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CONTROL OF GREENHOUSE WITH PARABOLIC TROUGH COLLECTORS

Ramona-Oana GRIGORIU[1], Alina VODA[2], Nicoleta ARGHIRA[3],
Vasile CALOFIR[4], Sergiu Stelian ILIESCU[5]

Resource management in nowadays agriculture imposes the use of new technological solutions for automation and energy efficiency and this paper concentrates on the control of internal temperature of a greenhouse using parabolic trough collectors (GHPTC) for internal heating. The actuator for the GHPTC control system is the conducting fluid pump that enables the liquid flow into the collector pipes. Both the nonlinear and linear models are presented in the paper in order to tune a classical controller. A comparison of controller performances (stationary and transient) was conducted by simulation, using Matlab/Simulink software. Also, the gradient descent method was applied for an optimal tuning of the temperature controller, imposing minimum overshoot.

Keywords: greenhouse; parabolic trough collector; controller tuning; optimal control

1. Introduction

The interest in smart grids and also the necessity of well-balanced resource management in nowadays agriculture imposes the use of new technological solutions for automation and energy efficiency requirements in greenhouses in order to provide an optimal growth climate.

The integration of renewable energy resources (RES) in domains like communications and power system [9], [8], [15], [4] is already common, so their use can be extended, for power management enhancement purposes, to other industries such as agriculture, transport, civil engineering, chemical etc. In the agriculture field, RES offers multiple advantages particularly for greenhouse

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[1] PhD Student, Faculty of Automatic Control and Computer Science, University POLITEHNICA of Bucharest, Romania, e-mail: grigoriu.oana@gmail.com

[2] Prof., Dept. of control Systems, GIPSA-lab, University Joseph Fourier Grenoble 1, France, e-mail: alina.voda@gipsa-lab.grenoble-inp.fr

[3], Lecturer, Dept. of Automatic Control and Industrial Informatics, University POLITEHNICA of Bucharest, Romania, e-mail: nicoleta.arghira@aii.pub.ro

[4] Lecturer, Dept.of Automatic Control and Industrial Informatics, University POLITEHNICA of Bucharest, Romania, e-mail: vasile@shiva.pub.ro

[5] Prof., Dept.of Automatic Control and Industrial Informatics, University POLITEHNICA of Bucharest, Romania, e-mail: iliescu@shiva.pub.ro

heating with the goal to improve energy management and to reduce thermal energy consumption.

This study concentrates on the control of internal temperature of a greenhouse using parabolic trough collectors (GHPTC) for internal heating. Although in several papers or books various experimental solutions for a solar greenhouse [1,5-7,14] have occurred, the focus was not on the advantages and efficient use provided by using parabolic trough collectors for heating a greenhouse.

The paper is structured in four parts: the first part makes a short state-of-the art on control methods for greenhouses and solar collectors, the second part shows the nonlinear and then linearized model designed for a GHPTC system, the third part proposes and simulates a classical control method and the last chapter shows the results of an optimal control approach.

2. Control methods for greenhouses and solar collectors

Several models for greenhouse control and separately for solar collectors were proposed in the last years and will be further synthesised.

An experimental solution for a solar greenhouse was developed by Esen et al. from Turkey **[14]**. They proposed a heating system for the greenhouse using various renewable sources like biogas, solar and a ground source heat pump. A greenhouse with dimensions 6m x 4m x 2.10m heated by mentioned alternative energy sources was build. Experimentally it was obtained that the ideal greenhouse temperature for plant growth is 23°C.

A thermal behavior for a greenhouse is presented by Jain et al. from India **[1]**. They presented a greenhouse heated by a ground air collector (GAC). The model was validated experimentally during the winter, the controlled parameter being the inside temperature of the greenhouse. Gurban et al. have designed a climate model for a greenhouse using a feedback-feedforward compensation technique in order to linearize the system as shown in figure 1.

