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"Development of an Adaptive Fuzzy Logic Controller (FLC) for Controlling of Heat Pump and Analyzing its Performance"

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Abstract—In both urban and rural cities, an exponential increase in demand of HVAC system is observed. This increase in demand leads to spike in demand of electrical energy as well. Thus, requirement of a system is felt to efficiently utilize the resources by reducing energy usage and operational costs as well without any compromise with output i.e., human comfort due to heating and cooling.

This work proposes the use of fuzzy logic controller to efficiently optimize heat pump speed thus saving energy. The controller utilizes various input parameters, based on which decision is taken for the level of controlling. Fuzzy logic controller has the ability to work just the way any expert of any particular field take decision. The inputs in present work are speed of heat pump based on particular temperature. The error and change in error are considered as source of information for proposed controllers. A comparative study is performed between conventional PI controller and fuzzy logic-based controller.

The work is done by preparing a Simulink model using Matlab/Simulink software. The result clearly indicates that the FLC based controllers outperformed conventional controllers in terms of speed of operation and stability of system.

Keywords:Heat Pump, HVAC, Temperature control, Fuzzy Logic Controller, PI controller, MATLAB/Simulink, Cooling systems.

I. Introduction

In comparison with other conventional heating cooling system, heat pump is far more economical and energy saving system. From all HVAC system it is expected to be as environment friendly as possible. The main reason to focus on making energy saving system is that,the importance of energy saving in present day and the side effect of global warming is very well understood to all. Most of the energy in India (70 %) is still generated using fossil fuel based power plants which make situation more vairable. Hence using an optimized heat pump, one can save a significant amount of energy thus making system more efficient. In buildings, cooling/heating is done using various different methods ranging from centralized cooling to separate section wise cooling [7]. Each technique has its own advantages and disadvantages. Controlling section wise is more adopted this days due to its high energy saving. The reason behind this energy saving is that instead of cooling each section, one can simply transfer heat form one section to another based on requirement. Hence, a lower use of refrigerant and heat exchange from outside environment will be required. The exchange can be further optimized using controllable heat pump operation which allow the flow of refrigerant according to demand. Hence by the knowledge of demand one should decide the appropriate quantity and speed of refrigerant flow in system. In this work use of Artificial intelligence (fuzzy logic is also a part of AI) is proposed for estimating the position of heat pump according demand and present condition.

The advantage of fuzzy has been observed in several area in last couple of years and is still going strong. The reason for its exceptional output in all cases is due to its ability to adjust itself based upon historical data (nonlinear) and to derive meaning from nonlinear data. It has proved to be of great help in areas in which parameters are of uncertainty in nature.

II. LITERATURE REVIEW

In the following section a brief discussion of work done in the field of optimizing heat pump performance using various techniques is discussed.

SahithullahMahaboob et. al. [1] in 2018 has proposed that most of the domestic, as well as industrial devices are power electronic based and are the main source of heat pump optimization system. In this work author has used a technique in which he utilized the concept of shunt active power filters along with

PPFO based algorithm for the sake of removing harmonic content

Satyavarta Kumar Prince et. al. [2] in 2018 has discussed that in recent times more dynamic load patterns are observed which eventually require optimized heat pump. The model has outperformed the conventional p-q theory-based PI controlled power quality improvement technique and the previous one was found superior in terms of performance.

Snehaprava Swain et. al. [3] in 2017 has proposed an controller for HVAC system which will make the generator be in continuous contact with grid so as to feed power continuously even at the time of fault situation. The results of this technique have been verified by designing and simulation the proposed model over MATLAB/Simulink software and the results are very much up to the mark.

Rini Ann Jerin et. al. [4] in 2016 has discussed that due to progressive integration of heat pump to the power system, loads have become more sensitive towards the change in input voltage supply. The authors has proposed a technique called DVR for providing assistant in such conditions. This DVR has the responsibility to provide firing angle to PWM based inverter supply.

