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# INTERIOR CLIMATE CONTROL OF MIMO GREEN HOUSE MODEL USING PI AND IP CONTROLLERS

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**ABSTRACT**

Climate control techniques in greenhouses are to improve plants requirements and prevent unnecessary power consumption. Several parameters may affect the growing of plants: internal air temperature, inside vapor pressure and Co2 concentration. The equilibrium of these settings is obtained by choosing the appropriate monitoring actions. Here we developed a dynamic and complex nonlinear coupled (MIMO) system of a horticultural greenhouse by using the MATLAB/SIMULINK environment. In this paper the most widely used proportional -integral (PI) controller was compared to the new integral -proportional (IP) controller.

**Keywords:** PI controller, IP controller, the mathematical model, internal climate, greenhouse.

## 1. INTRODUCTION

The greenhouses are areas that create an environment other than that found outside because of the imprisonment of the inside air and to the absorption of solar rays via a covered plastic or glass [1]. This produces a new environment in the greenhouse that is known as the microclimate. They give high performance productivity, and eliminate many of the risks caused by inappropriate weather and climate.

The simulation models describing the dynamic behavior of the interior air temperature and water vapor pressure and concentration dioxide in greenhouses have mainly focused on the determination of heating needs. Other schemes incorporate natural cooling ventilation, by evaporation, shading and control of irrigation. Analyzing these challenges take in consideration the coupled mechanisms involving mass and heat (air, water vapor).

Nonlinear models representing these processes have registered some success and provide a narrower interpretation of phenomena by concentrating in different fields such as physical models, black box models, and neuronal models [2-3-4-5]. The measurements of air exchange ratio and simultaneously recording climate parameters and of the opening areas were realized using an experimental greenhouse covered with a single polyethylene layer and fitted with the roof and the lateral apertures. The greenhouse is situated at the station Bioclimatology INRA in Avignon, France (Lat 43 ° 55 '). A schematic design of our greenhouse and his environment is represented in Fig.1. Scientists used several monitoring techniques in various domains. From the conventional control based on classical control theory like PID controllers and PI controllers, artificial intelligence such as: fuzzy logic controllers, neural networks representation and GA codes to advanced techniques like predictive, adaptive, robust and non linear control [6]. The above rementioned techniques were largely used in the research [7-8].

New studies have been conducted on climate control in greenhouses, among these works: Setiawan who was the first to implement the PD-OF structure to control the temperature of the greenhouse. [9]. PD OF structure is an improvement of the Pseudo-Derivative Feedback algorithm (PDF) that is designed by Phelan [10]. The proportional-integral-plus (PIP) was also used to control the ventilation ratio in greenhouses in order to regulate the temperature [11].

The parameters were initially controlled simultaneously using the structure of the proportional-integral-derival (PID) controller [12] and subsequently by using PI control shame [13].This paper presents the control of the internal climate using a nonlinear coupled multiple-input, multiple-output (MIMO) model of an horticultural greenhouse based on a system of tow models: an order two thermal model [14], and first order hydric model of this greenhouse system [2]. A comparative analysis between the proportional-integral (PI) controller and the new integral-proportional (IP) controller is realized.

## 2. THE GREENHOUSE CLIMATE MODEL

Various studies [2-15] were published on the simulation models to represent the dynamic behavior of the climate in greenhouses; those models are created to successfully control the climate in the greenhouse. Often, these models are elaborated to control efficiently the inside climate of greenhouse [1-2-14].

The state space description of the experimental greenhouse system is defined by energy balance and water vapor equations.

The virtual thermal mass equation is given by:

$$C_m \frac{dT_m}{dt} = h(T_i - T_m) + \beta.R_g + Q_{sol} \qquad (1)$$

Where:

- $h(T_i - T_m)$ is the heat exchange with the greenhouse air,
- $\beta.R_g$ is the profit solar directly absorbs by the thermal mass,
- $Q_{sol}$ is the soil heating flux proportional .

