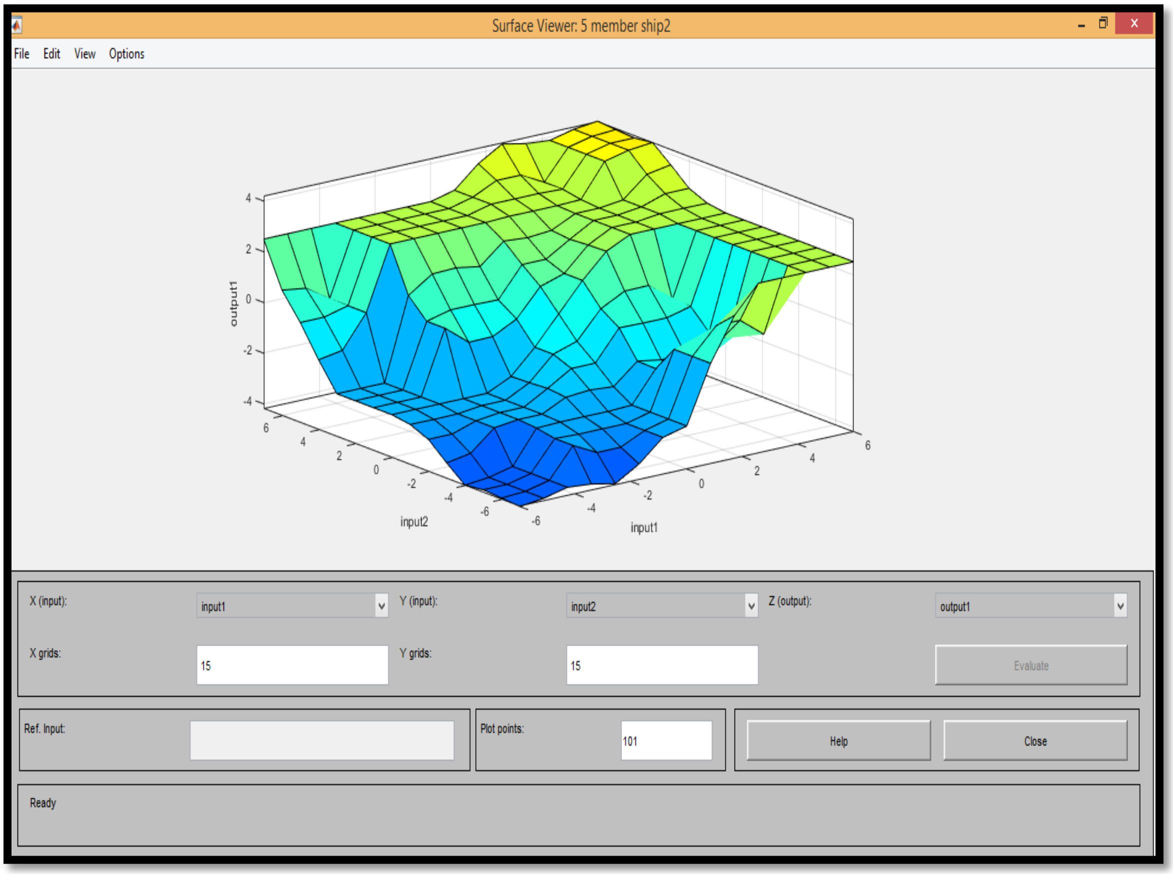

Figure 4-4 number of membership function tuning method of triangular

Changing the number of the fuzzy sets from three sets to five sets results in that: *the response in the max output range has been reduced* and the *problem of zero aera has been removed*. The inputs effect by the output value almost by the same level . finally the odd value has been eliminated.

