

**DESIGN AND ANALYSIS OF FUZZY LOGIC MODEL FOR THE
CONTROL OF COMPRESSOR MOTOR SPEED OF AN AIR
CONDITIONING SYSTEM**

**A
THESIS**

*Submitted in partial fulfillment of the requirements for the award of degree of
Master of Engineering (M.E.)*

**In
Thermal Engineering**

**Submitted by
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JULY 2014

DECLARATION

I, Vikram Singh Jamwal, hereby declare that work in this thesis entitled as, "*Design and analysis of fuzzy logic model for the control of compressor motor speed of an air conditioning system*", in partial fulfillment of the requirements for the award of degree of Master of Engineering in Mechanical Engineering with specialization in **THERMAL ENGINEERING** submitted in Mechanical Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Dr. Madhup Kumar Mittal.

The matter presented in this thesis has not been submitted for the award of any other degree in this or any other university.

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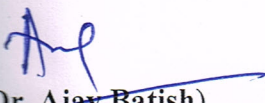
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

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ABSTRACT

Air conditioning is the most important aspect of increasing the thermal comfort and working efficiency of a human being. In an air conditioner, compressor is the component which alone consumes the 90% of the total energy consumption. Fuzzy logic is one of the most important methods for the control in robotics and automation now a day. This report presents the design and results from the analysis of the implementation of fuzzy logic control model on the compressor motor for its speed control. Analysis is done with the help of simulation in Matlab/Simulink. The model is based on a 1.5 ton air conditioner. It uses a 2HP, 3 phase induction motor, a 220V rectified single phase alternate current supply (means alternate current converted into direct current), fuzzy logic controller block, discrete Pulse Width Modulation Block and universal Bridge block. A comparison between the purposed model and the existing model shows that the proposed model is in compliance with them and is supposed to work faster. After comparison with the existing models the model is analyzed for three different target temperatures 20°C, 22 °C and 24°C. The air conditioner is started at the ambient temperature and the energy consumption is calculated till the target temperature is reached for the first time. And this energy consumption is compared with the conventional On/off air conditioner which we use at our homes. The comparison shows that the energy saved is quite significant. The energy consumed by the proposed system for target temperatures of 20°C, 22 °C and 24°C is found to be less by 36.29%, 49% and 41% less than what is consumed by the conventional On/Off air conditioning system

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NOMENCLETURE

e	Difference between T_{tar} and T_{act}
\dot{e}	Error rate change
T	Temperature
μ	Membership grade (≤ 1)
$R_1 R_2 R_3$	Fuzzy Rules
V	Voltage
I	Current
U	Result of Defuzzification of output variable
P	Number of singletons
M	Membership function after accumulation
I	Index
Min	Lower limit for defuzzification
Max	Upper limit for defuzzification
Sup	largest value
Inf	smallest value
B_i	Input signal
β_o	Output signal
θ	Time
k_p	Proportional control action constant
k_n	Integral control action constant
k_d	Derivative control action constant
K_p	proportional gain
K_i	integral gain

K_d	derivative gain
T_i	Integral time
T_d	Derivative time
T_{sh}	superheat
T_{sh0}	set superheat
m	mass flow rate
V	Voltage in Volts
I	Current in amperes
R	Resistance in ohms

CHAPTER 1

INTRODUCTION

An **air conditioning** system is designed to remove heat energy from a space or building to maintain a desired air temperature that would otherwise not be achieved due to heat flows (heat gain) from interior heat sources and the exterior environment. By ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) it is a system that must achieve four objectives simultaneously. These objectives are: control of air temperature; control of air humidity; control of air circulation; and control of air quality. Although the word “control” is often interpreted in different manner, encompassing anything from pin-point control for central computer facilities to ballpark control for residences, the requirement that an air-conditioning system simultaneously modify four properties of air requires reasonably sophisticated systems. An air conditioning system is a fully fledged system in itself which has various parts like.

1.1. Main parts of air conditioner:

1.1.1. A compressor.

1.1.2. A condenser.

1.1.3. An expansion device.

1.1.4. And an evaporator.

Diagram of a basic air conditioner is shown in the Fig 1.1

1.2. Operation of a Conventional On/Off air conditioning system.

When we switch the air conditioner on the thermostat control sends 120V of alternating current to the compressor and the fan motor. The compressor acts as a pump compressing refrigerant in the gas form into the condenser coils located near the back of the unit where the gas is condensed into a hot liquid. The condenser coils dissipate the heat as the liquid travels through them. Once the refrigerant has passed through the condenser coil and the capillary tube it travels through the evaporator

coils located near the front of the unit as the refrigerant liquid enters these coil it expand it to gas which makes the coils cold. The gas flows through the coils to a suction line attached to a compressor the compressor converts the gas back into the liquid and the cooling cycle continues. At the same time the fan motor rotates a blower wheel which draws in air to be cooled by the evaporator coils before recirculating it back into the room. The same motor also operates the condenser fan blade which blows outside air through the condenser coils to cool them. The air temperature is regulated by thermostat control depending on the model the control may be a thermostat switch and sensing bulb assembly or an electronic control board that works with the sensor. The sensing bulb or the electronic sensor is clipped to the front of the evaporator coil to monitor the temp of the air entering the coils. Once the room has sufficiently cooled the thermostat control shuts off the voltage to the compressor.

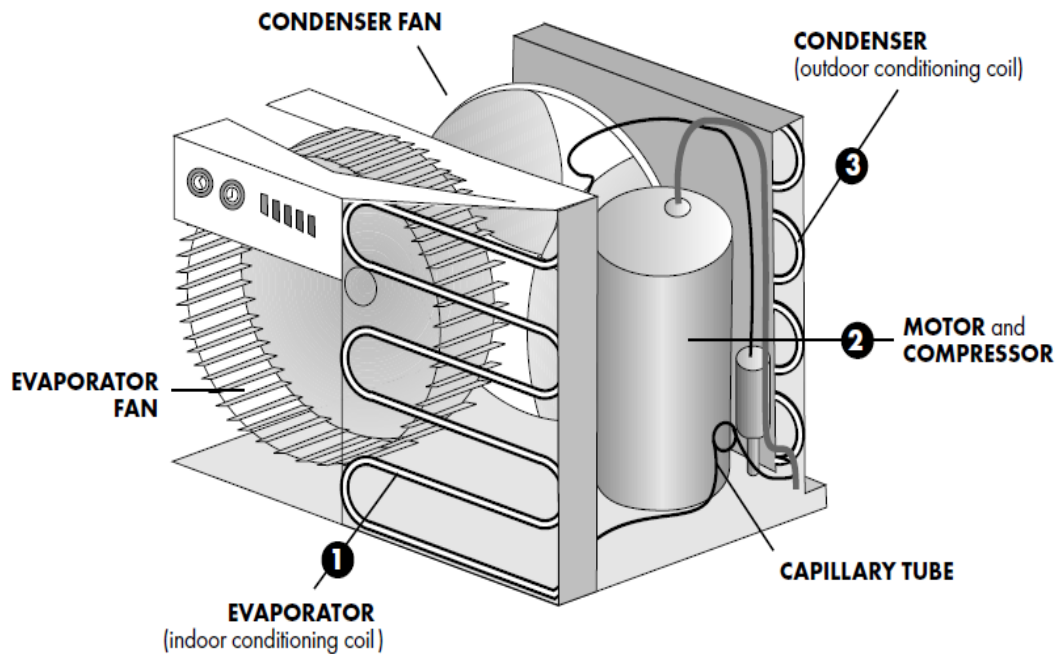


Fig 1.1: Basic diagram of an air conditioner.

1.3. Background

Today air conditioners are commonly found in homes and in closed spaces like offices etc due to the natural demand for thermal comfort. A basic air conditioning system consist of a conventional single speed air conditioning system i.e. all the rotating appliances in it like fans blowers and compressor motor etc run at a constant speed. A variable speed air conditioner is a system that can distribute conditioned air at different temperatures. A system with variable speed control can control the cooling capacity by changing the rotational speed of the compressor according to the requirement of the thermal comfort. It therefore must be aided with a good control scheme to have a good thermal comfort level at any conditions [Nasution et al, 2010]. The energy that is consumed in air conditioning in industrial, commercial and residential buildings constitute nearly 50 % of the world's total energy consumption. Therefore, an air conditioning system is very important to a building in order to keep the occupant comfortable. In modern intelligent buildings, a sophisticated control system should be provided for high energy efficiency and comfort.

The compressor is the most important part of the cooling cycle. The cycle starts when the compressor draws in cool, low-pressure refrigerant gas from the indoors. The compressor's only function is to compress the refrigerant, raising its temperature and pressure so that it exits the compressor as a hot and high-pressure gas [Nasution et al, 2010]. The energy consumed by the compressor accounts around 90% of the total energy consumption of an air conditioning system. It has been shown that 67% of the designers claimed that they intentionally oversized air conditioning design for about 10 to 15% for future extension, renovation and change of usage. Hence, it is natural that the most energy saving comes from the compressor.

Many methods were developed for the control of air conditioning system to increase the energy savings [Mirinejad et al, 2008]. First of all the system which were developed

were switching systems, in these systems the air conditioner used to keep working up to the target temperature and then was switched off. Then with the development of electrical and electronic controls came the era of PID controls. PID means proportional, integral and differential. These were used to make the system reach its target value faster. Then with the advent of fuzzy logic in the field of robotics

The Fuzzy logic was also introduced in the control of air conditioning.

Fuzzy logic has its roots way back in 1930s. It was the time when Lukasiewicz developed multivalued logic systems. This technique basically started in the engineering applications in 1965. And it started through the concept of fuzzy sets. And later in 1968 was used in fuzzy algorithms. [Singh et al, 2006] The concepts of fuzzy logic for dealing with the imprecise and vague data were developed. There were many basic aspects like role of fuzzy feed backs, execution of fuzzy algorithms, execution of fuzzy algorithms by humans, conjunction of fuzzy instructions assessment of goodness of fuzzy algorithm, the implication of compositional rules of inference and interplay between fuzziness and probability in behavior of humanistic systems fuzzy systems are capable of approximating any real function. The use of these kinds of approximators has been found to be of great use as compared to the conventional ones, especially when the information available for approximation is too imprecise or vague. The main advantage of using fuzzy approximator as compared to the conventional approaches is that no mathematical model is needed and its possible to use all available information about the process in design of fuzzy approximator to obtain more accurate results. A fuzzy logic converts a set of linguistic rules, based on expert knowledge, into an automatic approximation strategy. Employing fuzzy IF-THEN rules can model qualitative aspects of human knowledge and reasoning processes without employing precise quantitative analysis. Fuzzy logic applications are ranging from consumer products and industrial systems to biomedicine, decision analysis and recognition technology. [Singh et al. 2006]. It has been found that for the imprecise input data modeling is effectively done with the help of fuzzy logic. Some of the conceptual Knowledge is discussed below.

1.3.1. Concept building

A fuzzy logic system (FLS) can be defined as the nonlinear mapping of an input data set to a scalar output data [Zadeh, 1988]. A FLS consists of four main parts: fuzzifier, rules, inference engine, and defuzzifier. These components and the general architecture of a FLS is shown in Fig 2.

Figure 2: A Fuzzy Logic System. The process of fuzzy logic is explained as : Firstly, a crisp set of input data are gathered and converted to a fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions. This step is known as fuzzification. Afterwards, an inference is made based on a set of rules. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions, in the defuzzification step.

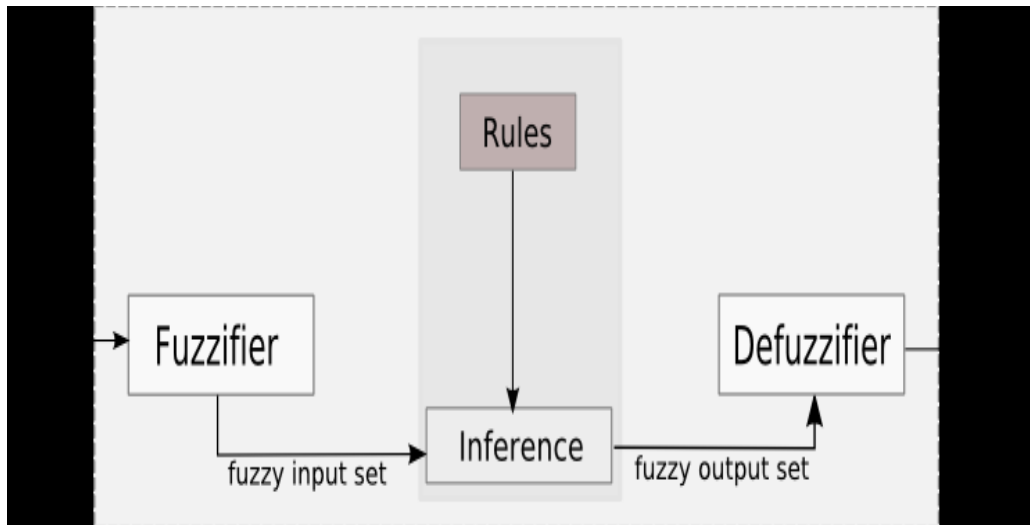


Fig 1.2: A fuzzy logic system

1.3.1.1. Linguistic Variables

Linguistic variables are the input or output variables of the system whose values are words or sentences from a natural language, instead of numerical values. A linguistic variable is generally decomposed into a set of linguistic terms. Example: Consider the air conditioner in Figure 2. Let temperature (t) is the linguistic variable which represents the temperature of a room. To qualify the temperature, terms such as “hot” and “cold” are used in real life. These are the linguistic values of the temperature.

Then, $T(t) = \{\text{too-cold, cold, warm, hot, too-hot}\}$ can be the set of decompositions for the linguistic variable temperature. Each member of this decomposition is called a linguistic term and can cover a portion of the overall values of the temperature.

1.3.1.2. Membership Functions

Membership functions are used in the fuzzification and defuzzification steps of a FLS, to map the non-fuzzy input values to fuzzy linguistic terms and vice versa [Zadeh, 1990]. A membership function is used to quantify a linguistic term. For instance, in the Fig. 3 below, membership functions for the linguistic terms of temperature variable are plotted. Note that, an important characteristic of fuzzy logic is that a numerical value does not have to be fuzzified using only one membership function. In other words, a value can belong to multiple sets at the same time. For example, according to Figure below, a temperature value can be considered as “cold” and “too-cold” at the same time, with different degree of memberships.