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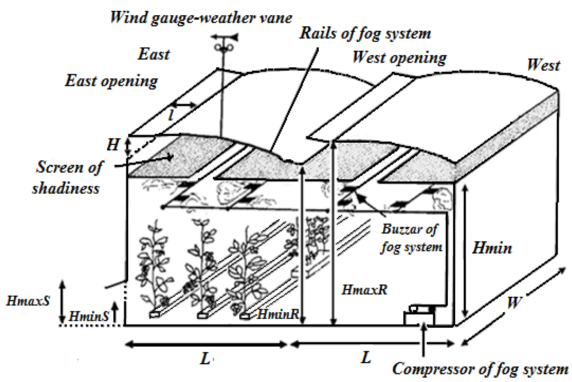


**Figure-1.** The structure of the experimental horticultural greenhouse.

The virtual thermal crop equation is given by:

$$C_v \frac{dT_v}{dt} = h'(T_i - T_v) \tag{2}$$

The first term of the right side is the heat exchange with the vegetable air.

The air thermal balance equation is given by:

$$\begin{aligned} &Q_{air} + \alpha.R_g + h(T_m - T_i) + h'(T_v - T_i) + K(T_e - T_i) \\ &+ K_s(T_e - T_i) + K_l(P_e - P_i) = 0 \end{aligned} \tag{3}$$

Where:

- $Q_{air}$ is the heating air level,
- $\alpha.R_g$ is the solar profit gain,
- $h(T_m - T_i)$ is the heat exchange with the thermal mass,
- $h'(T_v - T_i)$ is the thermal exchange with the crop,
- $K(T_e - T_i)$ is the overall heat exchange between inside and outside,
- $K_s(T_e - T_i) + K_l(P_e - P_i)$ are sensible and latent heat exchanges by ventilation and leakages, and, air water vapor balance.

The air water vapor balance is given by:

$$\begin{aligned} &C_l \frac{dP_i}{dt} = A\tau.R_g + B(P^*(T_i) - P_i) \\ &- K_l(P_i - P_e) + \varphi_l \end{aligned} \tag{4}$$

Where:

- $A\tau.R_g$ the crop transpiration (simply described as a linear function of global radiation and saturation deficit),
- $B(P^*(T_i) - P_i) - K_l(P_i - P_e)$ are the exchanges by the crops,
- $\varphi_l$ is the contribution of the fog system [16].

And the water vapor saturation pressure is described by [2]:

$$P^*(T_i) = 6{,}1070((1 + \sqrt{2}.\sin(\frac{\pi T_i}{540}))^{8.827} \tag{5}$$

The overall heat loss parameter through greenhouse plastic cover is described by:

$$K = 7.6 + 0.42V \tag{6}$$

The equivalent thermal capacitor of water vapor in air is given by:

$$C_l = \rho C_p v / \gamma S \tag{7}$$

The latent heat transfer coefficient driven by ventilation and the sensible heat transfer parameter driven by ventilation are cited respectively in (8) and (9):

$$K_s = \frac{\rho C_p G_v}{S} \tag{8}$$

$$K_l = \frac{\rho C_p G_v}{\gamma S} \tag{9}$$

$$G_v = \frac{(s + s_0)}{2} Al\sqrt{C}V + d_0 \tag{10}$$

Where the factor $Al\sqrt{C}$ of the model of natural ventilation is set at 0.2. The association of equations (1), (2), (3), (4) and (5) brought to get a coupled MIMO model of greenhouse with four unknown factors (*Tm, Tv, Ti, Pi*). In Figure-2, we have represented a block diagram model of greenhouse where variables to be controlled are indoor temperature (*Ti*) and the indoor water vapor pressure (*Pi*), the actions parameters are soil heating loads (*Qsol*), air heating loads (*Qair*), opening-wind (*s*), power of the evaporative cooling fog system ($\varphi_l$), (*Te,Pe*) are outdoor temperature and outdoor water vapor pressure, solar radiation (*Rg*) and the speed of wind (*V*).

