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Fuzzy Greenhouse Climate Monitoring and Control Simulation Using Sugeno Method

S. R. Potdar
Department of Physics, A. S. C. College, Rahata, Dist-Ahmednagar, Maharashtra, India

***Abstract* - In this paper we have presented Simulation of Fuzzy Greenhouse Climate Monitoring and Control System (FGCMC) using MATLAB-SIMULINK. The climate monitoring process is implemented using Mamdani type Fuzzy system and controlling is done using Sugeno type Fuzzy system. The temperature error and Humidity error are used to activate the various control strategies and simulation results are studied.**

***Index Terms* - Fuzzy Logic, Sugeno Method, Greenhouse Climate Control, Simulation.**

1.INTRODUCTION

The multifaceted climate variables present in the Greenhouse system makes it difficult to understand the crop fertility climate and further complicates the control action to optimize it. The other variables should be carefully monitored while adjusting single variable in the system. Fuzzy Logic is a powerful tool that reduces the efforts of the system designer in keeping track of various inter-reliant variables in the system while taking the control decision to optimize the crop growth climate[1]. Fuzzy Logic with the aid of linguistic variable values and the rule definition in simple IF…THEN syntax simplifies the development of monitoring system and delineation of the control system[2]. The FGCMC system takes the climate parameters comprising Internal Temperature, Internal Humidity, External Temperature and External Humidity. The FGCMC controls the subsystems such as Heater, Fogger, Exhaust Fan and Ventilators of the Greenhouse to manipulate the internal climate of the Greenhouse.

After receiving the inputs from the Greenhouse the error difference is calculated to define the amount and polarity of change in the climate variable from the optimal climate condition. The calculated error values are then provided to both the FIS systems to carry out the monitoring and control action. The entire FGCMC system using Simulink is given in figure 1.1. There are two Fuzzy systems: i) The Fuzzy Greenhouse Climate Monitoring (FGCM) system provides the current climate condition of the Greenhouse and ii) The Fuzzy Greenhouse Climate Control (FGCC) system manipulates the control subsystems to maintain the crop fertility climate to the desired level[3,4].

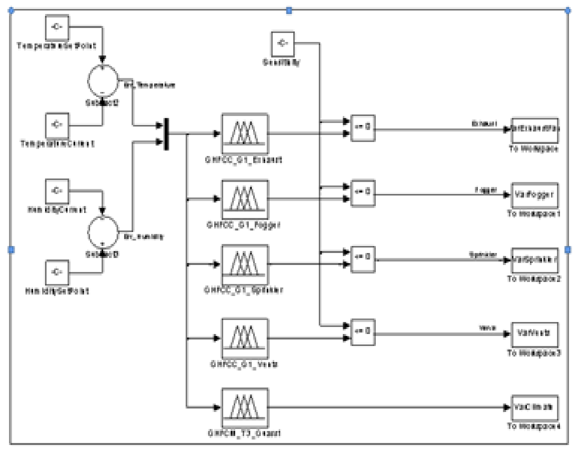

Figure 1.1 Simulink Model of FGCM system

2. FUZZY GREENHOUSE CLIMATE MONITORING (FGCM) SYSTEM

Temperature and humidity are the interdependent parameters of the Greenhouse. Defining the optimal climate condition of the Greenhouse that enables the optimal crop growth is not easy due to inherent inter-reliance characteristic of the variables. The FGCM system aids the user to understand the Greenhouse climate toggling around the required internal climate of the crop. The crop fertility climate condition provided by the FGCM system is in the linguistic form; therefore user can easily understand the Greenhouse health and takes the necessary actions if required. The graphical display of the climate condition gives the user the better idea towards which the system has to be guided to achieve the climate of the Greenhouse. The difference in set points and current values of temperature and humidity are provided to the FIS from which FGCM derives the output of the current climatic condition with the help of the Rulebase and the Database of the FIS. The FIS of FGCM is shown in the fig. 2.1.