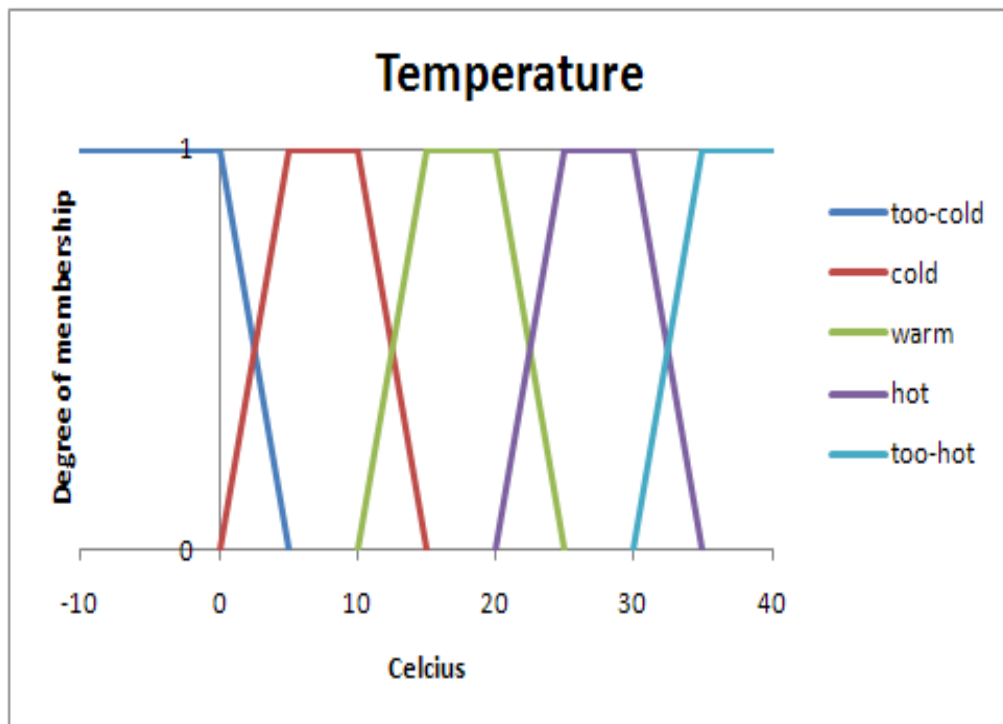


Fig 1.3: Membership function for temperature

There are different forms of membership functions such as triangular, trapezoidal, piecewise linear, Gaussian, or singleton as shown in Fig. 4. The most common types of membership functions are triangular, trapezoidal, and Gaussian shapes.

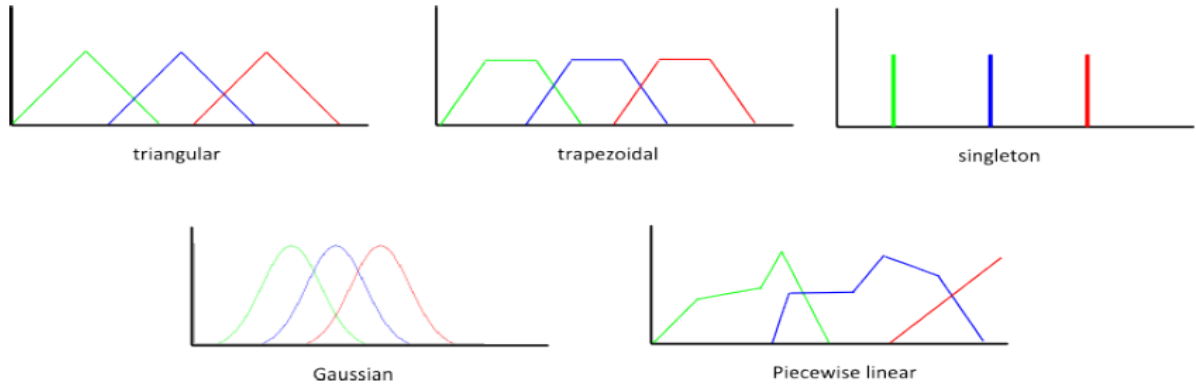


Fig 1.4: Different types of membership functions

1.3.1.3. Fuzzy Rules

In a FLS, a rule base is constructed to control the output variable. A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion. In Table below, sample fuzzy rules for the air conditioner system are listed. Table 2 shows the matrix representation of the fuzzy rules for the said FLS. Row captions in the matrix contain the values that current room temperature can take, column captions contain the values for target temperature, and each cell is the resulting command when the input variables take the values in that row and column. For instance, the cell (3, 4) in the matrix can be read as follows: If temperature is cold and target is warm then command is heat.

	Fuzzy rules
1.	IF (temperature is cold OR too-cold) AND (target is warm) THEN command is heat
2.	IF (temperature is hot OR too-hot) AND (target is warm) THEN command is cool
3.	IF (temperature is warm) AND (target is warm) THEN command is no change

Table 1.1: Sample fuzzy rules for air conditioning system

Temperature/target	Too cold	Cold	Warm	Hot	Too hot
Too cold	No change	Heat	Heat	Heat	Heat
Cold	Cool	No change	Heat	Heat	Heat
Warm	Cool	Cool	No change	Heat	Heat
Hot	Cool	Cool	Cool	No change	Heat
Too Hot	Cool	Cool	Cool	Cool	No change

Table 1.2: Fuzzy matrix table

1.3.1.4. Fuzzy Set Operations

The evaluations of the fuzzy rules and the combination of the results of the individual rules are performed using fuzzy set operations. The operations on fuzzy sets are different than the operations on non-fuzzy sets. Let μ_A and μ_B are the membership functions for fuzzy sets A and B. Table 3 contains possible fuzzy operations for OR and AND operators on these sets, comparatively. The mostly used operations for OR and AND operators are max and min, respectively. For complement (NOT) operation, Eq. 1 is used for fuzzy sets.

$$\mu_{\bar{A}} = 1 - \mu_A$$

OR (union)		AND (intersection)	
MAX	$\text{Max}\{ \mu_A(x), \mu_B(x) \}$	MIN	$\text{Min}\{ \mu_A(x), \mu_B(x) \}$
ASUM	$\mu_A(x) + \mu_B(x) - \mu_A(x) \mu_B(x)$	PROD	$\mu_A(x) \mu_B(x)$
BSUM	$\text{Min}\{1, \mu_A(x) + \mu_B(x)\}$	BDIF	$\text{Max}\{0, \mu_A(x) + \mu_B(x) - 1\}$

Table 1.3: fuzzy set operation

After evaluating the result of each rule, these results should be combined to obtain a final result. This process is called inference. The results of individual rules can be combined in different ways. Table 4 contains possible accumulation methods that are used to combine the results of individual rules. The maximum algorithm is generally used for accumulation.

Operation	Formula
Maximum	$\text{Max}\{ \mu_A(x), \mu_B(x) \}$
Bounded sum	$\text{Min}\{1, \mu_A(x)+ \mu_B(x)\}$
Normalized sum	$\frac{\mu_A(x) + \mu_B(x)}{\text{Max}\{1, \text{Max}\{\mu_A(x'), \mu_B(x')\}\}}$

Table 1.4: Accumulation method

1.3.1.5. Defuzzification

After the inference step, the overall result is a fuzzy value. This result should be defuzzified to obtain a final crisp output. This is the purpose of the defuzzifier component of a FLS. Defuzzification is performed according to the membership function of the output variable. For instance, assume that we have the result in Fig 4 at the end of the inference. In Fig.4 , the shaded areas all belong to the fuzzy result. The purpose is to obtain a crisp value, represented with a dot in the figure, from this fuzzy result.

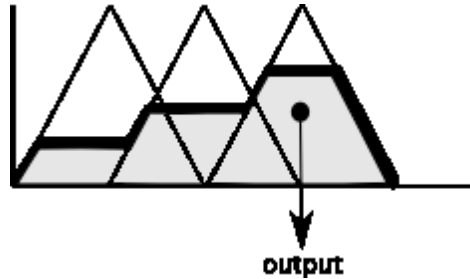


Fig 1.5: Defuzzification step of FLS

There are different algorithms for defuzzification too. The mostly-used algorithms are listed in Table 5. The meanings of the variables used in Table 5 are explained in Table 6.

Operations	Formula
Center of Gravity	$U = \frac{\int_{min}^{max} u\mu(u) du}{\int_{min}^{max} \mu(u) du}$
Center of Gravity for Singletons	$\frac{\sum_{i=1}^p [u_i \mu_i]}{\sum_{i=1}^p [\mu_i]}$
Left Most Maximum	$U = \text{inf}(\acute{u}), \mu(\acute{u}) = \text{sup}(\mu(u))$
Right Most Maximum	$U = \text{sup}(\acute{u}), \mu(\acute{u}) = \text{sup}(\mu(u))$

Table 1.5: Defuzzification formulae

Variables	Meanings
U	Result of defuzzification
U	Output variable
P	Number of singletons
M	Membership function after accumulation
I	Index
Min	Lower limit for defuzzification
Max	Upper limit for defuzzification
Sup	Largest value
Inf	Smallest value

Table 1.6: The variables in table. 5

1.4. Motivation for this study

There are only a few publications presented in the field of energy conservation using variable speed compressor control to air conditioning based on compressor performance and room temperature variation and energy analysis. A lot of papers discussed the adjustable speed fans to control the space temperature and humidity, the supply air flows to control opening of a damper, the refrigerant flow rate as a capacity control to control opening of an expansion valve, indoor temperature control, the simulation of air conditioning and HVAC (heating, ventilating and air conditioning) system and the refrigerant flow control of an evaporator.

so there were some methods for control that were developed. There were conventional control and intelligent control. There were some advantages and anomalies of all the methods developed and even in order to improve the performance efficiencies of the system to which they were applied to, the two or more methods were also combined. Now this research work here studies the effect of using a variable speed three phase induction motor used to control the compressor of the air conditioner, in energy consumption. The compressor speed is controlled using fuzzy logic control (FLC). The emphasis of the study is on energy consumption. The advantage of FLC as compared to other controls is as follows [Nasution et al., 2010]:

- a. The design of the FLC does not require complicated mathematical equations. It requires only a set of basic rules to form the decision table. Basically, all of the rules in the decision table are based on the operator's experience.
- b. Input and output variables can be handled simultaneously.
- c. It is inexpensive to develop. From a practical point of view, the development cost is one of the most important criteria for a successful product. Because FLC is easy to understand, the time necessary to learn the approach is short and the software cost is low. And, as FLC is simple to implement, the hardware cost is also low.
- d. FLC can be blended with conventional control. FLC does not necessarily replace conventional control methods, but can work in conjunction with them. This paper provides a brief summary of the performance of the compressor measure, FLC and its implementations and the experimental FLC system compared with on/off and PID controllers.

1.5. Objective of present work

- i. Design of fuzzy logic model for the control of the compressor motor speed of an air conditioning system.
- ii. To run the model for three different target temperatures i.e. 20°C, 22 °C and 24°C respectively.
- iii. To compare the energy consumption by the proposed system and the conventional on/ off air conditioning system.
- iv. And to show that setting of a higher target temperature saves a considerable amount of energy of energy.

1.6. Organization of thesis

Chapter 1:

This chapter first of all tells the basic working of the conventional On/Off air conditioning system. Then it discusses the historical background about the researchers' findings about the energy consumption by an air conditioning system. Then the development of fuzzy logic in control systems is discussed. Lastly in this chapter some very basic knowledge about the Fuzzy logic is given.

Chapter 2:

This chapter gives the classification review of various types of controlling techniques used over the period of the time of history to control the air conditioning system. It explains the all three classifications namely, traditional control, advanced control and the Intelligent control. As Fuzzy logic falls under the intelligent control, the discussion is focused on the research work on Fuzzy logic.

Chapter 3:

This chapter first of all discusses the design of Fuzzy logic controller. Then the Electrical circuit of the proposed system is designed. The method of simulation is highlighted. The relations used in the energy consumption calculation are also presented.

Chapter 4:

This chapter first discusses the validation of proposed model with the existing models of the researchers. After that the simulation results are discussed. Energy consumption of the proposed model is compared with that of conventional air conditioning system with the help of graphs. Energy savings are also shown.

Chapter 5:

In this chapter the conclusion and the recommendations drawn as a result of the simulation are discussed. Some scope for the future work is also presented.

CHAPTER 2

Literature review

This section is divided basically into three sections; the first section enlightens the traditional methods used to control the air conditioning systems. Second section discusses the use of advanced methods for control of air conditioning system. And the third discusses about the latest intelligent control of the air conditioning systems.

2.1 Techniques used in controlling air conditioning systems

The main aim of all the controlling techniques that have been developed is to maintain thermal comfort and energy efficiency of the occupants. Thermal comfort in itself is a Fuzzy concept which is different for every person. Carrying out of a research work by American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHARE) for the last few years has given out the most important parameters that affect thermal comfort as Temperature, Relative Humidity, Air Velocity and Radiant Temperature. However, thermal comfort is also affected by the clothing insulation and the activity level, but these are not measurable quantities. On one hand, Air Conditioning systems are used for comfort purposes, hence categorized in Comfort System; On the other hand, It's also used at commercial level in storage like in Cold Stores. Surveys have found and established that the consumption of energy by the air conditioning equipments in commercial and industrial buildings constitutes 50% of the world total energy consumption. This is the reason why air conditioning systems also fall under the category of Energy Management Systems (EMS). The Air Conditioning system is a system which is non linear, time variable and is having multiple variables, so it is hard to derive a mathematical model to describe the process accurately over a wide operation range.

The design of controllers for HVAC systems is a big challenge for practical engineers. Many methods of controlling these systems have been found over the period of time like, initially there were traditional controllers then came the advanced controllers and today there is a trend of intelligent controllers. What follows next is the thorough review of the variety of the control methodologies [Harold and Rush,

1988] as used in the area of control of HVAC systems. Such review helps the engineers to know the history of technological development and gives them the chance of taking out something positive out of it

2.1.1. Traditional control

Traditionally the control had been subdivided into two subgroups: On/Off control and PID. The advantage of a traditional controller is that it has a simple structure and is low cost, this is what makes it the first choice of the engineers to use it in HVAC systems. On/Off control gives out only two outputs, maximum (on) or zero (off). The control sensor is used as on/off thermostat; humidistat and pressure switch. On/off control system is very simple in structure and is cheap thus it has less accuracy and quality. Figure 2.1 shows the action of an on/off controller. These are discussed as follows.

