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FACULTY OF ELECTRICAL AND ELECTRONICS TECHNOLOGY AND INFORMATION AND COMMUNICATION TECHNOLOGY (DEPARTMENT OF ELECTRICAL AND ELECTRONICS TECHNOLOGY)

Design of Optimal multi-loop PI controller for Greenhouse climate control system using multi objective Evolutionary algorithm

MSc Thesis for the Partial Fulfillment of

Master of Science in Electrical Automation and Control Technology Management

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Addis Ababa, Ethiopia

Design of Optimal multi-loop PI controller for Greenhouse climate control system using multi objective Evolutionary algorithm

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled "**Design of Optimal multi-loop PI controller for Greenhouse climate control system using multi objective Evolutionary algorithm"** is the originality work by me, hasn't presented other master's thesis in this university or other universities and every source used to create this thesis paper has been fully acknowledged.

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TECHNICAL AND VOCATIONAL TRAINING INSTITUTE (TVTI)

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Thesis paper on

Design of Optimal multi-loop PI controller for Greenhouse climate control system using multi objective Evolutionary algorithm

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Abstract

Greenhouses are increasingly essential for creating the optimal situation for cultivation. The benefits of greenhouse avoid the solar radiation, outside humidity, ventilation, outside temperature and other disturbances that affect greenhouse environments. So avoid directly to the greenhouse cultivation for planting in a moderate conditions that is very important for good cultivation, according to cost minimizations, high quality productions and health production rate in agricultural industry. The difficulty of the greenhouse climate control is the great uncertainties of the weather and greenhouse climate. Although many control approaches have been proposed to solve this problem, the structures of the controllers are usually complex, and the reliability of the controllers is usually not good in practice. Therefore, to improve the reliability of the controllers, this article proposes, optimal multi-loop PI controller using Evolutionary algorithm. In dynamic complex climate control disturbance of greenhouse climate can improved by PI-controller parameters tuning using (NSGA), Evolutionary Algorithms depending on a variety of performance indicators, such as good set-point tracking and smooth control signals. The proposed tuning system is tested for temperature and humidity control by reduction of integrated absolute error (IAE) The minimization of error improve by set point tracking performance. Optimal PI controller for temperature and humidity 30°C and 12.46 g/m^3 respectively, then calculated error for reduced temperature and increased humidity from standard reference input of overall system would be 6.25% and 2.125% respectively. Based on the real weather data, the simulation was performed to illustrate the effectiveness of the proposed method, and a comparison study was done to observe the performance of the proposed method. The results indicate that control performance is good. MATLAB software can be used to obtain greenhouse dynamic complex climate control simulation results in accordance with the proposed controller with Simulink diagram.

Key Words: - PI (proportional integral), evolutionary algorithm, **integrated absolute error** (IAE),

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List of Acronyms

IAE	Integral Absolute Error
IAE	Integrated Absolute Error
ITAE	Integral Time Absolute Error
KC	Controller Gain
KD	Derivative Gain
KI	Integral Gain
KP	Proportional Gain
MIMO	Multi Inputs Multi Outputs
PO	Peak Overshoot
PI	Proportional Integral
PID	Proportional Integral Derivative
ST	Settling Time
VP	Vapor Pressure (Pa)

Chapter One

1. Introduction

1.1 Background

Greenhouses are increasingly being used to provide optimal environmental conditions for plant growth and development, regardless of the climatic circumstances of a location. Solar radiation raises the temperature within the greenhouse during the day. There are several types of models that could be used to simulate and predict the greenhouse environment. High productivity and product quality of modern greenhouses can be achieved only through proper control of the greenhouse environment and the nutrients fed to the plants, particularly. This study focuses on the air temperature and humidity as one of the important parameter inside in greenhouse [1].

Greenhouse atmosphere needs to be controlled to offer a good climate condition to the crop in order to achieve predetermined results, like high yields. It is necessary to find a solution to the greenhouse environment management challenge if high yield, good quality, and low crop costs are to be achieved as intended, because greenhouse environments are so challenging, to overcome this difficulty in the real world. They display time-varying behavior and are significantly influenced by outside variables like wind speed, ambient temperature and humidity, and others, due to their nonlinear, strongly linked, and MIMO (Multi-Input Multi-Output) characteristics. They are also constrained by a number of practical limitations (actuators, moistening cycle, etc). Because of its uncomplicated construction, ease of usage, and effective real-world performance [2], most modern greenhouse climate control techniques employ independent, set-point-based conventional PID controllers.

Tuning multiple controllers continues to be a challenge for greenhouse production operation engineers. Many controllers are poorly tuned in practice because of complex characteristics such important variable interactions, nonlinearities, diverse limitations, time-varying properties, and conflicting aims.

Greenhouse companies' major purpose is to supply agricultural products outside of the planting period. They offer a favorable interior climate for plants to acquire more fruiting and growth because the open fields are unsuitable.

Controlling the greenhouse's atmosphere entails regulating its fundamental environmental factors, including the atmospheric heat humidity, structure and light [3]. The comfort in a greenhouse is affected by several environmental conditions. The consistency of the cooling and heating is another essential design element for maintaining the proper set point conditions of the greenhouse environment parameters.

The primary purpose of this research provides strong, robust adjusting technique for greenhouse complex climate management employing two PI loops of MIMO process with nonlinearities, competing achievement goals, and strong interactions among process variables. The work is formulated as a multi-objective optimization problem to simultaneously tune the two PI controllers for bettor static-dynamic ability and appropriate smooth controllable signals. The gain parameters are encoded in the populations and the pertinent goal (cost) functions or (Price) operations are defined using the specifications of disturbance rejections, static-dynamic performance, and smooth control [4].

These factors continue to make PI controller tuning an interesting area of research. A few examples of these are designs based on trial-and-error learning, like the trial-and-error tuning technique,, designs based on linear control theory, such the Ziegler Nichols (Z-N) and Coon-Coon approaches, etc. Even today, it is challenging to achieve the appropriate greenhouse performance using conventional techniques that are based on linear models that are frequently adjusted around operating points. To regulate the greenhouse system, creative designs for fine-tuning PI parameters must be investigated.

Evolutionary algorithm (EA) have recently been introduced and applied successfully in a variety of plants [5]-[6] as the optimum tuning strategy for PI controllers, as a result of crude and idealistic managerial structure.

The majority of them either fail badly due to a lack of well-defined performance requirements or fall short of engineering design standards. Using multiple PI multi loops (MIMO) process and an intelligent tuning technique based on Pareto a solution, this work seeks to manage greenhouse environment. NSGA-II evaluates individual fitness in line with dominant property. All of the PI controllers must be modified simultaneously based on many, potentially conflicting criteria, such as precise tracking of input signals and as smooth as practical control signals. Although the PI tuning described in this thesis takes time, it will improve greenhouse climate.

1.2 Objective

1.2.1 General objective

The objective of the thesis is to design an optimal multi-loop PI control scheme for the Greenhouse climate control system using multi-objective evolutionary algorithm.

1.2.2 Specifics objective

The main specific objectives are: -

- ✓ To utilize mathematical model of the greenhouse climate control system.
- ✓ To formulate a multi-objective optimization problem.
- ✓ To design a multi-loop PI control scheme using multi-objective evolutionary. Algorithm.
- ✓ To improve the performance of the greenhouse dynamic complex climate control. System.

1.3 Statement of problem

The difficulty of the greenhouse climate control is the great uncertainties of the weather and dynamic behavior of greenhouse climate problems. In greenhouse there are deferent disturbances like humidity, temperate, solar radiation and so on are must be controlled. Researcher designed more recent controllers for a common greenhouse Multi-loop PI controller using Evolutionary algorithm a control oriented multivariable three-input and two-output model is used to design the multivariable closed loop control system.

1.4 scopes

Design of Multi-loop PI controller using Evolutionary algorithm for good performance improvement for problem of greenhouse complex climate control humidity and temperature are output control variable and ventilation ,heating and spraying are regulating input variable Then optimally tuned multi-loop PI controller is compared to conventional PI controller, and finally to success the goal and objectives of this work using the proposed controllers up to result and discussion is performed in Simulink/MATLAB software.

1.5 Significance

The main contribution of this thesis to control greenhouse complex climate like indoor air temperature and humidity, Due to the complexity and nonlinearity of greenhouse dynamic systems, it is difficult to optimize the PI controller to solve the optimization problem using multi objective evolutionary algorithm. Then, multi loop PI control scheme designed based on the linear model and combine with the nonlinear optimization part to obtain the control input. The main advantage of using multi loop PI control scheme is to provide good set point tracking and disturbance rejection performance. As the system uses an automated way of finding a multi loop PI controller, the plant growth and quality are increased. Finally, this thesis can also be an input for people who are engaged in the work of the greenhouse microclimate control system.

1.6 Limitation

Due to the complexity of greenhouse complex climate problems, in this thesis, only Humidity and temperature are considered. To solve the greenhouse climate control problems, the designing of the multi loop PI control scam with multi objective evolutionary algorithm is used. However, it does not include some other greenhouse disturbance like $Co_{2,}$ solar radiation and so on.

1.7 Methodologies

The methods to be employed to achieve the objective of the research are:

For the accomplishment of these work different tasks has been performed. The first tasks are describing the statement of problem and define the objective of the research. In this section many international journals, conference papers, articles and text books related to greenhouse control has been reviewed. Next, a detail mathematical model of greenhouse parameters are discussed, which is done by multi-loop PI control scheme it used to control greenhouse complex climate based on multiple performance measures such as good static-dynamic performance specifications and the smooth process of control.

This model is linearized and optimized using multi-objective evolutionary algorithm (NSGA II) is well-known, fast sorting and elite multi objective genetic algorithm. As generalized in block diagram shown in fig 4.2 and 4.3 below the controller parameters are tuned using multi loop PI controllers with multi objective algorithm in MATLAB.

1.8 outline of the thesis

The brief introduction of the organization of the thesis is shown as below

Chapter 1: An introduction of the thesis is given

Chapter 2: The relevant literature regarding multi-loop PI controller using evolutionary algorithm techniques are discussed.

Chapter 3: The mathematical modeling of greenhouse process

Chapter 4: An overview of the controller design methodologies is explained.

Chapter 5: It shows the result are shown and discussion is done about control system

Chapter 6: The conclusion of entire thesis work is done the future scope kept for further result.

CHAPTER TWO

LITERATRE REVIEW

Greenhouse environment used to grow crops in abounded walls and roof for the security of cultivation for high quality productions for a proper conditions cultivation. Relating to these study there are many researcher do their own research using different controller mechanisms some of scholar that is more related to this work listed below in the literature revie.

Shamshiri, Ramin in 2013 Greenhouses are covered buildings that provide a regulated environment for the growth of crops. Outdoor production makes it impossible to produce food and ornamentals during the off-season. In order to create a regulated climate and maximize crop yields, greenhouse technologies are therefore crucial. Additionally, growing within a greenhouse is more expensive than growing outside, which results in high production costs for the greenhouse business. In order to produce high output at a low cost and stimulate competition it is critical to monitor and manage environmental parameters like indoor heat, comparative ,humidity, CO_2 levels light and atmospheric quality plant nutrients, water, ratio and pest control [3].

Bingkun ZHU and Haigen HU, Lihong XU, Ruihua WEI, on March 26, 2011 "Multi-Objective Control Optimization for Greenhouse Environment Using Evolutionary Algorithms" is a paper presented at the conference. A good static dynamics thermodynamics law that impacts greenhouse climate is formulated to increase performance. These researchers employ integrated time square error (ITSE) to verify a greenhouse climate controller tuning technique in offline operations [2].

Harmut Pohleim and Adolf Heiner, These researchers go into detail about greenhouse climate control using optimal control in their paper, they used real-world meteorological data with evolutionary algorithms in time intervals range from 15 to 60 minutes. " Greenhouse complex Climate Optimality Control of Utilizing Real-World Weather Data and Evolutionary Algorithms" (short time scale Model) The paper explores greenhouse complex climate management optimization to reduce profit within certain bounds, however it does not provide the plant model, long-term scale model, or approaches to identify true ideal climate conditions [8].

In 16 January 2005 S. Pinon' a, E.F. Camacho a, B. Kuchen b, M. Pena This paper presents the performance of greenhouse climate control for a non-linear single input single output process using a temperature control technique that combines feedback linearization with traditional linear model predictive control. The researcher employs two controllers combined, however the heater/cooler constraint is not taken into account, therefore the optimal performance is subpar [6].