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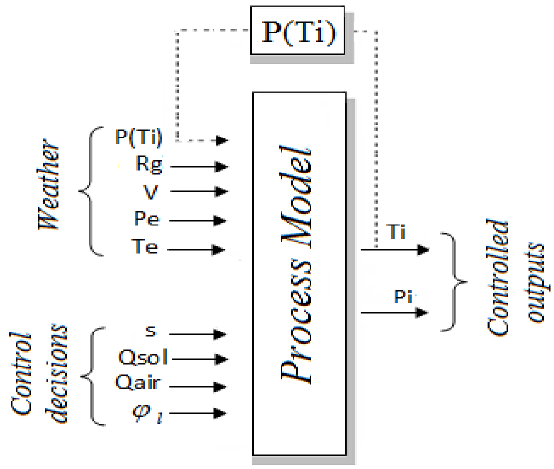


**Figure-2.** Variables in greenhouse system.

The final optimum parameters system settings are given by [17] and summarized in the table1. Comparisons between actual measurements inside the greenhouse and the MIMO model are shown in the Figure-3 and Figure-4.

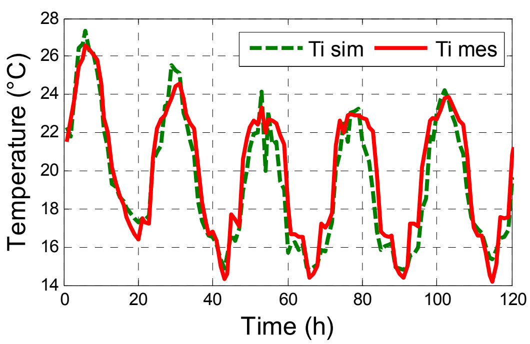


**Figure-3.** Measured and simulated inside air temperature.

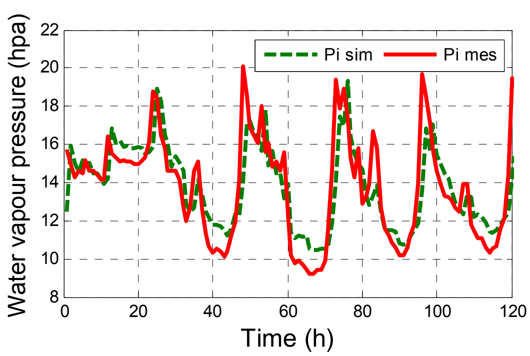


**Figure-4.** Measured and simulated inside water vapor pressure.

**Table-1.** Parameters values of the greenhouse model.

| Parameters | Values |
|---|---|
| $s_0$ ($m^2$) | 0.6215 |
| $d_0$ ($m^3s^{-1}$) | 0.5347 |
| $\beta$ (.) | 0.0834 |
| $\alpha$ (.) | 0.3395 |
| h ($Wm^2K^{-1}$) | 7.0225 |
| $h'$ ($Wm^2K^{-1}$) | 3.9555 |
| $C_m$ ($Jm^2K^{-1}$) | 187.5983 |
| $C_v$ ($Jm^2K^{-1}$) | 3.4374 |
| B ($Wm^2hPa^{-1}$) | 3.2626 |
| $T_{m0}$ (°C) | 19.5271 |
| $T_{v0}$ (°C) | 13.0403 |
| $P_{i0}$ (hPa) | 12.4786 |

## 3. THE CONTROL STRUCTURES

### A. Controller design of PI

Proportional integral controllers are largely used in commercial practice for over 60 years. It is the standard and proven solution for the most industrial use. The major reason is its relatively simple diagram that can be easily interpreted and implemented in practice range. A typical structure of those controllers involves two components: the proportional and integral gains. Proportional value specifies the reaction to the actual error and the integration value defines the reaction based on the total recent errors. The mathematical description of its control law is usually described in the according parallel form in equation (11).

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt \qquad (11)$$

where:

- $u(t)$ is the control signal,
- $e(t) = r(t) - y(t)$ is the error signal,
- *Kp* is the proportional gain ,
- *Ki* is the integral gain,.
- r*(t)* and *y(t)* represent respectively the tracking reference signal and the outing of the process.

The basic diagram of closed loop control system with PI control of greenhouse system is indicated for Figure-5.