2.1.1.1. On/off control:

On/Off control gives out only two outputs, maximum (on) or zero (off). The control sensor is used as on/off thermostat; humidistat and pressure switch and operates in such a manner that when the control variable is below a set point the circuit opens; this is known as direct acting. Operation the other way round i.e. circuit closes when the variable is above set point, is said to be reverse acting, and devices with changeover contacts are common. There is a time gap between circuit closing and opening when no signal change is given. The range, there is no change in control system, is known as the differential. As on/off control system gives only two outputs, cycling is bound to occur as shown in Fig 2.1, and such a system is apt for the high load systems where the time required to reach the target temperature is very long. Well in this case it should be kept in mind that the overshoot is higher than the differential, because of the thermal inertia of the system being controlled. The thermostats used in the room for purpose of heating have a slow response, because of which switching differentials are large. By employing an accelerator like a very high resistance heating element which works only when the thermostat needs heat. This is used to heat the sensing element artificially, thereby causing the heating effect on thermostat. This improves the response time as a result of which the differential is

reduced. There is another aspect of this particular set up. Internal heat to the thermostat is varied by on/off ratio of the thermostat with the increasing heat load of the space, thus altering the conditions of the space of interest. The variation in internal heat generally acceptable, but it does effectively produce a proportional band. There are some special forms of on/off controller that allow multiple stages of plant load variation. These are in the form of multistep thermostats and step controllers. The first ones are obsolete today except for some rare applications, but the second ones are used more often in collaboration with detectors and conventional controllers and solid state versions have now replaced the rotating cam types.

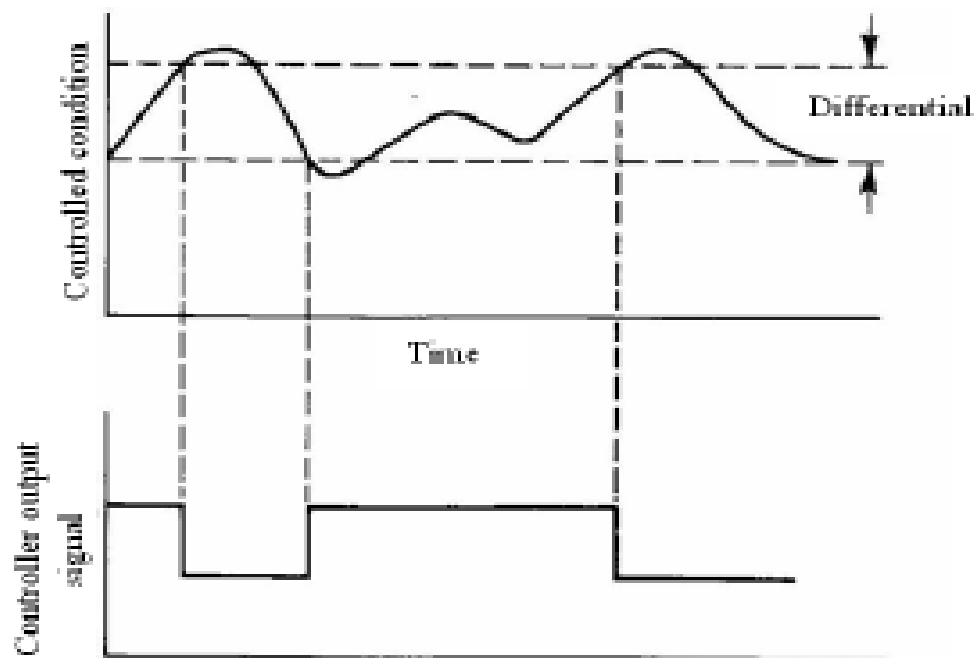


Fig 2.1: Action of an on/off controller

2.1.1.2. Proportional control:

In this type of a control the output signal produced by the controller is proportional to the input signal. The phrase proportional band means the range of input necessary to get a desired range of control output. It may be expressed as a physical quantity (e.g. °C, Pa, % humidity, lux, etc.) or as a percentage controller

scale range. If range of temperature controller is from 20 to 100°C, and the proportional band is set in such a way that in order to change the position of the valve from fully open to fully closed the controlled variable must undergo a change of 100°C, then the proportional band is $100/80 = 1.25$ or 125%. In a case where we want the full valve action to take place for a change of 20°C the proportion band is $20/80 = 0.25$ or 25%. Or we can say that in the second case the proportional band is 20°C Fig. 2.2. shows how the control action of the valve and the proportional band width are related, and states that only one particular position of FCE is reached then only the desired value results as an output by the controller. The above mentioned happens at 50% position of the valve. The figure is shows a heating system. For other load values, which falls under the stable control, certain value of offset will be present because of the proportional band setting and also because of existing load. For a proportional controller the result of output signal is given by:

$$\beta_o = -k_p \beta_i$$

here k_p is an action constant in case of a proportional control (which is equivalent to the inverse of the proportional band), β_i and β_o are the input and output signals respectively.

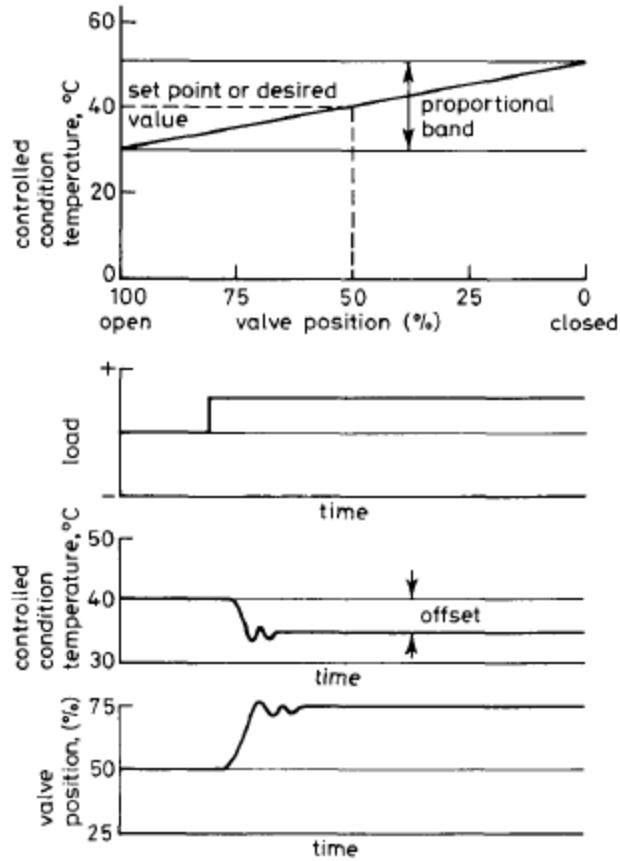


Fig 2.2: Action of a Proportional controller

2.1.1.3. Integral control

There should be a correction quantity which should remain constant when the space of interest in a desired condition, and should change in an accelerating manner which is proportional to the difference from the desired value. For an integral controller, the output signal is given by:

$$\beta_o = k_n \int \beta_i d\theta \tag{2.1}$$

Where k_n action constant for integral controller, and θ is time.

2.1.1.4. Derivative control:

According to this kind of control there should be a correction quantity so that the operation speed is proportional to the rate at which the value of variable of

interest changes. As a result of this action the problem of overshooting is eliminated for the case of quicker load changes. This kind of control is usually applied to special operation systems. For a controller with derivative action, the output signal is given by:

$$\beta_o = -k_d \frac{d\beta_i}{d\theta} \quad 2.2$$

where k_d is the action constant for derivative controller.

2.1.1.5. Combinations of basic modes

There are many combinations available for the existing modes, but besides proportional controller, other combinations that are used are:

- a. Proportional plus integral (P + I) control:

Now this method brings together the stability of a proportional controller and the accuracy of an integral controller which helps to remove the overshoot. Fig. 2.3, shows the characteristics of a P+I control and the output signal is given by:

$$\beta_o = k_p \beta_i - k_n \int \beta_i d\theta \quad 2.3$$

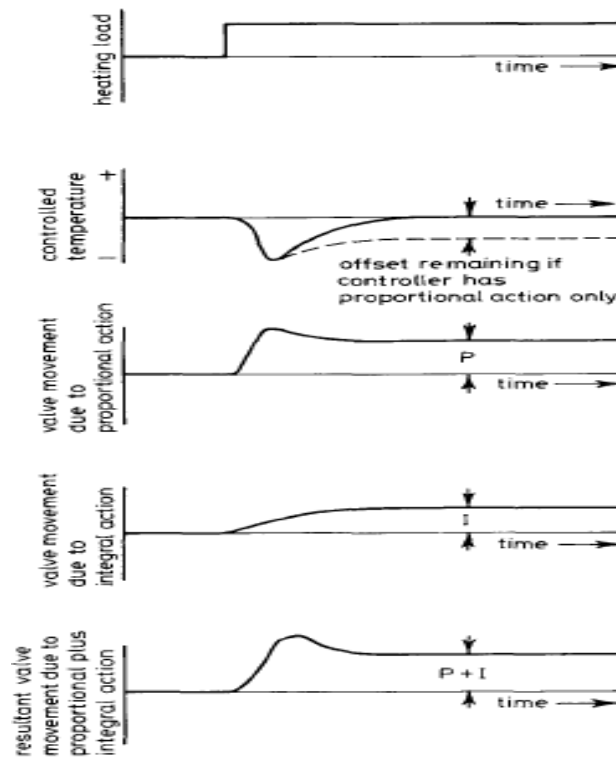


Fig 2.3: Action of proportional plus integral control

b. Proportional plus integral plus derivative (PID) control:

To deal with sudden change of loads and to eliminate the problem of overshooting of the state of the system, a combination of P+I control and derivative control is developed. (See Fig. 2.4). The output signal is given by:

$$\beta_o = -k_y\beta_i - k_n \int \beta_i d\theta - k_d \frac{d\beta_i}{d\theta} \quad 2.4$$

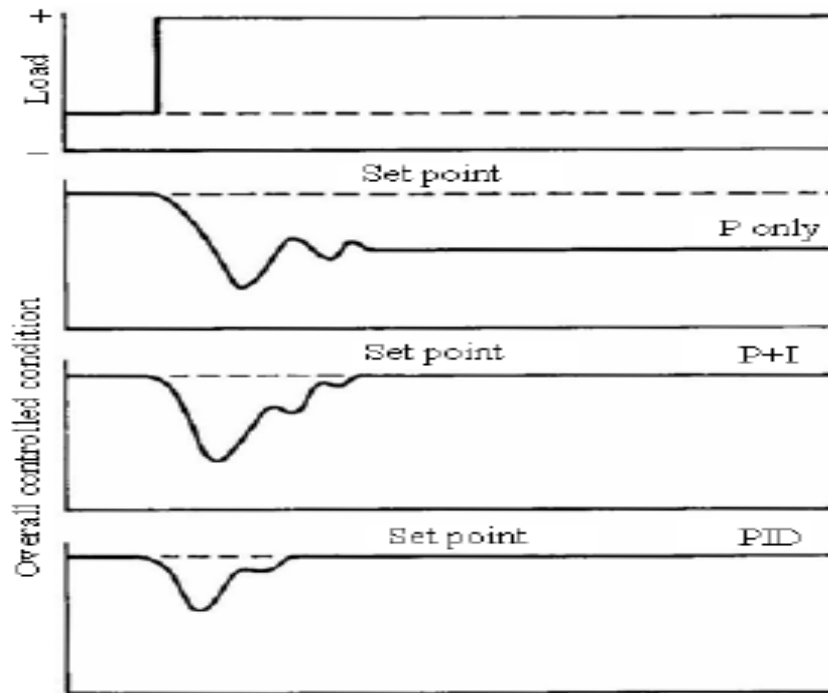


Fig 2.4: Action of a PID controller

Mirinejad et al. (2008), designed and simulated fully automated greenhouse using LABVIEW. This method was an ON/ OFF control. The control system for Greenhouse has following components.

- a. Sensors for acquiring data.
- b. Simultaneous comparison and processing of data in order to reach the desired state.
- c. Suitable action being taken by the components.

Their model main consisted of two subsystems i.e. temperature and humidity control subsystem and irrigation and fertilization subsystem. It was conclude that once the proposed system was designed, standardized and implemented it provides an

automated and accessible means for better and convenient control over the green house management. In order to increase efficiency.

Schumacher et al., (1998) developed a system named “Economizer tx2”.

An algorithm to control and optimize the operation of any full air conditioning plant was described. The function of tx2 is twofold:

- (1) It determined the state of the room air within a predefined comfort field, and
- (2) It controlled the operating point of the energy recovery by using algorithm in.

They used PID control. The aim of these independent actions is to minimize the overall energy input which was used to condition the supply air. They concluded that this model gives better energy savings than the convention system but can't be claimed perfect because of inadequate process information.

Though, traditional controllers functioned in an acceptable manner, but due to the low efficiency and the high maintenance, they were expensive to be used. Therefore, advanced controllers replaced them which produced more thermal comfort and used lower energy consumption.

2.1.2. Advanced control

Advanced controls are classified into three subgroups i.e. Auto-tuning PID, modern non linear controllers and optimal controllers. The tuning of a PID controller is an important aspect and its time consuming, expensive and a difficult work. Auto tuning saves a lot of time, effort and expenses [Pinella et al 1986].

2.1.2.1. Auto-tuning PID

Mirinejad et al. (2008) has discussed about PID auto tuning. PID auto-tuning means automatic determination of PID parameters by the controller all by itself. Generally, auto-tuning PID controllers make use of two types of algorithms:

- a. Model-based algorithms in which the parameters of the PID controller are related to the parameters of a transfer function model of the plant;

b. Empirical rule-based algorithms in which the parameters of the PID controller are determined by a set of heuristic rules.

Although Self-Tuning Control (STC) can offer many advantages and are normally superior to the PID control, this approach is limited to large range applications because model identification is required as initial step, together with model parameter identification in real time mode. Since air conditioning is a complicated process and air-conditioned space is subject to disturbance, the model may not be well identified.

2.1.2.2. Non linear controller

Since HVAC system is essentially a nonlinear system, a number of Nonlinear Controllers are designed and utilized in HVAC systems since the 80's. Some of these controllers made use of direct nonlinear control methods, as for example Serrano and Reyes (1999) who presented a nonlinear disturbance rejection state feedback controller for an HVAC system. They showed that the disturbance rejection controller is capable of reducing the effect of thermal loads (disturbances) on the thermal space and hence being more effective in keeping comfort conditions. Others convert a nonlinear HVAC model to a linear model via an algebraic transformation. Semsar *et al.*(2003), employed the feedback linearization and Back-Stepping methods for the control and disturbance decoupling in HVAC systems.

2.1.2.3. Optimal controllers

As stated earlier, two primary goals in the control of HVAC systems are occupants' comfort and energy efficiency. In most cases, the achievement of one of these goals requires that the other be sacrificed to a certain extent. If the relative importance of the two goals can be established, optimal control can be used to determine the minimum operating cost for the system to achieve the desired comfort level [House et al., 1995]. Optimal control of single-zone building and HVAC systems has been studied extensively. In comparison to conventional control strategies, optimal control has been demonstrated to have the potential for energy savings of 12-30% [Nizet et al., 1984].

2.1.3. Intelligent control

This category of controllers includes Neural Network based and Fuzzy Logic based Controllers.

2.1.3.1. Fuzzy logic based controllers

Since the HVAC systems are MIMO, nonlinear and time-varying systems, Intelligent Controllers seem to be the most proper choices for the control of these systems. Moreover, since the human sensation of thermal comfort is vague and subjective, fuzzy logic theory is well adapted to describe it linguistically depending on the state of the thermal comfort dependent variables [Hamdi et al, 1998].