Om Prakash Mahela et. al. [5] in 2016 has proposed that in order to regulate the operation of heat pump, DSTATCOM could be very useful. The objective is to control this reactive with the help of STATCOM device. The work has been tested over 13-bus system and has found to be affective.

Soumya Mishra et. al. [6] in 2016 has proposed a novel method called JAYA which has the responsibility to control the PI controlling units output which is used along with DSTATCOM. This work incorporate a controlled heat pump system. According to authors, the main advantage of JAYA, which make it far better, then algorithm-based techniques, is that it has no dependence over linear controlled parameters.

III. INTRODUCTION TO HEAT PUMP

A heat pump is an electrical device that extracts heat from one place and transfers it to another. The heat pump is not a new technology; it has been used in Canada and around the world for decades. Refrigerators and air conditioners are both common examples of this technology.

Heat pumps transfer heat by circulating a substance called a refrigerant through a cycle of evaporation and condensation. A compressor pumps the refrigerant between two heat exchanger coils. In one coil, the refrigerant is evaporated at low pressure and absorbs heat from its surroundings. The refrigerant is then compressed en route to the other coil, where it condenses at high pressure. At this point, it releases the heat it absorbed earlier in the cycle.

Refrigerators and air conditioners are both examples of heat pumps operating only in the cooling mode. A refrigerator is essentially an insulated box with a heat pump system connected to it. The evaporator coil is located inside the box, usually in the freezer compartment. Heat is absorbed from this location and transferred outside, usually behind or underneath the unit where the condenser coil is located. Similarly, an air conditioner transfers heat from inside a house to the outdoors.

The heat pump cycle is fully reversible, and heat pumps can provide year-round climate control for your home – heating in winter and cooling and dehumidifying in summer. Since the ground and air outside always contain some heat, a heat pump can supply heat to a house even on cold winter days. In fact, air at –18°C contains about 85 percent of the heat it contained at 21°C.

An air-source heat pump absorbs heat from the outdoor air in winter and rejects heat into outdoor air in summer. It is the most common type of heat pump found in Canadian homes at this time. However, ground-source (also called earth-energy, geothermal, geoexchange) heat pumps, which draw heat from the ground or ground water, are becoming more widely used, particularly in British Columbia, the Prairies and Central Canada.

IV. METHODOLOGY:

Following techniques are utilized in present work for the purpose of optimizing VRF:

Artificial Neural Networks (ANN): The evolution of ANN has been dated back in 1980's with the evolutions of computers. From the very same process of evolution, the term artificial neural network is been derived. The word artificial is used to denote the capability of this model to replicate the working of human brain. Usually machines possess a property work according to pre-defined instruction saved in it. However, this is not how human works. The brain of any human has the capacity to take decision based on its experience which we call training in computers language. Hence, it gives capability to brain to take decision that too right in cases which are new to it. Therefore, machine learning is a method by which we inherit this specialty of human biological thinking system and try to replicate same in computer/machine.

Now let's understand how human brain works to form exact algorithm which can give similar outputs. Brain consist of billions of neurons, which are interconnected with each other. These interconnections have a certain strength, which makes our memory storage. Based on these memories we take decision over everything in real time. The strength of these connections depends mainly on signal from various cells/neurons situated in each part of our body. These neurons continuously send signal according to sense organs response to brain in the form of electromagnetic pulses.

Fuzzy Logic: Introduction

The word 'fuzzy' usually used for cases in which there is no clear answer or boundary like there is a vague situation. Fuzzy unlike Boolean logic where things can be either 0 or 1 i.e. true or false represent value with the degree of truth. This fuzzy logic is applicable to all real-world problems because in none of them the boundary is clear. The value in fuzzy logic comprises of value between 0 & 1 Including two.

Fuzzy logic was proposed in the USA by Prof L. A. Zadeh, in the early 1960s. Lofti A. Zadeh. This method mimics the way operation of expert's opinion over any decision making. Let us understand the concept of fuzzy logic by taking a real-life event and comparing it with crisp set. Let there be a person named Rahul. Now we use crisp set which is also known as Boolean set then it can be represented by following figure

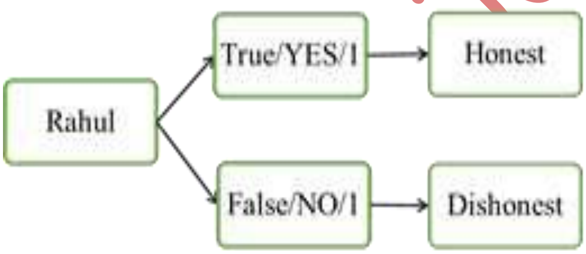

Figure 1 Boolean set logic

Now in this set Rahul can either be honest or dishonest. Now let's represent same situation using fuzzy logic. Now let's represent same situation using fuzzy logic.

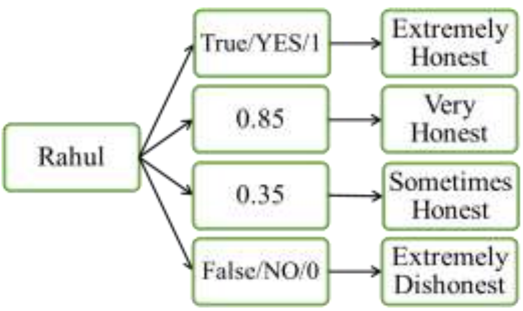

Figure 2 Fuzzy set logic

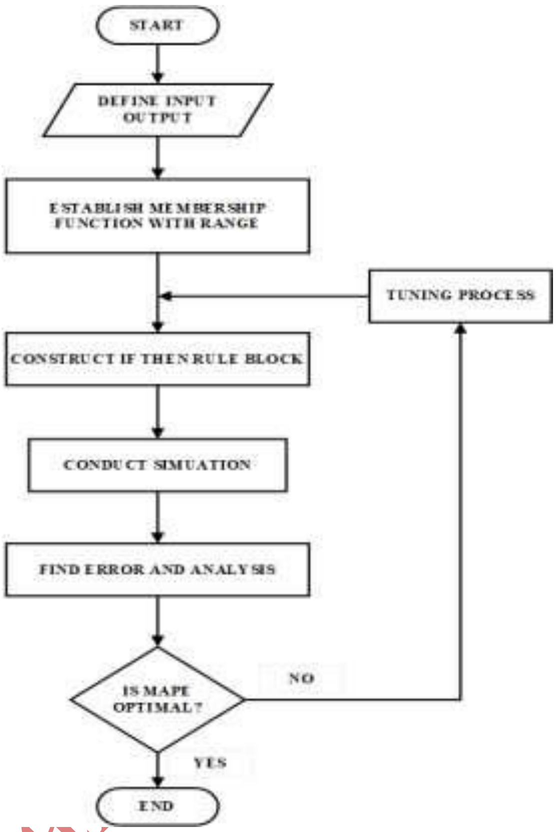

Figure 3 Flow chart for fuzzy logic

After defining membership function the next step is to develop rule base using knowledge base by expert opinion. These rules are defined based on if then conditional statement. Once these rules are formed a simulation is done based on input and output data. Based on this data error is calculated on forecasted and actual value of output parameter. After evaluation of error a comparison is done with the required optimum error value. If target is reached then no further training is required and process will end, otherwise a further tuning of the process is done to improve result and same steps are followed again.

V. RESULTS

In this chapter the results obtain from the proposed models are shown and discussed. The work comprises of two techniques one without fuzzy logic controller and other with fuzzy logic controller. The outputs obtained from two models are compared and conclusion on two is made.

Results obtained by Controller model without Fuzzy logic

The below is a block diagram for the design heat pump (fan) speed controller without fuzzy logic controller. The controller is designed with the help of PI controller.