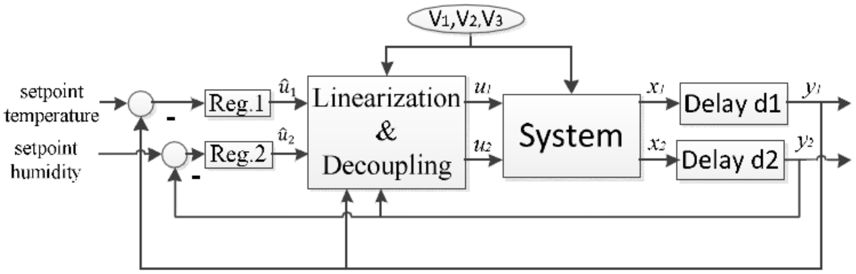

Fig. 1. Greenhouse climate system for control of temperature and humidity

This model was developed in order to ensure perfect condition of plant growth by controlling the temperature and humidity **[5]**. Starting from the mentioned model, the authors proposed a control method using Smith Predictor and a PID controller tuned by genetic algorithms as shown in figure 2 **[6]**, **[7]**.

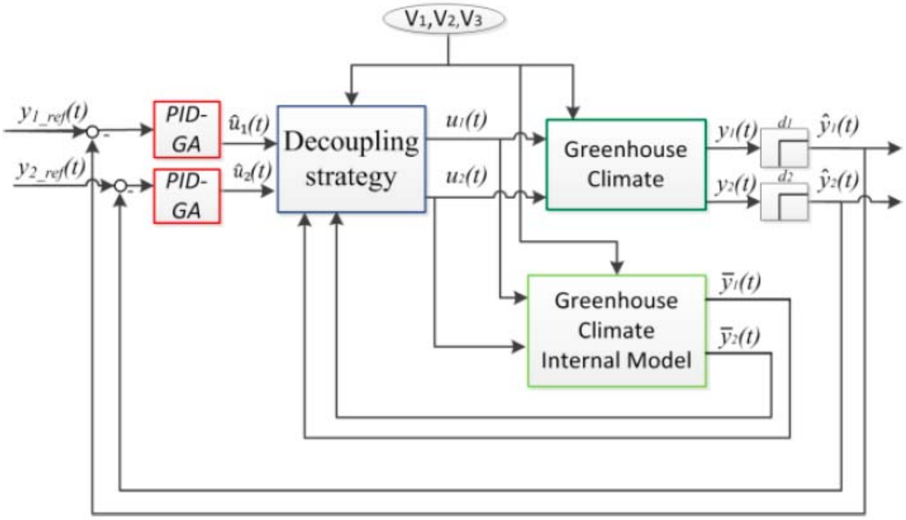

Fig. 2. Greenhouse climate system with decoupling using PID controllers tuned by genetic algorithms

One new trend is to use optimization control strategies for greenhouse climate model. These optimal strategies were applied by van Straten et al. for two subsystems: climate greenhouse and crop growth. The optimization control method used by the authors is the gradient method **[10]**.

A fuzzy approach for the temperature control of a greenhouse was described by Chen et al. from China **[12]**. They designed a fuzzy controller using the Visual Basic environment, in view of the accuracy of the proposed system.

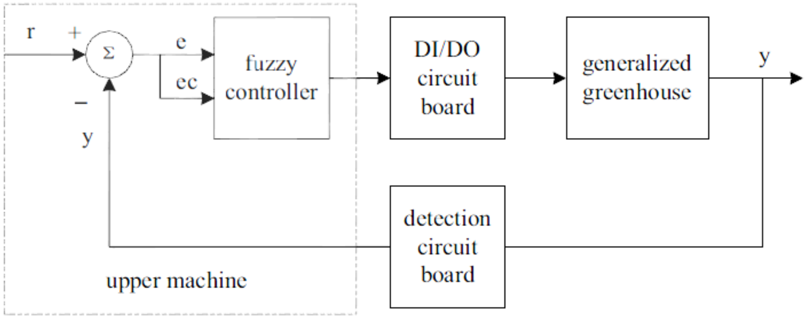

Fig. 3. Greenhouse control block diagram using fuzzy controller

Without additional measures for heating in winter season, the plant growth conditions are not fulfilled. So, the necessity of using fuzzy control techniques is required for ideal conditions of plant growth. The simulation results were obtained using Matlab/Simulink.

Another approach for the greenhouse climate system was proposed by Eredics et al. **[16]**, which consist in developing of two subsystems for heating and cooling using neural networks. The created model records the temperature and solar radiation measurements. This model should predict the future values for the greenhouse temperature in order to ensure plant comfort and minimize the costs.

However, a greenhouse with heat provided by a parabolic trough collector is not yet available. Considering this aspect, this paper describes a greenhouse system heated by a parabolic trough solar collector (GHPTC). The purpose of this system is to provide perfect conditions for the plant growth, by monitoring the temperature inside the greenhouse as an actuating variable the fluid flow.