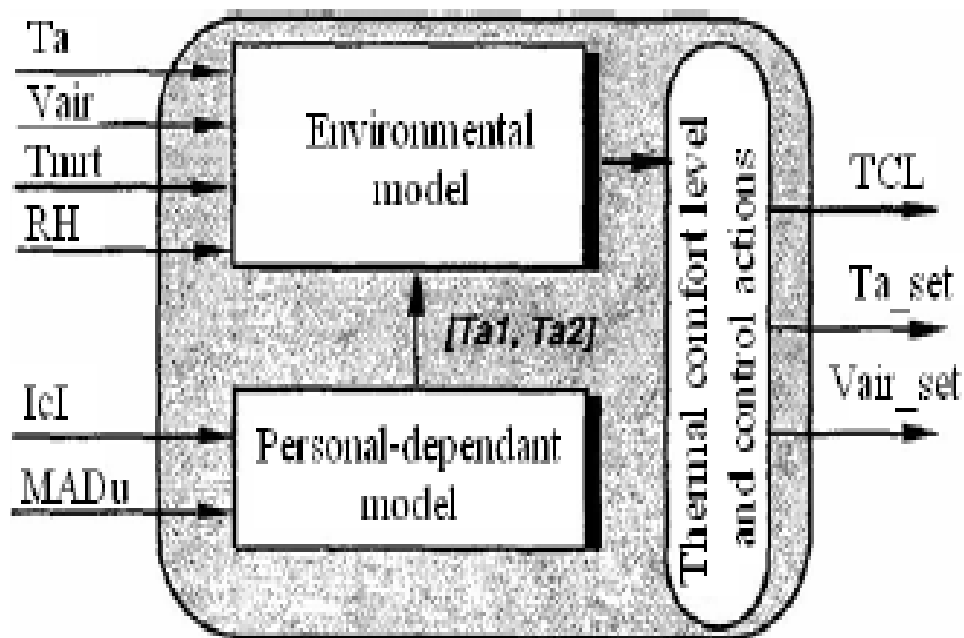


Fig 2.5: Thermal comfort level-based fuzzy system

2.1.3.2. Neural Network based controllers

Neural network (NN) as a whole is applied extensively in the control of HVAC systems, but there are two neural network based control systems used more commonly as Neural Network based Predictive Controller and Direct Neural Network Controller. In the Neural Network based Predictive Controller, the NN is exploited for the system model construction used in the controller regulating in

the nonlinear systems. This method is also named identification technique. There are two system identification approaches: forward system identification and inverse system identification.

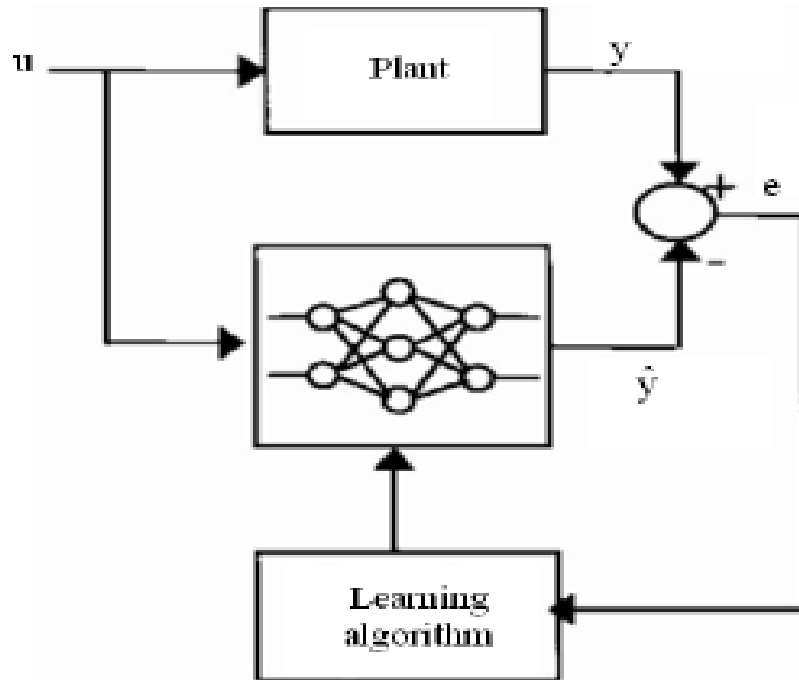


Fig 2.6: Forward system identification

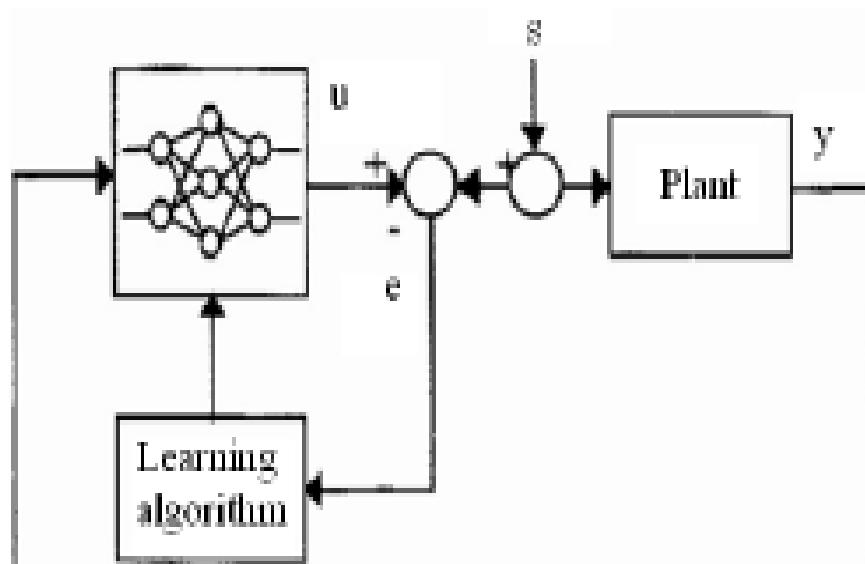


Fig 2.7: Direct inverse system identification

Becker et al., (1994) discussed control strategies for refrigeration systems based on fuzzy logic. Quality preservation of goods in cold stores as well as power consumption of refrigeration systems depend on the installed controller. This model is used to study the dynamic properties of the cold store, with emphasis on the coupling of temperature and relative humidity. The design with fuzzy logic allows to take into account the complex coupling of the dynamic variables temperature and humidity in a straightforward manner. In the control design the thermodynamic coupling of temperature on relative humidity is considered by using the temperature error as additional input for the fuzzy humidity controller. Though this model at that time felt did not do so well because of the lack of usage of the continuous actuator or the present day PIDs.

Typical automobile automatic climate control systems used linear proportional control to maintain comfortable interior environment. In the process of refining these systems, Davis et al., (1994) found two significant limitations of linear proportional control when viewed from the standpoint of an occupant's subjective comfort. First, there were certain control situations in any HVAC (Heating, Ventilation, and Air Conditioning) system that were inherently nonlinear. Second, it was not possible to realize occupant comfort merely by maintaining proximity to a desired temperature. In this paper, they described a fuzzy logic control system which addressed those limitations by including rules that provide nonlinear compensation, and by allowing the control to be expressed in the same heuristic terms that an occupant would use in describing the level of comfort. It was found that the use of fuzzy logic control in climate control systems strategy could result in improved occupant comfort. The ability to tailor gradual, nonlinear response allows the design of the strategy to address certain situations that have not been handled gracefully in the past. In particular, concerns such as blower speed onset during warm up in cold weather and ambient temperature compensation could be ameliorated by appropriate use of the additional flexibility that fuzzy logic provides.

Arima et al., (1995) employed a control algorithm using these either fuzzy logic reasoning or rough set theory. The controller deduced the appropriate control outputs from sensor readings. The system was capable of controlling temperature and humidity. To maintain temperature at the reference point, the controller adjusted the flow of hot water in a heating coil for heating operation or the flow of chilled air through the air duct for cooling operation. To control humidity, the controller turns on and off a humidifier. The fuzzy logic reasoning shows better performance in both temperature and humidity control than the rough set method.

Lea et al., (1996) discussed the conceptual design of a heating, ventilation, and air conditioning (HVAC) control system based on fuzzy logic principles. This system was embedded in microprocessors with interfaces to the sensors, compressor, and air circulation fan and installed in a test building for performance evaluation. Some results of the analysis and performance evaluation for the fuzzy logic control system are presented as well as a discussion of the performance of the system from a subjective point of view of humans living in the facility.

In this experiment made use of variable speed fan and compressor, considering more usual situations that occurs in home air conditioners, or even commercial systems, in which variable speed compressor doesn't exist due to expense. They achieved good results with multi speed circulation fan (three speeds) in and energy use performance. Initial results indicated that system will work well from comfort level stand point. This system could be adapted to a chilled water system such as might existed in commercial and state buildings that existed that time.

Chen et al., (1998) addressed the problems of ventilation system in a large road tunnel. The key issues concerning the ventilation system are higher visibility and lower concentration of carbon monoxide. Prior to designing the fuzzy control model, a configuration layout of the ventilation system including sensing, control and traffic prediction as well is conceptually constructed. Based on the layout that offers assignments of sensors and control elements, a fuzzy logic control model is developed. Membership functions of sensor errors and control increments are

physically submitted in order to set up the fuzzy logic rules. Timing and spacing filtering in terms of weighting approaches is employed in the fuzzy logic rules. A dynamic equation describing the concentration of air pollution is also given so as to cooperate with the fuzzy logic rules and to play roles in the computer simulation.

The result of computer simulation involving five cases indicates that a multi-level scheme is able to solve the engineering problems. The configuration layout including facility installation, pollutant distribution, sensing elements and control elements is described in detail and compiled with its following positioning of sensing elements and control elements. After the functional environment is set up, fuzzy logic control (FLC) with defined membership functions, inference and defuzzification is then applied to the ventilation control.

Hamdi and Lachiver, (1998), as compared to all other existing residential Heating, Ventilating and Air Conditioning (HVAC) control systems which are considered as temperature control problems, presented a new HVAC control technique that is based on the human sensation of thermal comfort. The proposed HVAC control strategy goal is not to maintain a constant indoor air temperature but a constant indoor thermal comfort. This is realized by the implementation of a fuzzy reasoning that takes into account the vagueness and the subjectivity of the human sensation of thermal comfort in the formulation of the control action that should be applied to the HVAC system in order to bring the indoor climate into comfort conditions.

The design of the thermal comfort-based fuzzy system is realized by extracting knowledge from Fanger's thermal comfort model. The architecture of the proposed control system allows easier evaluation of the indoor climate by using linguistic description of the thermal comfort sensation which make it simpler to understand and to process than having to solve iteratively a complex mathematical model. Simulation results show that the proposed control strategy makes it possible to maximize both thermal comfort of the occupants and the energy economy of HVAC systems.

Yang and Huang, (1998) presented a new dual fuzzy controller for the linear compressor of a split-Stirling cryocooler. Besides stroke, the phase of the working fluid, circulating from the compressor to the split regenerator, is an important parameter to the cooling efficiency. The non-linearities and uncertainties of a cryocooler make it impossible to use a conventional controller over a wide range of operation. This fuzzy controller is designed to consist of a fuzzy stroke control and phase control without any explicit system models, but driven in the human thinking mechanism. Computer simulations and experiments showed that the compressor piston in the displacement tracking control failed to catch up with the periodic sinusoidal command. However,

the dual fuzzy controller can successfully drive the piston to follow the stroke as well as the phase of the reference command.

This new fuzzy control methodology can be employed with split-type cryocoolers, whose stroke and phase both contribute to the refrigeration performance. The proposed dual fuzzy controller successfully performed the stroke as well as phase control of a linear compressor. No derivation of mathematical models is needed and no system identification is required for the implementation of fuzzy controllers, in which the fuzzy control law is robust to the values of membership functions, disturbances and loads.

Watanuki and Murata, (1999) proposed a fuzzy-timing Petri net method for distributed temperature control to achieve optimum air temperatures inside a car, considering the comfort of each passenger. The optimum HVAC control was applied to an air conditioning system for a car, and a fuzzy controller was used to independently control temperatures at various locations inside a car, considering each passenger's comfort temperature level and air velocity at each seat. They conducted experiments and confirmed that their method was useful for distributed temperature control in a car. In this paper HVAC control was applied to air conditioning system for a car, and a fuzzy controller was used to independently control temperatures at various locations inside a car, considering the comfort temperature levels and air

velocities of passengers at different seats. Their experiments had confirmed that the proposed methods are useful for temperature control for cars.

Mraz, (2001) designed an “intelligent” digital control for maintaining the temperature at a predefined level in a common kitchen refrigerator. The control works on the basis of modeling a thermostatic appliance and the use of fuzzy logic. Thermostatically simulated and fuzzy controlled model are presented successively. The latter is set-up on the basis of the Sugeno’s type of fuzzy rules and the Jang’s procedure of learning. MATLAB, SIMULINK and Fuzzy Logic TOOLBOX (FLT) are the programming environments used for realization of the model. The principal aim in designing the control is to assure the fastest and best transition possible from an analogue to digital control of the refrigerating appliance. The article presented one of the alternatives for a fast transition from classical thermostatic control to digital control of the refrigerating compressor on the basis of a fuzzy controller.

Eftekhari et al, (2003) designed and implemented a fuzzy controller for naturally ventilated buildings. The controller was implemented in a test room by the use of MATLAB™. Initially the controller was validated using simulated data. Simulations were carefully designed to allow simultaneous comparison between different controllers’ performances. Validation of the controller is performed in the test room by measuring the temperature distribution inside the room with no control action. The data are then compared to the open loop test results of the controller.

A practical application of a fuzzy logic controller in natural ventilating buildings had been studied and validated by experimental testing. Its aim was to improve thermal conditions in a single-sided naturally ventilated occupied space. Therefore the conclusion that could be made was that the available opening area is too small to avoid over-heating when the opening area is in a fixed position. Or it could be, it was not possible to avoid over-heating with or without the controller. However, better comfort achieved with the controller in action which adjusted the openings according to the outdoor weather conditions. Experimental results obtained from

validation on-line indicate that fuzzy controller is capable of operating the openings successfully.

Gottschalk et al., (2003) presented Improved climate control for potato stores by fuzzy controllers. The main tasks for climate controllers in potato bulk stores are to keep the storage climate in an appropriate condition for quality conservation. To avoid extra energy costs by using cooling systems the internal climate of potato bulk stores is controlled with outdoor air. A conventionally designed controller is difficult to adapt for an optimal climate control to reduce quality loss. However, a controller designed with fuzzy logic is found as advantageous for adapting control parameters to improve the control process. A test stand is built to ventilate and to control two samples of potato bulks simultaneously with the same outdoor weather conditions for comparisons. Several experiments were carried out to compare climate controllers with different control algorithms, i.e. conventional to a different conventional and conventional to fuzzy. In these tests it can be seen that the test with fuzzy control and optimized with GA lowered the all over energy consumption for the test period.