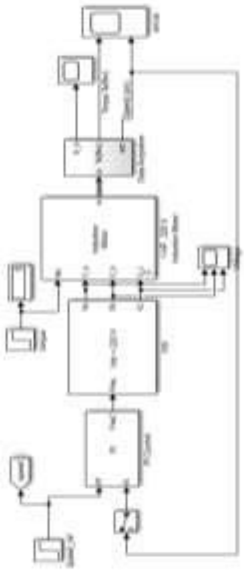

Figure 4Simulink Block diagram for PI control method

Figure 4 shows the simulation diagram for the above proposed model. The model comprises of a reference speed at which the system is expected to operate. The there is a feedback system which continuously send the present speed of heat pump in rpm. The error between the two is generated. This error signal is the one which will help is deciding the control signal. The signal is further transformed using voltage source inverter and PI controller. This provide a variable torque speed characteristics of heat pump based system.The results obtained with this are explained below.

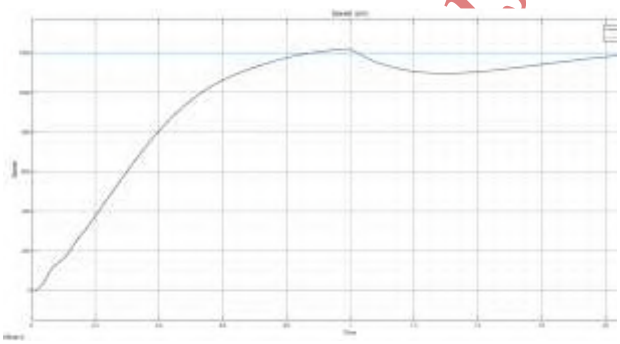

Figure 5speed vs. Time of a Heat pump for PI control method

FLC Controller-Based Speed Control Model and Results

In this section we will discuss the results obtained for fuzzy logic based controller. MATLAB software has a pre-designed fuzzy logic designed with the help of which we can design the required model for present work. The below figure shows the present work utilized model architecture. There are two input signals and an output signal.

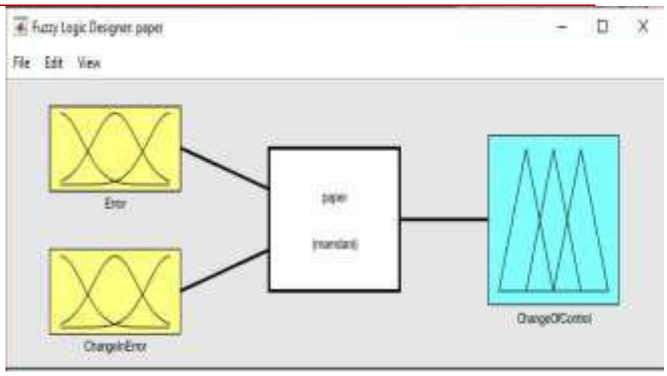

Fig.6 FIS Editor: rules window

The shown figures are for various different membership functions of inputs and outputs. The function designed on the basis of expert opinion. The shape and size of this signal functions will help in predicting the required results from the Simulink model.

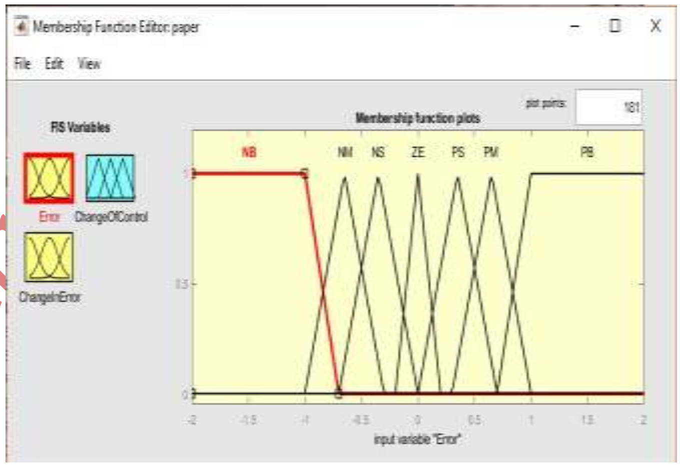

Figure7 MF of Input Error (e)

