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Modelling of Greenhouse using Parabolic Trough Collectors Thermal Energy

Ramona-Oana Grigoriu*. Alina Voda**
Nicoleta Arghira*, Sergiu Stelian Iliescu*

**Dept. of Automatic Control and Industrial Informatics, University Politehnica of Bucharest, Bucharest, Romania (e-mail: grigoriu.oana@gmail.com, nicoleta.arghira@aii.pub.ro, iliescu@shiva.pub.ro)*
***Dept. of Control Systems, GIPSA-lab, University Joseph Fourier Grenoble 1 Grenoble, France (alina.voda@gipsa-lab.grenoble-inp.fr)*

Abstract: The paper proposes a system developed to provide heat for a greenhouse using parabolic trough collectors (GHPTC) thermal energy. In order to ensure perfect conditions of growth for greenhouse plants, the GHPTC control system regulates the internal temperature of the greenhouse and it monitors the temperature of the conducting fluid through collector pipes. The GHTPC model is composed of two subsystems: the greenhouse model and the parabolic trough collector model. Each of these models were validated using real data, considering as a validation index the maximum error between the real and simulated data on a period of one day (24 hours). The proposed GHTPC model shows an energy gain by increasing the greenhouse internal energy even with no control applied on ether of the subsystems.

Keywords: greenhouse; solar greenhouse; thermal energy; parabolic trough collector; smart grid;

1. INTRODUCTION

Nowadays, the need for energy production efficiency is increasing due to higher environmental requirements. The concept of smart grid is more and more used not only in the power systems (Arghira 2012), (Camacho 2011), (Dragomir 2012), but also in connected fields (Marinescu 2014).

Renewable energy resources (RES) offers multiple advantages and they are put to better use in small scale applications in domains such as agriculture, transport, industry, in order to improve energy management and consumption.

A significant challenge associated with smart grids is the integration of renewable generation. In a traditional way, power systems have addressed the uncertainty of load demand by controlling supply. However, with RES, the uncertainty and intermittency on the supply side must also be managed.

Demand response and load control, such as providing price signals or other incentives for consumers to modify their loads is already being practiced in commercial and industrial facilities to adjust consumption (Camacho 2011).

With the accept put nowadays on ecological agriculture, the use of RES can be an effective answer to new issues. The interest in renewable energy sources for greenhouse heating is currently high and is still growing.

One new solution to increase efficiency and flexibility for a greenhouse is to use a solar collector system for heating purposes.

Although in the specialized literature have occurred various experimental solutions for a solar greenhouse, the accent was not on the benefits provided by using parabolic trough collectors for heating a greenhouse.

An interesting solution for a solar greenhouse was developed by Esen and Yuksel from Turkey (Esen 2013). They proposed an experimental evaluation of using various renewable energy sources for heating a greenhouse and they have focused on the biogas, solar and a ground source heat pump greenhouse heating system.

Also, an equivalent greenhouse climate model based on feedback-feedforward compensation technique responsible for linearization, decoupling and disturbance compensation of the greenhouse complex model was designed by Gurban and Andreescu, (Gurban 2012, 2013, 2014).

A dynamic model for parabolic trough reflector has been presented by Leo et al. from France, (Leo 2014). This model describes the behaviour of the output steam parameters (pressure and enthalpy) and it can be used to develop a control strategy for a combined cycle power plant using the coupling of the collector with a conventional power plant.

The present work aims to provide a thermal model for the Greenhouse Parabolic Trough Collector system (GHPTC) to ensure optimal growth climate conditions which leads to an increasing demand of high efficiency greenhouse control systems.

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The paper is structured in five parts: the first part shows the modelling and simulation methods used in this work, the second part describes the greenhouse model, the third part presents the parabolic trough collector model, section five proposes a model designed for a GHPTC system and the last one concludes the paper and highlights further improvements of the model.

2. MODELLING AND SIMULATION METHODS

2.1 System modelling and simulation

The proposed GHTPC system has 2 subsystems: the greenhouse and the parabolic trough collector. In order to simulate the complete system, a priori, each of the two subsystems are modelled, simulated and validated.

Each subsystem is modelled using the thermal differential equations.

The proposed model is simulated in Matlab /Simulink which uses an implicit integration method. The ode45 (Dormand Prince) solver with relative tolerance 10^{-3} is used. Several authors studying differential equations solvers declare this method as more accurate than the Runge-Kutta-Fehlberg method, discovered in 1960.

The Dormand-Prince method has seven stages, but it uses only six function evaluations per step because it has the FSAL (First Same As Last) property: the last stage is evaluated at the same point as the first stage of the next step.

Dormand and Prince chose the coefficients of their method to minimize the error of the fifth-order solution. This is the main difference with the Fehlberg method, which was constructed so that the fourth-order solution has a small error.

For this reason, the Dormand-Prince method is more suitable when the higher-order solution is used to continue the integration.

2.2 Model validation indexes

A maximum absolute error during a day (24 hours) can be calculated with the following equation:

$$\max\ (err) = \max_{i=1,24} \left\{ \left| T_{in,i} - T_{inr,i} \right| \right\} \quad (1)$$

where $T_{in,i}$ is the internal temperature at hour i obtained by simulation, $T_{inr,i}$ is the real internal temperature at hour i and the index i is used to cover the 24 hours interval in a day.

Also, in order to compare the real and simulation data, a maximum absolute percentage error during a day (24 hours) was calculated with the following equation:

$$\max(err\%) = \max_{i=1,24} \left\{ \frac{\left| T_{f,out,i} - T_{f,outr,i} \right|}{T_{f,outr,i}} \right\} \cdot 100[\%] \quad (2)$$

where $T_{f,out,i}$ is the output fluid temperature at hour i obtained by simulation, $T_{f,outr,i}$ is the real output fluid temperature at hour i and the index i is used to cover the 24 hours interval in a day.

This percentage error is more suggestive since is independent of the measured parameter.

3. GREENHOUSE THERMAL MODEL

3.1 Greenhouse description

This section is addressed to the greenhouse thermal model. The greenhouses provide an ideal and safe environment for the culture of plants.

Taking into consideration the climate change, pollution, population growth and increasing demand of vegetable and fruit, there are significant requirements for efficient greenhouse climate models, (Gurban 2013).

One new trend for greenhouse climate model is an implementation which includes short and long term optimization objectives. This model was developed by van Straten who approached optimal control strategies for two main subsystems: greenhouse climate and crop growth, (Straten 2011).

Traditional greenhouses typically rely on the sun to supply their lighting needs, but they are not designed to use the sun for heating. However, several greenhouses were designed to use solar energy for both lighting and heating (Esen 2013).

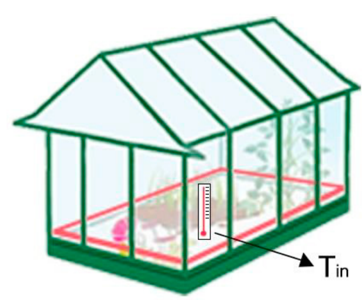

Fig. 1. Greenhouse schematic description

One of the most used greenhouse thermal model was developed by Albright, (Albright 2001), which describes two differential equation based on energy and mass equations for the greenhouse. The output variables used in the model are the greenhouse interior temperature and the interior absolute humidity.

3.2 Greenhouse model

Starting from the above mentioned model and considering the conditions for achieving GHPTC system for monitoring internal temperature of the greenhouse, the following differential equation for the greenhouse was obtained: