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A Hybrid Approach for Temperature and Humidity Control in HVAC System and Optimization With Fuzzy Logic

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ABSTRACT

The main objective of this paper is to shed light on this new but highly promising hybrid approach of fuzzy logic and adaptive neuro-fuzzy network, its use in control systems, particularly in the field of computer science and engineering applications. The original objective of this paper is to study the variations in the energy consumption by changing the input parameters and the stability of the system in terms of system response time and error arising during changing the input values of the system. This paper takes the model a step forward, in that the mathematically based and derived model is modified to use in design a practical fuzzy controller and to apply it in a real-life application, such as the temperature control problem. This model is modified to make traditional controller some explicit when multiple constrained resources available. This model is derived to provide a robust quantified fuzzy system that can find out the level of satisfaction and provide a practical and intelligent tool for further accessing the impact of different options available to the fuzzy logic controller.

Keywords: *Heating ventilating air conditioning (HVAC) system, fuzzy logic, artificial neuro-fuzzy inference (ANFIS) system, fuzzy logic controller (FLC) and proportional-integral-derivative (PID) controller.*

1. INTRODUCTION OF SYSTEM

Minimization of energy consumption and maintaining the thermal comfort level are two main topics in the heating, ventilating and air conditioning system. The reliability of the controller is also important. A first-hand approach for building the fuzzy logic based controllers in Matlab/Simulink environment is presented in this paper.

The architecture and training procedure major ANFIS (artificial neuro-fuzzy inference system) presents the concept, due to this a fuzzy inference system executed in the adaptive networks. By using a hybrid learning outlook, the offered ANFIS was assembled an input-output mapping based on both human knowledge (in the form of fuzzy if-then rules) and required input-output data. In the simulation process, the ANFIS architecture was engaged to model uneven functions identify uneven components in a control system. Controllers of HVAC systems were expected to be able to operate the inherent nonlinear characteristics of these large-scale systems that also have uncertain interference factors big thermal inertia, pure lag times and restriction.

In this concept, indoor thermal comfort was also affected by both temperature and humidity. To control these coupled characteristics and solve nonlinearities effectively, this project proposed a hybrid approach of ANFIS and FUZZY control strategy. The model was first trained using triangular membership method for Nonlinear Regression algorithm with data collected from both buildings and HVAC system tools.

This model was tuned using the FIS editor to enhance the stability of the overall system and reject disturbances and uncertainty effects. For comparison purpose, normal fuzzy and hybrid PID Cascade control schemes were also tested. The results of this approach are demonstrated like superior performance, adaptation, and robustness of the proposed control strategy.

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The results of this approach are demonstrated like superior performance, adaptation, and robustness of the proposed control strategy. The simulation results obtained by FLC are also compared with the results obtained using PID controllers for applicability validation of the developed FLC block in Matlab/Simulink environment. Results indicate that the selections of certain parameters or combinations of parameters, affect greatly the performance and stability of the fuzzy controllers.

2. INTRODUCTION OF HVAC SYSTEM.

A heating ventilating air conditioning (HVAC) system is comprised of all the components of the appliance used to condition the interior air of a building. The HVAC system is needed to provide the occupants with a comfortable and productive working environment which satisfies their physiological needs. Temperature and relative humidity are essential factors in meeting physiological requirements. When the temperature is above or below the comfort range, the environment disrupts person's metabolic processes and disturbs his activities. Therefore, an HVAC system is essential to a building in order to keep occupants comfortable. A well designed operated and maintained HVAC system is essential for a habitable and functional building environment. Out of date, unsuitable, or misapplied systems result in comfort complaints, Indoor Air Quality issues, control problems, and outrageous utility costs. [1]

Many HVAC systems do not maintain a uniform temperature throughout the structure because those systems employ unsophisticated control algorithms. Heating, ventilating and air conditioning (HVAC) systems in the many existing industrial and commercial buildings consume a large amount of the world's energy. Although the development of modern control techniques for HVAC systems is focused on improving energy efficiency, most HVAC equipment in existing buildings is still insufficient and high energy consumption. Thus, providing more effective control of HVAC systems and improving the energy efficiency of existing HVAC equipment are important for energy saving. The first thing for saving energy in HVAC systems is to analyze the space thermal loads.

The prediction of room thermal load makes it possible to fulfill the goals of energy efficiency. However, both thermal space loads and HVAC systems are complex and coupled. The prediction of the thermal load will be affected by outdoor weather, indoor thermal gains and other elements of the HVAC systems. It is difficult to detail their nature with exact mathematical models. Many studies have substituted simplified and linearize models for actually nonlinear HVAC systems. The simplified and linearize mode cannot work well in real engineering operations. Meanwhile, the thermal load changes can be regarded as alterations of the air enthalpy in the room. Therefore, the theory of enthalpy can be utilized to predict space air conditions. In a modern intelligent building, a sophisticated control system should provide excellent environmental control.[2]

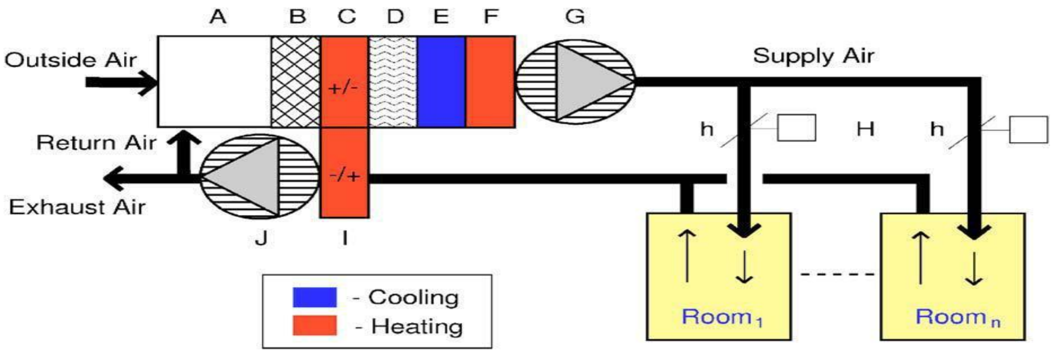

Figure 1: It Shows a Typical Office or Industrial Building HVAC System

3. CLASSIFICATION OF HVAC CONTROL TECHNIQUES

A brief classification of control techniques in HVAC systems is illustrated in Figure 2.

Classical Control

Classical controllers consist of the most commonly used control techniques, such as on/off control and P, PI, and PID control. The on/ off controller uses an upper and lower threshold to regulate the process within the given bounds, The P, PI, and PID controllers use error dynamics and modulate the controlled variable to achieve accurate control of the process.

Hard Control

Hard controllers are based on a theory for control systems composed of gain scheduling control, nonlinear control, robust control, optimal control and MPC. In gain scheduling control, a nonlinear system is divided into piecewise linear regions. For each of the linear regions, a linear PI or PID controller is designed with a different set of gains.

Self-tuning PI or PID controllers vary the controller gains based on the state of the process.

Soft Control

Soft control techniques such as those based on FL [3] and ANN [4] are comparatively new techniques made possible by the advent of digital controllers. In an FL controller [5], control actions are implemented in the form of if-then-else statements. The FL also can be incorporated for the auto-tuning of PID controller gains in which PID control represents the local scope of control, and the FL supervisor is often used to optimize the response of the system on the global scale. The fuzzy supervisor also acts as an arbiter and resolves conflicting objectives from the local level controllers by prioritizing certain controllers over others based on the common goals of reduction in energy consumption and maintenance of thermal comfort.

The ANN is trained on the performance data of the system and fits a nonlinear mathematical model to the data. The algorithm is a black box modeling technique that does not require an understanding of the underlying physics of the process. The ANN is commonly used in feed-forward control, and ANN can be trained on the controller input/output in an attempt to replace a conventional controller in that application. Examples of ANN design include a PMV-based thermal comfort controller for zone temperature control [6], optimization of air conditioning setback time based on outdoor temperature [7], and fan control of an air-cooled chiller [8].

Hybrid Control

Hybrid controllers are produced by the fusion of hard and soft control techniques. Several controllers, including quasi-adaptive fuzzy control [9] adaptive-neuro control [10] and fuzzy-PID control [11] have been proposed for the control of HVAC systems. Hybrid controllers are composed of soft control techniques such as ANN at higher levels and hard control techniques such as adaptive controllers at the lower levels of the control structure. In fuzzy-PID systems, controller gains can be auto-tuned using FL. Both hard and soft control techniques complement each other, and a combination of both can solve problems that may not be solved by each technique separately. Examples of hybrid control include a fuzzy self-tuning PI controller for systems supply air pressure control [12] and a quasi-adaptive fuzzy controller for zone temperature control [13] using convector-radiator power control.

Other Control Techniques

Other control techniques, such as direct feedback linear (DFL) control[14] pulse modulation adaptive controller (PMAC)[15] pattern recognition adaptive controller (PRAC) preview control[16] two parameter switching control (TPSC)[17] and reinforcement learning control[18] have also been proposed for the control of HVAC systems. Reinforcement learning control [18] have also been proposed for the control of HVAC systems.

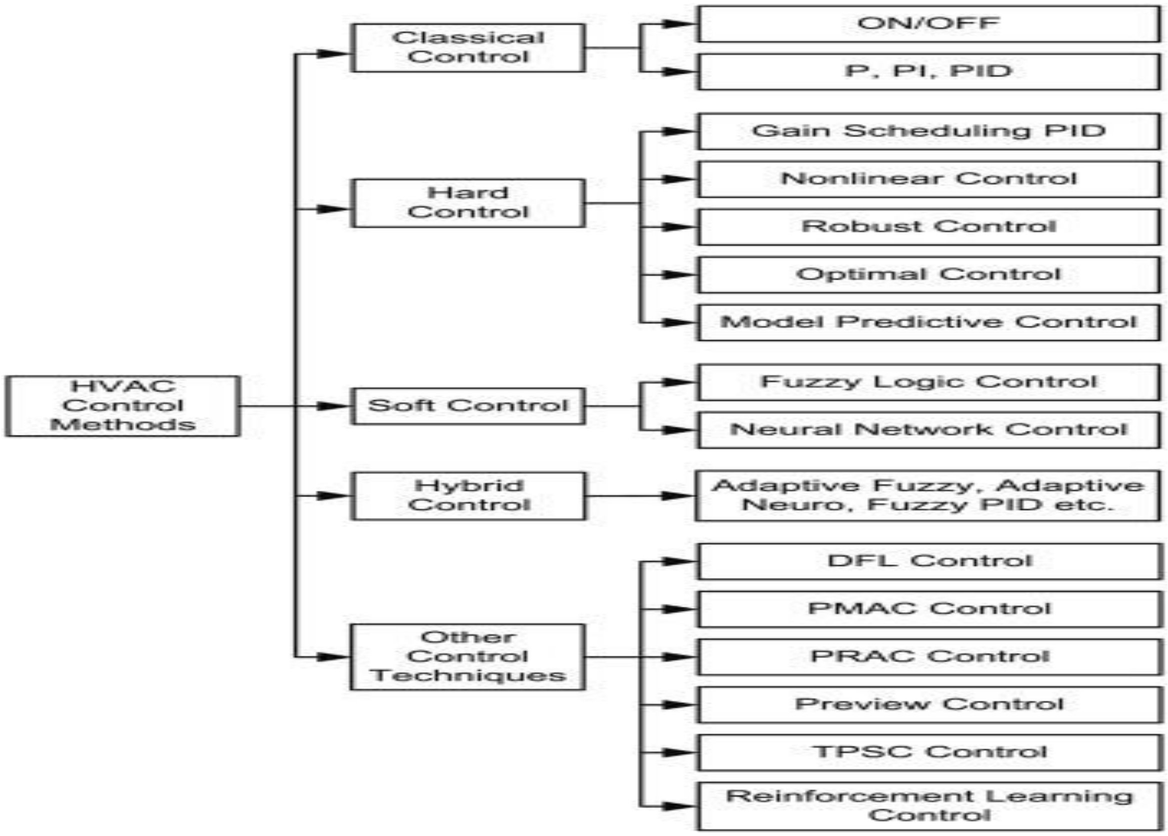

Figure 2: Classification of Control Techniques in HVAC

4. IMPLEMENTATION OF MODEL USING MATLAB

System Design with PID Controller

A PID controller is a control loop response mechanism that commonly used in industrial control systems. A PID controller continuously calculates an error value e(t) as the difference between the desired set point and a measured process variable and applies a correction based on proportional, integral, derivative terms (sometimes denoted P, I, and D respectively) which give their name to controller type. (Figure 3)

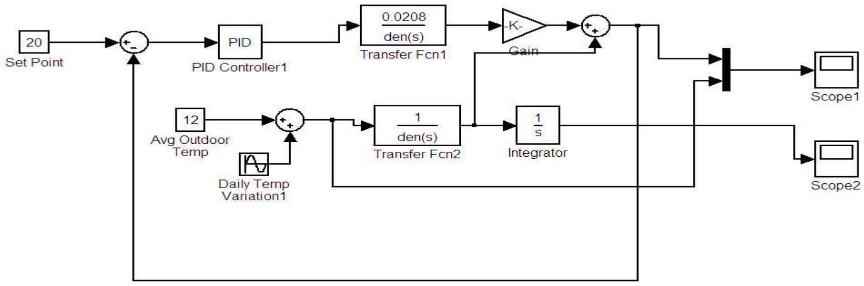

Figure 3: Simulink Model Design for PID Controller

The controller attempts to minimize the error over time by adjustment of control variable u(t), such as the position of the control value, a damper, or the power supplied to a heating element, to a new value determined by a weighted sum:

$$u(t) = k_p\, e(t) + k_i \int^t e(t)\, dt + k_d \frac{de(t)}{d(t)}$$

Where k_p, k_i, and k_d all denote the coefficients for the proportional, integral and derivative terms respectively.

System Design with Fuzzy Logic Controller

In this Simulink model, a PID controller is replaced by the fuzzy logic controller which has one input and one output. The input is the temperature difference between indoor and outdoor temperature (i.e. temperature difference) and output is energy consumed by the controller. The variation in controlling temperature and energy consumption will show in results. By run simulation again, we could see how the real indoor temperature is very close to the desired temperature.

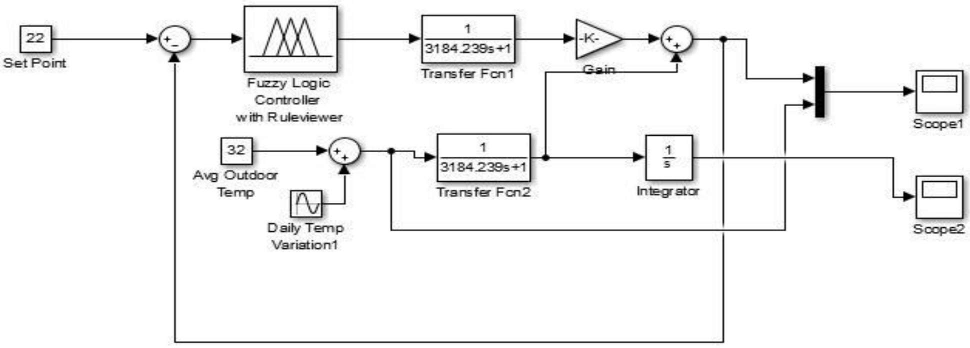

Figure 4: Simulink Model Design for Fuzzy Logic Controller with one Input and one Output

This Simulink model is now modified with two inputs instead of one input. The two inputs are the temperature difference between indoor and outdoor temperature and humidity level and output is energy consumption. By this modification, we can see the sharp changes in indoor temperature and energy consumption result graphs. The data for average outdoor temperature is taken from the record from Wikipedia report at New Delhi and “a share” transaction for weather forecasting. This given temperature is the average mean temperature of recorded data.