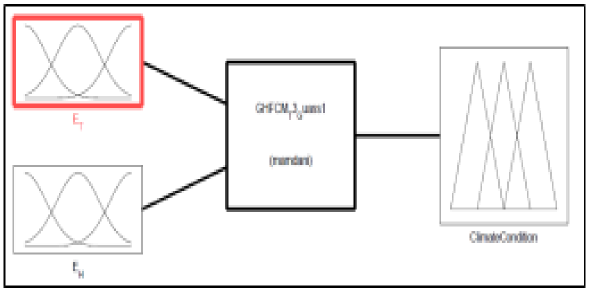

Figure 2.1 FGCM System FIS for Climate Monitoring

The FGCM defines the climate condition inside the Greenhouse with the help of the two input variables 'Error in Temperature' (ET) and 'Error in Humidity' (EH) which can be calculated as by equations (1.1) and (1.2) respectively.

$E_T = SP_{TEMP} - PV_{TEMP}$ ------------------ (1.1)

$E_H = SP_{RH} - PV_{RH}$.----------------- (1.2)

E_T : Error in Temperature
E_T : Error in Humidity
SP_{TEMP}: Temperature Setpoint
SP_{RH} : Humidity Setpoint
PV_{TEMP}: Present Temperature Value
PV_{RH} : Present Humidity Value

2.1 FGCM Fuzzy Inference System Design

Mamdani type with two input one output FIS is used to implement the FGCM with bell shape (Gaussian) membership functions for both input and output variables. The defuzzification method selected is of Centroid type. The UoD of all the variables are partitioned in to five fuzzy sets.

2.2 Fuzzification

The input variables viz. Internal Temperature and Internal Humidity interrelated to each other are selected for Fuzzification. Based on the on-line data the operating ranges are decided and variables are assigned meaningful linguistic values. Fuzzification has been carried out by appropriate membership functions over previously proven or currently set ranges. The fuzzy sets so obtained are then labeled using Term sets as follows-

Error Temperature (E_T)= {T_N, T_{NS}, T_Z, T_{PS}, T_P}

Error Humidity (E_H) = {RH_N, RH_{NS}, RH_Z, RH_{PS}, RH_P}

Climate Condition = {Bad, Poor, Average, Mediocre, Healthy}

Where,

T_N = Temp. Error Negative	H_N = Humidity Error Negative
T_{NS} = Temp. Error Negative Small	H_{NS} = Humidity Error Negative Small
T_Z = Temp. Error Zero	H_Z = Humidity Error Zero
T_{PS} = Temp. Error Positive Small	H_{PS}= Humidity Error Positive Small
T_P = Temp. Error Positive	H_P = Humidity Error Positive

Table 2.1 Labels used in FGCM system

The Gaussian type membership functions of FGCM FIS are depicted in fig. 2.4-2.6. The membership functions for input are designed so that the center function will denote the minimal error in the input variable and the error rate distributes toward both sides of the membership functions. The output membership function for Climate Condition defined to distribute health condition towards right side of the membership function.

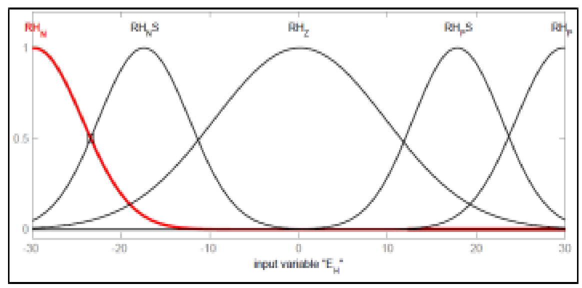

Figure 2.2 MF for input EH

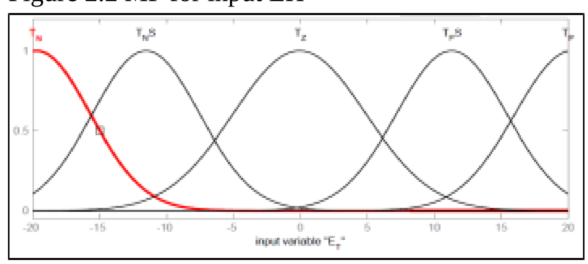

Figure 2.3 MF for input ET

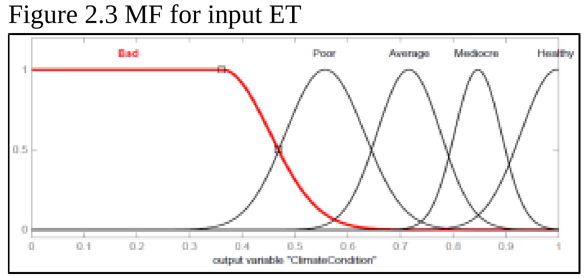

Figure 2.4 MF for Output Climate Condition

2.3 Knowledge Representation

The knowledge pertaining to the Temperature and Humidity control strategy is structurally formulated in terms of situation based action rules. These refer to the required information from the database. The knowledge base is thus composed of database and rule base.

a. Database

This includes the following-

- Membership functions representing the meaning of linguistic values of Temperature and Humidity.
- Labels of the fuzzy sets representing linguistic values of variables
- Operating ranges of FIS variables

b. Rulebase

The control policy of temperature and humidity inside the Greenhouse is formulated in terms of fuzzy inference rules. Total of twenty five (25) IF…THEN rules have been defined in conjunction with the AND operator. This rule base represents the control strategy employed in the Temperature and Humidity control of the Greenhouse. Typical set of rules is given in the table 2.1.

The rules in the Rulebase can be formulated in different groups depending upon the following factors-

- Crop development phases
- Crop types
- Greenhouse Topography
- Natural Climate Seasons

User can modify the rulebase to suit well to climate control policy according to the crop growth. The incoming Error in Temperature and Humidity values (E_T and E_H) after error calculation intersects with input fuzzy sets falling in the range of errors and accordingly fire two or more rules from the rulebase. The FIS then enters into fuzzy inference process.

Humidity / Temperature	Negative (RH_N)	Negative Small (RH_NS)	Zero (RH_Z)	Positive Small (RH_PS)	Positive (RH_P)
Negative (T_N)	Bad	Poor	Average	Poor	Bad
Negative Small (T_NS)	Poor	Average	Mediocre	Average	Poor
Zero (T_Z)	Average	Mediocre	Healthy	Mediocre	Average
Positive Small (T_PS)	Poor	Average	Mediocre	Average	Poor
Positive (T_P)	Bad	Poor	Average	Poor	Bad

Table 2.2 Rules defined for FGCM FIS

2.4 Fuzzy Inference Engine

The inference scheme employed in Temperature and Humidity control is based on the individual rule firing where contribution of each rule is evaluated and an overall decision is derived. During inference process each rule is individually fired by crisp values of ET and EH and fuzzification module determines Degree of Satisfaction (DoS) of rules. This generates clipped fuzzy sets (CFS) which represent the control command for the actuators of Control subsystems.

The Rule Viewer displays a roadmap of the whole fuzzy inference process. It shows the membership functions referenced by the antecedent i.e. if-part of each rule, the membership functions referenced by the consequent i.e. then-part of each rule and represents the aggregate weighted decision for the given inference system. This decision will depend on the input values for the system. The Rule Viewer allows the interpretation of the entire fuzzy inference process. The Rule Viewer also shows how the shape of membership functions influences the overall result. Rule Viewer further helps to see one calculation at a time and in great detail. In this sense, it presents a sort of micro view of the FIS that is of immense significance for optimization of final results

2.5 Defuzzification

Defuzzification of clipped fuzzy sets generated in the fuzzy reasoning process yields the single crisp value of climate condition that represents the aggregate fuzzy outcome. The centroid defuzzification method being simple yet stands as a good compromise of all other methods and it is shown in fig. 2.5.

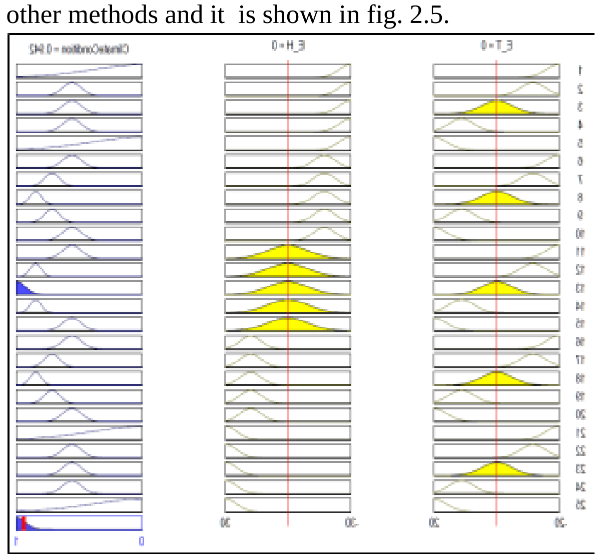

Figure 2.5 FGCM Rule Viewer

3. FUZZY GREENHOUSE CLIMATE CONTROL (FGCC) SYSTEM

Fuzzy Greenhouse Climate Control (FGCC) is a sub module of the Fuzzy Greenhouse Climate Monitoring and Control (FGCMC) system to act according to the control strategies. This module alters the climate by the means of different climate control subsystems and maintains the desired healthy climate inside the Greenhouse. This module is divided into sub modules according to the various control subsystems and their role in the climate adjustment. We here considered major four subsystems those can severely hamper the internal climate of the Greenhouse are as follows-

1. Exhaust Control Subsystem
2. Fogger Control Subsystem
3. Vent Control Subsystem
4. Sprinkler Control Subsystem

These four control subsystems are having prime role in the control of climate parameters like humidity and temperature. These subsystems are therefore carefully operated and controlled to get the sustained environment in the Greenhouse for the better growth of the implanted crop. The controlling algorithm is mainly responsible for this task and that leads to efficient use of energy and high profit if implemented successfully. The choice of Fuzzy Control for the subsystem interoperation is made to avoid sudden change and render flexibility in changing the desired climate parameter setting according to the crop type[5].

These four FIS systems receive the error in the humidity and temperature as calculated by equations (1.1) and (1.2). While four subsystems are of bi-state, ON and OFF controller type, hence are controlled by Sugeno method of inference. The fuzzy sets employed for Sugeno method are shown in fig. (2.2, 2.3). These are then labeled using Term sets as follows-

Error Temperature (E_T) = {T_N, T_{NS}, T_Z, T_{PS}, T_P}
Error Humidity (E_H) = {RH_N, RH_{NS}, RH_Z, RH_{PS}, RH_P}
Exhaust = {On, Off}
Fogger = {On, Off}
Vent = {On, Off}
Sprinkler = {On, Off}

3.1 FGCC_Exhaust Fuzzy Inference System Design

FGCC_Exhaust FIS is shown in fig. 3.1. This system enables the control of Exhaust subsystem using the Sugeno method of Fuzzy inference. The exhaust system is mainly responsible for controlling the temperature and humidity inside the Greenhouse. It seems useful when the internal temperature and humidity exceeds the desired temperature and humidity required for optimal climate of the Greenhouse. Fig 2.2 and 2.3 shows the membership functions of the input variables temperature and humidity. Both the MFs are of Gaussian type. Rulebase used for the FGCC_Exhaust FIS is given in the table 3.1 where a bi-state control of the exhaust subsystem is considered and implemented using the Sugeno method of inference[6,7].

Err_Humidity / Err_Temperature	(RH_N)	(RH_NS)	(RH_Z)	(RH_PS)	(RH_P)
(T_N)	ON	ON	ON	ON	ON
(T_NS)	ON	ON	OFF	OFF	OFF
(T_Z)	ON	OFF	OFF	OFF	OFF
(T_PS)	OFF	OFF	OFF	OFF	OFF
(T_P)	ON	ON	OFF	OFF	OFF

Table 3.1 Rulebase For FGCC Exhaust Subsystem

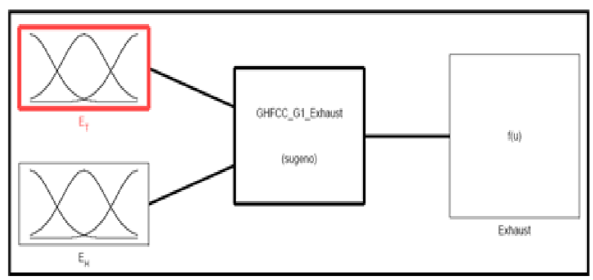

Figure 3.1 FGCC_Exhaust FIS for Exhaust Subsystem Control

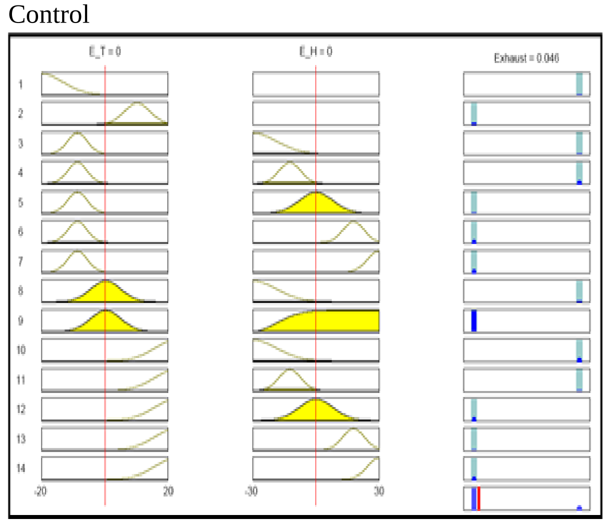

Figure 3.2 Rule Viewer for FGCC_Exhaust Subsystem Control

3.2 FGCC_Fogger, FGCC_Sprinkler, FGCC_Vent Fuzzy Inference Design

All these inference systems are designed by opting same methodology as given in section 3.1. The following figures and tables gives these designed systems.

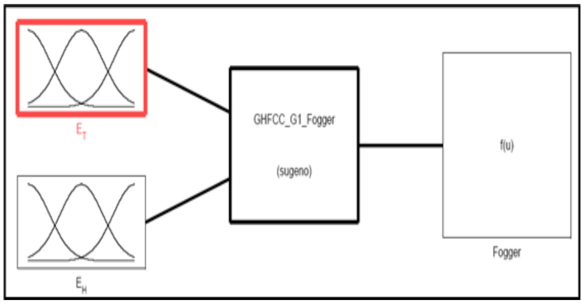

Figure 3.3 FGCC_Fogger FIS for Fogger Subsystem Control

Err_Humidity / Err_Temperature	(RH_N)	(RH_NS)	(RH_Z)	(RH_PS)	(RH_P)
(T_N)	ON	ON	ON	ON	ON
(T_NS)	OFF	OFF	OFF	ON	ON
(T_Z)	OFF	OFF	OFF	OFF	ON
(T_PS)	OFF	OFF	OFF	OFF	ON
(T_P)	OFF	OFF	OFF	OFF	ON

Table 3.2 Rulebase For FGCC_Fogger Subsystem

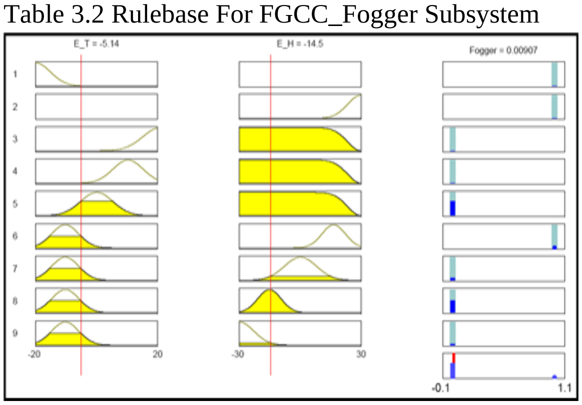

Figure 3.4 Rule Viewer for FGCC_Fogger Control

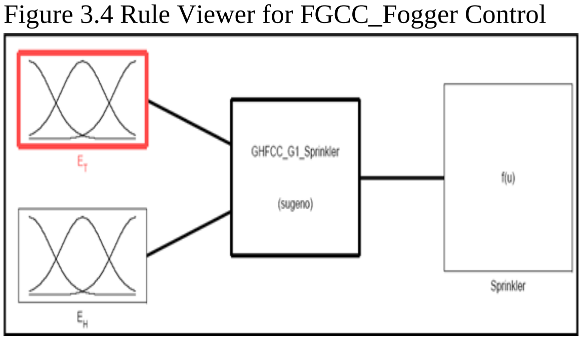

Figure 3.5 FGCC_Sprinkler FIS for Sprinkler Control

Err_Humidity / Err_Temperature	(RH_N)	(RH_NS)	(RH_Z)	(RH_PS)	(RH_P)
T_N)	ON	ON	ON	ON	ON
(T_NS)	OFF	OFF	OFF	ON	ON
(T_Z)	OFF	OFF	OFF	OFF	ON
(T_PS)	OFF	OFF	OFF	OFF	ON
(T_P)	OFF	OFF	OFF	OFF	ON

Table 3.3 Rulebase For FGCC_Sprinkler

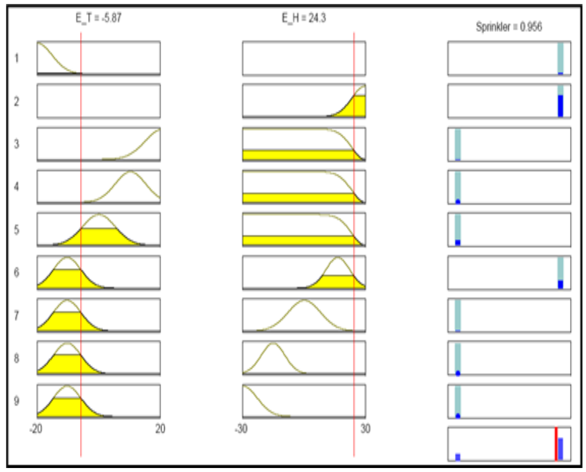

Figure 3.6 Rule Viewer for FGCC_Sprinkler Control

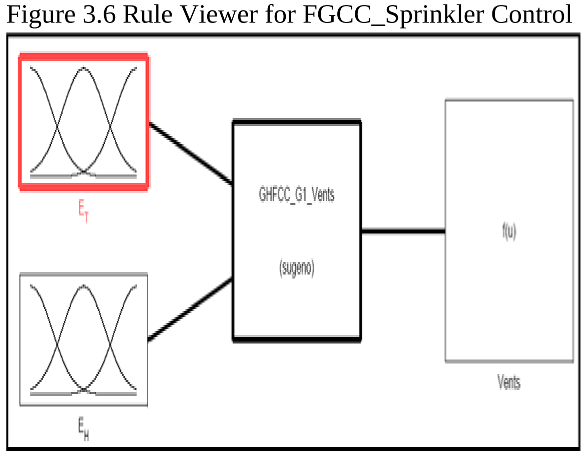

Figure 3.7 FGCC_Vents FIS for Vent Control

Err_Humidity / Err_Temperature	(RH_N)	(RH_NS)	(RH_Z)	(RH_PS)	(RH_P)
(T_N)	ON	ON	ON	ON	ON
(T_NS)	ON	ON	OFF	OFF	OFF
(T_Z)	ON	OFF	OFF	OFF	OFF
(T_PS)	OFF	OFF	OFF	OFF	OFF
(T_P)	ON	ON	OFF	OFF	OFF

Table 3.4 Rulebase For FGCC_Vent Subsystem

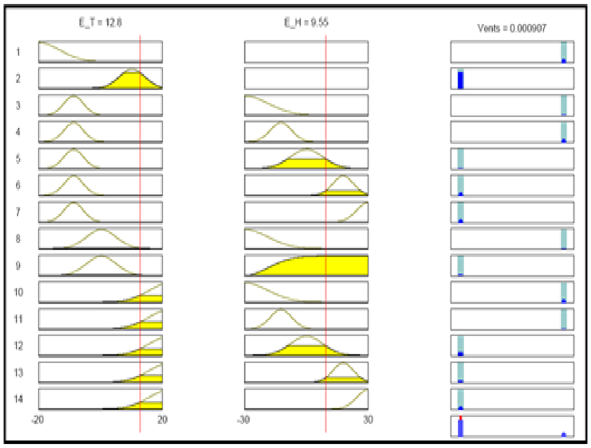

Figure 3.8 Rule Viewer for FGCC_Vent Control

3.1 4. Simulation Results of FGCC:

FGCC system comprises with for different sub modules those are playing an important role in the control of Greenhouse climate to the optimal level. Every control sub module function in different way and results a significant effect on one or more climate parameter/s deciding the internal climate of Greenhouse. Each subsystem is operated with the separate sub module of FGCC designed using Sugeno method of inference of Fuzzy Logic. These fuzzy sub modules are enlisted as follows-

1. FGCC_Exhaust FIS for Exhaust Subsystem Control
2. FGCC_Fogger FIS for Fogger Subsystem Control
3. FGCC_Sprinkler FIS for Sprinkler Subsystem Control
4. FGCC_Vent FIS for Vent Subsystem Control

These subsystems are operated in bi-state mode (ON and OFF). The FIS system results the linear output with the gain adjusted in tuning process while the trigger level to turn ON or OFF the subsystem is decided by the crop sensitivity calculated according to the crop development phase and crop type with the help of standard database.

Fig. 4.1 shows the Simulink model to test the performance of the FGCC_Exhaust system. The performance of the exhaust subsystem was evaluated with varying Error_temperature (ET) and Error_Humidity (EH) and with crop sensitivity of 0.5 point which is considered as normal crop sensitivity. The fig 4.1 also depicts the output performance of exhaust subsystem with respect to the Climate Condition with all possible input conditions.

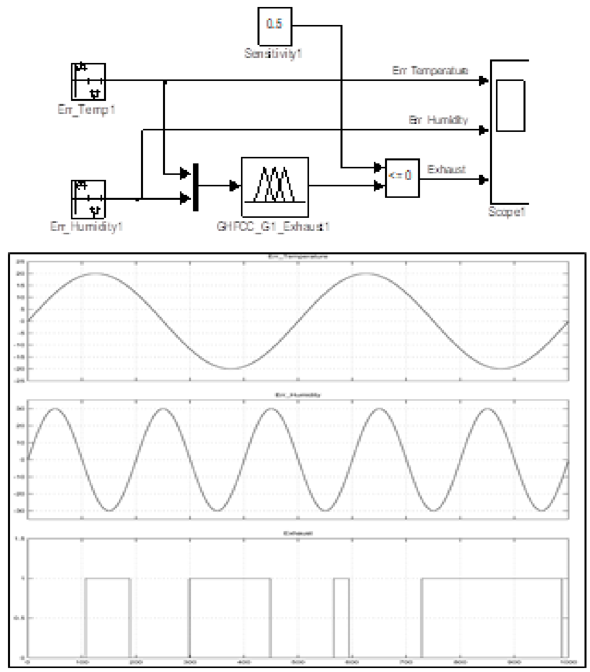

Fig.4.1 FGCC Exhaust FIS Model for Control of Exhaust Subsystem and Simulation Performance with variable E_T and E_H

The fogging subsystem which is mainly responsible for humidity variation is modeled for the simulation is depicted in fig. 4.2. its performance for varying Error_temperature (ET) and Error_Humidity (EH) with respect to Climate Condition is alos displayed graphically.

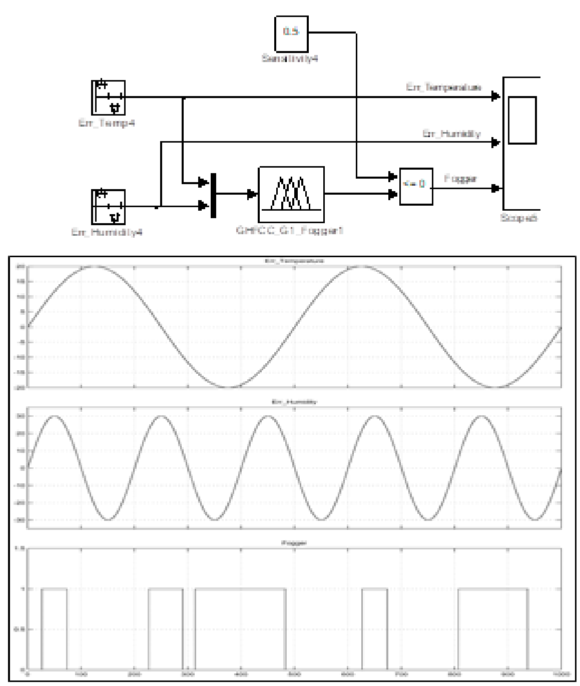

Fig.4.2 FGCC Fogger FIS Model for Control of Fogger Subsystem and Simulation Performance with variable E_T and E_H