Aprèa et al., (2004), referring to a vapor compression refrigeration plant subjected to a commercially available cold store, a control algorithm, based on the fuzzy logic and able to select the most suitable compressor speed in function of the cold store air temperature, is presented. The main aim is to evaluate the energy saving obtainable when the fuzzy algorithm, which continuously regulates the compressor speed by an inverter, is employed to control the compressor refrigeration capacity instead of the classical thermostatic control, which imposes on/off cycles on the compressor that works at the nominal frequency of 50 Hz. The variation of the reciprocating compressor speed is obtained by controlling the compressor electric motor supply current frequency in the range 30–50 Hz, as it is not possible to consider values smaller than 30 Hz because of the lubrication troubles due to the splash system. In this range, two among the most suitable working fluids proposed

for the R22 substitution, such as the R407C (R32/R125/R134a 23/25/52% in mass) and the R507 (R125/R143A 50/50% in mass) are tested.

Comparing the compressor speed fuzzy control with the classical thermostatic control, frequently used in the cold stores and in other refrigeration systems, the experimental results show a meaningful energy saving equal even to about 13% when the R407C is used as a working fluid. In particular, to explain from the energy saving point of view the best performances of the refrigeration plant when the compressor speed varies, an exergetic analysis is realized. Besides, with regard to the inverter cost, the pay-back period determined is more than acceptable for the plant size examined.

Calvino et al., (2004) introduced the design of a fuzzy proportional, integrative and derivative (PID) regulator, aimed at the control of the indoor thermal-hygrometry comfort conditions. The control and the monitoring of indoor thermal conditions represent a pre-eminent task with the aim of ensuring suitable working and living spaces to people. Especially in industrialized countries, in fact, several rules and standards have been recently released in order of providing technicians with suitable design tools and effective indexes and parameters for the checking of the indoor microclimate. Among them, predicted mean vote (PMV) index is often adopted for assessing the thermal comfort conditions of thermal moderate environments.

Unfortunately, the PMV index is characterised by non-linear features, that could determine some difficulties when monitoring and controlling HVAC equipment.

In order of overcoming these problems, a fuzzy control for HVAC system is here described. It represents a new simple approach, focused on the application of an adaptive fuzzy controller that avoids the modelling of indoor and outdoor environments.

Even with the variability of the outdoor climatic conditions, the regulation shows a very stable behavior, allowing an effective and fast control of the indoor

microclimate conditions. These features candidate the present system as a promising control tool for climatized indoor environments. Moreover, it could be also adopted for driving operable parts of the building envelope, so enabling the control of the solar radiation entering the room and the illuminating indoor conditions.

Li et al., (2004) described the improvement of the refrigerant flow control method by using an electronic expansion valve (EEV) which was driven by a stepper motor in automobile air conditioning system. An EEV can make a quick response to the abrupt change in the refrigerant flow rate during the change in automobile speed and the thermostatic on/off operation. The flow rate characteristic of the EEV for automobile air conditioning was presented. A microcontroller was used to receive the input signal and generate the output signal to control the opening of the EEV. The fuzzy self-tuning proportional–integral–derivative (PID) control method is employed.

e = superheat error; ec =the rate of change of superheat error; K_p =proportional gain; K_i =integral gain; K_d =derivative gain; T_i integral time; T_d =derivative time; T_{sh} =superheat; T_{sh0} =set superheat; m =mass flow rate of refrigerant; u =output

Experimental results showed that the new control method could feed adequate refrigerant flow into the evaporator in various operations. The evaporator discharge air temperature dropped by approximately 3 °C as compared with that of the conventional PID control system.

He et al., (2005) presented a multiple model predictive control (MMPC) strategy based on Takagi–Sugeno (T–S) fuzzy models for temperature control of air-handling unit (AHU) in heating, ventilating, and air-conditioning (HVAC) systems. The overall control system was constructed by a hierarchical two-level structure. The higher level was a fuzzy partition based on AHU operating range to schedule the fuzzy weights of local models in lower level, while the lower level is composed of a set of T–S models based on the relation of manipulated inputs and system outputs correspond to the higher level. Following this divide-and-conquer strategy,

the complex nonlinear AHU system is divided into a set of T–S models through a fuzzy satisfactory clustering (FSC) methodology and the global system is a fuzzy integrated linear varying parameter (LPV) model. A hierarchical MMPC strategy is developed using parallel distribution compensation (PDC) method, in which different predictive controllers are designed for different T–S fuzzy rules and the global controller output is integrated by the local controller outputs through their fuzzy weights.

Simulation and real process testing results show that the proposed MMPC approach is effective in HVAC system control applications. Compared with the conventional single model approaches, the different operating conditions in AHU process can be well described by T–S models which are simple and more suitable for design linear controllers. Simulation and pilot plant testing results demonstrated that the designed MMPC can meet the control performance requirements at different operation points. Since other function blocks in HVAC systems have similar characteristics, the methodology developed in this paper can be easily modified and extended.

Rashid and Islam, (2010) designed and implemented an intelligent temperature control at a desired level in a refrigerator. The control works on the basis of modeling a thermostatic appliance and the uses of fuzzy logic. A refrigeration system control device using fuzzy logic for controlling a plurality of refrigeration compressors such that the closest capacity is selected to match the load to each of a plurality of evaporators comprising, a control having an input adapted to be connected to a means to sense the temperature in the controlled space wherein a control signal is indicative of the maximum refrigeration load of the controlled space, a means for determining whether the primary control variable in said space is above or below a single predetermined desired target. Thermostatically simulated and fuzzy controlled model are presented successively. The latter is set-up on the basis of the Mamdani's type of fuzzy rules. MATLAB, SIMULINK and Fuzzy Logic TOOLBOX (FLT) are the programming environments used for realization of the model. The principal aim in designing the control is to assure the fastest and best transition possible from an analogue to digital control of the refrigerating

appliance, which represents the basis of a functional expansion demanded by the present market.

This study reveals that the evaporative condenser can be modeled using Fuzzy logic controller in efficient way.

CHAPTER 3

MODELLING, SIMULATION AND CALCULATIONS

The objective of the control system is to regulate the room temperature to the desired value, T_{tar} . The block diagram of the air-conditioning control system is a simple closed loop system as shown in Fig. 3.1. The controller is designed to provide the proper value of the AC voltage frequency so that compressor of the air conditioner runs with such a speed that the room temperature is maintained at the desired set point.

3.1. Fuzzy controller design

There are two inputs to the controller namely, error (e) and error dot (\dot{e}). Where e is the difference between the T_{tar} and the T_{act} of the room and error dot is the rate of change of that difference. The output is in the form of frequency of the voltage to be supplied to the compressor induction motor. Therefore the rules can be made in the following manner.

If the e is negative and \dot{e} is positive (slow) then the frequency should be high.

If the e is negative and \dot{e} is positive (fast) then the frequency should be low.

3.1.1. Structure of Fuzzy logic controller

To control the room temperature, the controller first reads the error (e) and then the error dot (\dot{e}) [Nasution et al., 2010]. The temperature error e and its rate of change \dot{e} are then computed and used as the inputs to the fuzzy temperature controller.

$$e = T_{tar} - T_{act} \quad 3.1$$

$$\dot{e} = \frac{d(T_{tar} - T_{act})}{dt} \quad 3.2$$

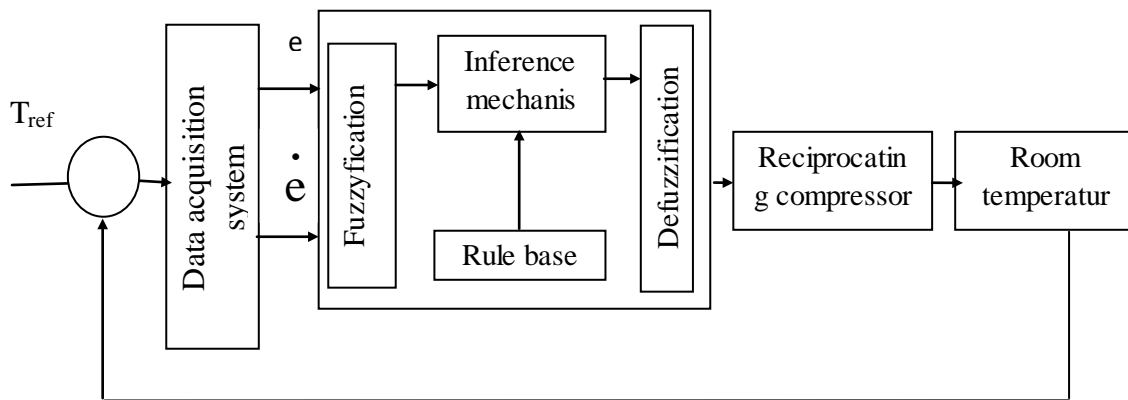


Fig 3.1: Block diagram of the Fuzzy control system.

3.1.2. Membership Functions for fuzzification

In the fuzzy controller, the If-Then rules are written using fuzzy sets, which are characterized by membership functions. Three fuzzy sets are defined for each input variable. They are for e , negative, zero and positive, for \dot{e} , slow, medium fast. Membership function for error (e) is shown in Fig. 3.2.

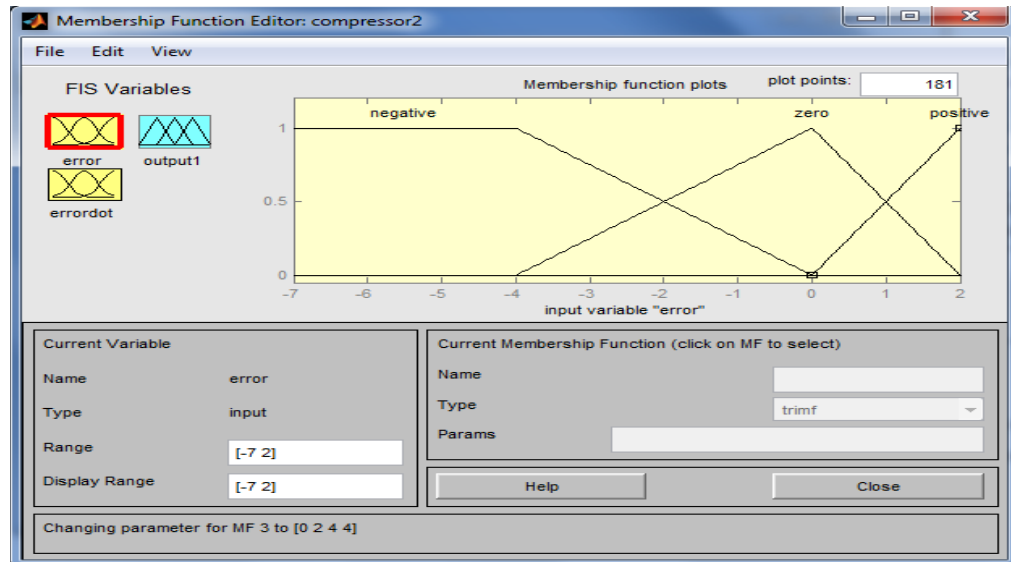


Fig. 3.2: Membership function for error (e)

Triangular membership functions are used here because they are simple and have been proven to be sufficient in many applications. Fig. 3.2 shows the antecedent membership functions. They are used for the temperature error e and its rate of change \dot{e} .

The membership grade μ of the membership function is given as [Wang et al., 2009]:

$$1. \text{ Negative: } \mu_1 = \begin{cases} 0 & x = [0, +\infty] \\ 1 - \frac{|x+4|}{4} & x = [-4, 0] \\ 1 & x = [-4, -\infty] \end{cases} \quad 3.3$$

$$2. \text{ Zero: } \mu_2 = \begin{cases} 1 + \frac{x}{4}, 1 - \frac{x}{2} & x \in [-4, 2] \\ 0 & \text{otherwise} \end{cases} \quad 3.4$$

Now positive part is not important because it's a summer air conditioning system.

Similarly the membership grade of all membership functions can be worked out.

Similarly the membership function of the error dot and output can be generated.

Membership functions must cover the input range. The shape of membership functions has effect on the performance of the fuzzy controller. Higher resolution and sensitivity are obtained if the sides of the triangles have steeper slopes. On the other hand, gentler slopes lead to a smoother control action and greater stability. The distribution of membership functions need also be taken into consideration in their definition. In the neighborhood of zero, a high-resolution function is chosen. Low-resolution membership functions are defined in areas far from zero to achieve higher robustness and stability.

3.1.3. Fuzzy rules

Now to get a suitable output from the input and output membership functions rules are to be formulated, the rules can be formulated in the following manner.

1. If (error is negative) and (error dot is slow) then (output1 is fast)
2. If (error is negative) and (error dot is medium) then (output1 is medium)

3.1.4. Inferencing

The root sum square (RSS) method of inferencing is employed here. The RSS method combines the effect of all applicable rules, scales the functions at their respective magnitudes and computes the fuzzy centroid of the composite area. This method is more complicated mathematically than other methods. For example;

$$\text{negative} = \sqrt{R_1^2 + R_2^2 + R_3^2} \quad 3.5$$

Where R_1 , R_2 and R_3 represent the rules which support cooling.

Similarly for linguistic variable zero;

$$\text{zero} = \sqrt{R_4^2 + R_5^2 + R_6^2} \quad 3.6$$

Where R_4 , R_5 and R_6 represent the rules which support no change.

As a result of the equations 3.5 and 3.6 a fuzzy output is obtained as shown in Fig 3.5.

3.1.5. Defuzzification

Now the Fuzzy output obtained from the inferencing is to be converted to a crisp output.

For this simply the centroid of the shaded area is to be found. And the centroid is given by [Ali, 2012]:

$$\text{output} = \frac{\text{negative center} \times \text{negative strength} + \text{zero centre} \times \text{zero strength}}{\text{negative strength} + \text{zero strength}}$$

3.7

Negative centre= the point of negative membership function peak;

Negative strength= result obtained from equation 4.5.

Similarly for zero membership function zero centre and zero strength can be found

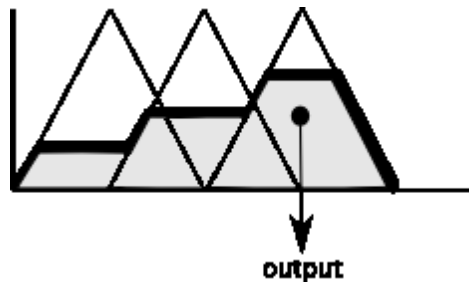


Fig 3.3: Fuzzy output

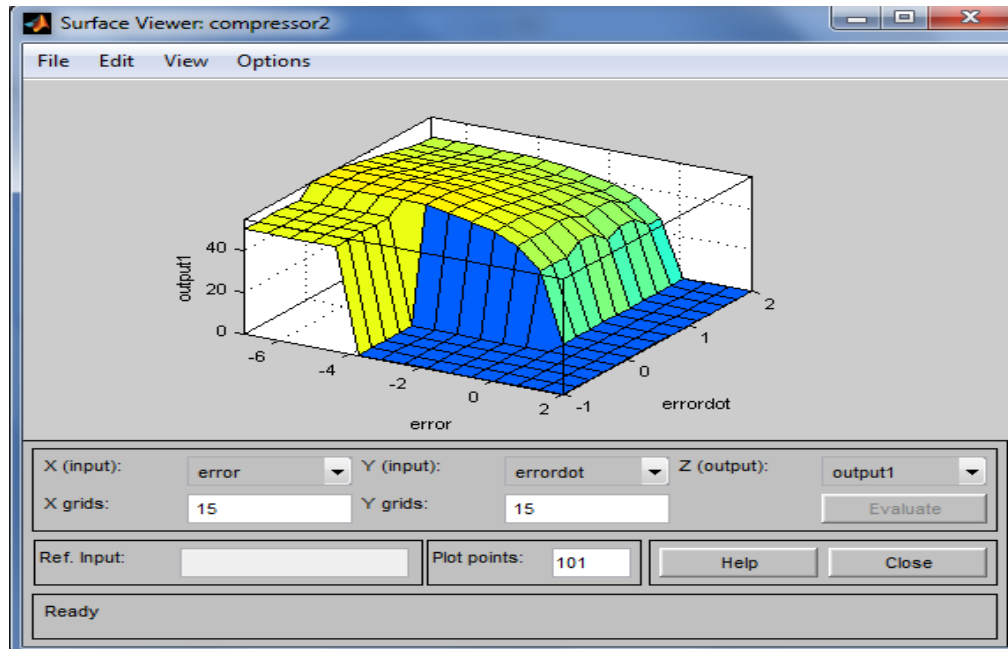


Fig 3.4: Output surface viewer

3.2. Electrical Circuit design

The basic electrical circuit diagram for speed control of 3 phase induction motor is shown in the Fig 3.5 [Fonseca et al., 1999].

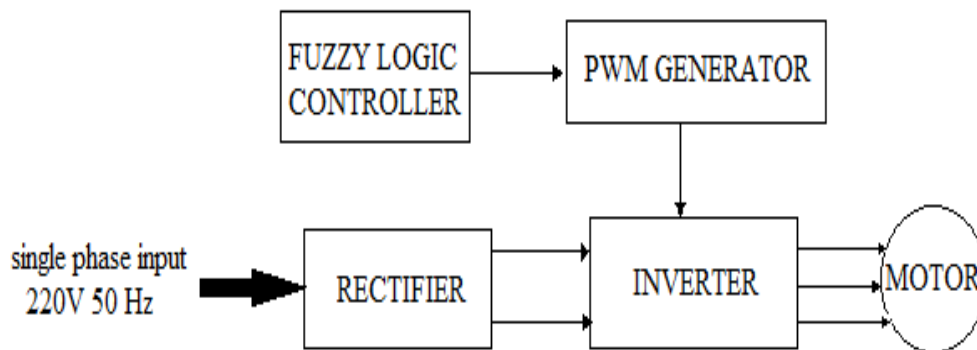


Fig 3.5: Basic configuration of the Proposed SIMULINK MODEL.

3.2.1. Power supply

Power supply in this case is a single phase Alternate current of 220 V and 50 Hz frequency.

3.2.2. Implementation of the fuzzy logic controller

The Fuzzy logic controller as applied to the circuit is shown in the Fig 3.9

The fuzzy controller takes in the value of error and error dot and gives the value of appropriate voltage frequency. This is then used and converted into a format required by the discrete PWM generator gates.

3.2.3. Pulse width Modulated generator

This is the most important part of the circuit that is responsible for varying the frequency of the AC voltage the parameters set in this cases are given as shown in the Fig 3.6. This block sends signals to the Universal Bridge so that the desired voltage frequency is generated.

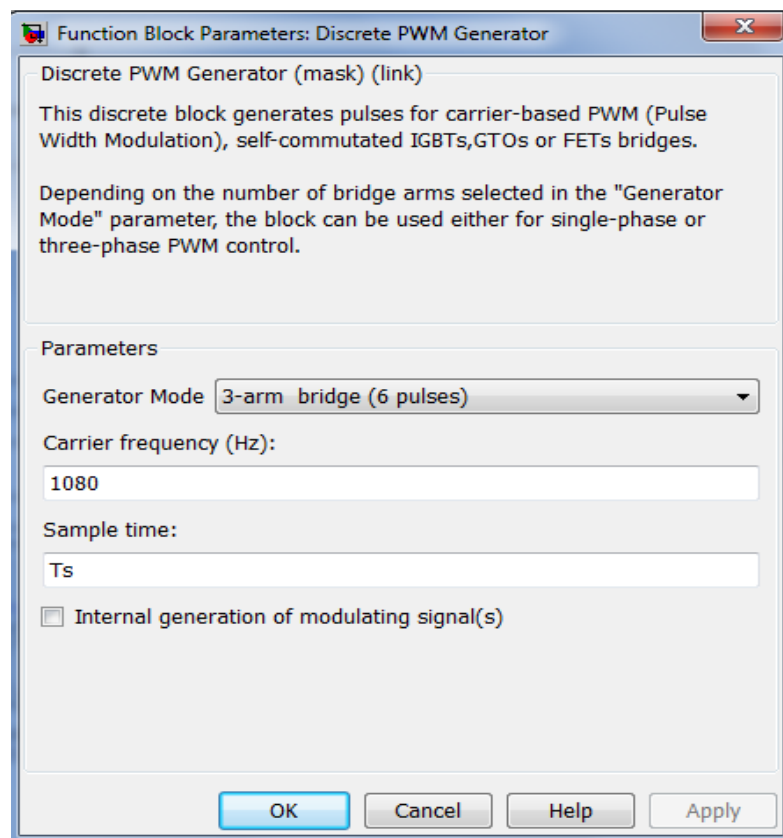


Fig 3.6: Discrete PWM generator block

3.2.4. Invertor

The inversion is done with the help of universal Bridge block as shown in the Fig 3.7

The signals received from the PWM generator results in opening and closing of various transistor switches which makes the desired value 3 phase Voltage frequency generated. The values set for various parameters of universal Bridge are shown in the Fig 3.7.

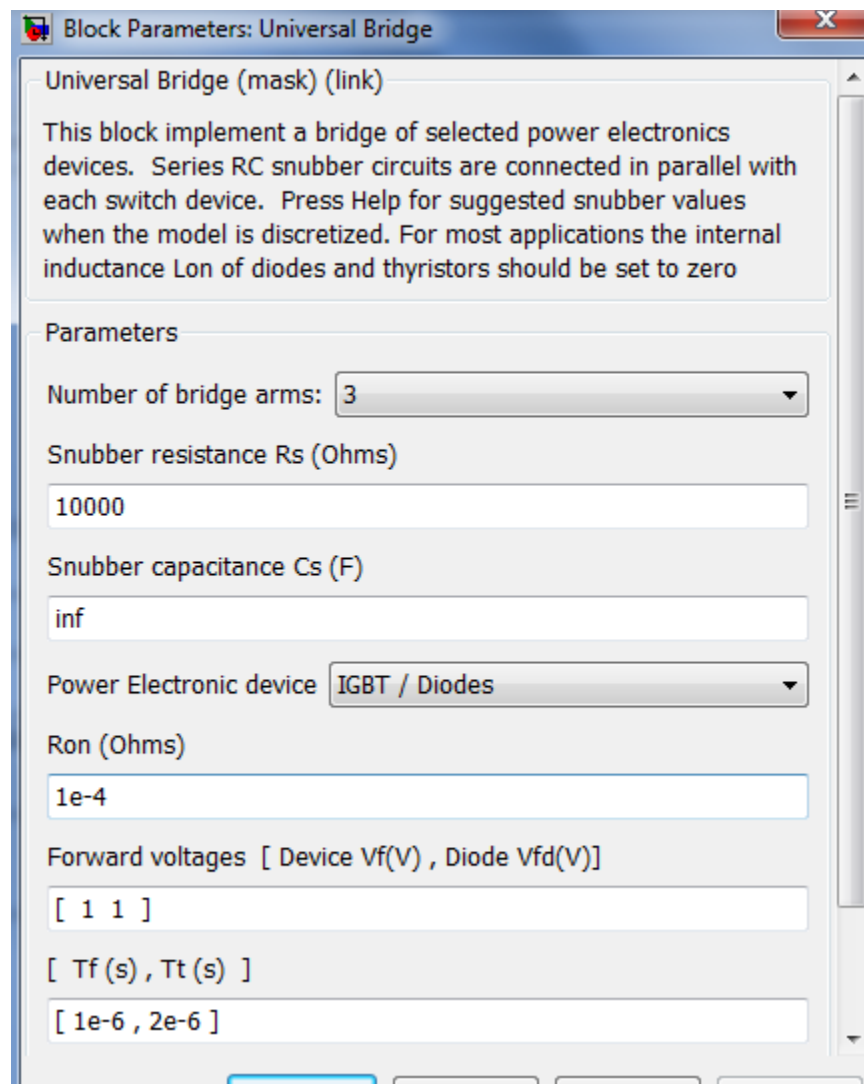


Fig 3.7: Universal bridge block

3.2.5. Induction Motor

Now the desired frequency current is supplied to the Induction motor. The induction motor is a 3 phase 2 HP motor. Various parameters set are as shown in Fig 3.8.

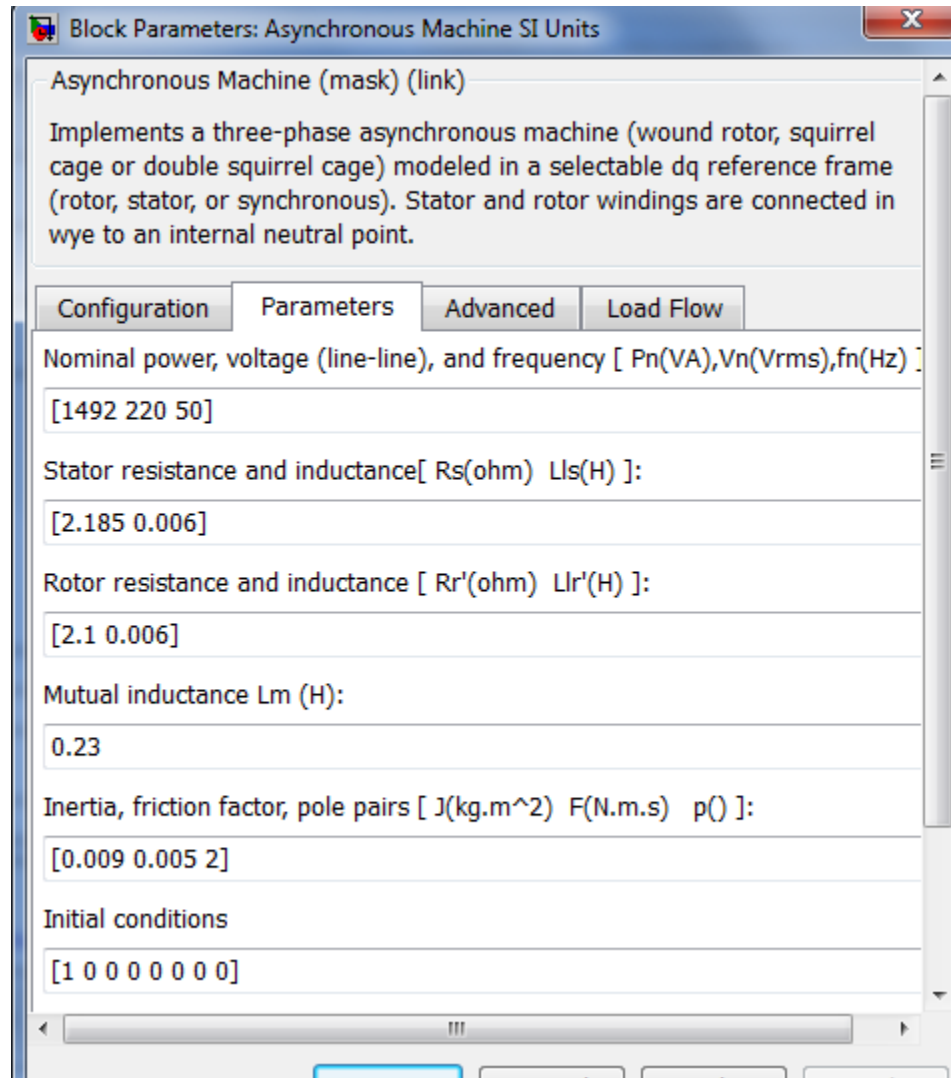


Fig 3.8: 3 phase induction motor block

The complete circuit is shown in Fig 3.12.