A parabolic trough collector model (PTC) was shown in **[2], [3]** by Camacho et al., his purpose being to maintain the output temperature of the fluid passing through collector's pipe at a desired level, in spite of disturbances.

Another dynamic model for parabolic trough reflector has been developed by Leo et al. using a control strategy approach for a Combine Cycle Power Plant (CCPP) **[11]**. This model uses the principle of a moving-boundary configuration and a dynamic state-space description is obtained.

3. GHPTC system modeling and simulation

3.1. GHPTC architecture

This chapter proposes a parabolic trough collector based system developed to provide the heat for a greenhouse. Figure 4 shows a representation of this system.

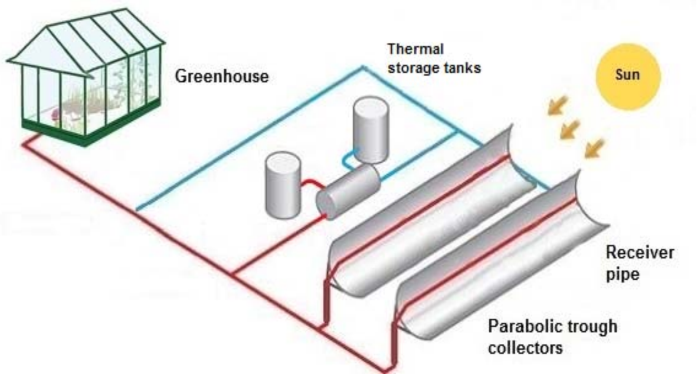

Fig. 4. GHTPC system architecture (schema)

A special fluid/oil circulates through the Parabolic Trough Collector and it is able to gain heat useful for the greenhouse. A water flow q_w is pumped from the thermal storage tanks through pipes in the greenhouse. This pump has a variable flow and it acts as an actuator for the internal temperature control.

3.2. The nonlinear model

The differential equation system for the GHTPC model, depending on both internal and external temperature and also on the greenhouse constructive parameters, is defined as follows:

$$\begin{cases} \dfrac{dT_{in}(t)}{dt} = \dfrac{1}{\rho_a V c_a}\{[(1-u)D\rho_a c_a + \alpha S + T_{f,out} c_{fluid}](T_{in}(t) - T_{ext}(t)) + P\} \\ \dfrac{dT_{f,out}(t)}{dt} = \dfrac{nGI}{\rho_f c_f A_f} - \dfrac{q(t)(T_{f,out}(t) - T_{f,in}(t))}{A_f n_o L} - \dfrac{H_l}{\rho_f c_f A_f} \end{cases} \tag{1}$$

where T_{in} [°C] is temperature of the greenhouse, q [m^3/s] is oil flow, c_{fluid} [kJ/kg°C] is the specific heat of the fluid passing through collector's pipe and $T_{ext}(t)$ is the atmospheric temperature.

The model is based on the fact that the parabolic trough collector heat Q_e [W] dependant on the specific heat of the fluid passing through collector's pipe and its temperature. The Simulink model used to simulate the GHPTC is represented in figure 5.

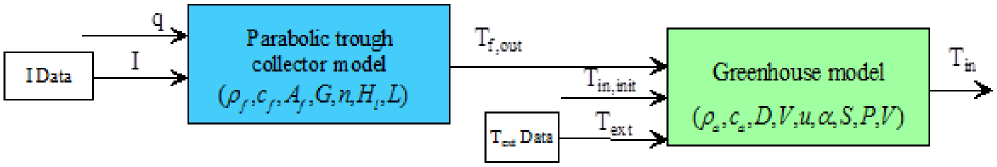

Fig. 5. Greenhouse using thermal energy from PTC

Real data for irradiance I and external temperature T_{ext} was provided by Prof. Gurban from Faculty of Automation and Computers, University Politehnica Timisoara, Romania.

$T_{f,in}$ was modelled as a step signal, in order to see its influence for the internal temperature T_{in}.

Real data for irradiation (I Data) and external temperature (Text Data) were available and the variable that links the two systems is the thermal fluid temperature $T_{f,out}$.

The internal temperature of the greenhouse (T_{in}- the process output) is determinate by the oil flow variation of the parabolic trough collector's heat (q - process input).