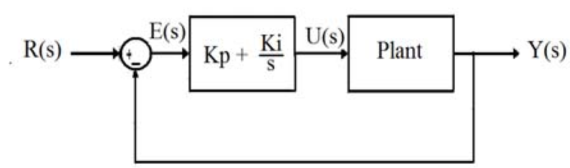


**Figure-5.** PI Controller structure.

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**B. Controller design of IP**

Among the most popular control systems on the industrial sector is the IP controller. The IP correction is essentially different from the PI corrector in that it does not present a zero in the transfer function of the closed loop, and its release will not represent any discontinuity in the application of a standard set level [18-19]. The basic diagram of the actual control using IP corrector is exemplified by the following Figure-6. The control law of the IP controller is specify by the following equation (12).

$$u(t) = K_p K_i \int_0^t e(t)dt - K_p y(t) \quad (12)$$

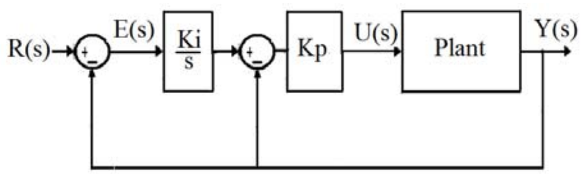


**Figure-6.** IP Controller structure.

**4. RESULTS AND DISCUSSIONS**

All inputs and controlled parameters of the MIMO greenhouse model are collected once per minute and averaged out of 1 hour. For keeping the greenhouse inside temperature and vapor pressure at the optimum values that are appropriate for the growing of crops, two monitoring techniques (PI controller and IP controller) are suggested. The PI controller and IP controller are tested at the same time for comparison. The greenhouse system depends on the external environmental conditions, construction of the greenhouse, category and condition of the crop, on the impact of the control actuators [20]. Here, the main way for monitoring the greenhouse clime is done by using ventilation and heating. The application of these controllers is accomplished in Figure-7 and Figure-8. The reference temperature was brought to 14 °C at 25°C and the water vapor pressure set point was maintained between 13 hpa and 20 hpa. The simulation results clearly indicate that the outputs do not interact between them and that the response of the closed-loop system is significant for the process variable temperature and water vapor pressure. It is remarked that, the greenhouse inside temperature tracks during 120 hours the reference temperature as reported by Figure-9 and Figure-10. The fluctuation in temperature greater than one degree, noticed during simulations are linked to the complexity and the nonlinearity of the model, are not detrimental on the growth of crops. Also, the controlled water vapor pressure during 120 hours is represented in Figure-11 and Figure-12, which indicates a very strong performance, because there is a small overshoot, and rapid establishment time.

We notice that after these simulations PI and IP controller gives good performances for water vapor pressure variable than inside temperature variable. The values of *Ki*, *Kp* of the PI and IP controllers are presented in Table-2 and Table-3.

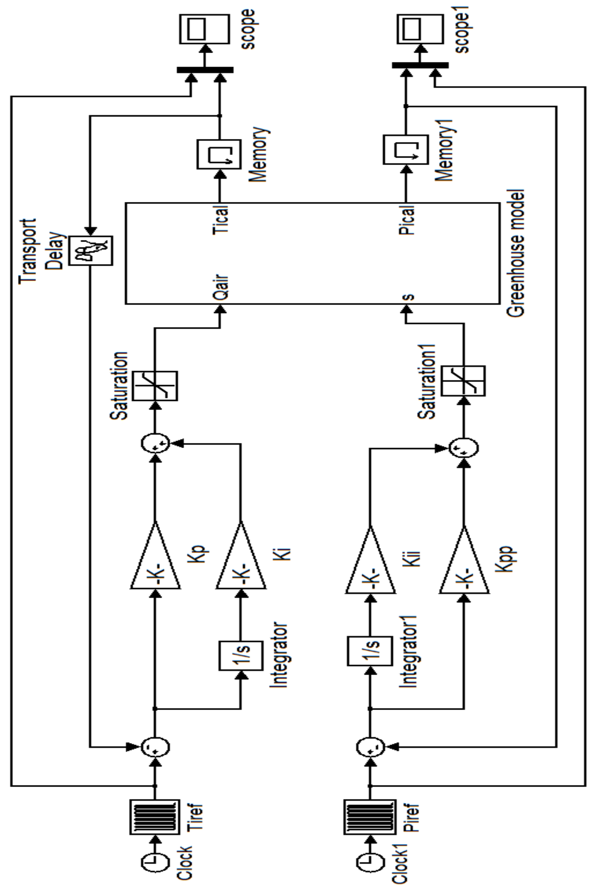


**Figure-7.** Simulink model using PI controller.

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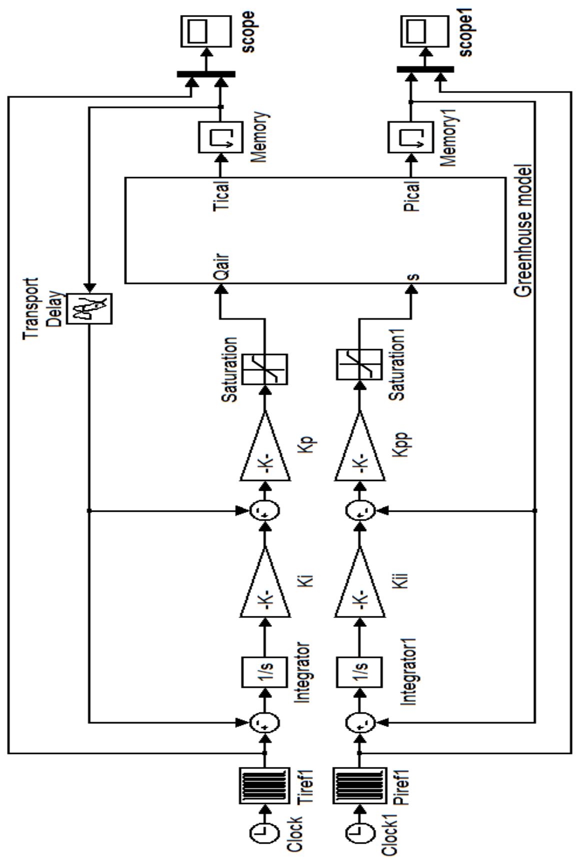


**Figure-8.** Simulink model using IP controller.

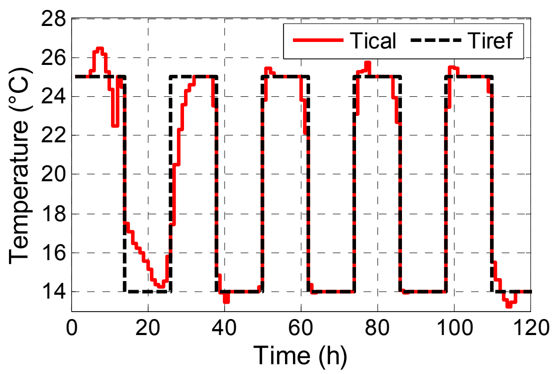


**Figure-9.** Greenhouse indoor temperature with PI controller.

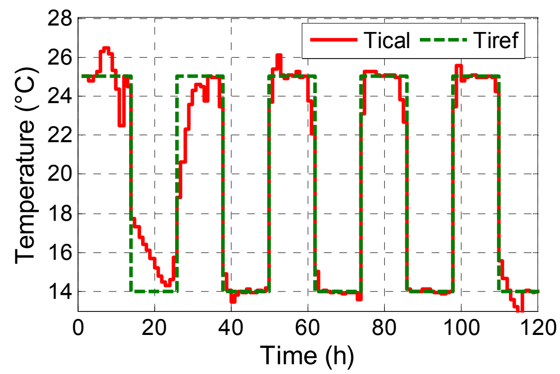


**Figure-10.** Greenhouse indoor temperature with IP controller.

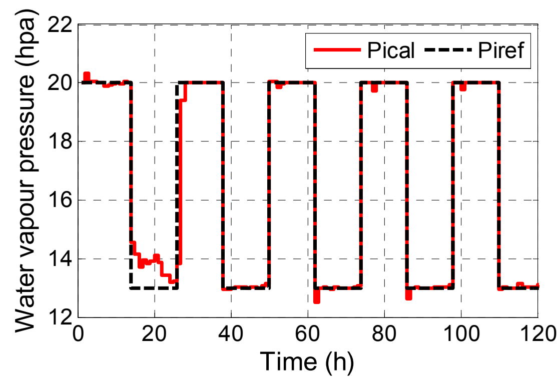


**Figure-11.** Greenhouse water vapor pressure with PI controller.

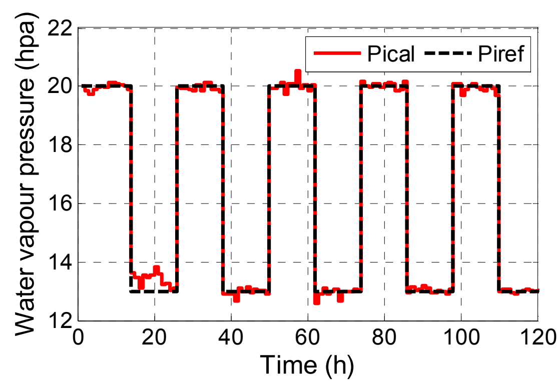


**Figure-12.** Greenhouse water vapor pressure with IP controller.

**Table-2.** PI controller parameters.

| Parameters | Ki | Kp |
|---|---|---|
| Temperature | 275.5 | 5.75 |
| Water vapour pressure | -2.75 | 0.079 |

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**Table-3.** IP controller parameters values.

| Parameters | Ki | Kp |
|---|---|---|
| Temperature | 27 | 11.58 |
| Water vapour pressure | -100 | 0.092 |

Performances indicators used to assess the quality of our control strategies illustrated in Figures 7-8 are the root means squared error (RMSE) and the mean absolute deviation (MAD) which are defined as:

$$RMSE = \sqrt{\frac{1}{N}\sum_{k=1}^{N} e_k^2} \quad (8)$$

$$MAD = \frac{1}{N}\sum_{k=1}^{N} \left| e_k \right| \quad (9)$$

Where $N$ is the size of our data samples and $e_k$ is the error between the outputs results and the sets points Table-4 and Table-5. The analysis values of Table-4 and Table-5 demonstrates that the PI controller provides a good performance that PI controller for the air temperature however the IP controller performs slightly better than the PI controller for the water vapor pressure. The error result between the results and the desired signal outputs are shown in Figures-13-16.

**Table-4.** Comparison of the simulation results of air temperature.

| Control method | RMSE | MAD |
|---|---|---|
| PI controller | 1.2174 | 0.5813 |
| IP controller | 1.1929 | 0.6311 |

**Table-5.** Comparison of the simulation results of water vapor pressure.

| Control method | RMSE | MAD |
|---|---|---|
| PI controller | 0.6340 | 0.1693 |
| IP controller | 0.1841 | 0.1196 |

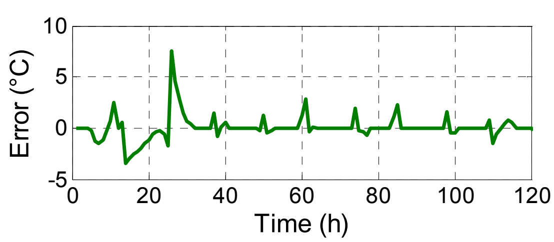


**Figure-13.** Evolution of the error result between the output (Ti) and desired air temperature using PI controller.

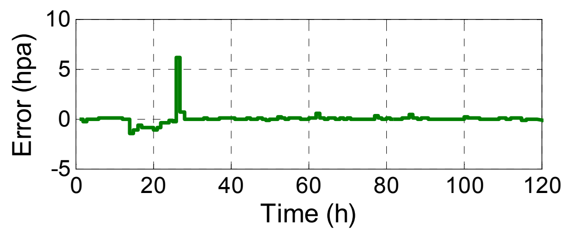


**Figure-14.** Evolution of the error result between the output (Pi) and desired water vapor pressure using PI controller.