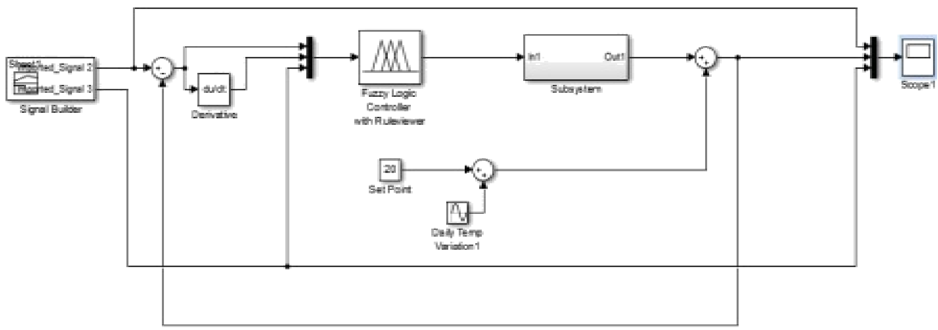

Figure 5: Simulink Model Design for Fuzzy Logic Controller with two Inputs and one Output

This Simulink model is again modified with three inputs and one output. The three inputs are the temperature difference, the rate of change of temperature and humidity level and the output is energy consumption. The design of the fuzzy controller is related to the choice of the knowledge base, decision- making logic, and defuzzification mechanism. This model also has done a great change in output corresponding to given inputs.

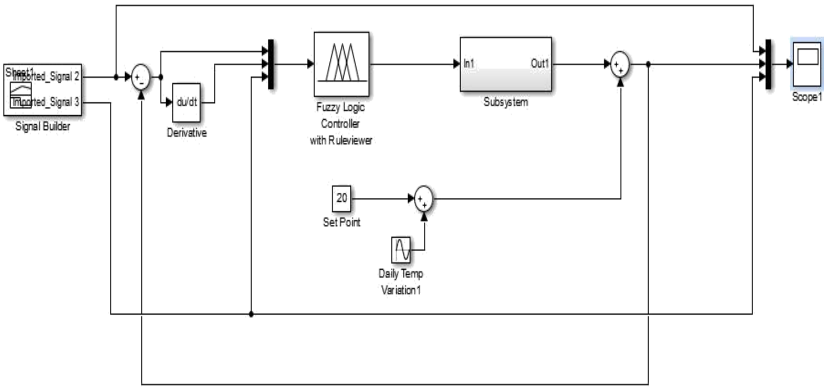

Figure 6: Simulink Model Design for Fuzzy Logic Controller with three Inputs and one Output

System Design with Fuzzy Logic Controller Trained by ANFIS

Selection of the appropriate membership functions and the rule base affects ANFIS controller accuracy. In the ANFIS controller, neural network algorithm is used to select a proper rule base which is accomplished using the back propagation algorithm. The used fuzzy inference technique is Sugeno method. A hybrid training algorithm is used where a combination of the gradient descent algorithm and a least squares algorithm is used for an effective search for the optimal parameters. The main benefit of ANFIS is that it converges much faster since it reduces the search space dimensions of the back propagation method used in neural networks.

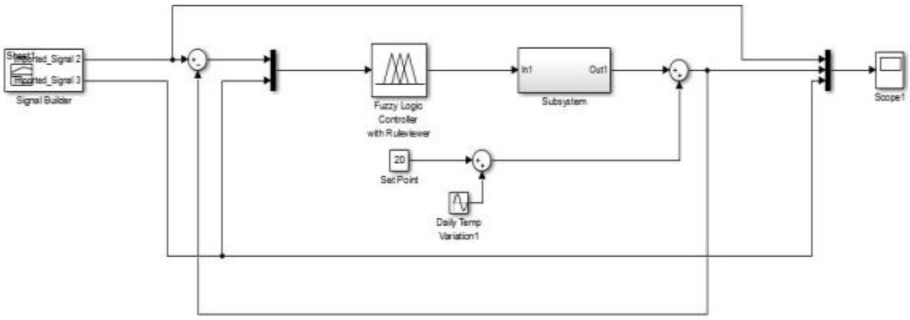

Figure 7: Simulink Model Design for Fuzzy Logic Controller Trained with ANFIS

5. EXPERIMENTAL RESULTS OF SIMULINK MODEL

Output Graph for Simulink Model

We get the result in the graphical form and in the sound form also by using Fuzzy, Simulink, etc. The result clearly shows that the oscillations are reduced from the indoor temperature.