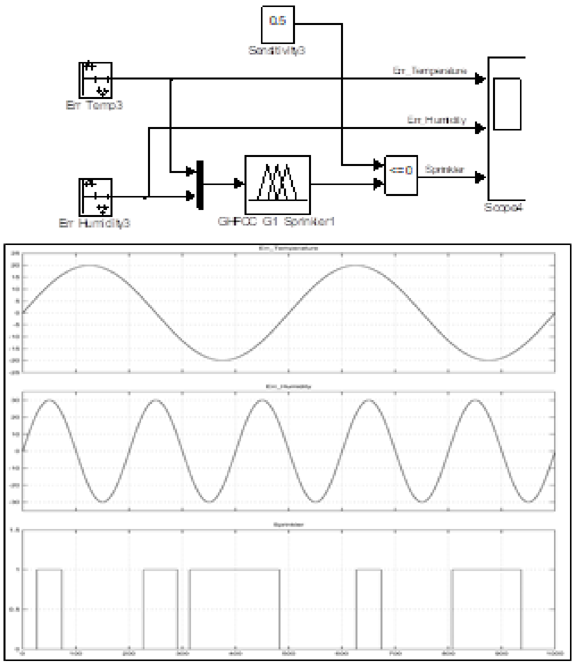

Fig.4.3 FGCC Sprinkler FIS Model for Control of Sprinkler Subsystem and Simulation Performance with variable E_T and E_H

Fig. 4.3 shows the Simulink model to test the performance of the FGCC_Sprinkler system. It depicts performance of the sprinkler subsystem evaluated with varying Error_temperature (ET) and Error_Humidity (EH).

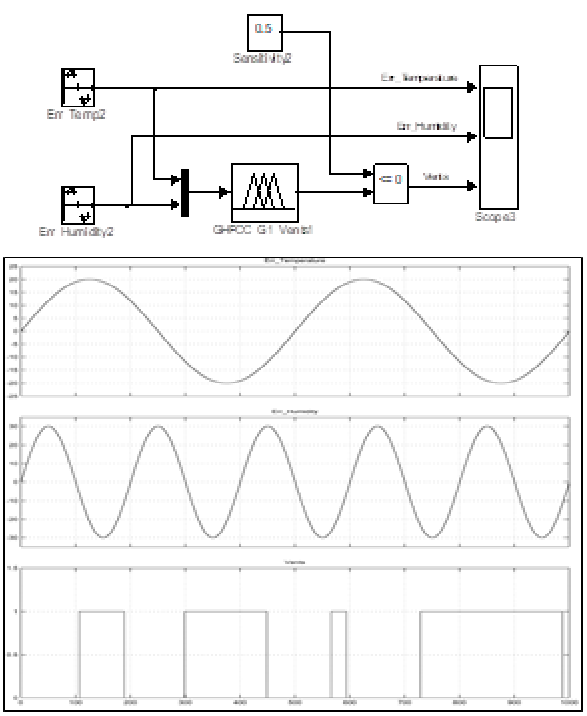

Fig.4.4 FGCC Vent FIS Model for Control of Vent Subsystem and Simulation Performance with variable E_T and E_H

Fig. 4.4 represents the Simulink model that analyses the performance of the FGCC_Vent system with crop sensitivity of 0.5 points. The graphical plot of the performance of the Vent subsystem evaluated with Error_temperature (ET) and Error_Humidity (EH).

5. CONCLUSION

The rigid testing of the individual control subsystem for optimal performance is then helps out to form a complete control system which is responsible to control the internal climate of the greenhouse. The simulation model is worked out with the varying Error_temperature (ET) and Error_Humidity (EH) so that all possible variations in input conditions could be met. The simulation performances of the various subsystem of FGCC are achieved individually and in conjunction with the supportive subsystems. The FGCC system provides ON-OFF action (SUGENO Method) of various subsystems to control the climate of the Greenhouse. Internal Temperature and Internal Humidity defines the current status of the internal climate of the Greenhouse. The simulation results are useful in designing practical climate control system for greenhouse climate control.

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