3.3. The linear model

The linear model is obtained by linearization of nonlinear model around the equilibrium point, using expansion in Taylor's series method **[17]**.

The state space model of GHTCP system, around the equilibrium point, is defined as follow:

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned} \tag{2}$$

$$\text{where } x = \begin{bmatrix} T_{f,out} \\ T_{in} \end{bmatrix}, y = [T_{in}], u = [q]$$

Finally, the matrices of the state space model are given next:

$$A = \begin{bmatrix} -0.0008876 & 1.373 \\ 0 & 170.9 \end{bmatrix}, B = \begin{bmatrix} -5128 & 0 \\ 0 & 0 \end{bmatrix}, C = \begin{bmatrix} -0.008876 & 0 \\ 0 & 1.373 \end{bmatrix}, D = 0$$

The following transformation from state-space representation to transfer function can be used in order to obtain the transfer function of the model:

$$H(s) = C^T (sI - A)^{-1} B + D \tag{3}$$

The model for the GHPTC system used for further control purposes was set as follows:

$$H(s) = \frac{5128.4}{1126.6s + 1} \tag{4}$$

4. Temperature control of the GHPTC system

The GHPTC control system has the goal to maintain the temperature inside the greenhouse at a desired level as an actuating variable the fluid flow.

In order to establish the best type of controller (P, PI and PID) for the system, the Ziegler-Nichols method is used based on the stability limit.

The simulation results are depicted in figure 6 and the internal temperature variation can be observed.

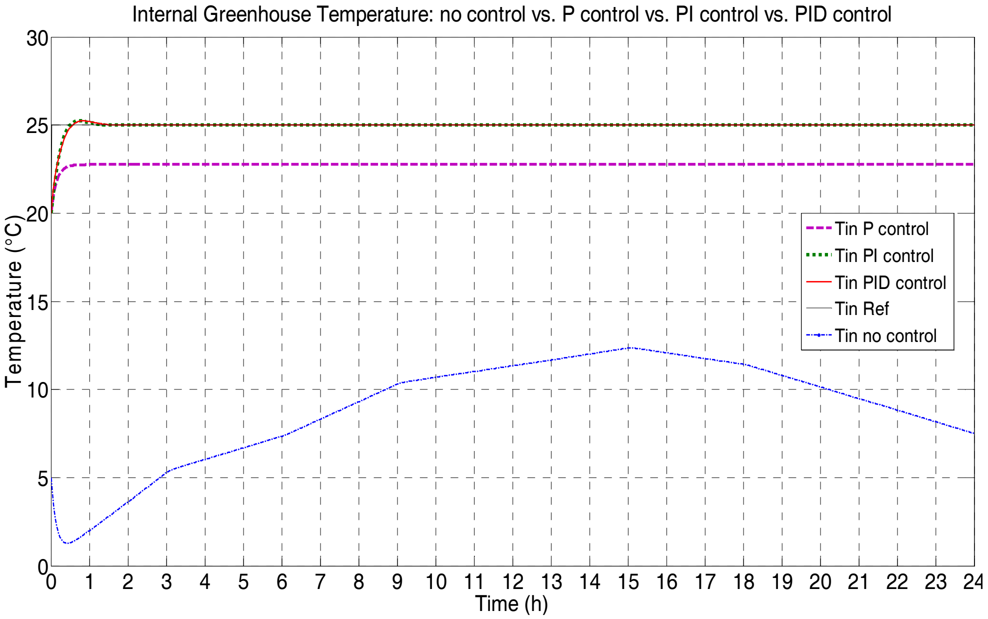

Fig. 6. Internal Greenhouse Temperature: no control, P, PI and PID control

Taking into account the imposed control performances, the derivative component can be choose in order to improve the transient performances and the integral term would help in obtaining a null stationary error.

Still, the performance of the controller is established by both stationary and transient performances. The PID controller has the best control performances (the overshoot - 4.6%, transient time - 33 minutes and a null stationary error) in comparison to P or PI, as seen in **[17]** and this type of controller will be further used.

5. Optimal temperature control approach

This chapter proposes an optimal control approach to increase the GHPTC system transient performance (reduce the overshoot), starting with the PID controller parameters which were computed in chapter 4.

The simulation was performed by using the Design Optimization toolbox from MATLAB/SIMULINK and the results are depicted in figure 7:

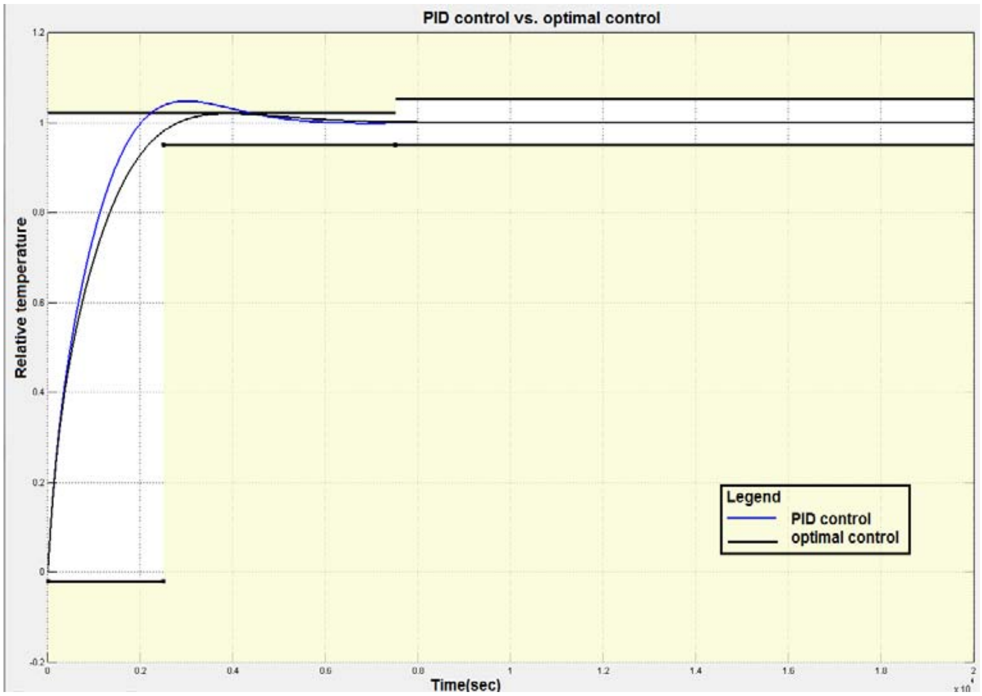

Fig. 7. Internal Greenhouse Temperature: PID control vs. optimal control

The optimization of the tuning parameters K_p, T_d, T_i using the Gradient descent technique was done. The initial values for the PID parameters were set before when Ziegler Nichols criterion was applied. The imposed performance parameters were: $\varepsilon_s=0$; $\sigma=2\%$; $t_t \leq 60$ minutes.

Table 1

Transient and stationary performances before and after optimization

Optimization Parameter	Before	After
σ	4.6%	2%
t_t	33 min	66.6 min
ε_s	0	0

The transient performances of the temperature control system are better after the optimization, especially in terms of overshoot which decreases by 2.6% as seen in figure 7 and table 1.

The transient time of the control system with the optimized parameters is higher than before, but this result does not influence the conditions of growth in the greenhouse since a fast increase of temperature in the GHPTC system could damage the growth of plants.

6. Conclusions and future work

In the context of ecological agriculture, the use of RES (in particular solar panels) can be the answer to different challenges (environmental, industrial etc) for a sustainable agriculture.

This paper proposed a new system that provides heat for a greenhouse using parabolic through collectors that can be installed close to the location. The circulating oil that flows through the collector pipes will increase the temperature in the greenhouse; during the night a storage tank will act as buffer for the internal temperature loop.

The nonlinear model was composed from thermal differential equations and the GHPTC linear model was obtained by applying the expansion in Taylor's series around the equilibrium point on the nonlinear model. The temperature inside the greenhouse is influenced by the oil flow variation passing through collector's pipe and the output oil temperature is the mutual parameter in both the collector and the greenhouse model.

Based on the proposed linear model, controller tuning was conducted. Comparing the P, PI, PID controllers performances, best results were obtained for a PID controller which was further used. An optimal control with a gradient descent strategy was applied in order to improve the transient performances of the GHPTC temperature control system.

A comparison of the proposed method results and similar research aiming the optimization of the control of the GHPTC system could not be achieved, considering the fact that a real pilot is not yet available.

Further work will consider testing intelligent control methods for this system, in order to improve the transient performances.

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