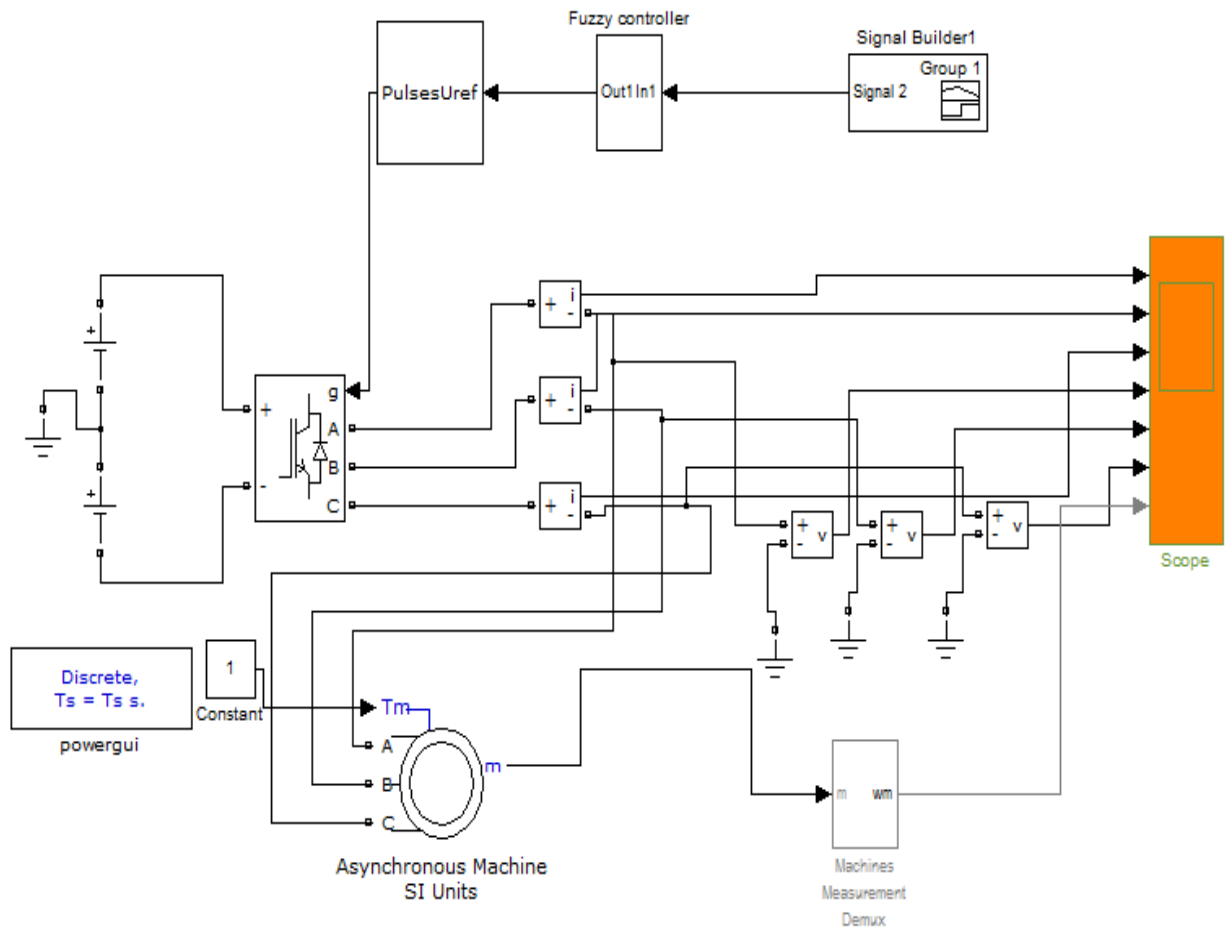


Fig 3.9: The complete circuit

3.3. Simulation

Now as the system is fully set up. The simulations are run for certain Target temperatures.

These target temperatures are 20°C, 22°C and 24°C. Initially the temperature is equal to ambient temperature. The temperature difference variation is fed to the system by the signal builder of Fig 4.10. the temperature variation fed to the system is in close compliance with the temperature results obtained by Nasution et al, (2010). As the temperature variation is fed to the fuzzy controller it gives out the desired frequency of the AC voltage. This output is then utilized by the PWM generator hence it sends signal to the gate of Universal bridge which as a result produce a three phase AC of desired frequency from DC voltage supplied to it. This three phase AC is then used to run the induction motor. The speed variation of the motor is obtained by the Scope.

3.4. Calculations

As the simulation results are obtained the calculations are to be done for the energy consumption by the system. The relation used for the power consumption by the Induction motor is given by:

$$\text{Power} = \frac{\sqrt{3} \times V \times I}{1000} \text{ kW} \quad 3.8$$

$$\text{Energy} = \text{Power} \times \text{time (in hr)} \text{ kWh} \quad 3.9$$

This energy calculation is to be compared with that of the Conventional ON/OFF air conditioning system. The power of the conventional system is given by:

$$\text{Power} = V \times I \text{ kW} \quad 4.10$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 VALIDATION OF SIMULINK MODEL

The proposed model is an approach to energy saving and uses fuzzy logic to control the speed of the compressor motor. To study the performance of this model a model in MATLAB/ Simulink version 7.12.0.635(R2011a) is developed. The performance of the model is studied for three air conditioning target temperature points that are, 20⁰C, 22⁰C and 24⁰C respectively.

The model uses a 2 HP 3 phase induction motor (which is not in built in Simulink, but obtained by setting the parameters of Asynchronous motor Block accordingly), a single phase supply converted to DC by rectification (rectifier is not included and direct DC voltage is used as an input to make the model simpler) and an inverter. The inverter uses pulse width modulation to reproduce 3 phase supply.

4.1.1 Validation of the Simulink model with Dash et al. (2012) model simulation result

The comparison between the proposed model and Dash et al. model can be made by looking at Fig. 4.1 and 4.2. Proposed model 3D graph is among output(ordinate), temperature difference and rate change of temperature difference Dash et al. model 3D graph is among output(ordinate), number of occupants and temperature difference, and. The proposed model gives the output in the form of maximum attainable voltage frequency which 60 Hz and the Dash et al. model gives the output in the form of percentage of maximum speed attainable by the compressor motor which 100%. But we know that the compressor motor speed is proportion to the voltage frequency. The difference in the surface pattern is only because of the third axis which is temperature

difference rate change in the proposed case and number of occupants in the Dash et al. (2012) case. But if we consider the red lines in the Fig 4.1 and 4.2 which are close to the 0 value of the third coordinate we can see that they follow a very similar trend.

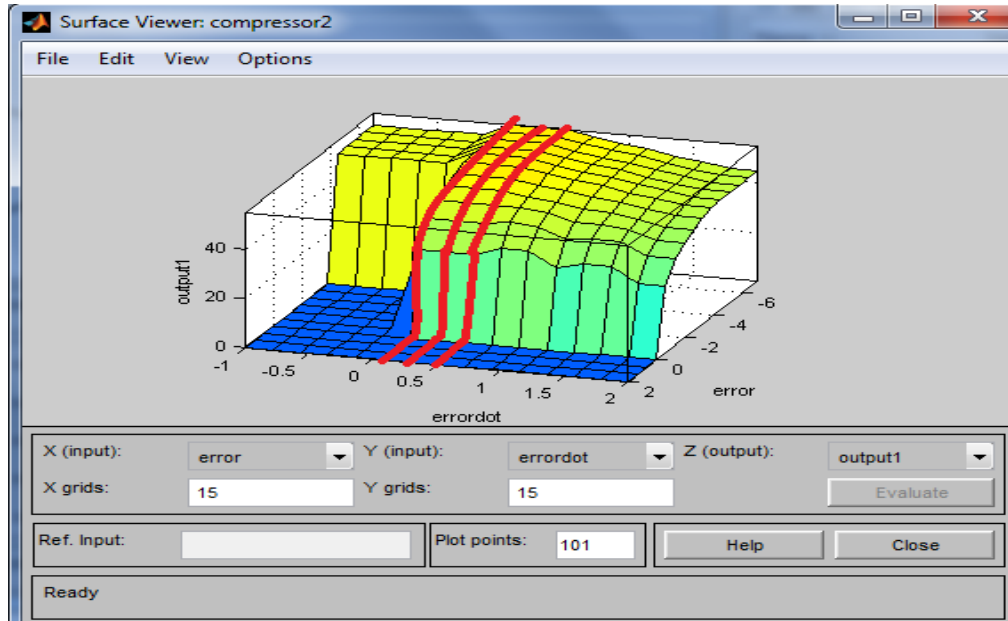


Fig 4.1: Surface plot for proposed model.

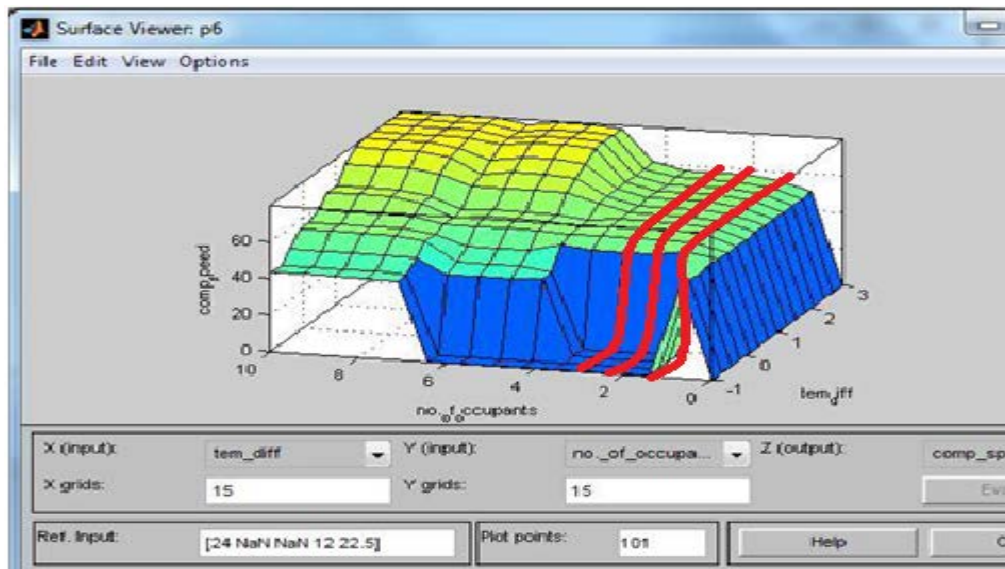


Fig 4.2: Surface plot for Dash et al.(2012) model

4.1.2 Validation of mathematical model with Nasution et al. (2010) experimental model for energy analysis of air conditioning system using Fuzzy logic controller.

The comparison between proposed model and Nasution et al. (2010) can be made by looking at the Figure No. 4.3. It's a graph between speed in rpm and time in minutes. The curve with triangular points depicts the experimental model compressor speed variation with time and the curve with the circular points that of proposed model. These curves are made for the same temperature inputs as that of experimental model taken after every 5 minutes. The curve of proposed model shows same trend but is smoother and doesn't have sharp edges. The curve of proposed model is slightly higher because of the higher maximum working frequency which is 55 Hz in case of proposed and 50 in case of experimental model. This suggests that for the same initial conditions the proposed model will do the cooling faster. The experimental model uses a single phase 2 HP compressor motor and the proposed uses 3 phase motor of same power.

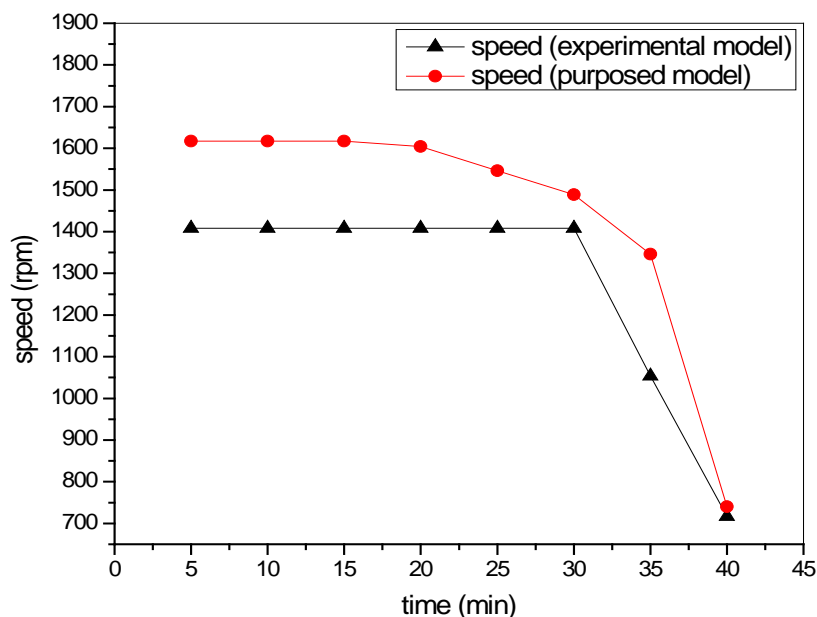


Fig 4.3: Motor speed response for proposed and Nasution et al. (2010) model

4.2 Simulation of the proposed model for target temperatures of 20, 22 and 24 °C

4.2.1 Simulation of the proposed model for a set temperature of 20 °C

The temperature variation is input to the proposed model and the speed response is recorded which is shown in Fig. 4.4. It can be seen for a target temperature of 20 degree Celsius the compressor motor runs at a constant speed for some time and as the temperature go on approaching the target temp there is an abrupt dip in speed. This variation of the speed is because as the system approaches the target temperature with compressor still running the variation of the temperature becomes fast and hence according to the rules of fuzzy system speed of compressor will also decrease faster. Now with this speed variation the power consumed will vary over the period.

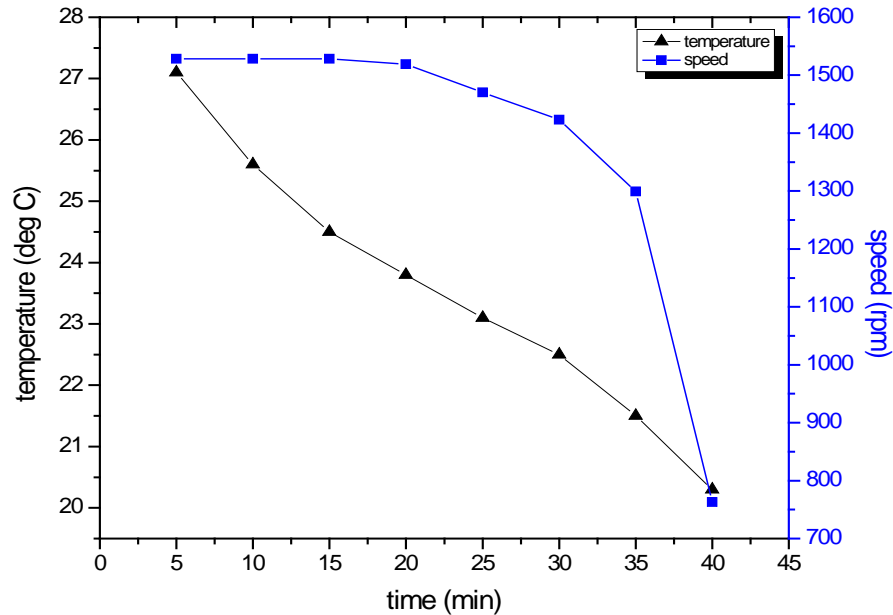


Fig. 4.4: Speed response with the temperature variation 20 °C target temperature.

The comparison of the energy consumption between conventional on/off air conditioner and the proposed model is shown in the Fig. 4.5. The conventional system consumes 1.386kWh of energy and the proposed system uses 0.877kWh of energy. There is a way less energy consumption by the proposed Fuzzy system as compared to the conventional system. This is because of the fact that the current amperage plays a great role in the energy calculation as mentioned in the equations before. The amperage required by a 3 phase motor is about 40 % less as compared to its single phase counterpart. For example, a 1 phase 2 HP motor has amperage of 7A and a 3 phase 2 HP motor has up to 4A.

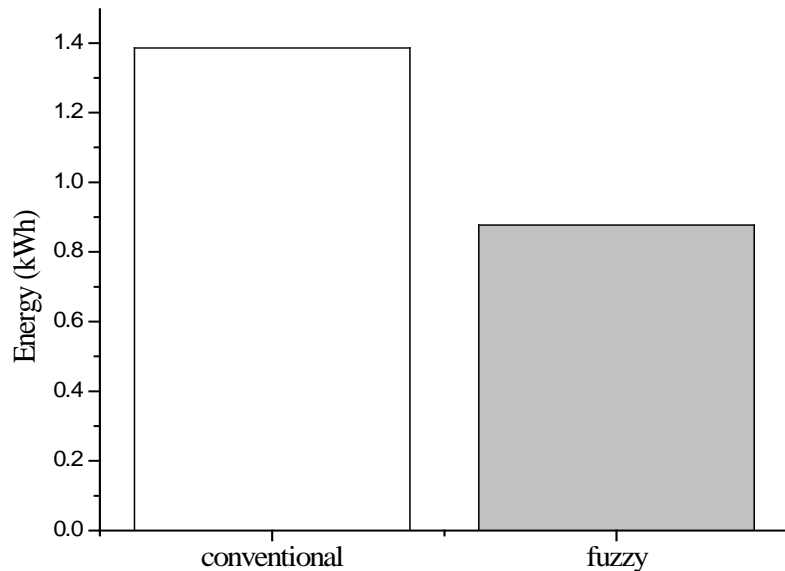


Fig. 4.5: Comparison of energy consumed by conventional A/c and Fuzzy A/c for 20 °C target temperature.

4.2.2 Simulation of the proposed model for a set temperature of 22°C

The speed response of the compressor motor for 22 °C target temperature is shown in the Fig. 4.6. In this case the motor runs at full speed for very less time, about 5-6 minutes and then its speed starts reducing with the approach of the temperature to the target temperature. This is because of the fact that the temperature difference between the target temperature and the recorded temperature is not too much as in the previous case for 20°C. So the fuzzy rule system does not allow to run at full speed for too long. And as the target temperature is reached the speed becomes constant.

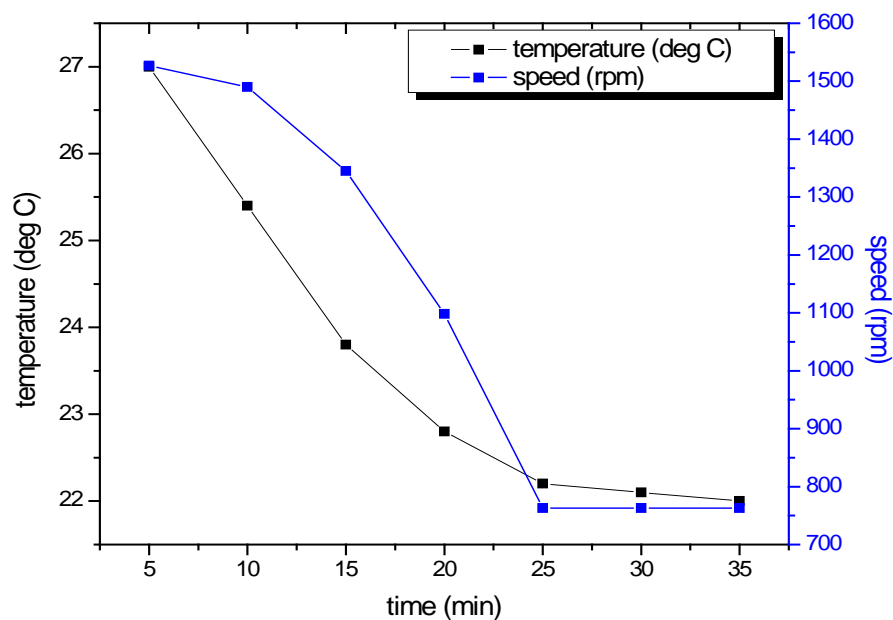


Fig. 4.6: Speed response with the temperature variation for 22 °C target temperature

The comparison of the energy consumption between conventional on/off air conditioner and the proposed model for the target temperature of 22°C is shown in the Fig. 4.7. The conventional system consumes 1.155kWh of energy and the proposed system consumes 0.588kWh of energy. The energy consumed in this case is less compared to the previous case because the target temperature is reached quite in a lesser time because of the fact

the temperature difference between the target temperature and the recorded temperature was less.

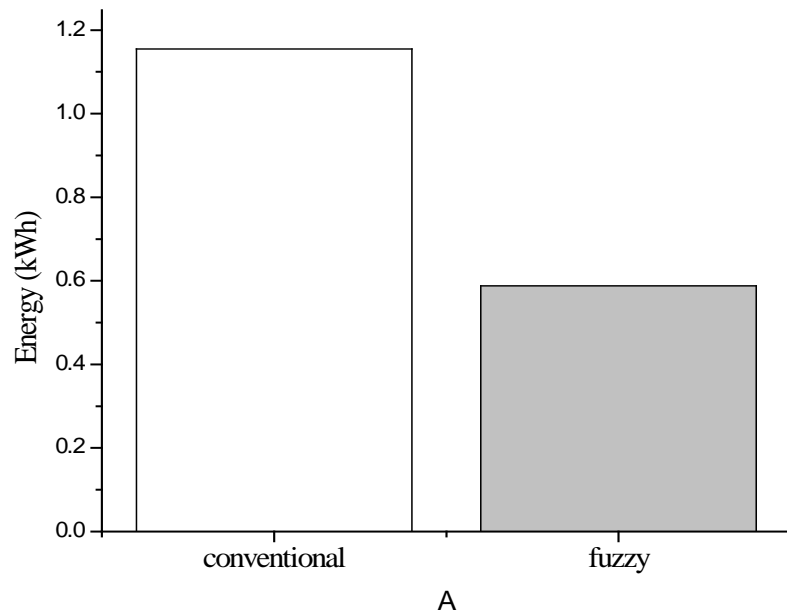


Fig. 4.7: Comparison of energy consumed by conventional A/c and Fuzzy A/c for 22 °C target temperature

4.2.3 Simulation of the proposed model for a set temperature of 24 °C

The speed response of the compressor motor for 24 °C target temperature is shown in the Fig. 4.8. In this case again the difference between the target temperature and the recorded temperature is even less than the previous case. Hence the speed variation is at quite a faster pace and the target temperature is reached very soon in around 20 minutes. As a result of which the Energy consumption is also quite less as compared to previous two cases which is what is suggested by the Fig 4.8. The conventional system consumes 0.924kWh of energy and the proposed system consumes 0.541kWh of energy.

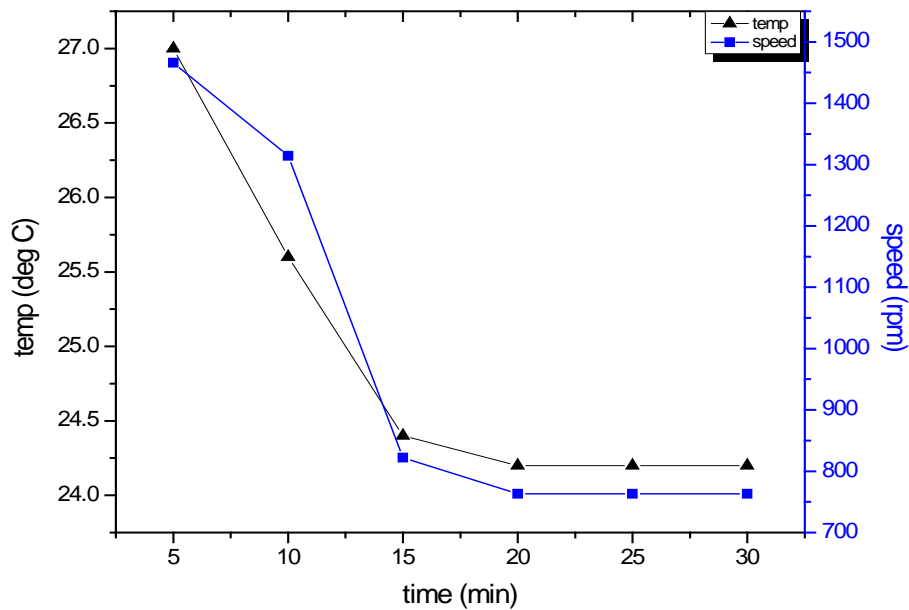


Fig. 4.8: Speed response with the temperature variation 24 °C target temperature.

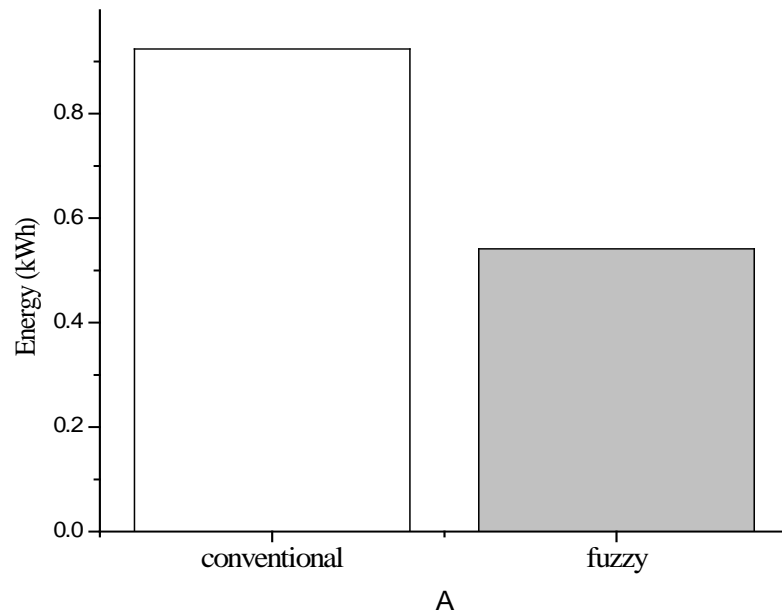


Fig. 4.9: Comparison of energy consumed by conventional A/c and Fuzzy A/c for 24 °C target temperature

Comparison of the energy consumption by the proposed system at various target temperatures is shown in Fig 4.10. It can be seen in the figure that the higher percentage of energy is saved when the proposed system is run at higher target temperature. This is because the higher target temperature is achieved faster and easier. And the higher target temperature is easier to achieve because it is always closer to the environmental temperature when the Air conditioner is switched on. So when the air conditioner is switched on for the higher target temperature the compressor motor has to do lesser work as compared to when the air conditioner is switched on when the target temperature is lower. It can be observed from the Fig.4.11 that even for the Conventional ON/OFF air conditioner the energy consumed is less for the higher set target temperature.

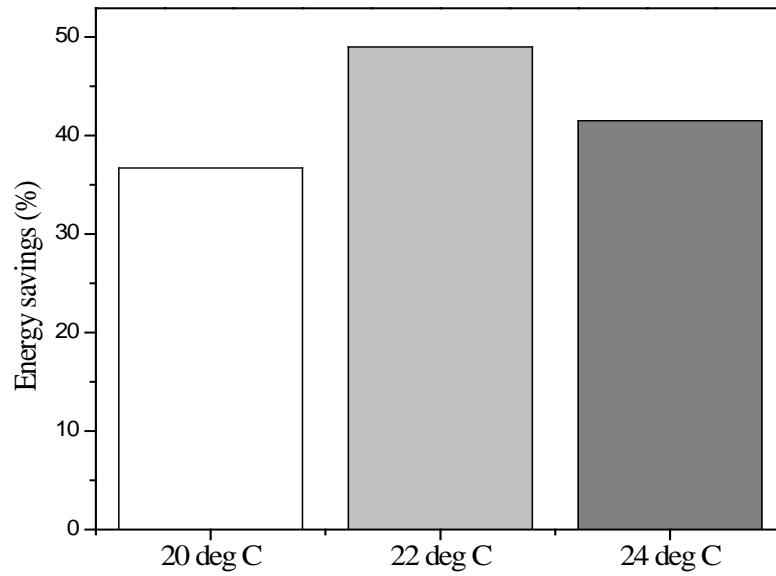


Fig 4.10: Comparison of the energy consumption at all the target temperatures.

The overall comparison of energy consumption by both conventional ON/OFF air conditioner and the proposed system is shown by Fig. 4.10. It's clearly visible that whatever maybe the target temperature the proposed Fuzzy system is more efficient than the convention ON/OFF air conditioner. And for the higher set target temperature point the energy saving is higher.

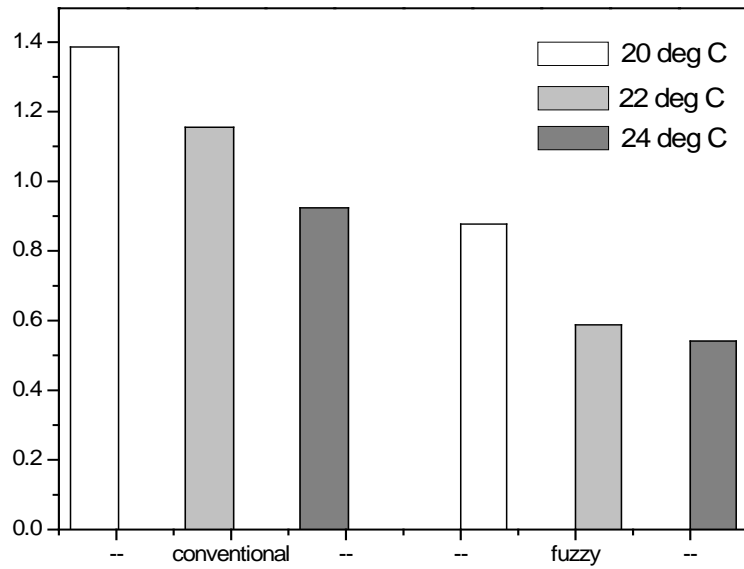


Fig. 4.11: Overall comparison of energy consumption by conventional ON/OFF air conditioner and the Fuzzy A/C system

CHAPTER 5

CONCLUSION

- Use of Fuzzy logic to control the speed of a 3 phase induction motor saves considerable amount of energy. The energy consumed by the proposed system for target temperatures of 20°C, 22 °C and 24°C is found to be less by 36.29%, 49% and 41% less than what is consumed by the conventional On/Off air conditioning system.
- For the lower target temperature the energy consumption is more whether it's a conventional On/Off air conditioning system or the air conditioning system with the intelligent control. Like in this report the energy consumption for the lowest target temperature of 20°C is 1.386kWh by conventional air conditioning system and 0.877kWh by the Fuzzy system. But for Higher target temperature of 22°C and 24 °C the energy consumption is low i.e. 1.155and0.924 respectively (for conventional system) and 0.588 and 0.541 respectively (for Fuzzy system).
- Fuzzy logic control to control the frequency of the voltage of alternate current which in turn controls the speed of 3 phase induction motor make the system to achieve the target temperature faster and hence save considerable amount of energy.

Future scope of the research work

- The proposed system has to be investigated experimentally to verify the results of this report.
- Similar system can be used for the control of Humidity which is also an important aspect of air conditioning.
- Similar control can be used to control the fan speed of the air conditioner

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