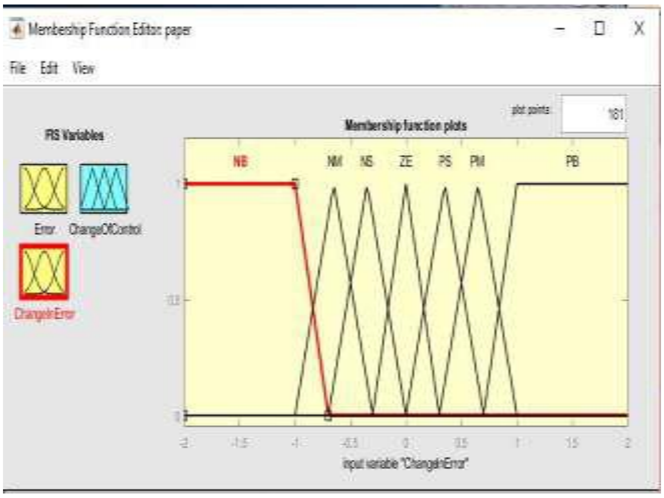

Figure 8 : MF of change of control (Δe)

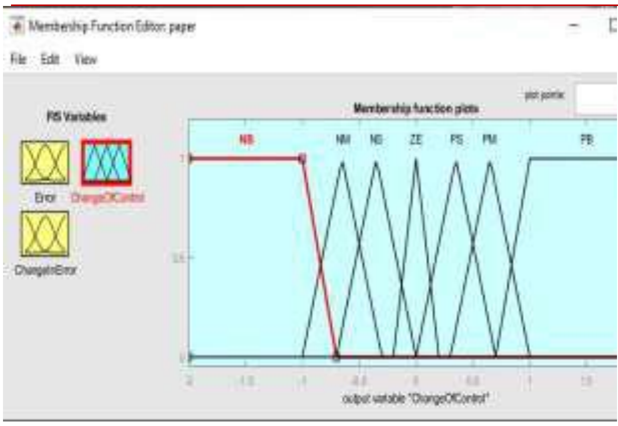

Figure 9 MF of output change of control

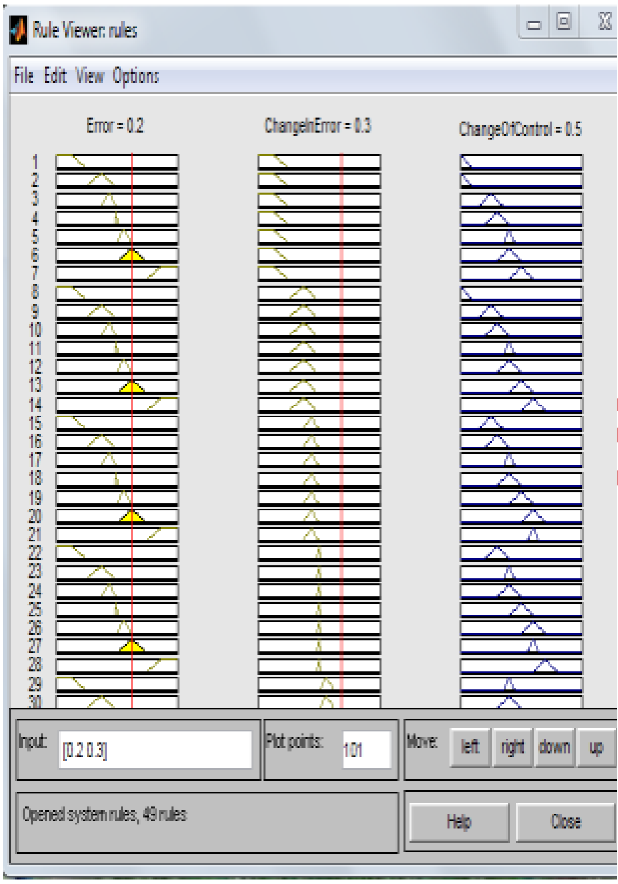

Figure 10 Rule Viewer with e = 0.2 and Δe = 0.3

The figure shown below is the Simulink block diagram for present wok. Similar to previous case it also have a reference speed at which heat pump is required to operate at minimum possible time. Again a feedback signal is provided to the input side to calculate the error signal. This error signal is than moved towards fuzzy logic controller before which it is delayed by a step to calculate the change in error. The value this two is provided to FLC which gives output in the form of required signal to v/f controller. This controller will generate the required signal for inverter to generate output according to the required speed by controlling voltage and frequency. The signal so generated is a 3 phase signal for a large turbine system.

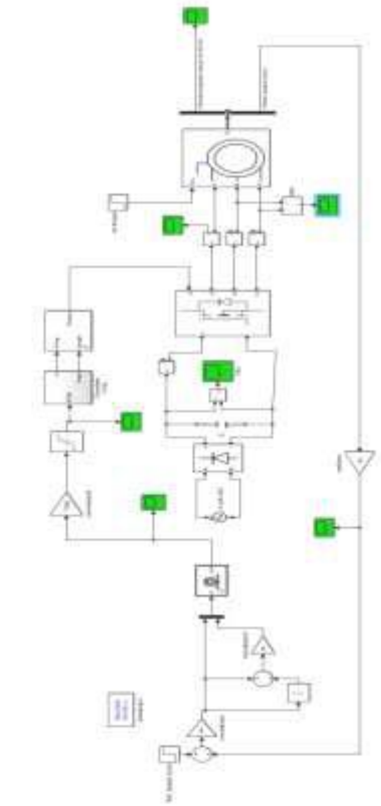

Fig 11 Block diagram of Fuzzy Logic based Speed controller

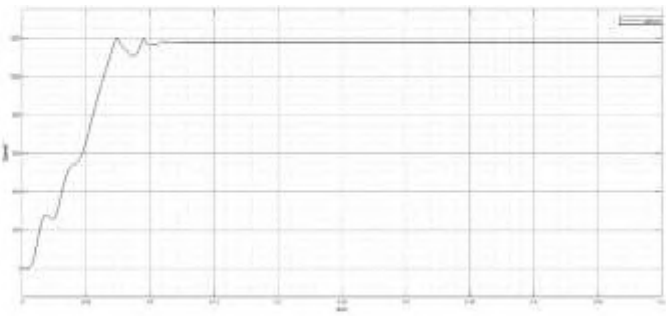

Figure 12:Speed vs. Time of Stator of heat pump based on using Fuzzy controller

VII. CONCLUSION

By far in this work a through discussion is dine over heat pump and its controlling. Work has successfully discussed the motivation and objective behind present work. Then in this work a detailed discussion by various authors has been done chapter 2. In their chapter a brief introduction too heat pump and its component has been done. In forth chapter we have discussed in detail regarding the proposed methodology that is Fuzzy logic and its mathematical operations. Then in Chapter 5 Results are presented. In first section simulation model of speed controlling of fan of Heat Pump without use of Fuzzy logic is presented. On simulation it is observed that the time take by this model to reach desired speed has been 2 sec, means in this time the machine will be back in stable state and at full operating condition. Then in next section simulation model of fuzzy logic controller based heat pump is discussed. On evaluating results it has been seen that that the in which the model retain its stable state by reaching desired speed is 0.2 sec. On comparing the results of two model it is clear that fuzzy logic has an upper hand in controlling heat pump fan in quick duration of time.

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