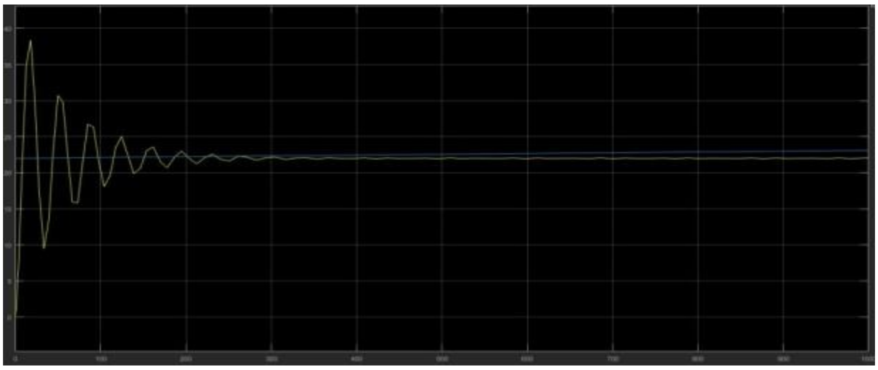

Figure 8: Simulation Result of PID Controller

This model gives a very high oscillated output in indoor temperature and very high energy consumption (Figure 8). Next result for the optimized model, this result shows the variation in temperature is close to desired temperature and oscillations reduced to linear the variation in temperature. Energy consumption is also low as compare to PID controller. This Simulink model (Figure 9) is based on the fuzzy logic controller with one input and one output.

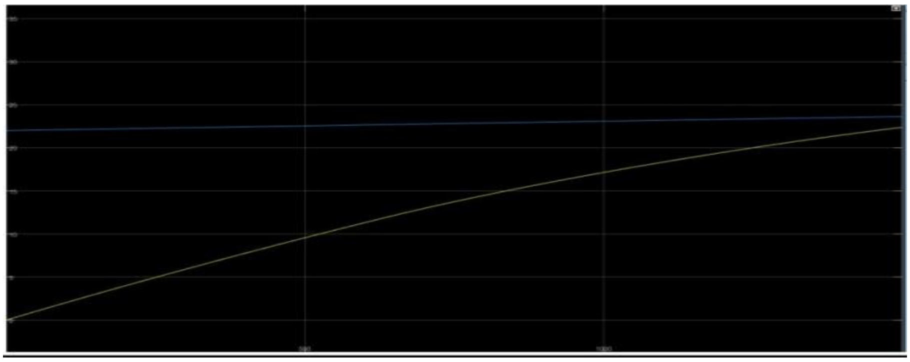

Figure 9: Simulation Result of Fuzzy Logic Controller with one Input

The fuzzy based Simulink model is modified with one new membership function (i.e. humidity level). In this model, the fuzzy controller has two inputs and one output. This model has a curve graph which tends to be linear and very close to desired temperature (Figure 10). The energy consumption also becomes efficient as compare to fuzzy controller based model for one input.