4.1.4 Results after changing the membership function

i. **Change the membership function from triangular to trapezoidal:**

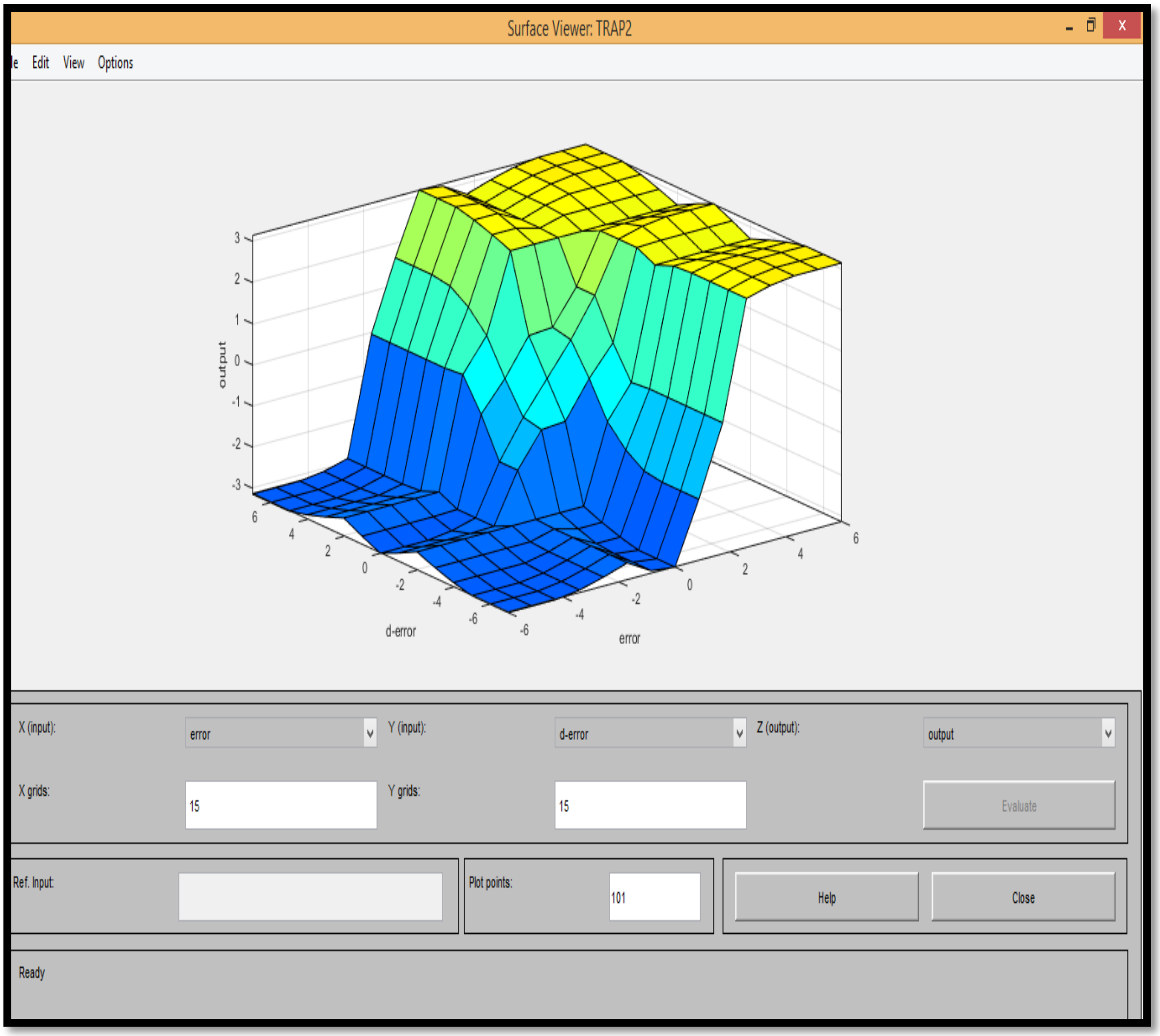

Figure 4-5 change membership function tuning method

In this method the membership function is changed from triangular to trapezoidal, although the top of the shape is still not smooth but there are many advantages of this method which are zero area has been eliminated, the output effected by the inputs approximately in the same level.