On July 10, 2006, Pucheta, J. A. Schugurensky, C. Fullana, R. Patio, H. Kuchen, and B. presented research on "Optimal greenhouse monitor for tomato-seedling plant." This thesis research focuses on controlling plant growth under protected climates by using iterative dynamic programming and constrained optimal control of continuous processes [14]. A flaw in the system's dynamic model has led to poor performance of the suggested controller. The system's definition of robustness includes stable, unstable, and unstable, for which we don't know the operation's end result [3].

Al-Jaded Moghaddam, Ghasem Zarei, Davood Momeni, and Hamideh Faridi in 2022 controlling the greenhouse microclimate is crucial for crop growth. A number of environmental factors, including temperature, relative humidity, light, and carbon dioxide, must be carefully considered during monitoring. In addition to boosting agricultural yields, maintaining the proper temperature range also protects plants from being stressed by heat or cold. Similar to this, lowering relative humidity lessens the possibility leaf moulid development, which can seriously harm crops. Because of outstanding potential to increase the productivity and quality of agricultural products, the microclimate control of greenhouses is consequently gaining a lot of attention nowadays (Van, straten et al.2010), and as a result, a number of control strategies have been offered by researchers.

In 2020 Su, YuanpingYu, Qiuming Zeng, Lu, Two independent PID controllers are used in this control method to generate control inputs for the heating and ventilation systems, respectively. Their parameters can be adjusted adaptively by using a neural network to estimate the Jacobian with respect to the control variables, and the heating and ventilation control inputs only depend on the tracking errors of the interior air temperature and humidity, respectively. Since the ventilation also has a direct impact on the humidity and CO2 concentration within the greenhouse, it is obvious that this PID control technique is insufficient to meet.

The requirements of all the controlled climatic variables, Therefore, the PID control method must be able to manage the multi-variable coupling of the system when considering the coupling control of the temperature, humidity, and CO2 concentration[4].

Sigrimis and colleagues 1999; Tap 2000; Sigrimis and colleagues 2001; Pasgianos et al. 2003; **Van Henten 1994)** In general, various investigations. Have focused on performance indicators to control an environmental factor such as interior temperature In fact, a variety of intricate natural and atmospheric factors influence crop development and photosynthesis. As a result, providing one-factor control method to meet the needs of optimum crop growth is difficult. As a result, developing a practical multifactor control technique is critical. It should be noted, however, that multi-factor controller design and implementation are intrinsically difficult tasks due to their inherent complexity [7].

Kazuhisa Itoa* and Tsubasa Tabei in 2021, Facility gardening is useful for increasing product yields in harsh climes, such as winter or seasons with little sunlight, as well as for enhancing product value. By using heaters, humidifiers, ventilation fans, carbon dioxide generators, water supplies, and other equipment, the optimal environment in greenhouses can be achieved based on diverse demands for vegetables, fruits, and flowers. Many nations in Australia and Southeast Asia are seeing an expansion of the facility gardening market [9].

Sara Abdelgadir Saeed in 2017, Technology used in greenhouses is a special way to give plants ideal environment. Plant cultivation is both an art and a science, despite numerous obstacles, man has figured out how to grow plants in their natural environment. Man has created a technique for cultivating high-value crops known as greenhouse technology that allows crops to flourish even in extremely unfavorable climatic conditions when none are capable of growing. This technique is employed to shield plants from harmful environmental factors like cold, wind, precipitation, excessive radiation, extreme heat, insects, and disease. greenhouse technology modifies the atmosphere so that any plant can be grown at anytime and anywhere with the right environmental conditions[5].

Optimization with multiple objectives in PID Controller by **Qingyang Xu, Chengjin Zhang, Li Zhang, and Chaoyang Wang was published in 2014**. There are several goals to be accomplished for the PID parameters optimization, as stated in Section 3.2. Based on Pareto solutions, the NSGA-II assesses individual fitness in accordance with dominant property.

The best method for achieving multi-objective optimization and finding the genuine Pareto front is the Pareto-based approach. The population's non-dominated members are thought to be the fittest, and the members who are dominated are given lower fitness ratings. In this sense, the fitness values-rather than the value of objective function-will be determined by the proportion of dominated people. NSGA-II introduced a measure of individual's density with respect to the Pareto solutions to maintain the diversity in those solutions[6].

Researchers are interested designing and developing various methods to monitor the greenhouse's fundamental environmental factors like indoor temperature, indoor humidity, and carbon dioxide, because a controlled environment is the primary requirement for improving the capacity of plants in every greenhouse. The interior climate control of a greenhouse has thus been the subject of numerous research publications utilizing standard techniques like PID and optimum control techniques, such as predictive control[7][3][8], multivariable control[2][9], fuzzy logic[[10], fuzzy and PID and neural network control. In this thesis, some current publications are provided. The feedback-feed forward technique is used to linearize the nonlinear greenhouse system and create isolate network. Fuzzy logic and PID controllers were recommended in the literature to control the decoupling system.

2.1 classification of greenhouse system

Various factors are used to differentiate and classify greenhouses. Crop growing, solar energy collection, and crop drying are the three main applications of the greenhouse, respectively [11]. According to the kind of buildings, type of glazing, and environmental management, greenhouses are classified in this study as indicated in Figure 2.1.

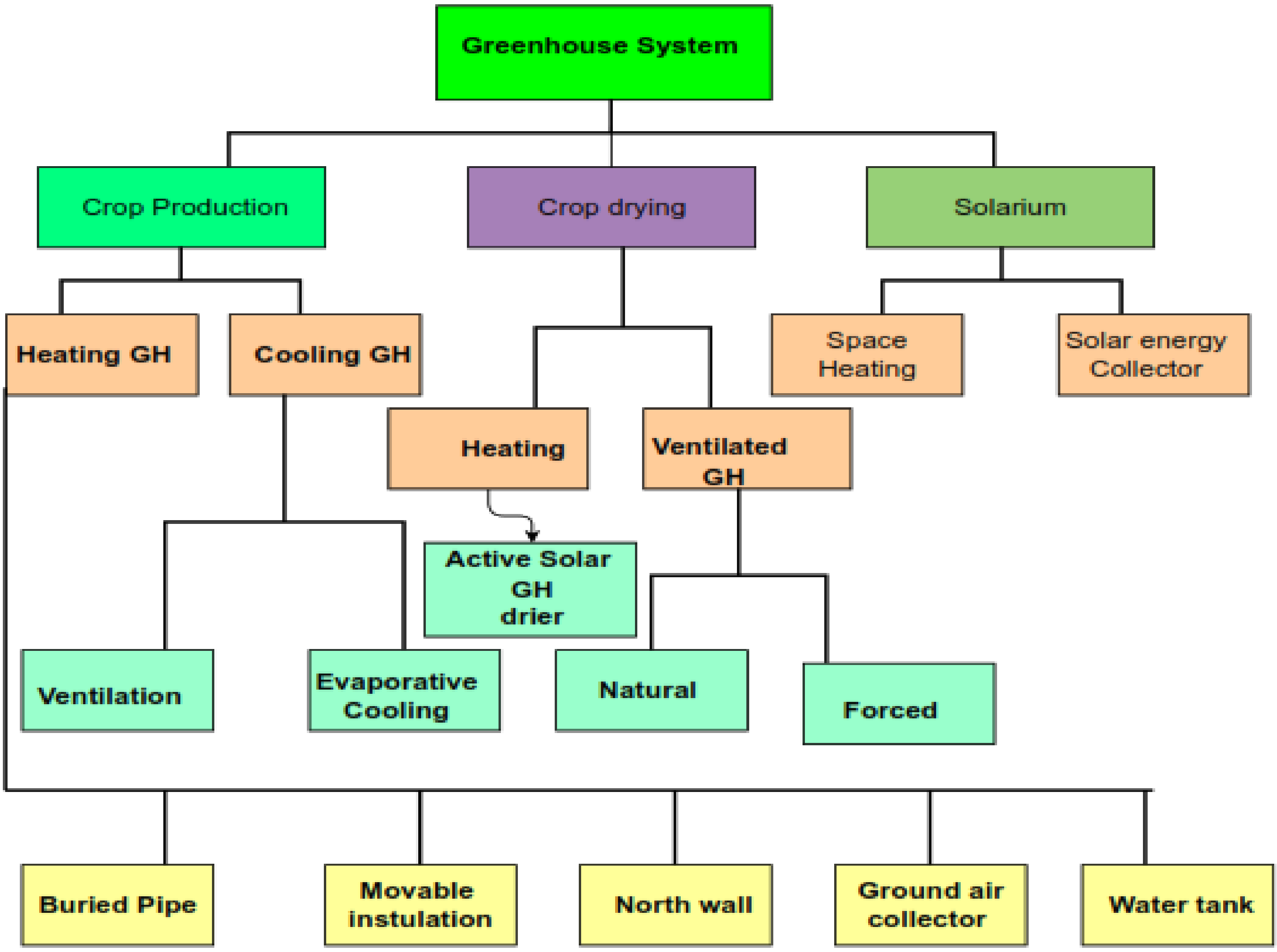

Figure 2.1 Classifications of greenhouse due to principal and working [13]

2.2.1 Based on the structure Greenhouse classification

2.2.1.1 Q-shaped greenhouse

A greenhouse is known as a Q-shaped greenhouse based on its construction. The trusses are supported in this type of greenhouse by pipe purling that runs its full length.

Polyethylene is the material utilized for the greenhouse's enclosure. Greenhouse techniques production of crops plant drying Solarium warming of GH Heating and ventilation of GH Interior heating collector for solar power Biological Forced Solar active GH dryer ventilation Dehydration cooling Biological Forced Pad-fan Fogging cellular insulation hidden pipe Western wall Ground air accumulator 8th water tank In a small, constrained space, it is less expensive and preferable to greenhouses connected to gutters.

The two primary connection types employed in these greenhouses are standing and interlocking. In the event of interlocking, it is necessary to grow vegetation in the spaces created by adjoining homes' truss parts overlapping. In this kind, a single sizable cultural venue accommodates a collection of dwellings. The automation and migration of labor are better suited to this structure[34].

Figure 2.2 Q-shaped greenhouse [14]

2.2.1.2 Gable roof of greenhouse

Common greenhouse designs include those with gable roofs. They provide adequate space to grow numerous plants while absorbing the most sunlight possible [14].

Figure 2.3 Greenhouse with a gable roof [14]

2.2.2 Glazing classification

2.2.2.1 Glass Glazing

Of all the greenhouse glazing materials, glass is the most traditional. As implied by its name, this kind of greenhouse uses glass as a glazing material, as seen in Figure 2.4. Compared to summer cultivation, it is more efficient in the winter. This is owing to the high noon temperatures during the summer. A glass glazing greenhouse is not advised due to the high capital costs, challenging construction, and frequent glass damage brought on by high wind velocity [3].Milford tempered glass, on the other hand, the best type of glass glazing due to its longevity. Furthermore, it reduces the risk of injury by shattering into little square pieces in the case of damage, and the small fragments was not injure in our plants. [3].

Figure 2.4 Greenhouse with glazing made of glass [16]

2.2.2.2 Glass made of fiberglass-reinforced plastic

There are two variations of this sort of greenhouse. Corrugated and flat panels are these; the corrugated is utilized because of its corrugated design, which gives the panels for the greenhouse roof strength and stiffness. For sides, vents, and windows, however, the flat is usually used [16]. FRPs are flexible enough to be curved into a curvature which matches the Quonset style greenhouse framework, while being categorized as rigid plastic [15]. They can also be classified as corrugated sheets and plain sheets.

Figure 2.5 Sheets of the corrugated type [17]

2.2.2.3 Plastic film

At the level of the greenhouse's canopy, a flat solid might make a great light diffuser. Because fewer bracing and trusses are often used in the construction of a synthetic resin greenhouse, it also casts little shadows. It is an excellent option for novice greenhouse growers. Additionally, it is categorized as Sill Pauling and ultraviolet stabilized low-density synthetic resin [14].

Figure 2.6 Plastic (polyethylene) [18]

2.2.3 Classification of greenhouses depending on environmental control

Numerous elements, including temperature, solar radiation, carbon dioxide, and humidity, have an impact on the greenhouse environment. Thus, these factors must be properly controlled. Every greenhouse has a mechanism in place to regulate the environment. This approach aids in creating a controlled atmosphere that is uniform. Numerous issues arise in plants when the environment is not uniform, including potential illnesses, applications of hormones or nourishment that have irreversible effect, and variations in plant growth rates. As a result, managing the plant's production system is challenging [19].

The main objective of greenhouse's climate management system is to drastically cut summertime heat. Entering solar radiation and temperature from air exchange are significant sources of this heat. Therefore, by reducing such heat sources and increasing the proportion of energy consumption through latent heat, the temperature inside the greenhouse can be decreased. The best methods for reducing sun exposure are white wash and shade netting.

Additionally, ventilation during cold outside temperatures removes any additional heat created by air exchange between the inside and outside. Evaporative cooling is the alternative popular method. This method lowers the sensible heat load by increasing the latent heat fraction of the dissipated energy [20]. The information that follows gives a complete overview of several issues, including ventilation and cooling systems. Effective strategies for reducing sun radiation.

2.2.3.1 Ventilation

In a greenhouse, two forms of ventilation are utilized. They either use mechanical ventilation or natural ventilation. When mechanical ventilation is used, exhaust fans, inlet holes, and power are used to run the fans [21]. In order to achieve adequate cooling under a variety of environmental circumstances, a good design is necessary [22].

The two primary natural ventilation phenomena that depend on these phenomena are thermal buoyancy and the wind effect. Ventilation has an impact on greenhouse interior temperature when incident solar radiation is high. To provide a uniform air exchange between the inside and exterior of a greenhouse, excess heat must be removed [22].

There is a differential in pressure inside the greenhouse due to the wind and temperature differences between the interior and exterior. Natural ventilation happens through apertures in the greenhouse's framework in order to help regulate humidity and temperature within. It can also provide appropriate air exchange.

The greenhouse has effective ventilation thanks to the combination of fans, roof vents, and front doors. A good way to lessen the temperature difference between indoor and outside air is to enhance ventilation [23].

Figure 2.7 Naturally ventilated [24]

2.2.3.2 Cooling system

When the ventilation system's cooling capacity is no longer sufficient to maintain the greenhouse's temperature, an extra cooling system may be necessary. Fog systems and pad-fan cooling systems are further water-evaporating cooling technologies [22]. In fog systems, little water droplets are blown at high pressure into the air above the plant [20].

As a result, the value of liquid surface in contact with the air increases. The relative humidity increases during the fogging system while the greenhouse's interior is cooled [13]. The following is a description of these two cooling systems.

1. System of fan with cooling pad

The right size systems for pads and fans should employed to achieve the optimum level of cooling effectiveness. An open-sided greenhouse can use passive ventilation as these systems are not usually required. It is advantageous to create appropriate cooling without utilizing any energy for a particular crop. If sanitation or insect limitations are the main concerns in a particular greenhouse, a closed greenhouse with fans and a cooling pad system may be required [25].

Figure 2.8 Fan and pad greenhouse evaporative cooling system [22]

For minerals and algae to grow, resulting in low efficiency and reduced airflow in the cooling pads. As a result, they require regular maintenance to be effective. Numerous factors might have an impact on the fan and pad cooling systems [25].

The main factors that affect greenhouse are

- greenhouse Location and orientation
- flow rate of the water
- Issue with cooling system
- Considerations for operations

2. Fogging cooler system

The fundamental components of the greenhouse's fogging system are a pump unit and fogging lines. The pump unit includes pumping water tank, water conditioner, filtration, fine, pressure regulating regulator, a valve, and the low-density polyethylene (LDPE) tubing makes up the fogging lines [24].

Fog-containing tiny water droplets are produced using a high-pressure pumping device. These droplets are so minuscule that they can stay suspended in the air during evaporation. The cooling system, which circulates all through the greenhouse and cooled the air everywhere, reduces the risk of illness and insect assault when the foliage isn't damp. As a result, the plants remain dry throughout. Because it eliminates the requirement for a mist system, this method is also utilized for seed germination and seedling growth. The greenhouse air temperature can be lowered by using any sort of summer cooling system [25].

Since the amount of the droplets of water in fog is so small, the fan-pad can only reduce the temperature gradient between the dry and wet bulb by 80% while the cloud cover may reduce the incoming air temperature by 100%. As a result, all of the water in the fog system has evaporated [26].

Figure 2.9 Greenhouse cooling system [26]

2.2.3.3 Shade

One method of greenhouse cooling is shading. Utilizing it lessens the quantity for radiation reaching crops. By reducing its solar load, which reduces the air temperature difference, the greenhouse's real air temperatures are brought closer to those outside.

In greenhouses, heat uptake is mostly caused by direct sun radiation. Shading may have an impact on greenhouse plants' development and photosynthesis because of the loss of light and potential impacts of ventilation rate. Therefore, consideration must be given to the type of shade and related control techniques [19].

In times or locations with unfavorable temperatures and sun radiation, the proper choice and construction of shed nets can help to increase crop productivity. By shielding the plants in the green roof system from intense sun radiation, shade plays a significant function [27].

Figures 2.10 Aluminum shade type greenhouse [28]

2.3 Summary of literature review

Since a controlled environment is the main prerequisite for improving the quality of the plants. Many scholars are interested in constructing and developing various regulatory systems to govern the greenhouse's basic environmental disturbance, like ambient temperature, indoor humidity, and indoor carbon dioxide. The interior climate control of a greenhouse has thus been the subject of numerous research publications employing optimal control techniques such as predictive control [14] [15].

Observer based fuzzy and PID multivariable control, and standard techniques such as PID. Fuzzy logic control, PID and fuzzy and neural network control [17], [18] [29] fuzzy adaptive control Model predictive control Predictive control [30] [31] [32] feedback-feed forward linearization and decoupling and so on, In this thesis, "Multi-Objective Controller Optimizing for Plant Community Using Evolutionary Algorithms," a suitable static dynamical thermodynamics rule that impacts greenhouse climate is created in order to increase performance measure. This researcher's uses integrated absolute error (IAE) to test greenhouse climate controller tuning scheme [4].

Using a variety of controller settings and nonlinear thermodynamic concepts, the setting of a greenhouse is depicted. By reducing the integral Times Square error (ITSE) and the controlling incremental or rate in a simulation experiment, the suggested tuning strategy for greenhouse climate control is evaluated. The results show that the controllers can create step responses with effective control performance, including short settling time, minimal overshoot, little rising time, and little steady state error by modifying the gain settings. Additionally, it can be used to tune systems with various characteristics, including substantial interdependencies between variables, nonlinearities, and competing performance standards. With the use of multi-objective optimization techniques for complex greenhouse production is a very productive and promising tuning strategy, according to the findings [4].

The article, titled "Greenhouse Optimal Control Using Real-World environmental Data and optimization method of Evolutionary Algorithms," explains how to control the greenhouse's climate using evolutionary algorithms and real-world weather data at intervals of 15 to 60 minutes (short time scale Model). The work discusses optimization of greenhouse complex climate management to minimize profit under specific constraints; however the plant model, long-time scale model, and methodologies to determine actual ideal climate conditions are not indicated [12].

This study constructed and simulated a self-tuning proportional controller for the greenhouse with set point tracking. Methods of disturbance rejection were taken into account when the system was built. Despite the fact that temperature and humidity have a significant impact on how well plants function and grow. The control of humidity is the topic of this study. As a result, the paper's restriction on greenhouse temperature management is a flaw.

CHAPTER THREE

MODELING

3.1 Modeling of greenhouse climate control system

The models designed in (Albright et at.b2001) was greenhouse climatic dynamic complex models that is most frequently utilized in control literature. The typical block diagram displayed in fig. 2.11 provides a summary of it.

Two nonlinear differential equations defining the latent and sensible heat, as well as the water vapor balance, which are the controllable variables, are included in this simplified model, which is based on the energy and mass balance within the greenhouse [33]. Only fundamental disturbances, such as outside temperature and humidity, in addition to solar radiation, are taken into account in order to simplify the model (Gurban and Andreescu 2012) this simplified model, based on energy and mass balance inside the greenhouse. To simplify the model, only basic perturbations such as external temperature and humidity, as well as solar radiation, are considered (Gurban and Andreescu 2012). In this work, three environmental variables including inside air temperature and humidity are considered as the controlled variables, and greenhouse heating, fogging, and ventilation are used to regulate the indoor climate, so there are three input variable and two out pout variable greenhouse climate control system has four control input variables and three output variables,

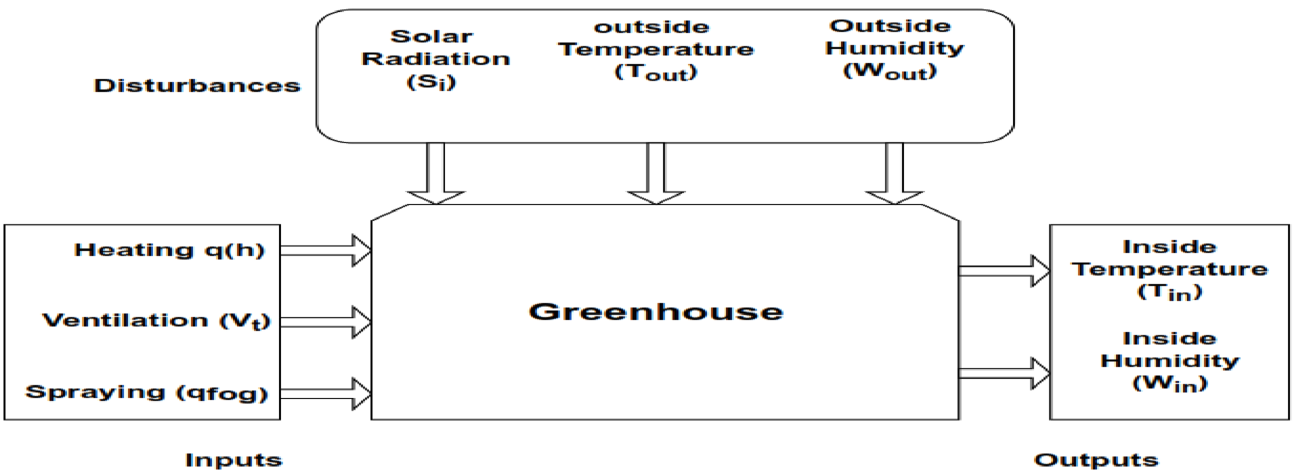

Figure 3.1 Model of greenhouse climate control

The following differing equation govern sensible heat, water vapor, and greenhouse volume

$$\frac{dT_{in}(t)}{dt} = \frac{1}{\rho C\rho\, V}\left[Qh(t) + si(t) - yQfog(t) - \dot{V}t\,\frac{(t)}{V}[T_{in}(t) - T_{in}(t)]\right] \quad (3.1)$$

$$\frac{dT_{in}(t)}{dt} = \frac{1}{\rho V}Qfog(t) + \frac{1}{\rho V}E(si(t), T_{in}(t)) - \dot{V}t\,\frac{(t)}{\rho V}\,[W_{in}(t) - W_{out}\,(\mathrm{t})] \quad (3.2)$$

Where:

T_{in}(t) - the indoor air temperature (°C),

T_{out}(t)-the outdoor temperature (°C),

ρ -the air density (kg/m^3),

Cp -the specific heat of air (j)/kgk)),

V-the greenhouse volume (m^3,)

Qh -the heat provided by the greenhouse heater (w),

Si - the intercepted solar radiant energy (W/m^2),

Q-fog-the water capacity of the fog system (water vaper mass per second, in g/s), $\dot{V}t - the\ vantlation\ rate$ (m^3/s),

U- Represents for the overall heat transfer coefficient W/($m^2{}_k$)).

A-the heat transfer surface area (m^2),

Wout & Win the internal and external moisture content and the humidity ratio (measured in grams per cubic meter of dry air),*E (Si (t), Win (t))* - the evapotranspiration rate of the plants (g/s).

The energy balance of the greenhouse is used to create equation (3.1).That the very first component on the right hand side shows the heat Throughout period, the greenhouse air's energy level.

The sensation thermal losses to the outside are indicated by the second and third terms, which are, respectively, conduction and conviction. Equation (3.2) is calculated using the liquid water's material balance inside the greenhouse. The moisture provided for spray system is represented by the first term on the right side, the humidity provided for plant evapotranspiration by the second term, and liquid waste matter as a result of condensation and ventilation of water vapor on the structure cove is represented by the last term. To keep internal temperature very important for greenhouse, during summer, the standard temperatures can fall between 13-32°C (55-90°F). as the standard value researcher take input temperatures of 32°C of maximum after applying the controller the final temperature of 30°C therefore researcher controller solves the error by 93.75%

The optimal relative humidity set point for most plants is around 80%. At this level, growth rates are highest for common greenhouse plants. This means humidity in between 6.6g/m^3 and 7.5 g/m^3 for lower value and maximum of 12.8 g/m^3 therefor our controller take action by taking the lower input value of 7.46 g/m^3 the final output is 12.46 g/m^3 this indicates that 77.87% solve the initial input humidity relative to 80% of standard humidity for greenhouse (https://www.tis-gdv.de/tis_e/misc/klima-htm/)

Equation (3.1) And Equation (3.2) describe a greenhouse climate model that can be utilized as a multisession model. Because this article only considers summer operations, a heater element is not used.

i.e *gh =0w*. Hence, the two altered parameters are ventilation rate v-t and water capacity of t fog system *Qfog*. And the simplified relation for the plant evapotranspiration rate E (*Si* (t), W_{in} (t)) (pasgianos et al. 2003) mainly depending on the intercepted solar radiation Si and the interior humidity ratio win, is expressed as follows:

Where C seems to the value adjusted for index of leaf area and shading (C= 0.1249), where T is the coefficient used to take into account thermodynamics constants and other variables that impact evapotranspiration (in this particular instance, T = 0).

By setting the derivative of equation (3.1) & (3.2) to 0 and considering environmental constants, Condition (Si,$T_{out} W_{out}$, V_t *Qfog*), it's also conceivable to determine the equilibrium point, represented by:

$$T_{ino} = \frac{1}{\rho C\rho \bar{V}_t + UA}[\overline{si} - \gamma\overline{qfog}] + \overline{T_{out}}. \quad (3.3)$$

$$W_{ino} = \frac{1}{\bar{V}1 + \beta T}[\overline{qfog} + \alpha\frac{\overline{si}}{y} + \bar{V}_t\overline{W_{out}}]. \quad (3.4)$$

The parameters displayed in table 3.1 are taken into consideration for the simulation test scenario Aβ.

Table 3.1 considered changing values of greenhouse climate control parameters

Variable	Value	Variable	Value
V	$4000m^3$	Cp	1006j/(kgk)
UA	25.000w/k	$\dot{V}$t	$10m^3$/s
ρ	1.2kg/m^3	ϒ	2257j/g
Qfog	18g/s	Qfog MAX	150g/s
Si	300 w/m^2	T_{out}	25℃
W_{out}	4 g/m^3	$\dot{V}$t MAX	$23m^3/s$

The continuous-time matrix models of the transfer function, p_n(s), and the results identification tests utilizing the following is the structure of the nonlinear model surrounding the operational point [36].

$$G_P(s) = \begin{bmatrix} \frac{-0.1806}{150s+1}e^{-89.5s} & \frac{-0.05705}{140s} + 1e^{-101s} \\ \frac{-0.8357}{580s+1}e^{-220.s} & \frac{-0.134}{610s+1}e^{-180s} \end{bmatrix} \quad (3.5)$$

CHAPTER FOUR

CONTROL DESIGN

4.1 PI controller structure

The proportional, integral values make up the conventional structure of PI controller. The response to the current error is decided by proportional value, the reaction is determined by the total recent errors by the integral value. The control scheme is typically described mathematically in its ideal state in equation (4.1) alternatively using the equivalent form

$$u^{(t)} = k_p(e(t) + \frac{1}{Ti}\int_0^{\tau} e(\tau) \qquad (4.1)$$

$k_p and k_i$ Non-negative, denote the coefficients for the proportional and integral terms respectively (sometimes denoted *P* and *I*).

$u(k) = k_p e(t) + K_i \int_0^t e(\tau) d\tau$

Where:-k_p is the proportional gain, a tuning parameters

k_i is the integral gain, a tuning parameters

τ is the variable of integration (takes on values from time 0 to the present t

t is the time or instantaneous time (the present)

$e(t) = SP - PV(t)$ is the error (SP is the setpoint, and $PV(t)$ isprocess output ,

4.2 PI controller for greenhouse climate system

Multi-loop PI controllers have been extensively used in the greenhouse production process owing to their simple architecture, easy implementation and excellent performance. However, the tuning of several controllers in the complex greenhouse environment is a challenge to process engineers and operators. Many controllers are poorly tuned in practice due to the complexity of the controlled greenhouse such as the dynamical behavior of greenhouse climate and control requirements, which present strong interactions among variables, non-linearity's, multiple constrains and conflicting objectives. It should be noted that the dynamic greenhouse system indicated in the perverse chapter is a continuous time nonlinear system with two inputs and two outputs. Researcher takes into consideration a figure 4.1 multi-variable PI control scheme.

Researcher use a Runge-Kutta method of fourth order with a tiny enough integration step to mimic its actions on a digital computer, can choose the sampling period as a time step. In light of this, the relevant control law for each loop in a common PI control method is stated as follows:

$$u(t) = e(t) + k_p(e(t) - e(t-1) + k_{ie}(t)) \quad (4.2)$$

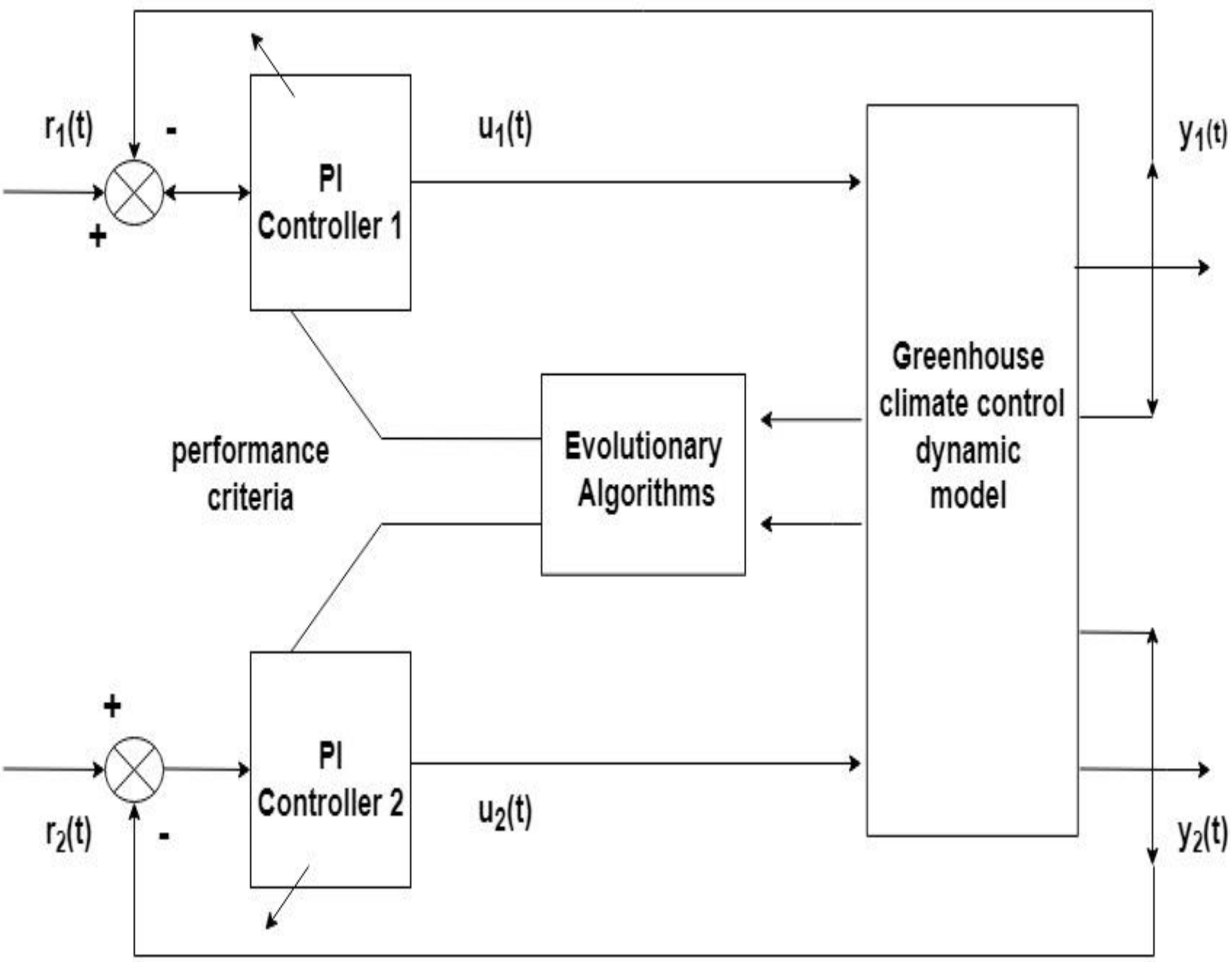

Figure 4.1 Schematic diagram for greenhouse climate control system

4.3 Performance Criteria

The most frequently used accurate indicator of system performance is integral error. Control system design frequently makes use of a variety of these performance criteria, including integrated absolute error (IAE), integrated square error (ISE), integrated time square error (ITSE), and integrated time absolute error (ITAE). Killingsworth et al. have shown this. [27] That integral time square error can result in enhanced closed-loop capability, including the smallest overshoot, the quickest.

Additionally, the performance requirements for each loop in a MIMO process may differ from one another, and some outputs may be given higher priority than others. In this study, we just take a few performance criteria from the same class into consideration integral Absolut error

(IAE) is used. As a result, the system must be practical to system simulation in digital form. The MIMO system's performance index in equation (4.5) is revised to read as follows:

$$J_1 = \sum_{i=1}^{\infty} |e(t)| \tag{4.5}$$

The time of the kth iteration is represented by t(k), where I is the kth close loop.

Another issue is that seriously oscillatory control signals are unacceptable for controller design since they can seriously harm actuators. Therefore, in order to prevent this situation and carry out a slick enterprise, we take into account another performance index specified as

$$J_2 = \sum_{k=1}^{\infty} |u(t) - u(t-1)| \tag{4.3}$$

It is important to note that while decreasing the second performance index J_2will execute a smooth operation and prevent the serious oscillation of actuators, reducing the first J_1will give superior static-dynamic performance and better disturbance rejection.

4.4 Multi-objective Evolutionary Algorithm J1and J2

Evolutionary algorithms use algorithms to model the many of the fittest in biological evolution, and they are increasingly useful in resolving practical engineering issues. Multi-objective evolutionary algorithms have significant advantages over single-objective. Evolutionary algorithms are particularly useful for issues with multiple competing goals. For instance, they can look for a set of solutions from the standpoint of the simultaneous optimization of several rival.

Optimization of several conflicting goal functions simultaneously. Such a remedy many performance criteria, like strong static-dynamic performance and smooth control operation, must often be satisfied in the controller's design.

The above needs, however, cannot be fulfilled concurrently, for instance, looking for certain dynamic parameters frequently results in a significant deviation in the control law and severe actuator oscillation.

As a result, reducing the performance index J1 and J2, A satisfying compromise must be achieved and a set of ideal solutions must be offered. To put it another way, J2 and J1 are viewed as 2 suitability or objective (cost) function for the optimal solution. Multi-objective optimal methods are employed to find a pareto solution for numerous, conflicting objectives. Many algorithms, such as pareto-optimal Archived evolution strategy (PAES) [27], strength pareto evolutionary approach 2 (SPEA2) [26], and NSGA-II [17], seem a quite promising. Ways to mimic pareto fronts. We choose NSGA-II, a computationally efficient algorithm that implements the concept of a selection method based on classes of dominance of all the solutions, in order to improve the performance criteria in this work while taking into account recently develop and multi-objective evolutionary algorithms that are versatile. The gain parameters of the PI controller are represented by every individual in the evolutionary algorithm. Consequently, the issue might be stated as follows:

Proportional gain and integral gain tuning parameters of the control output independent variable conventional and optimal PI controllers

Find ind.= [$k_{p1,}K_{i1}K_{p2,}K_{i2}$]

To improve $\boldsymbol{j_2}$(ind, u), J1 (ind, u),

Subject to $\alpha i \leq bi, cj \leq uj \leq dj$

When i = 1. . . 6, j =1, 2

Where I and bi are the gain parameters' bound constraints, which are selected by simulation studies including trial and error? The bound restrictions of the control input are Cj and dj.

Greenhouse environment control mechanism for the specified maximum value and minimum value for proper control mechanisms that was important for crop production in greenhouse.

If the control mechanism was under minimum and over maximum as indicated in the MATLAB Simulink block during simulation study the production of crop in the greenhouse is not normal and not as the research need

Figure 4.2 indicates the Simulink model block diagram of greenhouse dynamic climate control system with convectional PI controller having step input researcher get the an integral absolute error (IAE) and control effort of total variation (TV) 5993 and 7572 respectively

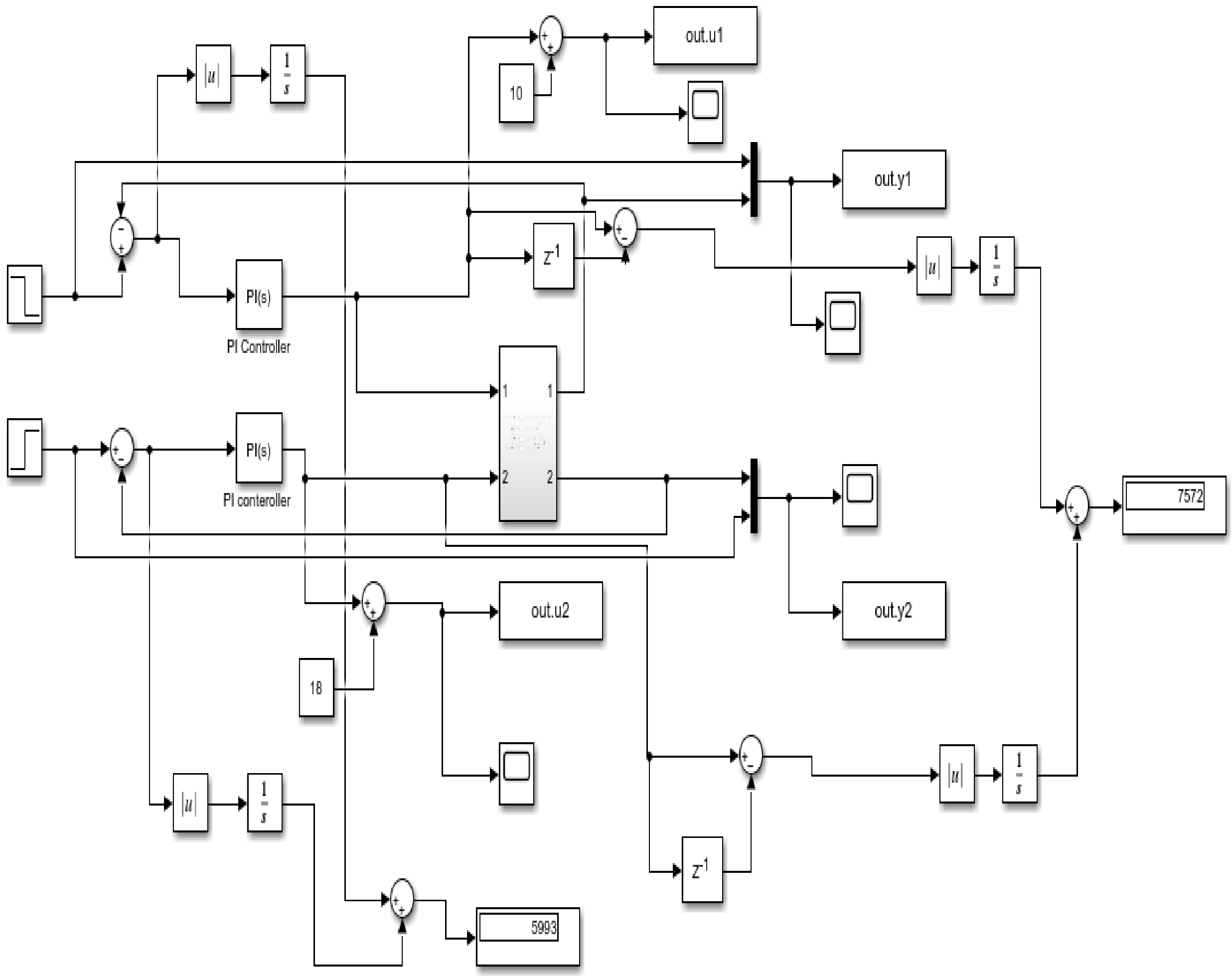

Figure 4.2 Simulink block for conventional PI controller of greenhouse climate control

Figure 4.3 The Simulink model block diagram of greenhouse dynamic climate control system with Optimal PI Controller having step input researcher get the an integral absolute error (IAE) and control effort of total variation (TV)5006 and 8001 respectively

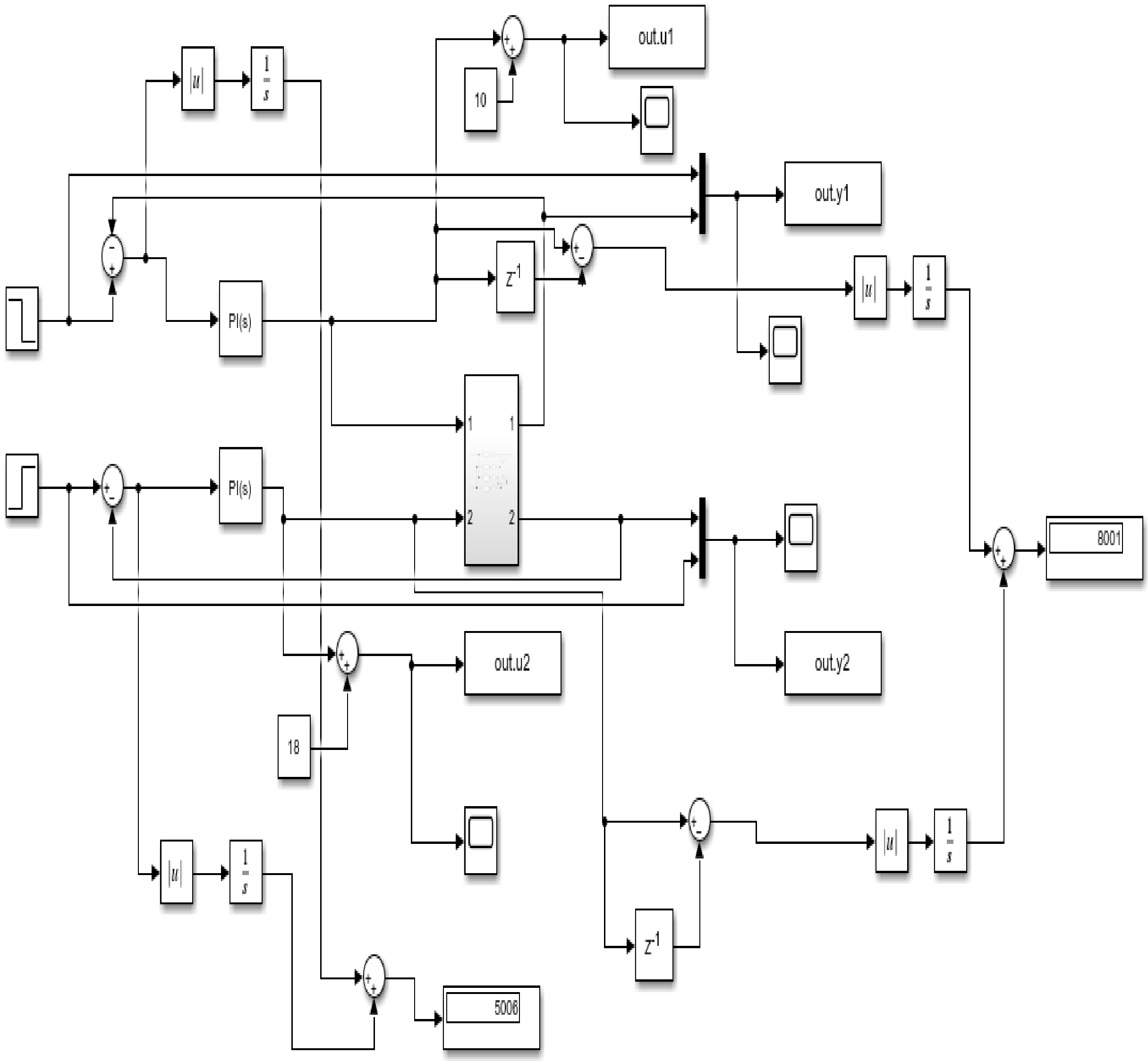

Figure 4.3 Simulink block for optimal PI controller of greenhouse climate control

4.5 NSGA-II (Non-dominated Sorting Genetic Algorithm)

NSGA-II is one of the most popular multi objective optimization algorithms with three special Characteristics, fast non-dominated sorting approach, fast crowded distance estimation procedure and simple crowded comparison operator [35].

NSGA-II is a well-known, fast sorting and elite multi objective genetic algorithm. Process parameters such as cutting speed, feed rate, rotational speed etc. are the considerable conditions in order to optimize the machining operations in minimizing or maximizing the machining performances.

NSGA-II is one evolutionary algorithm that has the following three features:

- It uses an elitist principle, i.e. the elites of a population are given the opportunity to be carried to the next generation.
- Is uses an explicit diversity preserving mechanism (Crowding distance)
- It emphasizes the non-dominated solutions.

NSGA-II uses a more adaptive scheme through its crowding distance operator for the same purpose

At each generation of NSGA-II, non-dominated sorting is first employed to select solutions with lower ranks from the population combining parent population with offspring population, and crowding distance is used as the secondary metric to distinguish solutions in the same rank by favoring solutions with a large one of the multi-objective algorithms proposed by Deb et al. that is the most successful is this one (2000). Figure 4.4 depicts the algorithm mechanism as it was reported by Deb et al. the NSGA II algorithm's pseudo-code is shown in figure 4.4.

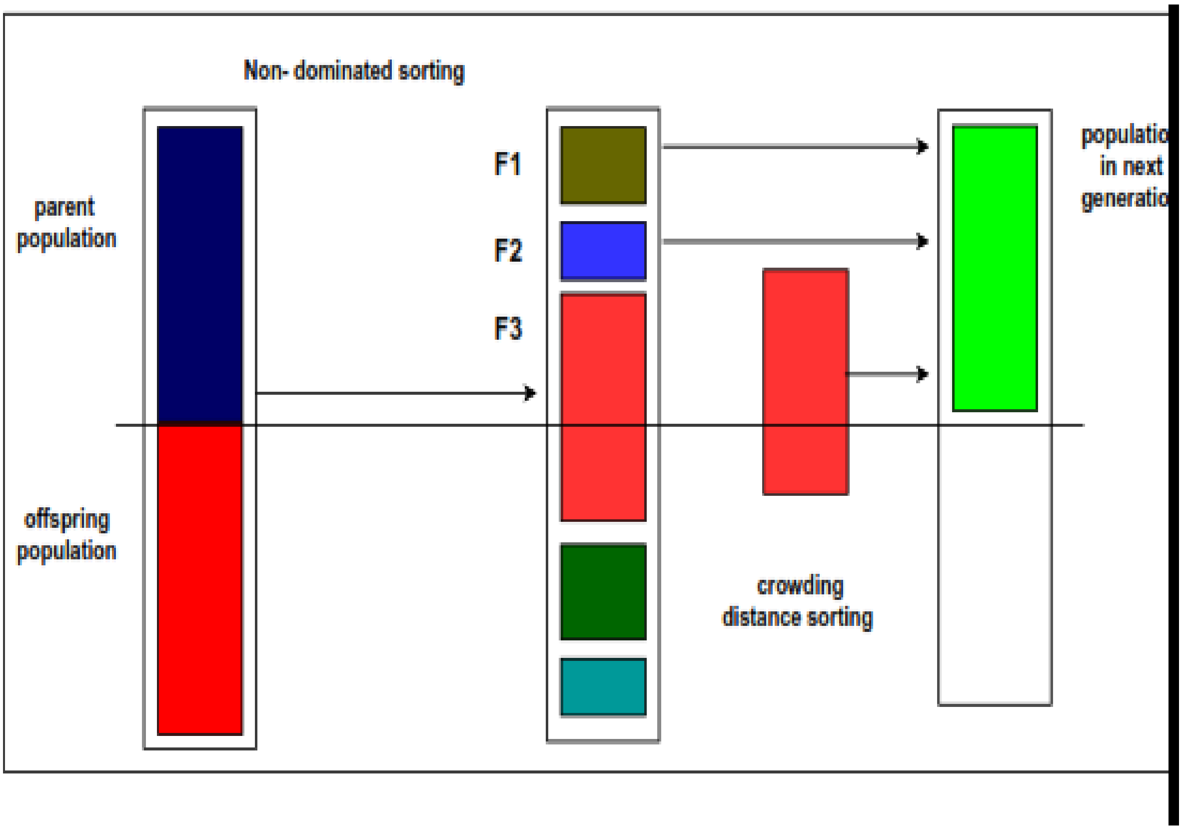

Figure 4.4 Mechanism of NSGA II (deb et AL, 2000)[37]

4.6 Initialization parameter of NSGA-II

Probability of mutation operator (cP),

Probability of mutation operator (mP),

Number of algorithm iteration (Maxit),

Initial population size (Ipop),

4.7 Problem chromosome

Because NSGA II is a population-based algorithm, each solution (the algorithm chromosome) is regarded as a matrix of rank s*2, where s is the number of sub-systems and the first and second rows reflect the number and type of assigned component to each sub-system, respectively.

The structure of the problem chromosome is presented in the Figure below

Table 4.1 Chromosome presentation

n_1	n_2	____	n_{s-1}	n_s
z_1	z_2	____	z_{s-1}	z_s

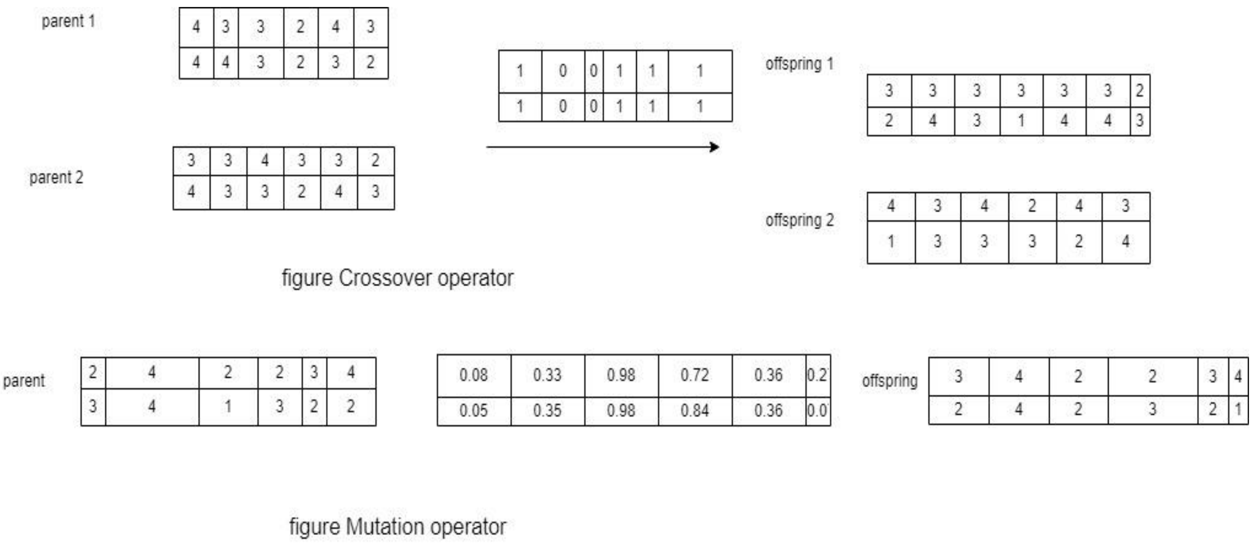

Figure 4.5 Structure of presented chromosome

Crossover operator

Crossover gen and change (1997) by Tavakkoli-Moghaddam et al. serves as the crossover operator in this work (2008).In this form of crossover operator, two parents are picked using a roulette wheel, and each genome of the parent's chromosome is assigned a binary to 1, and the parent's genome does not change. This type of crossover operator is depicted in the figure4.5.

Mutation operator

For the mutation operator, if the mutation rate for each genome of chromosome is less than the mutation rate (0.1 in this work), the genome will be mutated randomly; otherwise, the genome will not be altered, as demonstrated in figure4.5.

CHAPTER FIVE

SIMULATION RESULT AND DISCUSSION

The nonlinear mathematical formalism produced in equation (3.1) and (3.2) as reflecting the plant, and its interpolation as the nominal modeling in this chapter, is accepted in all supplied simulated outcomes equation (3.3).The initial condition for the original climate is given Tin = 32 ∘C and Win = 7.46 g/m^3. The other variable was startup with the values in Table 3.1. The open loop unit step response from the initial conditions to be shown in Figure 5.1. This response shows that temperature response has negative gain.

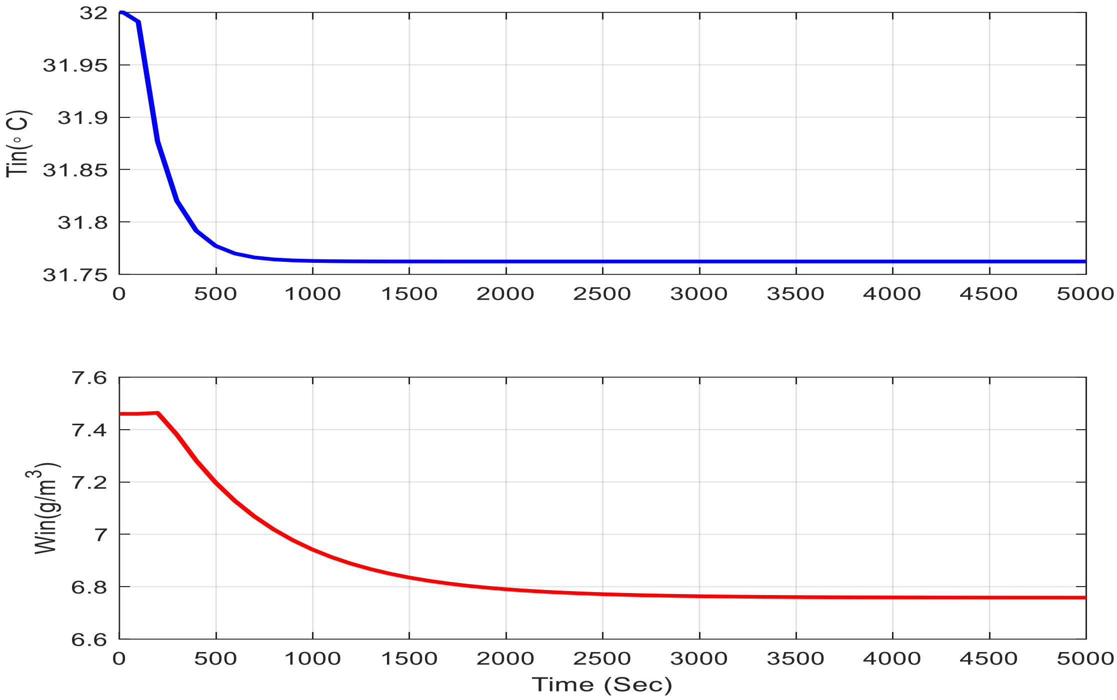

Figure 5.1 Unit step input response for initial condition temperature and humidity greenhouse climate system

5.1 Simulation results of conventional multi-loop PI controller

The tuned conventional multi-loop PI controller is listed in Table 5.1. PI controller 1 parameters are negative because the temperature response has negative gain. Closed loop simulated outcomes are shown in Fig.5.2, for the scenario where the At t = 50 s, set-point temperature decreases by 2 C. and the humidity set-point is increased by 5 g/m^3 at t = 50 s. The corresponding controller response is shown in figure 5.3.

Table 5.1 Multi-loop conventional PI Controller Parameter

	Kc	Ki
PI Controller 1	-3.9432	-0.0051
PI Controller 2	4.6732	0.0060

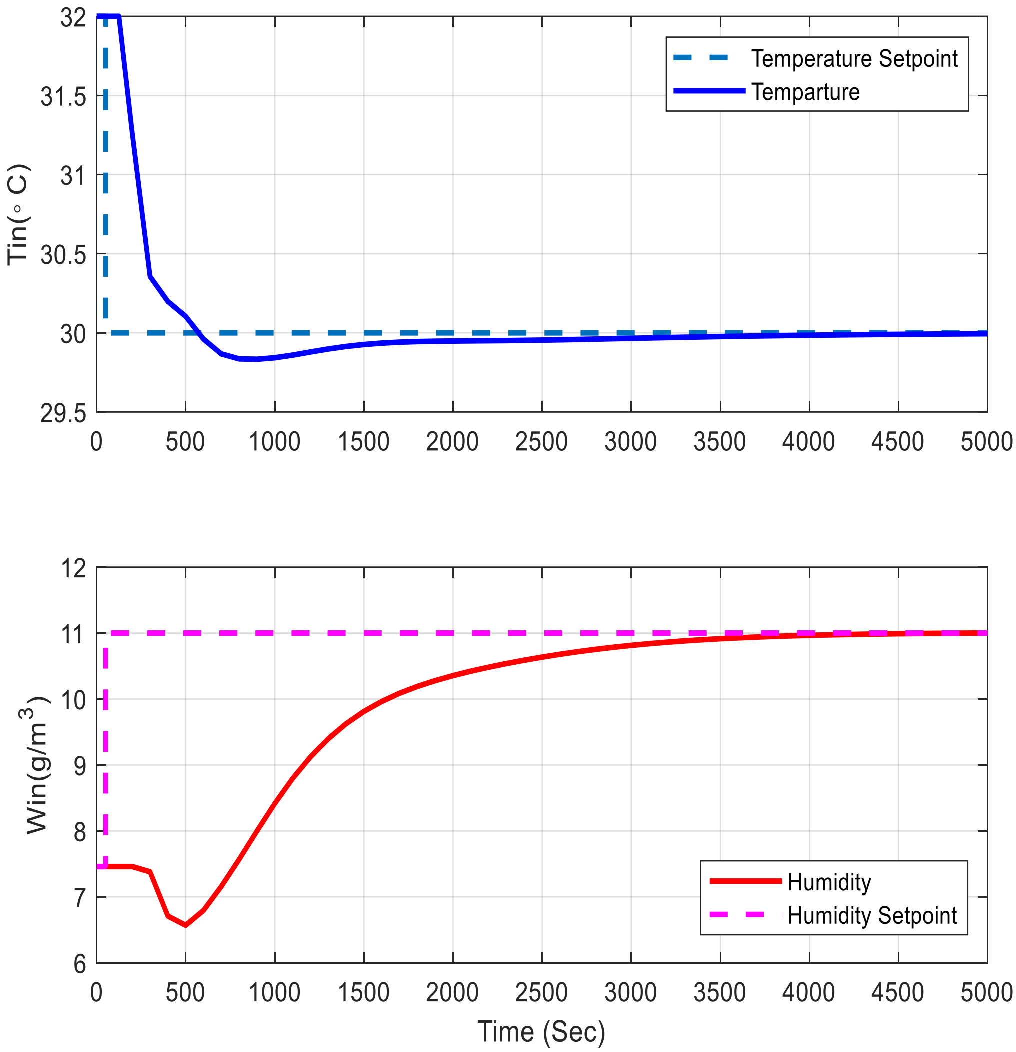

Figure 5.2 Closed loop tracking response of greenhouse climate control system with conventional PI controller

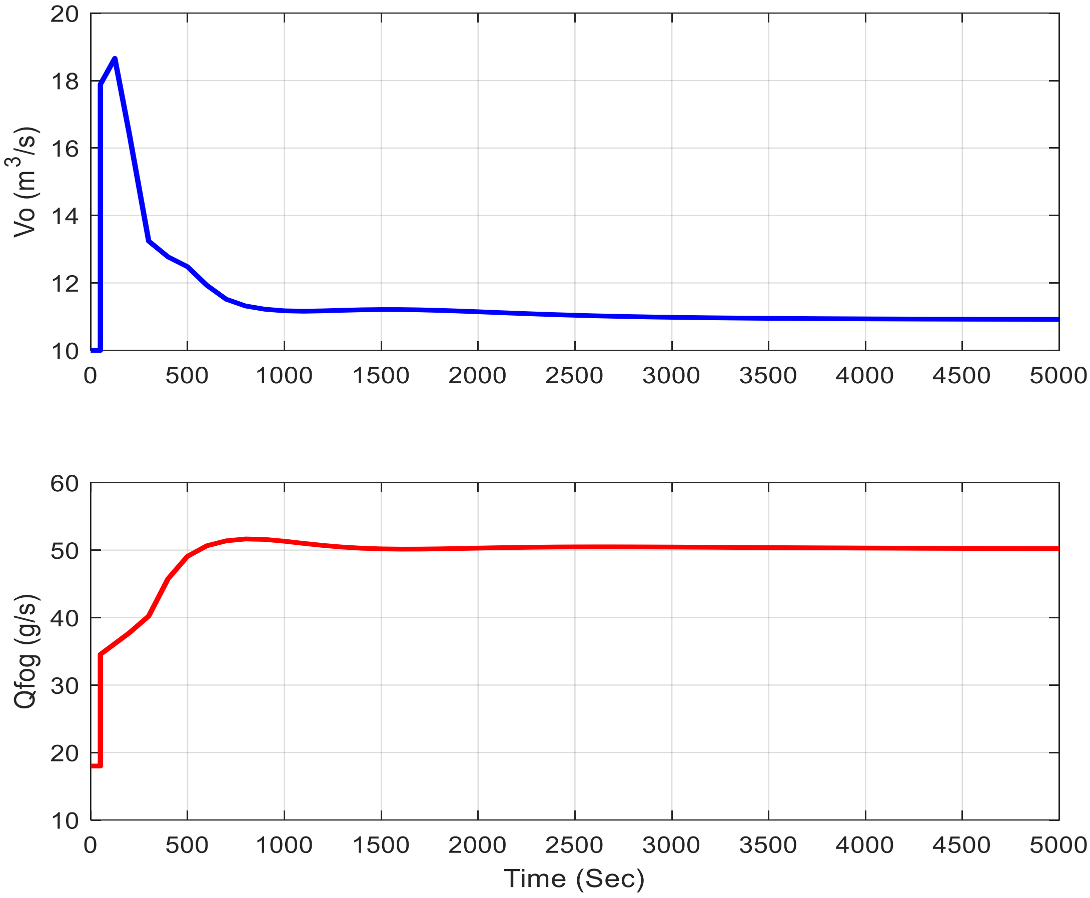

Figure 5.3 Controller output of greenhouse climate control system with conventional PI controller

In this study, the optimization problem is solved using real-coded NSGA-II. For the set-points of controllers, unit step inputs are provided. Pareto optimal front of simulation results using NSGA-II is shown in Figure5.4, and the findings demonstrate the selected performance targets are competing decision criteria. We understood to in Figure 5.4, the amount of the objective J2 drops sharply as that of the objective J1 increases on the left of point A, whereas the index J2 remains almost unchanged with the increase of the index J1 on the right of point B. It implies that the Pareto Front AB is the best desired region in most instances. As a result, a good tradeoff may be found in the region, and the Decision Maker (DM) can choose the best final option based on his or her preferences.

Figure 5.4 depicts the decision maker. Figure 5.5 depicts the best ideal value that meets both criteria. The multi-loop controller with the finest performance the values are listed below.

Table 5.2 Optimal PI Controller Parameter

	P	I
PI Controller 1	-3.141	-0.0037
PI Controller 2	4.23	0.0079

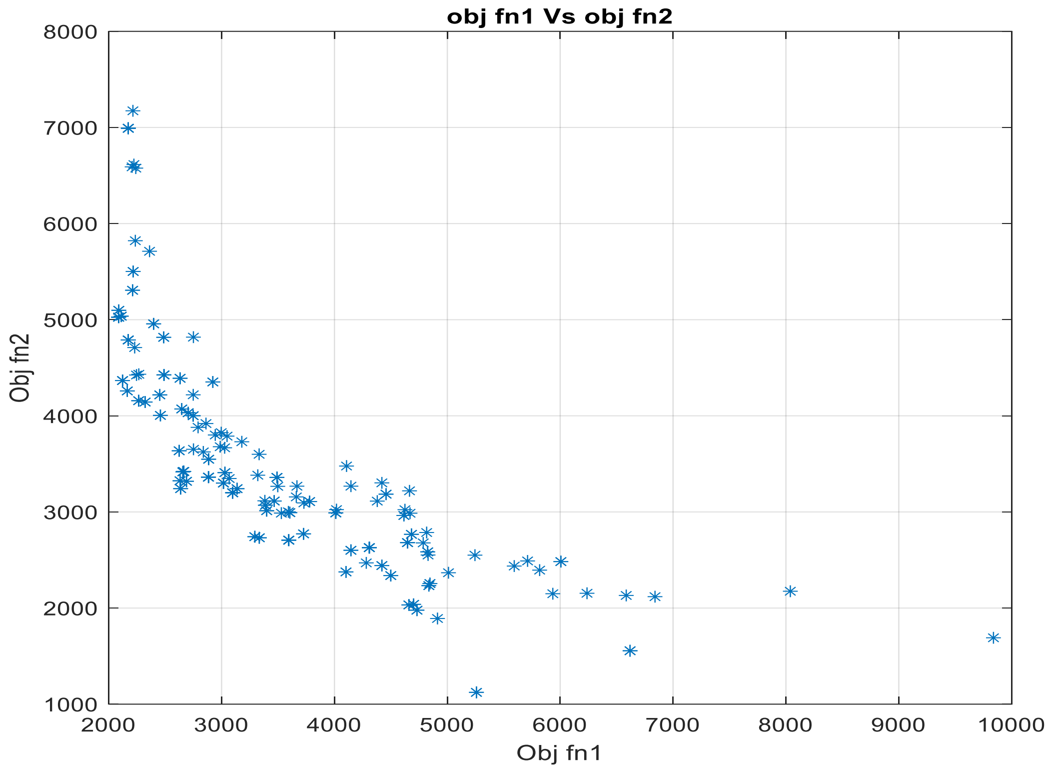

Figure 5.4 Pareto-optimal Front of performances objective function1 (J1) and objective function2 (J2)

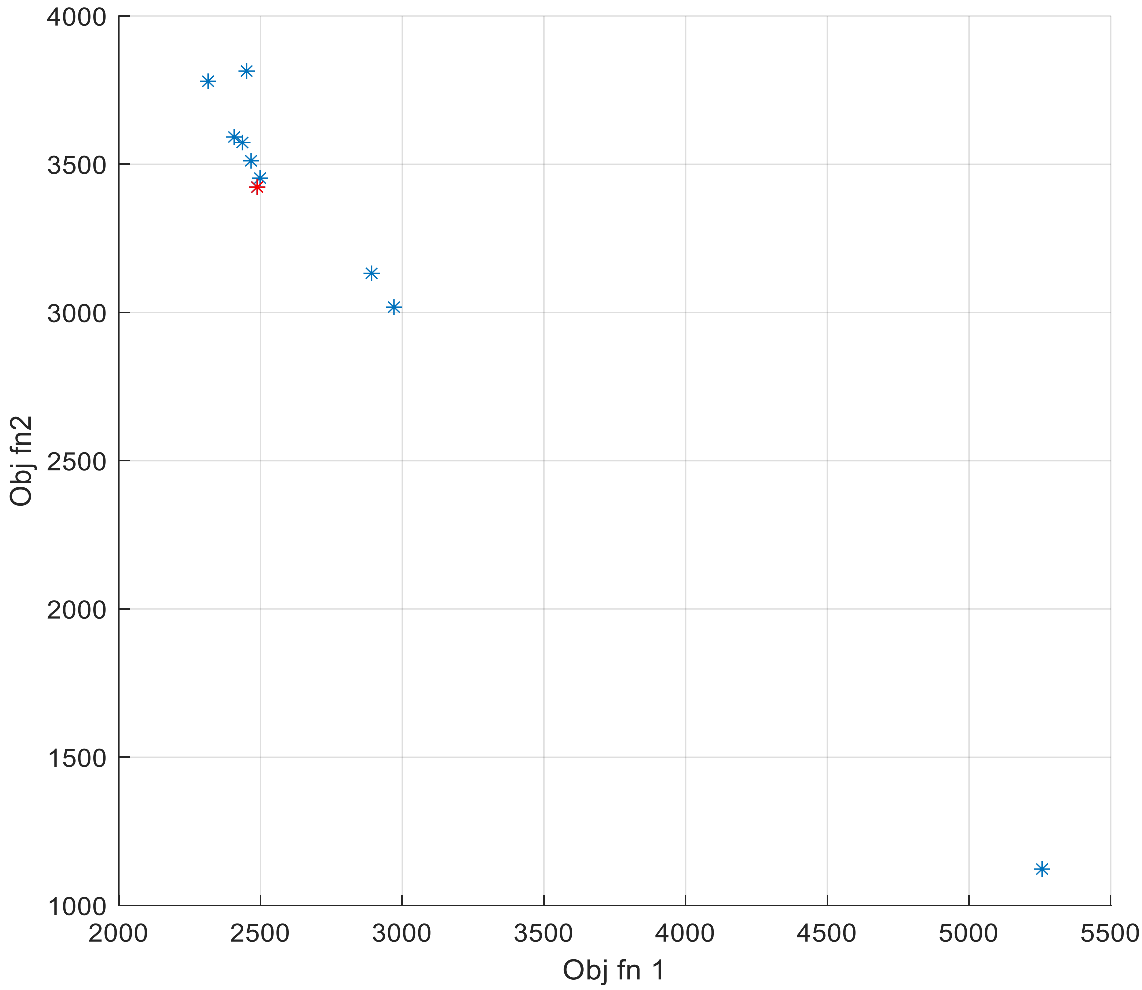

Figure 5.5 Selection of best solution from Pareto Front solution

Closed loop simulation of optimal multi-loop PI controller the outcomes are displayed in Figure 5.6, the event in which the temperature set-point decreases by 2 ◦C at t = 50 s, and the humidity set-point is increased by 5 g/m^3 at t = 50 s. The corresponding controller response is shown in figure 5.7. The performance comparison of conventional and optimal multi-loop PI controllers is listed in Table 5.3.

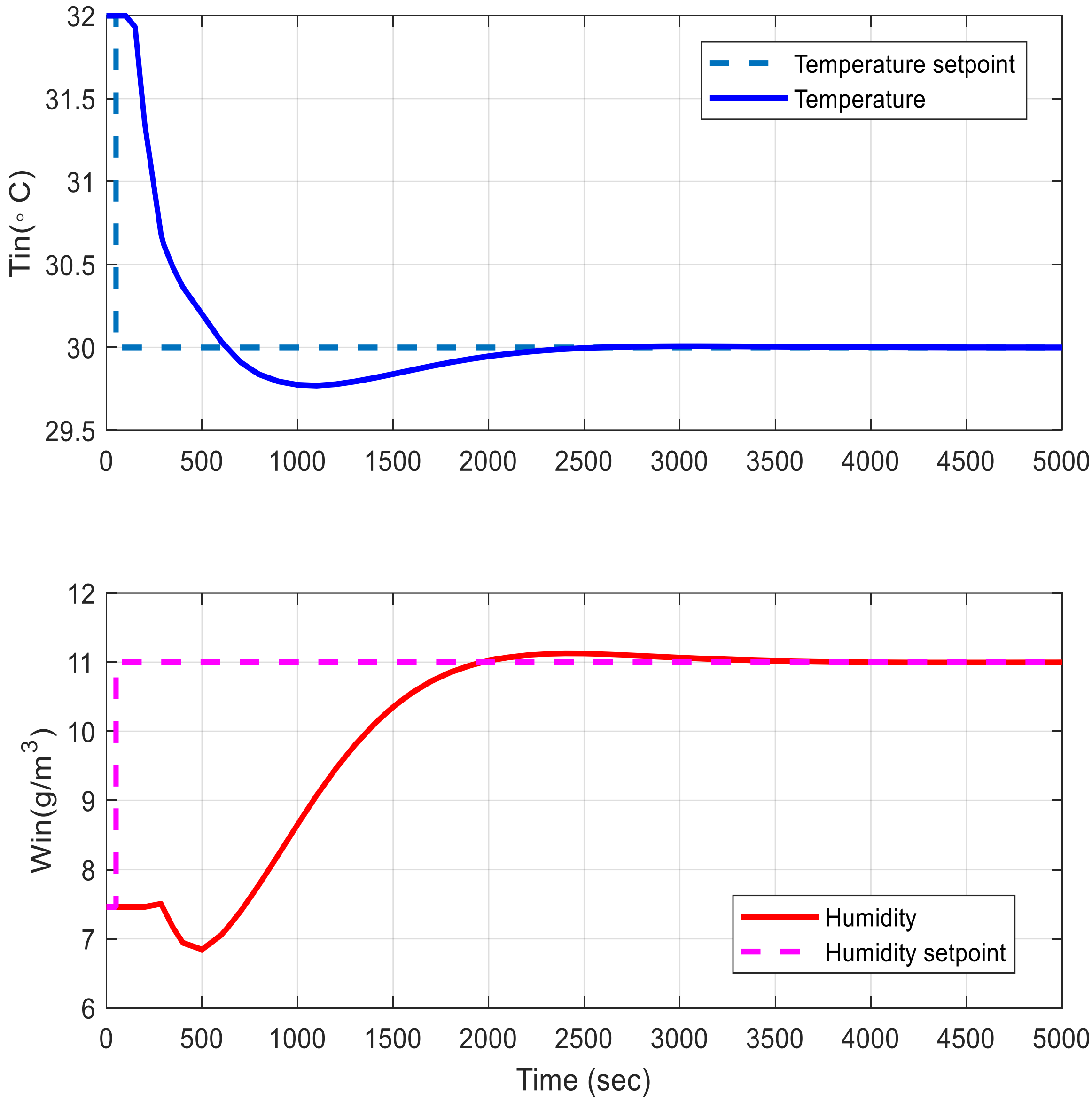

Figure 5.6 Closed loop tracking response of greenhouse climate control system with optimal Controller

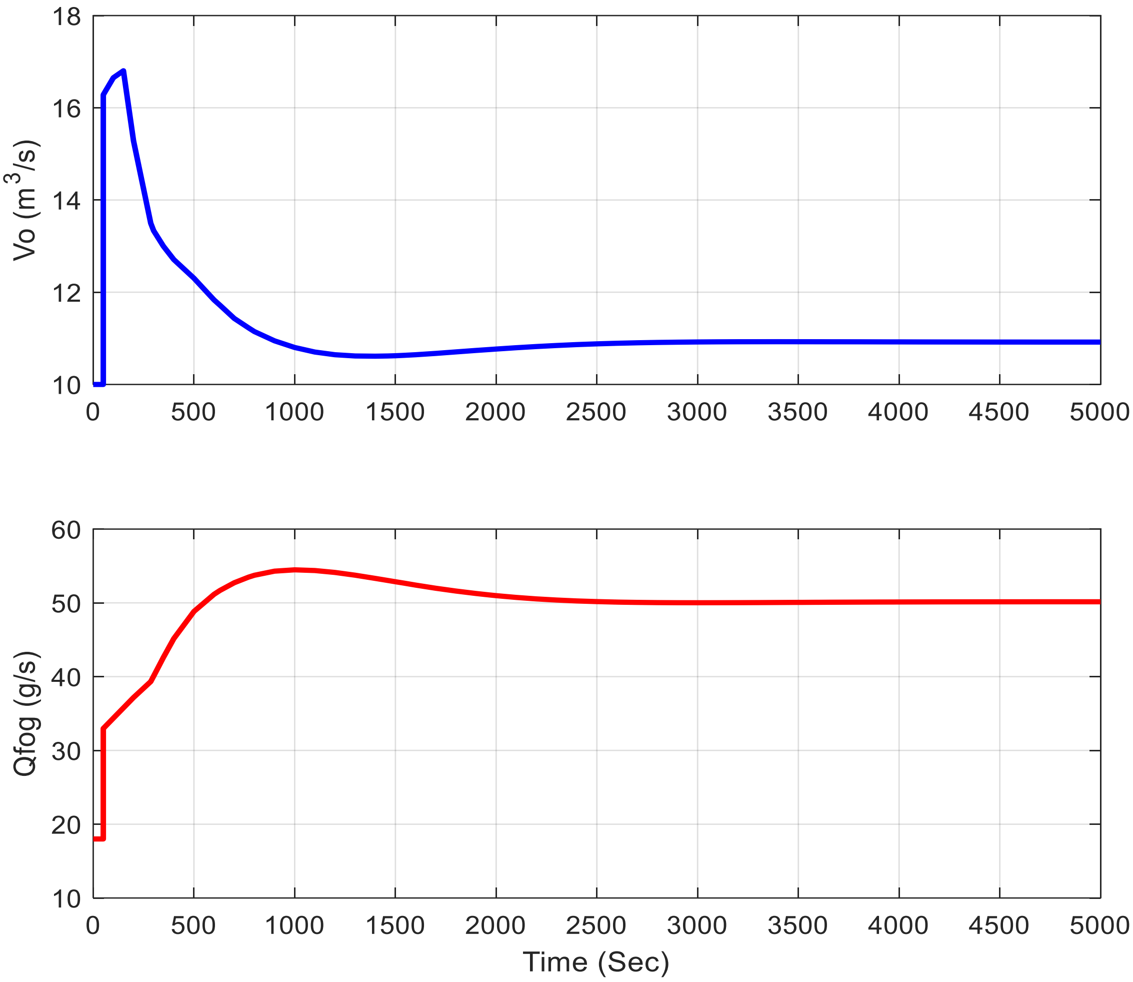

Figure 5.7 Controller output of greenhouse climate control system with optimal PI Controller

Table 5.3 performance comparison

	J1 (IAE)	J2(TV)
Optimal PI Controller	5000	3505
Conventional PI Controller	5000	2632

Control system design involves satisfying different performance objectives. In this work error minimization performance and controller effort minimization are taken as multi-objective optimization.

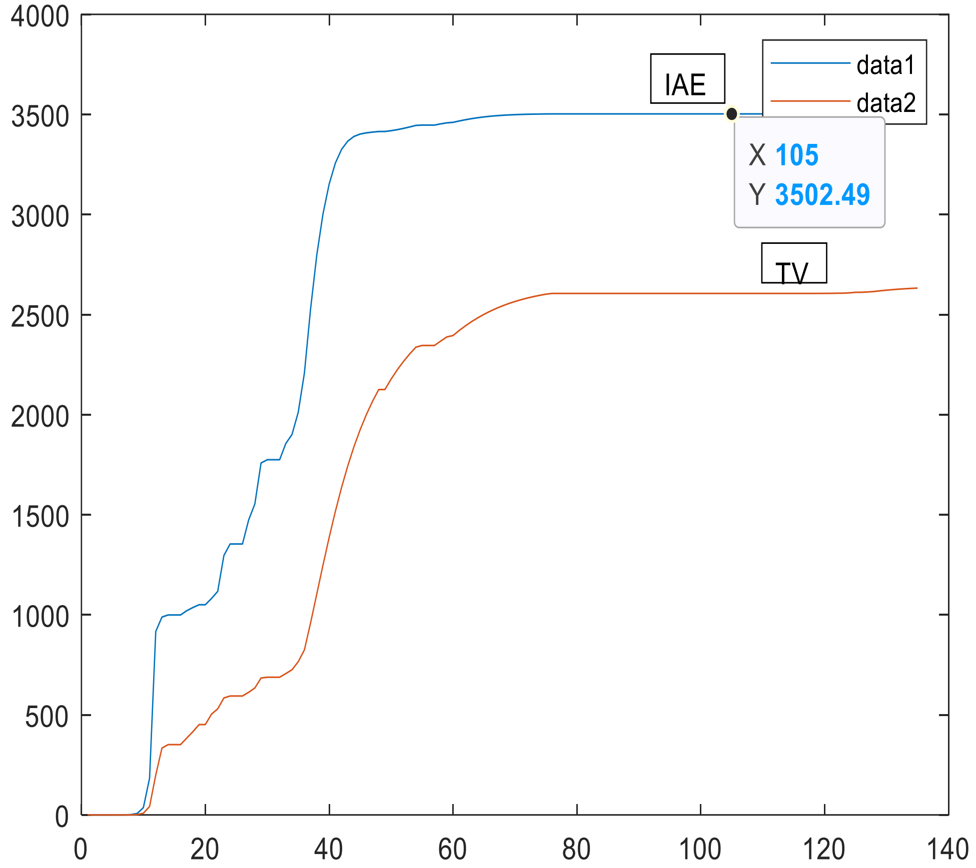

Figure 5.8 Pareto-optimal Front of performances objective function1 (J1) and objective function2 (J2)

CHAPTER SIX

CONCLUSION & RECOMMENDATION

6.1 Conclusions

Greenhouse environment is more important for optimal environment for cultivation. The optimal environment is achieved by properly designed control system. In this work, a control oriented multivariable two-input and two-output model is used to design the multivariable closed loop system. The multi-loop PI controller design process is formulated as a multi-objective optimization problem. The Integral Absolute Error (IAE) and control effort Total Variation (TV) is selected as a two contradictory objective functions. In this work the NSGA-II is real-coded performed for solving the multi-objective optimization problem. This Pareto-optimal front of NSGA-II simulated results demonstrates that the chosen performance targets are competing choice criteria. The closed loop system response is simulated in order to get the best optimal value that meets both objectives. The performance of the optimally tuned multi-loop PI controller is compared to conventional PI controller. The optimally tuned controller shows improved performance than the conventional PI controller.

6.2 Recommendations

The following aspects may be considered as future work.

The model considers the main two-inputs and two-output systems. The other greenhouse process variables can be considered for higher accurate model.

The disturbance variables effect can be considered and its effect in the greenhouse performance may be analyzed.

The other multi-objective algorithm may be considered for solving multi-objective optimization problem

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APPENDIX

Appendix A

A.1 Appendix related to multi-objective evolutionary algorithm

MATLAB code for optimal function of NSGA

```
close all
clear all
clf;
clc;
%warning off
t0 = clock;
rand('state',sum(100*clock));
 % global variable declaration
global dim  n_obj n_con  equal_con err_tol pop_number max_gen pc pm etac etam
xl xu p dim
p=2;%Enter Problem number 1 to 5 for Promblm No PM1 to PM5
tdim=[2 2 2 2 2];
dim =tdim(p);
txl=[-5 -5;-20 -20;0 0;0 0 ;0.1 0.1];
txu=[10 10 ;20 20 ;10 10 ;1 1;1 1];
 n_obj=2;
if p<=4
   func_name='test_case';
else
   func_name='test_case_with_true_paretofront';
end
if p==5
   true_pareto=load ('-ascii','deb_MO');
end
equal_con=0;
n_con =1;

%%%%%%%%%%%%%%%%%% VMP %%%%%%%%%%%%%%%%%%%%
```

```
xl=txl(p,1:dim);%lower bound vector
xu=txu(p,1:dim);%upper bound vector
% input_parameters
feval_max=10000;%maximum number of functional evaluation
pop_number=100;   pc=0.8;  pm=1/dim;  etac=2;  etam=20;r=0.55;
max_gen=1.5*round(feval_max/pop_number);

% err_tol-setting
err_tol=0;
if equal_con~=0,
    err_tol=10^-3;
end
 % Intial population generation
ww(pop_number,dim+n_obj+n_con)=zeros;
ww(:,1:dim)= rand(pop_number,dim);

gcount =1;feval_count=0;
% initial population - - objective function evaluation
for ii=1:pop_number
[ww(ii,dim+1:dim+n_obj+n_con)]=feval(func_name,ww(ii,1:dim));
end
ww1 = ww;  %% important

feval_count=feval_count+pop_number;
% Iteraion
for gcount=2:max_gen
    gcount
       rc=randperm(pop_number);
    for tt=1:pop_number/2
        rr1=rc(2*tt-1);
        rr2=rc(2*tt);
        if rand< pc,
```

```
ww1(rr1,1:dim),ww1(rr2,1:dim)]=sbx_cross_new(ww(rr1,1:dim),ww(rr2,1:dim),p
m,gcount,etac,etam);
        end
    end
     % subsequent population -- objective function evaluation
    for jj=1:pop_number
    [ww1(jj,dim+1:dim+n_obj+n_con)]=feval(func_name,ww1(jj,1:dim));
    end
    feval_count=feval_count+pop_number;
     ww_total=[ww;ww1];
     % Calling nsga-II
    [no_of_fronts ww] = nsga_II(ww_total,dim,n_obj,err_tol);

    fronts(gcount) =  no_of_fronts;
         ww_temp =ww;
%     size(ww)
%     pause
    ww = ww(1:pop_number,:);
      ww1=crowded_tour_selection(ww_temp,dim,n_obj,pop_number);
if feval_count>=feval_max,break,end
end
 pareto_opt_soln = ww(:,1:dim+n_obj+1);
et=etime(clock,t0);
if (p==5)
    obtained_pareto=sortrows(pareto_opt_soln(:,dim+1:dim+2),1);
    gama=convergence_metric(true_pareto,obtained_pareto)
    delta=spread_metric(true_pareto,obtained_pareto)
end
% figure
plot(pareto_opt_soln(:,dim+1),pareto_opt_soln(:,dim+2),'*');
xlabel('Obj fn1')
ylabel('Obj fn2')
title('obj fn1 Vs obj fn2')
```