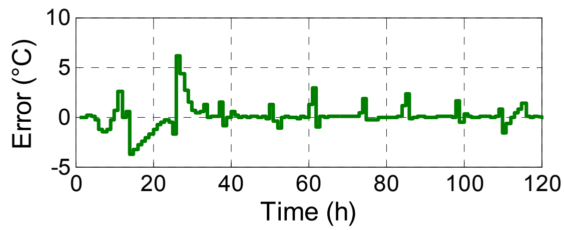


**Figure-15.** Evolution of the error result between the output (Ti) and desired air temperature using IP controller

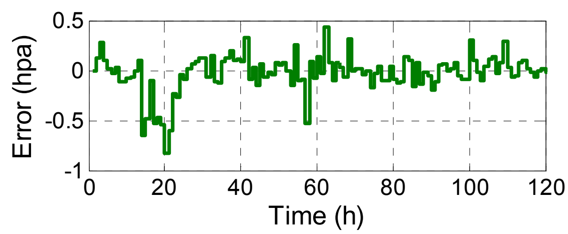


**Figure-16.** Evolution of the error result between the output (Pi) and desired water vapor pressure using IP controller.

## CONCLUSIONS

In the present work a multivariable and nonlinear system of a greenhouse climate is simulated taking into account considerations of crops. The goal of the control was carried out, and the desired trajectory was successfully followed by the typical methods including PI and IP control as shown by the results. It also observed that PI controller offers significant advantage over the traditional IP controller like limiting the overshoot in water vapor pressure. It is a challenge to model the interactions among greenhouse environmental parameters. Due to complexity in greenhouse environment model, it is highly difficult for theses approach using PI and IP control to achieve the coordination control of the greenhouse environmental factors. Therefore, in the future works, we *will* focus on the auto tuning of theses controllers using an appropriate optimisation algorithm theory, and by the application of the fuzzy logic control, to obtain the best performance benefits.

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**Nomenclature**

| | |
|---|---|
| $Al\sqrt{C}$ | Factor of natural ventilation model (.). |
| B | Coefficient of the model of transpiration ($Wm^{-2}hPa^{-1}$). |
| $C_p$ | Thermal capacitor of the greenhouse air constituent ($Kg^{-1}K^{-1}$). |
| $C_m$ | Water vapor thermal capacitor ($Jm^{-2}K^{-1}$). |
| $C_v$ | Heat-storage capacitor of the crop ($Jm^{-2}K^{-1}$). |
| $d_0$ | Leakage ($m^3s^{-1}$). |
| h | Air/sol convective exchange parameter ($Wm^{-2}K^{-1}$). |
| $h'$ | Air/crop convective exchange parameter ($Wm^{-2}K^{-1}$). |
| K | Global heat loss parameter by greenhouse wrap ($Wm^{-2}K^{-1}$). |
| $K_l$ | Latent heat transfer parameter resulted by ventilation ($Wm^{-2}hPa^{-1}$). |
| $K_s$ | Sensible heat transfer parameter driven by ventilation ($Wm^{-2}K^{-1}$). |
| $P*(T_i$ | Water vapor saturation pressure at Ti (hPa). |
| $P_e$ | Outing humidity (hPa). |
| $P_i$ | Inside humidity (hPa) . |
| $Q_{air}$ | Air heating loads ($Wm^{-2}$). |
| $Q_{sol}$ | Soil heating loads ($Wm^{-2}$). |
| $R_g$ | External global radiation ($Wm^{-2}$). |
| r | Repot (s/m). |
| S | Exchange area between two components of the greenhouse ($m^2$) . |
| s | Vents overture area ($m^2$). |
| $s_0$ | Leakage area ($m^2$). |
| $T_e$ | Outing temperature (°C). |
| $T_m$ | Virtual mass temperature (°C). |
| $T_i$ | Insider temperature (°C). |
| V | Speed of wind (m/s). |
| $v$ | Greenhouse volume ($m^3$) . |
| $\alpha$ | Report absorption of the total radiation by the aerial compartment of the greenhouse (.). |
| $\beta$ | Report absorption of the total radiation by the thermal mass compartment of the greenhouse (.). |
| $\gamma$ | Psychometric factor ($hPaK^{-1}$). |
| $\varphi_l$ | Injected evaporative cooling by fog process ($Wm^{-2}$). |
| $\rho$ | Air density ($kgm^{-3}$). |
| $\tau$ | Greenhouse covers transmittance factor (.). |

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