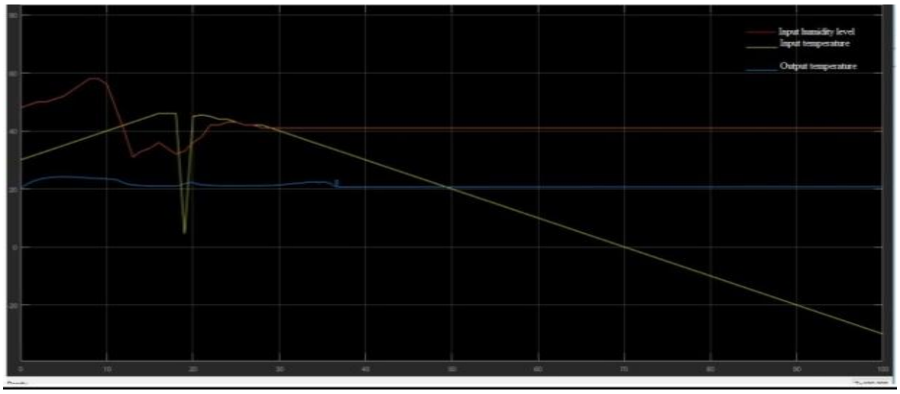

Figure 10: Simulation Result of Fuzzy Logic Controller with two Inputs

The fuzzy based Simulink model is again to be modified with one new input. This model has three input membership function and one output membership function. In this model, the fuzzy controller has three inputs (temperature error, rate of change of temperature and humidity level) and one output (energy consumption). In the output of this model, a constant linear graph is shown in (Figure 11) which tends to become similar to desired temperature and energy consumption is also very efficient than other two models discussed in this analysis.

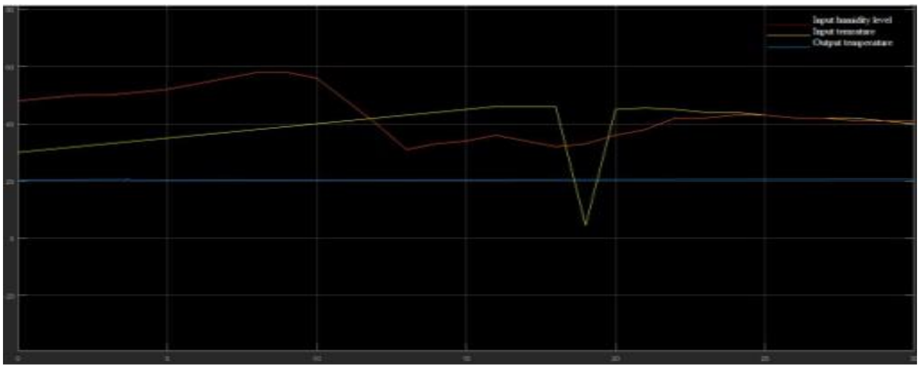

Figure 11: Simulation Result of Fuzzy Logic Controller with three Inputs

The fuzzy based Simulink model is again to be modified by training of controller with the help of ANFIS. This model has three input membership function and one output membership function. In this model, the fuzzy controller has three inputs (temperature error, the rate of change of temperature and humidity level) and one output (energy consumption). In the output of this model a constant linear graph is shown (Figure 12) which tends to become similar to desired temperature and energy consumption is also very efficient among all the models discussed in this analysis. This model shows a faster and smoother simulation then the other models.

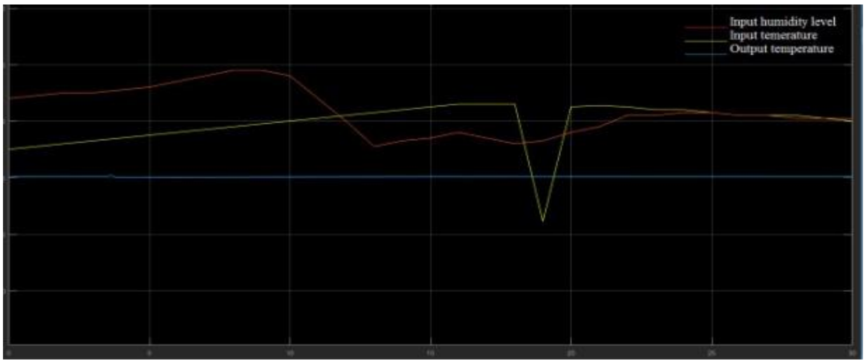

Figure 12: Simulation Result of Fuzzy Logic Controller Trained with ANFIS

6. EXPERIMENTAL RESULTS

To evaluate the goodness of the proposed technique, several experiments have been carried out within the framework of the MATLAB/SIMULINK. Five Simulink models were available for the experiments. The first one is provided with PID controller while the second belongs to a fuzzy logic controller. From now on, the latter will be modified version of the fuzzy logic controller with one input, two inputs, three inputs and fuzzy logic controller trained with ANFIS. In all cases, the main objective was the energy performance but maintaining the required indoor comfort levels. To run the proposed tuning technique, accurate models were provided with the expert knowledge base. These models assess the tuning algorithm for fitness computation. Then, the data contained the output obtained from the experimental work were used for forming ANFIS model. The realized HVAC system's data were used in this study to train and test the ANFIS models. All program codes were generated by using MATLAB. One of the outputs was controlled by using the required value for indoor temperature while the output controlled by using the required value for indoor humidity.

Half of each indoor temperature/humidity data were used to training stages and the other parts were used to test stages. Indoor temperature, the difference between the indoor temperature and the ambient temperature and the first derivation of the difference between the indoor temperature and the ambient temperature were used as input for the first ANFIS model and the energy consumption was used as ANFIS model output. The results obtained were very satisfactory, especially for the fuzzy logic controller trained with ANFIS model. Due to a large number of results, this will work only with a limited data of inputs of the models.

7. CONCLUSION

Throughout this research paper the points that have been concluded that under certain restrictions and assumptions, the fuzzy control system can be expressed analytically with theoretical foundations and can be used effectively in real life applications. This point leads to the possibility of establishing a standard design procedure in a similar fashion to conventional control methods. The similarities and differences between the conventional approach and fuzzy approach are highlighted throughout this concept so that the exchanged benefits between the two are utilized. The second point concluded is that the fuzzy logic control system can be applied successfully to complex nonlinear systems as well as simple linear systems. The knowledge needed to design such control systems can be minimized, provided that the fuzzy controller design processes are standardized. Standardization of the fuzzy logic controller design processes saves time and makes it possible for the designer to obtain the needed information about the system.

In this concept, many simulations have been carried out to study the implementation of fuzzy logic control in HVAC control system. The simulations also include the study on the previous controller, which is PID controller. The performance of both types of control techniques is carefully studied.

A fuzzy-based HVAC control system has been developed and successfully demonstrated. The system has been designed for maintaining the temperature and humidity at any desired value. The membership function can be modified to achieve any desired temperature. The use of fuzzy logic provides very fast response and reliable operation. Through this concept, we implement the approach of ANFIS which helps the fuzzy logic system to trained with its algorithms. The results of the trained system give better, fast and smoother output as we see in simulation results. As the software is more or less common for all control application, this can use this fuzzy control for other applications including non-linear systems. The ultimate advancement possible will be Incorporation of Simulink model in combination with the fuzzy algorithm. Simulink model can be used to completely authorize the design process of fuzzy systems.

8. MERITS OF ANFIS

The merits of ANFIS can be concluded in the following three aspects. First, stability is a very complex issue, which contains various complicated non-linear relationships between variables. The ANFIS approach can easily handle the complex non-linear MFs and is suitable for temperature stability. This study validates that the complex non-linear MFs can be easily applied in ANFIS models. Second, the ANFIS has the advantage of time-saving, especially in membership function optimization. For traditional pre-defined membership functions, it is difficult and time-consuming to execute the membership function optimization because each membership function is based on experts' knowledge. Experts need to spend a lot of time to define the parameters of each fuzzy set of MFs, which indicates that the more MFs used in the HVAC system, the more difficult and time-consuming it is. For ANFIS approach, it is easy to define the parameters and optimize the MFs, and the process is time-saving because it is based on the data training rather than the expert knowledge.

9. FUTURE SCOPE

In this research paper concept lays the groundwork for in-depth analytical studies and the development of a more generalized fuzzy based HVAC system. Future work could continue on the same path as the one presented in this research paper. The future studies could be concentrated on the investigation of the spline-based membership functions. The choice of the membership functions for the inputs and outputs of the fuzzy controller should be investigated based on the generalization characteristic of the normalized spline-based membership function. The future goal in this regard should be directed toward obtaining an adaptive and selective fuzzification algorithm so that the choice of the membership function shape and the overlapping ratio is selected automatically to fit the system design criteria. The software development for designing and simulating a fuzzy controller should also be the focus of any future studies as well.

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