ii. **Results after changing the range of the fuzzy sets of trapezoidal MF**

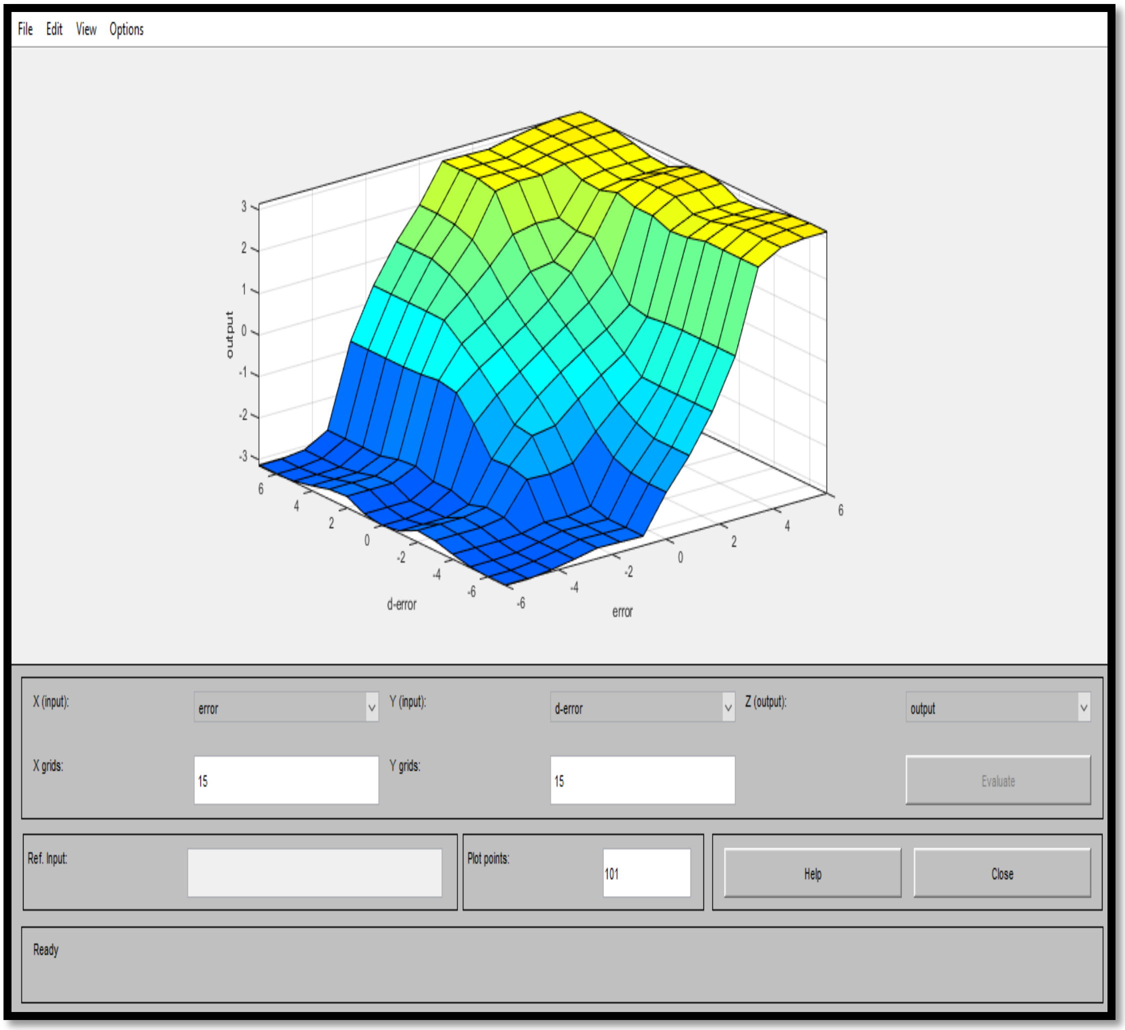

Figure 4-6 change range tuning method of trapezoidal

In this case the range of trapezoidal sets is changed, the response shows that the output affected by both inputs almost at the same level, also the control signal equal zero only when there is no error and derivative of error (both e and $\Delta e = 0$). Finally the odd values have been eliminated.

iii. Results after changing the number of fuzzy sets of trapezoidal MF:

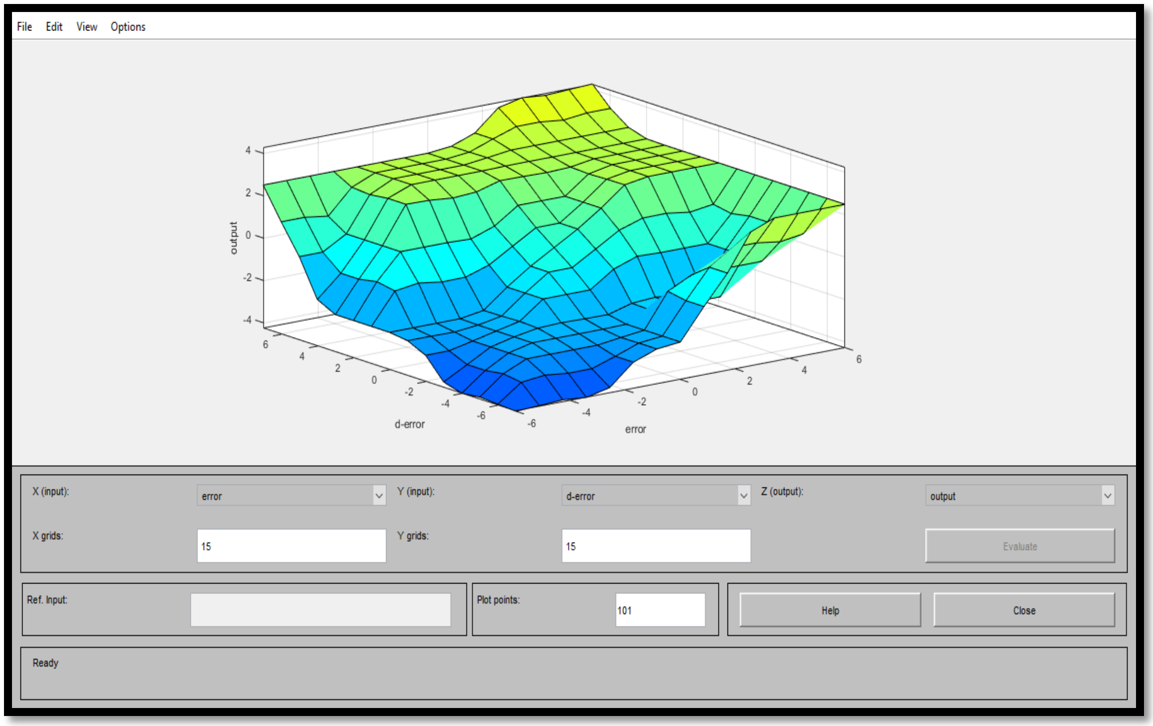

Figure 4-7 change number of set of trapezoidal

After changing the number of the fuzzy sets of the trapezoidal membership function (from three sets to five sets).Figure (4-8) illustrates that, *firstly there is no zero area*, secondly *the error and derivatives of error affected almost in the same way by the control signal (Δu)*, *thirdly* the odd values is eliminated. Lastly, the shape shown that when there is a small change in values of the e and Δe, there is corresponding change in the control signal.

4.2 Summary

From previous sections the results can be summarized as: The changing of the number of fuzzy sets in both triangular and trapezoidal have the best response compared with the other tuning methods, but the trapezoidal has better response than triangular; because when there is a small change in the value of the error and derivative of error ,there is a change in the control signal (Δu).Increasing the number of fuzzy sets improves the response generally by eliminating the problems of other tuning methods.

5 Chapter five: Conclusion and Recommendation

5.1 Conclusion

A study of environmental control system (ECS) has been done; because it is important not only for the comfortable and safety of the passengers and crew but also for the aircraft to perform missions successfully.

Fuzzy logic controller chosen as a type of intelligent controller to be used because it considered as a better choice for complex system s such as ECS than other control techniques.. Fuzzy logic controller (FLC) has been implemented on aircraft air-condition system. Different tuning methods of the controller has been used to improve the output response .tuning methods utilized are : changing the range of the fuzzy sets, changing number of the fuzzy sets and changing the type membership function from triangular to trapezoidal. Detailed discussion of obtained results has been presented for all points regarding the design and simulation steps.

The objectives have been met. The analysis shown that the FLC system has ability to deal with the complexity of environmental control system (ECS) by controlling each subsystem separately, using error and derivative of error method in simple way using Matlab FLC tool box.

5.2 Recommendations

Make a prototype of FLC of aircraft air-condition system.

5.3 Future works

Intelligent control have many feature which enhancement aircraft systems and overcome various problem and limitation, thus:

1. Another intelligent control systems can be applied to aircraft air-condition system, also
2. A combination of multiple intelligent systems can be applied

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